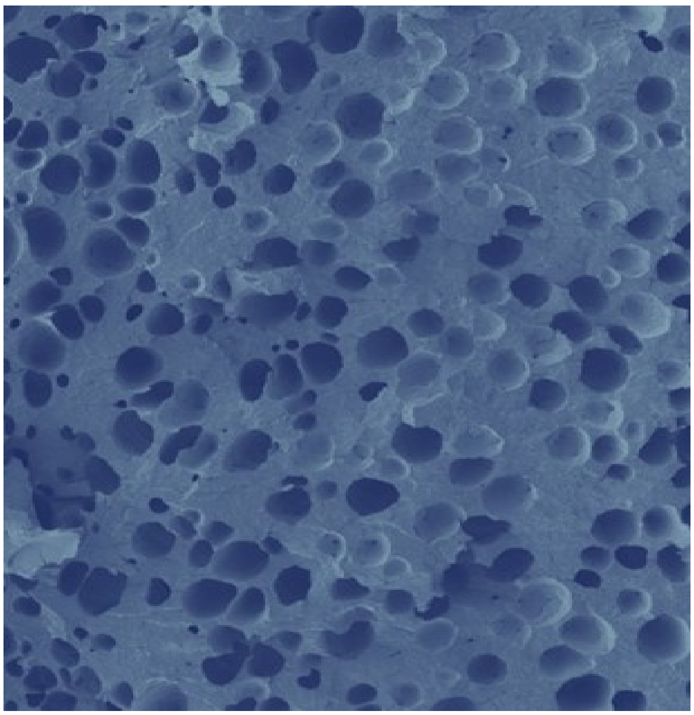
# A GUIDE TO THE MUCELL® MICROCELLULAR FOAM INJECTION MOLDING PROCESS – T SERIES



*Fundamentals, Set-up, Optimization & Troubleshooting*

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# Table of Contents

# Introduction

The foundations of this useful process technology can be traced back to Dr. Nam Suh's work at the Massachusetts Institute of Technology (MIT). In the 1980's, Dr. Suh and his students established the fundamental principles regarding the formation of microcellular structures in plastic parts.  In 1995, Trexel Inc. obtained an exclusive license to the MIT technology and continued the development and commercialization of microcellular foamed plastics parts produced by extrusion, blow molding and injection molding.  Trexel has since exited the extrusion and extrusion blow molding markets and is not focused only on injection molding and automotive blow molding.

This processing guide will cover the technical fundamentals, optimization and troubleshooting of MuCell microcellular foam technology as it relates to injection molding and the Trexel T-Series SCF System.

# Microcellular Molding Fundamentals

To create a microcellular structure in injection molded parts, the MuCell process relies on the homogeneous cell nucleation that occurs when a single-phase solution of polymer and supercritical fluid (SCF) passes through the injection gate into the mold cavity. The pressure drop as the solution enters the mold causes the SCF to come out of solution creating cell nuclei. The cells then grow until the material fills the mold, the expansion capabilities of the SCF are expended, or the flow front freezes. The process runs on molding machines that have been modified to allow the metering, delivery and mixing of the SCF into the polymer to create the single phase solution.

The creation of the single-phase solution, in which the SCF is fully dissolved and uniformly dispersed in the molten polymer, takes place inside the injection barrel under carefully controlled process conditions: The SCF must be accurately mass flow metered into the polymer for a fixed amount of time. And during that dosing period, the right conditions of temperature, pressure and shear must be established within the barrel. Back-pressure, screw-speed and barrel-temperature control, as well as Trexel's patented restriction element mixing screw and SCF Delivery System, all play a role in establishing the process conditions that create the single-phase solution.

The importance of creating and maintaining a single-phase solution can't be overstated. *In fact, all process optimization and troubleshooting activities start with confirmation that the SCF and polymer have indeed come together in a single-phase solution.*

Once the single phase solution has been created, a MuCell-capable molding machine maintains it in a pressurized state until the start of injection. The machine does so through the combined efforts of a shutoff nozzle and screw position control. The shutoff nozzle prevents depressurization and premature foaming into the mold. Either active or passive screw position control prevents depressurization through the backward movement of the screw. During active screw position control, the position of the screw is continuously monitored, and the pressure applied to the back of the screw is adjusted to maintain a position setpoint or a constant pressure is held on the back of the screw. This technique is most common on OEM molding machines built to support the MuCell process. In passive position control, the oil used to regulate back pressure is prevented from draining to its tank at the end of screw recovery. This residual oil keeps the screw from moving backward due to the pressure of the single phase solution. Passive position control is used for MuCell Machine Upgrades (MMUs) and on some OEM machines.

Proper mold design also helps maintain the single-phase solution. Molds with a hot runner system need valve gates to prevent material drooling from the nozzles on mold open. Molds in which the machine nozzle breaks contact with the sprue bushing during normal operation–such as stack and tandem molds–require a shutoff on the sprue bushing. Otherwise, the pressure from the hot runner will be relieved through the sprue bushing.

**Microcellular Foam Essentials**

MIT researchers established three conditions that must occur for microcellular foams to form:

- **Single-phase solution**. A supercritical fluid must be uniformly and completely dissolved into the plastic.
- **Pressure drop**. Cell density, or the number of cell created per unit volume, depends on the SCF level and the rate of pressure drop.
- **Controlled cell growth.**

**Types of Supercritical Fluids**

The MuCell molding process relies on either nitrogen or carbon dioxide as the foaming agent. Each foaming agent has its place, depending on the application objectives.

Nitrogen is by far the most commonly used of the two. As the more aggressive foaming agent, it provides a greater weight reduction and a finer cell structure at a much lower weight percentage than carbon dioxide. In fact, nitrogen levels will typically be at least 75 percent lower than the carbon dioxide level required to achieve comparable parts. Carbon dioxide, however, is the preferred foaming agent in two situations: when viscosity reduction is the primary processing goal or when the application can't tolerate nitrogen's more aggressive foaming action.

Differences in the effectiveness of two foaming agents stem from their behavior in the polymer melt. Carbon dioxide, which becomes an SCF fluid at 31.1 C and 72.2 bar, is 4 to 5 times more soluble in polymers than nitrogen, which becomes a supercritical fluid at -147 C and 34 bar. For example, the saturation point in an unfilled polymer is about 1.5 to 2 percent by weight of nitrogen, depending on temperature and pressure conditions, while the saturation level of carbon dioxide is closer to 8 percent by weight. Carbon dioxide also exhibits a greater mobility in the polymer, allowing it to migrate further into existing bubbles than nitrogen. From the perspective of cell nucleation, greater solubility and mobility means fewer cells will be nucleated, and those that do nucleate will tend to be larger.

Solubility, however, becomes an advantage when the goal is viscosity reduction. An SCF dissolved in a polymer acts as a plasticizing agent, reducing the viscosity of the polymer. Because viscosity reduction is partly a function of the amount of SCF added to the polymer and because carbon dioxide has a higher solubility limit than nitrogen, the ability to reduce viscosity with carbon dioxide is greater.

Carbon dioxide is also preferred when the amount of nitrogen needed to produce a part is so low that it is not possible to consistently process parts. Given that carbon dioxide is a much less aggressive foaming agent, there are times where it is easier to run low levels of carbon dioxide, 0.15 or 0.2 percent, as compared to very low levels of nitrogen, less than 0.05 percent. This occurs primarily with soft materials and parts with thick cross sections. It some instances, low levels of carbon dioxide can be added to existing solid molded parts without any or with only minor changes in that part's surface appearance.

**Material Effects**

In general, injection molding materials can be categorized as amorphous and semi-crystalline and, within these two broad polymer families, there are filled and unfilled materials. The MuCell processing characteristics of the materials within each family tend to be similar, though there may be slight variations between individual grades. For example, unfilled amorphous materials tend to have similar processing characteristics. Glass-filled semi-crystalline materials likewise share their own set of processing characteristics. Here's an overview of what to expect within the most common polymer families:

- **Olefin semi-crystalline materials.** Unfilled polyolefins, such as HDPE or polypropylene, typically require higher nitrogen levels than most other materials need to achieve a good cell structure (see Table on page 20). As a rule of thumb, expect that the typical nitrogen levels for unfilled HDPE or unfilled polypropylene will be at least 0.6 percent. Levels as high as 1 percent are not uncommon. Unfilled polyolefins are also more likely to have cell structure variation from the gate to the end-of-fill. This variation will be aggravated when the wall thickness exceeds 2.0 mm (0.08 inches). As with all materials, the addition of fillers improves the "cell creation efficiency" of the SCF. Polypropylene commonly takes talc and calcium carbonate fillers. As talc levels approach 20 percent or more, the typical nitrogen level will be 0.4 to 0.6 percent. With a more efficient nucleating agent like glass filler, the typical nitrogen level can be decreased to 0.25 to 0.4% percent.

- **Semi-crystalline engineering materials.** Like polyolefins, unfilled engineering engineering polymers also tend to show cell structure variation from gate to end of flow. They also require relatively high nitrogen levels of 0.5 to 0.7 percent in order to achieve good cell structure. Adding 20 percent or more of glass fiber will allow the nitrogen level to be dropped to a range of 0.15 to 0.3 percent. Other filler types, such as mineral, will also act as a nucleating agent and allow for good cell structures at lower SCF levels, though mineral filler will also limit weight reduction potential. The presence of impact modifiers in materials such as toughened PA will necessitate higher SCF levels. One unique concern with unfilled POM is shear induced crystallization. This can cause the formation of voids in the molded part even when the SCF is in solution. This condition is the result of high shear through the gate and can typically be eliminated by changes to injection speed or gate size. It has also been seen that the typical nitrogen level for an unfilled POM is 0.15% to 0.2%.
- **Amorphous materials.** These resins included polystyrene, polycarbonate, acrylic and SAN, which do not contain an impact modifier, as well as ABS, HIPS and impact modified PC, which do contain an impact modifier. Unfilled amorphous resins will almost always require lower nitrogen levels than unfilled semi-crystalline resins although the presence of impact modifiers increases the SCF requirement to some degree. For those materials which do not contain an impact modifier, nitrogen levels will be about 0.2 to 0.4 percent. These materials typically achieve excellent cell structure at relatively low levels of supercritical fluid. Cell structure will be essentially uniform from gate to end of fill. However, these materials will have a MuCell Process Pressure (MPP) setting of as much as 207 bar (3000 psi). Adding an impact modifier has the effect of tending to increase cell size at a given SCF level. In order to achieve a cell structure that is microcellular or close to microcellular, nitrogen levels typically need to be closer to 0.3 to 0.6 percent with an increase in MPP up to 241 bar ( (3500 psi). In amorphous materials, the addition of as little as 10 percent glass fibers will allow nitrogen level to be cut in half while still maintaining a microcellular structure.
- **Thermoplastic Elastomers (TPEs).** The TPE family includes a variety of soft, flexible thermoplastics. These materials have a wide variety of chemistries, including polyolefin based (TPO and TPV), polyester based, polyurethane based (TPU), styrene block copolymers (SBS and SEBS) and more. In general, amorphous TPEs tend to offer superior cell structure and higher weight reductions than semi-crystalline based TPEs. Regardless of their chemistry, all of these soft elastomers are susceptible to "post blow," which occurs when excessive internal cell pressure cause the part to expand after the mold opens. Because of the post blow issue, it is typical that when using TPE's, the primary goals cannot include cycle time.

**Wall Thickness Effects**

The MuCell process has been applied to parts with a wall thickness as low as 0.25 mm and as great at 12 mm. Most applications, however, are 3 mm and less.

There are two key attributes linked to wall thickness. The first is density reduction.

The second is cycle time which is a function of wall thickness and material stiffness. As the part is filled and gas expansion occurs, there is a residual gas pressure that on mold open is higher than atmospheric pressure.

As such, the skin layer of the part must have sufficient rigidity to withstand this internal gas pressure. If this condition does not occur, cell growth continues when the mold opens and the part swells.

There are some noteworthy trends regarding fillers that apply across all materials. Fillers act as nucleating agents, improving cell structure and increasing the efficiency of a given SCF dose. Of all the fillers, glass fiber is the most beneficial in terms of controlling cell structure and achieving weight and cycle time reductions. Talc, calcium carbonate and mineral fillers are less effective at reducing weight and cycle times. As with conventionally molded parts, the choice between fillers usually comes down to the desired mechanical properties. For example, talc and calcium carbonate both have a similar effect on cell nucleation and cell growth. Yet their influence on mechanical properties differs, with talc-filled materials tending to have higher stiffness and calcium carbonate-filled materials tending to have better impact and elongation. The application requirements, rather than the molding requirements, may drive the choice between the two.

# Setting up The Process

MuCell set up procedures all revolve around establishing a controlled, gentle SCF dosing into the injection barrel under screw speed, temperature and pressure conditions that result in a single-phase solution. Logic built into the MuCell controller prevents many SCF dosing errors–by allowing the SCF injector to actuate only when the screw is rotating under position control and is in a position that corresponds to no more than 80 percent of the shot size.

**Initial Setpoints**

With the controller ensuring that the basic conditions of SCF dosing are met, the molder has only five process setpoints to adjust. They are the following:

- **MuCell Process Pressure (MPP)** sets the plastic pressure against which the SCF is dosing during screw rotation. As such, it refers to both the specific plastic back pressure during screw recovery and also to screw position control during screw idle. The MPP setpoint is a function of the material type and can range from roughly 70 bar (1000 psi) to 220 bar (3200 psi). Typically setpoints for material families are:

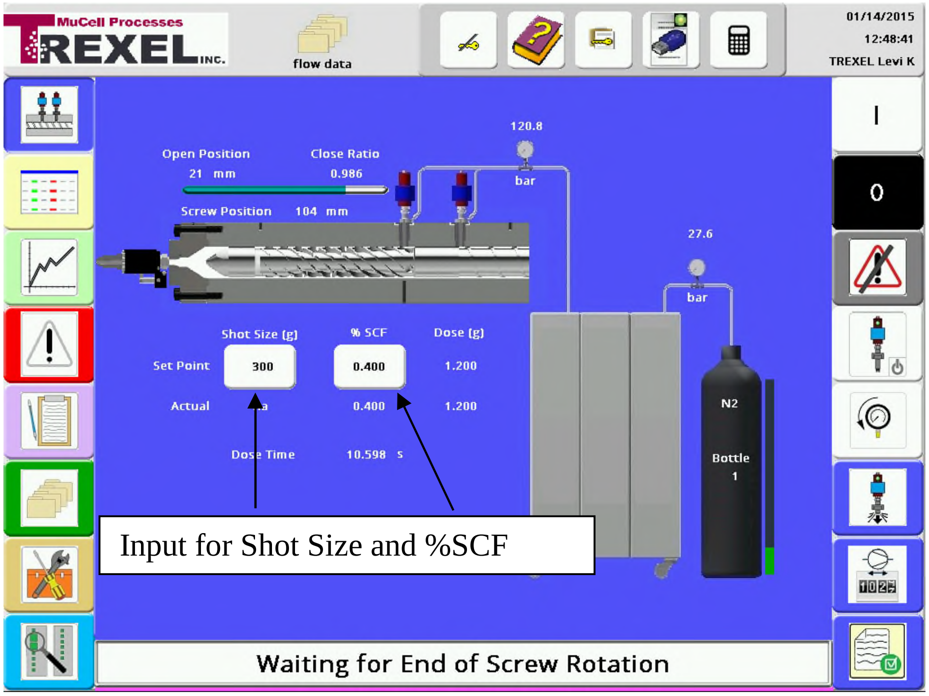
| | |
|---|---|
| • Filled PA6, PA6.6, PBT, PET | 90 - 110 bar (1300 - 1600 psi) |
| • Filled PP (20-40% talc/CaCO3/GF) | 120 – 140 bar (1750 - 2000 psi) |
| • Unfilled Semi-crystalline | 170 bar (2500 psi) |
| • Unfilled Amorphous | 200 – 220 bar (2900 – 3200 psi) |
| • Filled Amorphous | 140 bar (2000 psi) |
| • LGF PP | 70 – 80 bar (1000 – 1150 psi) |

- **SCF Delivery Pressure** sets the feed line pressure to SCF injector. The default setpoint for the T series SCF system is 103 bar (1500 psi). The T series is always in automatic mode and will adjust the delivery pressure to provide a 6 bar (90 psi) pressure drop at the start of SCF dosing. Depending on the dose size and the actual plastic pressure, the correct delivery pressure will be reached in less than 10 shots. Alternatively, the starting setpoint can be changed on the configuration page. The system will then convert to automatic control after the first dose. When setting an initial delivery pressure, choose a value that is approximately 15 bar (215 psi) higher than the MPP.

- **SCF Injector Open Position** sets the screw position at which the SCF dosing starts. This position should be set so that the pressure in the barrel during screw recovery has become stable prior to the start of dosing. Note that the polymer pressure inside the barrel does not stabilize in the first few rotations of the screw, so SCF dosing should not start as soon as the screw starts rotating. In order to allow the barrel pressure to stabilize, set the open position in the range of 10 to 15 mm. This is an offset from the forward most screw position and as such, this position will be maintained regardless of cushion.

  This is a general guideline based on normal shot size recommendations, minimum 1D of screw stroke. When the screw stroke is less than 25 mm, this open position will need to be adjusted down.

- **Shot size and % SCF** control the actual mass of SCF dosed during each cycle. The shot weight is for the expected MuCell process and not the solid shot weight. It should be the combined weight of all parts and cold runners. The %SCF is the target %SCF desired. These values are input on the process page. The T series will then optimize dosing time and flow rate to provide the maximum dosing time allowed.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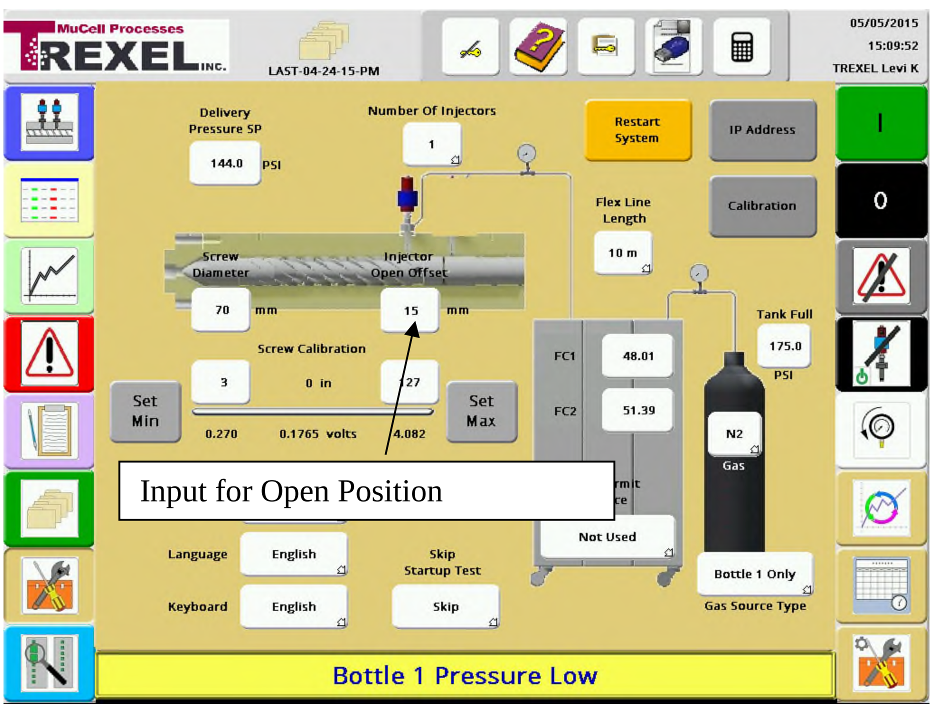
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**T Series SCF Dosing Optimization**

The T series SCF Delivery System is designed to optimize the dosing. This is accomplished by maximizing the dosing time and minimizing the flow rate (pressure difference between the pre-metering pressure and the delivery pressure). This is accomplished by targeting a closed position of 75% of the screw stroke, this is a close ratio of 1. The flow rate, P1-P2, is optimized to allow for the correct dose of nitrogen using the open position and a close position of 75% of stroke.

If the P1-P2 drops to 20 bar, the pressure is no longer decreased but instead the injector will close early, at a close ratio less than 1. If the P1-P2 decreases to 20 bar and the dosing time drops to less than 2 seconds, a warning, MFE too Large, is generated.

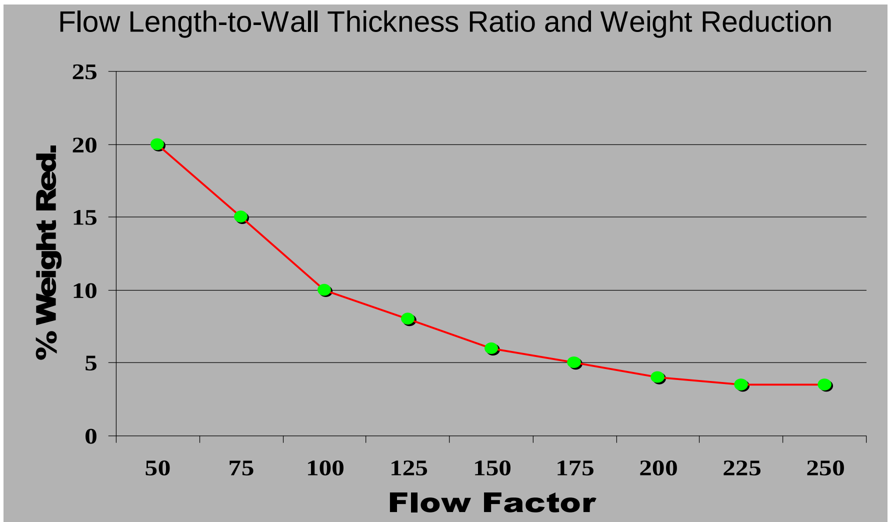
On the other side, if the pre-metering pressure reaches 340 bar (5000 psi) and the required dose cannot be reached with in the allotted dosing time, a warning, "MFE too Small", is generated.

# Optimization

When properly optimized, the MuCell process offers a variety of molding benefits, including reductions in part weight, cycle time and warpage. Another important benefit is the ability to lower the clamp tonnage needed to produce a given molded part.  In some cases, it may be necessary to prioritize as some of the process approaches to improve one benefit may have a negative effect on others.

**Weight Reduction**

Optimizing the process for weight reduction needs to start with a realistic understanding of the limitations imposed by part and mold design attributes such as flow paths, venting and gas traps. Consider the effect flow paths have on weight reduction. As flow length-to-thickness ratios increase, opportunities for weight reduction decrease (see graph at right). Poor venting, which traps gas in the mold cavity, is another barrier to weight reduction.  In the MuCell process, foam expansion is the driving force that completes the filling of the mold cavity and packs out the part.  Because foaming fills and packs at low pressures, it can easily be defeated by the pressure from unvented gas in the mold cavity.  Poor venting can, in fact, cut the density reductions by as much as 50 percent. To fix venting problems, try to decrease the clamp tonnage by up to 50 percent. Another method is to put a piece of masking tape on the parting line, giving trapped gas an escape route.  Both techniques, on a temporary basis, improve venting and should improve the ability to reduce part weight. For a more permanent fix, modify the mold to increasing perimeter vent depth by 25 percent and vent width by 50 percent.




The dominant influence on weight reduction is the part's flow length-to-wall thickness ratio. This value places an inherent limit on the maximum weight reduction possible with the MuCell process.

Gas traps, or gas entrapped by "race tracking" flow fronts, likewise reduces the potential for weight reduction. Unresolved gas traps can cause a MuCell part to weigh almost as much as a comparable solid molded part. Fixing gas traps usually involves both mold and part design changes.  One minor mold modification involves venting trapped gas through ejector pins or blades. If there is an ejector mechanism at the trap location, it may be possible to create a vent by machining a small flat on the ejector. If an ejector pin or blade is not available, it might be possible to insert a dummy pin. This strategy, however, is less effective than an ejector pin as dummy pins are not self-cleaning and will eventually clog with off gases. Two other options are adding flow leaders to promote flow into and through thin sections and, where possible, limiting wall thickness transitions to less than a 25 percent difference between thick and thin sections.

Other than mold changes to resolve venting and gas traps, there are also a handful of processing changes that reduce part weight by maximizing the proportion of the part that completely foams:

- Increasing Process Temperatures. Increased melt and mold temperatures increase the time before the material freezes off, giving the polymer and SCF solution more time to fully expand in the mold cavity. Experience has shown that melt temperature is typically more effective in increasing weight reduction whereas mold temperature has a more significant effect on cycle time.
- Increasing SCF Level. The overall driving force to foam expansion is the internal gas pressure in the individual cells. As the SCF level increases, the internal gas pressure increases, resulting in more fully foamed, lighter parts. Increasing SCF level will increase surface splay.
- Increasing Injection Speed. As injection speed increases, the material cools less during the filling process which allows for more expansion to occur before the material reaches the critical cooling point. Increasing injection speed can increase surface splay.

**Always Maintain Quality Cell Structure**

While it is always best to use the minimum amount of nitrogen necessary to achieve the desired results, it is important to consider cell structure along with weight reduction when optimizing the process.

A quality microcellular cell structure is critical to the retention of mechanical properties of the material. It is possible to attain significant weight reductions and cycle time improvements, but have an unacceptable cell structure. After achieving the desired weight reduction it, may take a higher SCF level to develop the optimum cell structure.

The best method of evaluating cell structure is to break parts open. Cutting parts whether with a knife, saw or gate cutters will collapse the cell structure making proper evaluation difficult. Instead, the surface should be scored with a knife or razor blade. The part can then be broken at the location of the score mark. The best areas to check are the end of fill, weld lines, the base of ribs and bosses and near gates.

**Cycle Time**

The MuCell process has two characteristics that reduce cycle time. The first is that the pack-hold phase of the solid molding process is replaced by an SCF expansion that occurs simultaneously with filling. Therefore, most of the solid pack-hold time can be eliminated.

The second is that mold temperature recommendations in standard injection molding, particularly for amorphous materials, tend to be high based on the need to minimize residual stresses caused by the decreasing gradient of pack pressures from gate to end of fill. With MuCell's pack and hold coming from a uniform gas expansion, the usual residual stress patterns are reduced without the use of high mold temperatures. The ability to reduce these mold temperatures allows for a reduction in cooling time.

Limitations on cycle time reductions are typically associated with "post blow," which occurs in areas of the part where the internal gas pressure is greater than the strength of the part wall. When the ejected part is no longer constrained by the mold cavity, the cells resume their expansion and cause a localized deformation of the part surface. Post blow will always occur in the same part location, that which corresponds to the hottest location of the mold or the thickest cross-section of the part.

These hot spots occur for one of two reasons, poor cooling or a thick cross section of material. Areas with poor cooling are often the result of uncooled slides and cores as well as sections of tooling that form deep pockets. While mold temperature can be reduced, this typically has very little effect on the local temperature of these types of tooling conditions.

Thick sections in the part also result in hot spots. In conventional injection molding, thick sections can suffer from sink marks or vacuum voids due to excessive material shrinkage. When using the MuCell process, thick areas result in post blow as the core of the material stays hot and continues to expand after the part is ejected from the mold. Since the thermal conductivity of plastics and more specifically of foamed plastics is low, changes to mold temperature have very little effect on this condition. The best solution is to core out these sections to eliminate the thick sections.

When tooling changes are not possible, the most effective process approaches are reductions to process temperatures and SCF levels. With process temperatures, start with a reduction to the mold temperatures, since it tends to have a greater effect than reducing melt temperature. To gauge the effectiveness of the temperature reductions, make significant reductions in the range 10 to 15 C.

Reducing the SCF level minimizes the driving force behind post blow, which is the residual gas pressure in the cells. Another way to reduce residual pressure is to increase the weight reduction, which has the effect of expending more of the gas pressure in cell growth.

**Warpage**

When residual stress from uneven pack pressures, molecular orientation, glass fiber orientation, or some combination of these factors causes a differential shrinkage of the part, warpage results. Because the MuCell process provides a uniform packing phase–the expanding foam exerts the same packing pressure throughout the part – the process can reduce or even eliminate residual stress as a source of warpage. A weight reduction of 5 percent or more is usually needed to completely eliminate residual stresses in unfilled or talc-filled materials.

Warpage reduction is more difficult to achieve with glass-filled materials because glass fiber orientation will cause warpage. Still, the MuCell process can have some effect on the orientation of glass fibers. The primary variable effecting glass fiber orientation is a part's wall thickness. At 2.5 mm (0.10 inches) and thicker, it is possible to eliminate most of the glass fiber orientation. From 2.5 mm down to 1.75 mm (0.6 inches), orientation can be reduced but not entirely eliminated. Below 1.75 mm, no change occurs. A secondary factor is the level of glass fiber. At 10% to 15%, a greater degree of dimensional improvement will be seen in the thickness of 1.75 to 2.0 mm. As glass fiber levels approach 30%, the wall thickness will need to be closer to 2.25 to 2.5 mm to see changes in warpage.

The key process variables effecting glass fiber orientation are weight reduction and SCF levels. In order to maximize the benefits of the microcellular process on fiber orientation a weight reduction of at least 8 percent must be achieved. Increasing SCF level will also reduce fiber orientation. While typical nitrogen levels for glass filled materials are in the range of 0.25 to 0.3 percent, it is possible to run as much 0.5 percent. Assuming a desired weight reduction of at least 8 percent, it should not be necessary to run nitrogen levels above 0.3 percent for parts with a wall thickness of 2.5 mm or greater. As wall thickness decreases, the nitrogen level will most likely need to be increased to achieve the same 8 percent weight reduction.

Increased injection speed and decreasing mold temperature have also been shown to help with fiber orientation problems.

**Surface Appearance**

In general, the surface appearance of parts produced with the MuCell process will appear to be lighter in color and lower in gloss than a solid part. The reason relates to the structure of microcellular foams, which typically consist of two solid skins over a foam core. While these skin layers are solid, they are not smooth. Instead, the walls of cells at the flow front will elongate and then tear during mold filling, leaving micro-depressions in the flow front. When the material contacts the mold, these depressions freeze against the mold surface. Given that the gas expansion used to pack the MuCell parts is low pressure, the material is not pushed against the mold surface with sufficient force to press out the micro-depressions. These residual depressions cause microcellular foam parts to reflect light differently than solid molded parts, causing the color and gloss differences.

When using the MuCell microcellular foaming process, the goal should be to produce a part with a uniform surface finish. Adding texture to mold surfaces tends to improve the uniformity of the part surface while highly polished mold surfaces only highlight the surface imperfections.

There are a couple of processing variables that can help in achieving a more uniform surface appearance. SCF level and shear through the gate are the processing characteristics that have the largest effect on surface appearance. For glass-filled, semi-crystalline engineering resins–especially glass-filled PBT, PA6 and PA6.6–lower SCF levels improve surface appearance. At times, the SCF level for these materials can be as low as 0.1 percent. For unfilled materials and filled PP, by contrast, surface finish will become more uniform as SCF level is increased up to visually obvious point of diminishing returns.

In glass-filled PBT, PA6 and PA6.6, surface splay is minimized by decreasing SCF levels. The part starts to look somewhat lighter in color but relatively splay free. With the other materials, small amounts of SCF create the appearance of moisture or heat splay. The small amounts of SCF form isolated steaks on the part resulting in high gloss and low gloss areas of the part. As SCF level increases, a point will be reached where there are no longer visible high gloss areas on the part but only a uniform but low gloss surface.

Points of high shear create large disturbances in the flow of the material resulting in heavy swirls on the part surface. Profiling of injection speed so that there is an initial low-shear slow flow through the gate followed by an increased speed to complete the part filling is a common practice with the MuCell process. The profiling approach usually involves setting all injection steps to a common value and then gradually reducing each step as needed to decrease the heavy splay and move it closer to the gate. Once a speed is reached at which the splay no longer shows on the part surface, increase the last step of the injection profile to a normal value for the material and part. Then gradually increase the screw position at which the transfer from the slow to the fast speed occurs until the splay forms again near the gate. Once the splay shows near the gate, reduce the transfer position slightly. Note that decreasing injection speed will require a shot size increase to avoid a short part.

There are special processing techniques and material grades that have successfully offset some or all of the appearance issues. Variotherm processing, in which an elevated mold surface temperature keeps the skin of the part more pliable through injection and packing, has been effective at eliminating surface splay. Though effective, variotherm techniques are most likely not economically viable unless they used to replace a secondary operation such as plating or painting.

As for materials, there are grades of filled PA6 and PA 6.6 that produce a MuCell parts with a surface finish equal to solid. Many commercial grades of PA6 produce excellent surface finish as currently produced.

**Clamp Tonnage & Injection Pressure**

Cavity pressure, and therefore required clamp tonnage, are typically reduced with the MuCell process. Due to the lower packing pressures, the cavity pressure reductions are typically in the range of 25 percent for parts with a 4 percent weight reduction and 50 percent or more for a 6 percent density reduction.

And since SCF to a molten polymer has the effect of reducing the material viscosity, injection pressure requirement can drop too. Assuming identical process temperatures and speeds, it's possible to achieve injection pressure reduction of up to 25 percent with amorphous materials; 15 percent with filled, semi-crystalline engineering resins; and 10% with unfilled crystalline material. Remember, if maximum viscosity reduction is critical, carbon dioxide should be used as the foaming agent.

Taken together, the reductions in clamp tonnage and injection pressure allow parts to run on smaller molding machines than they might otherwise require, offering molders the opportunity to save money on operating expenses or even capital expenditures.

# Troubleshooting

## Insufficient Molding Benefits

**If weight reduction is lower than expected...**

As noted in the discussion section, any evaluation of weight reduction should be viewed from the perspective of the overall flow length to thickness (F/t) ration (Diagram on page 8 – Optimization). Once it has been verified that based on the F/t ratio, the weight reduction is still below expected results, there are both process related and mold related troubleshooting aspects.

In many cases, it is relatively easy to determine if the limitation on part weight is based on part shape or gas trap/venting. These limitations can generally be quickly evaluated and should be addressed first.

*Account for any thin sections at the end of fill.* MuCell mold filling takes place through the actions of the high-pressure injection screw and the low-pressure gas expansion. As the target weight reduction increases, the gas-expansion component of filling increases. And when thin sections are present at the end of fill, the foaming may provide insufficient expansion to complete fill before the flow front freezes. In these instances, an increased shot size can force plastic into the thin sections. But the improved filling comes at a cost: It compresses the cell structure from the gate to the thin section, leading to heavier parts. Without changing the part design, this situation can be improved by slowing the cooling effect on the polymer – by increasing mold temperature, melt temperature. or both. Alternatively, increase injection speed, which allows the material to reach the mold extremes faster and, thus, at a higher temperature. Increasing SCF level can increase the expansion capabilities of the foam, though this method is usually less effective than slowing the cooling effects.

*Eliminate Gas Traps*. Back filling and hesitation in the material flow can trap gas away from the perimeter of the part – and therefore away from an easily vented location. When gas traps occur in solid molding, molders usually try to apply additional hold pressure or time in an effort to squeeze out the gas. In the MuCell process, this strategy will compress the part's cell structure, significantly increasing its weight. In fact, the part weight will increase until it almost equals that of a solid part before the gas trap is eliminated. The two solutions to a condition such as this are to add a flow director which will change the material flow in the area of the gas trap or to vent this area though an ejector pin or dummy pin. There is no good processing solution for gas traps.

*Troubleshoot the perimeter venting.* First, reduce clamp tonnage to about 40 percent of that required for solid molding. If perimeter venting is an issue, reducing the clamp tonnage should allow for a significant change in weight reduction, up to an additional 50 percent. In some instances, the limitation to weight reduction will be venting in only one location of the part perimeter. Assuming the part doesn't have problems with thin sections, venting in the area can be improved by putting a piece of masking tape at the parting line. If venting is the cause of the limitation, the part should fill.

If the weight reduction is not being limited by the conditions above, there are 3 key process conditions that should be evaluated for increasing density reduction: % SCF, injection velocitiy, and melt temperature. As injection velocity is the easiest of the setpoints to change, increase injection velocity by 50% and reduce shot size until the parts are short. Adjust shot size back to just achieve a full part. Then increase %SCF by 50% at the higher injection velocity and repeat the process of decreasing shot size until just short and then adjust slightly larger until a full shot is achieved. The final step is to increase the melt temperature by 20C and again reduce shot size until short and then adjust back to full. This short process will provide a method for achieving the maximum density reduction. It should be noted that increasing injection velocity and %SCF will most likely have a negative impact on surface finish. Increasing melt temperature will have a negative effect on cycle time.

**If cycle time is longer than expected...**

*Cool the hot spots.* Limitations on cycle time often go hand in hand with hot spots and a resulting post blow defect (see entry below under Visual Defects). Hot spots are often caused by thick part cross sections of the type that produce sink or vacuum voids in solid molded parts. In MuCell molding, however, the hot areas experience post blow: That is, the core of the plastic melt stays hot and continues to expand after the part is ejected from the mold. Poor part cooling due to uncooled slides, cores or deep pockets in the tool can also be responsible for hot spots. Tooling and design changes, such as adding cooling to mold components or coring out thick cross sections, are most effective ways to eliminate hot spots. When tooling or part design changes are not possible:

- ***Reduce process temperatures.*** Mold temperature changes tend to have the greatest effect and should be reduced before melt temperature. Make the reductions significant, 20-30 degrees, to evaluate the effectiveness of this approach.
- ***Reducing SCF level/*** minimizes the residual gas pressure in the cells, which in turn minimizes the driving force of post blow.
- ***Increased weight reduction setting*s** can also reduce the residual gas pressure is to increase weight reduction by the effect of expending more of the gas pressure in cell growth.

**If parts are warping...**

*Increase the weight reduction to eliminate residual stresses.* At weight reductions of five percent or more, MuCell essentially eliminates a molded part's residual stress, one of the sources of warpage. Residual stresses disappear because the pack pressure in a microcellular foaming process is applied locally and equally throughout the part. In solid molding, by contrast, pack pressure is highest as the gate and becomes less as the distance from the gate increases. As shrinkage is a function of pack pressure, this variable pack pressure results in variable shrinkage which in turn causes warpage in solid molded parts.

*Improve glass-fiber orientation if possible.* The MuCell process has a wall-thickness-dependent ability to alleviate warpage caused by glass-fiber orientation. At 2.5 mm and thicker, the process can eliminate most of the glass fiber orientation. Below 2.5 mm, orientation can be reduced but not entirely eliminated. And below 1.5 mm, no change occurs. With those wall thickness limitations in mind, adjust the following to maximize improvements to orientation:

- **Set weight reduction to 8 percent or higher.**
- **Increase SCF levels.** While typical nitrogen levels for glass filled materials are in the range of 0.25 percent to 0.3 percent, it is possible to run up to 0.5 percent. Assuming a weight reduction of at least 8 percent can be achieved, it should not be necessary to run nitrogen levels above 0.3 percent for parts with a wall thickness of 2.5 mm or greater. As wall thickness decreases, nitrogen levels most likely will need to be increased to achieve the 8 percent weight reduction.
- **Increase injection speed.** Faster injection helps fiber orientation because the material fills the cavity with minimal cooling, resulting in higher weight reduction and a thicker core.

*Lower the mold temperature.* The fundamental reason reduced mold temperature improves warpage isn't understood, but experimentation has shown the strategy to be effective in some cases.

## Cell Structure Issues

**If cells only form at the end of fill...**

*Increase the SCF level***.** To achieve a uniform cell structure, the SCF level must be high enough to achieve cell structure throughout the entire part. When too little SCF is introduced the cells always form first at the lowest pressure area, which is the end of fill. As SCF level is increased, the cell structure moves closer to the gate. This problem is more common in unfilled materials and easy to evaluate in transparent and translucent materials.

**If cells are too large with a uniform dispersion...**

*Increase SCF in 0.1 percent increments.* Large, uniformly dispersed cells can indicate a low SCF level in a glass-filled materials or a low SCF level combined with a low weight reduction. As glass fibers are a very good nucleating agent for cells, it is possible to get a uniform cell structure in a part with very low SCF levels, as low as 0.05 percent. However, at this SCF level, the cells will be larger and in many cases not microcellular.

**If cells are too large at the end of fill/...**

*Increase injection velocity.* This condition is not always correctable, but the best approach is to increase injection velocity, which has the effect of increasing the cell nucleation. A higher cell density results and the mold fills more quickly, both of which help control cell growth. A colder mold can also help, but not always. This problem most often occurs when running unfilled, semi-crystalline materials.

## Processing Inconsistencies

**If screw recovery time and injection times vary with random short shots or powdery material on the flow front...**

*Follow the advice under Out-of-Solution Blisters (see below).* Aside from blisters, out-of-solution conditions also cause large variations in screw recovery time of +/-3 or more seconds, injection pressure fluctuations of 20 percent or more, random short shots in which 25 percent or more of the part is missing, or a powdery material on the flow front.

**If shots are short in the same spot on the part...**

*The molding process may be running at its limit – or "running on the edge."* These conditions typically occur when part and mold design issues–such as incorrect gating locations–limit the potential for weight or cycle time reductions. Molders may try to process around the design issues with high injection speeds, very short hold times and, occasionally, excessively high SCF levels. Short shots with the location of the short in the same spot and post blow typically results from running the process on the edge of either weight reduction or cycle time. To correct the problem, design changes may be needed. The advice for correcting Post Blow (see below) may also help.

**If part weight varies...**

*Eliminate the cushion if one is being used. Increase the combined pack and hold time to 1.0 seconds. Reduce injection speed by 20%.* These changes might result in a slightly heavier part, but they should provide better consistency on the transfer point. While a part produced with the microcellular foam process will typically have a higher weight variation than a solid part, that variation should be less than one percent. These part weight variations can occur even with the process running in solution and with an appropriate amount of weight reduction. *Note: The weight variation associated with microcellular foam molding does not translate into increased dimensional variation in the molded parts.*

**If the process varies between short and full shots...**

*Follow the advice for Part Weight Variations (above). Also increase shot size slightly and reduce clamp tonnage to improve venting on the perimeter.* It might also be necessary to add or increase the vent in the area of the short shot.

## Correcting Visual Defects

### Post blow

This distortion of the part surface takes place when the internal gas pressure in the cells is greater than the strength of the frozen skin. At mold open, the foam continues to expand, pushing the surface of the part up. In some instances, the skin layer will crack allowing foam to escape from the inside. Because post blow and out of solution blisters (see below) can appear similar from the outside, parts should be cut open to distinguish between the two defects. If there is cell structure under the distorted surface (rough surface inside), this defect is post blow. If there is a large void under the surface (smooth surface inside), it's a blister. Unlike blisters, post blow usually occur every shot, and always in the same location – the hottest region of the part or the thickest cross sections.

**Solutions:**

- *Increase cooling time to create a stronger, thicker skin layer before the mold opens.*
- *Decrease mold temperature, again to create a stronger, thicker skin layer before mold open occurs.*
- *Reduce melt temperature, though this method is much less effective than decreasing mold temperature.*
- *Reduce SCF level to minimize residual gas pressure in the cells.*
- *Increase the weight reduction to minimize internal gas pressure of the part – because the gas has to expand more to provide the desired weight reduction.*
- *Improve mold cooling and core out thick section to eliminate post blow problems.*

### Blisters: Flow Induced

Flow induced blisters form due to the hesitation effect on the melt near flow interrupters such ribs or bosses. They are most commonly observed in unfilled and talc-filled PP. These blisters always form in the same place on a part, typically just downstream of the flow interrupter. In most cases, there will be a single blister, although there are some instances with multiple small blisters in a path leading away from the flow feature.

**Solutions:**

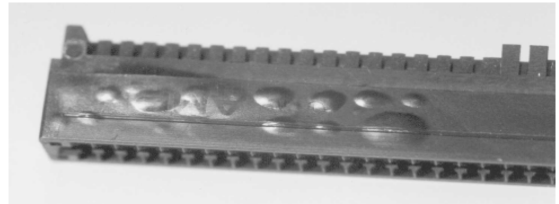
- *Incorporate flow directors, proper radii and, in some cases, increased venting.*
- *Reduce injection velocity as the melt front approaches these flow interrupters.* This method requires a trial-and-error search for the corresponding shot stroke locations and speed adjustments.

Blister Confusion
Flow-induced, large shear-induced and out-of-solution blisters can look outwardly similar. One way to tell them apart is to remember that out of solution blisters occur

### Blisters: Shear Induced

Shear induced blisters can take two different forms. The first type occurs around the gate, tends to be less than 3 mm in diameter and has a very thin skin layer. These blisters occur when injection velocity, an undersized gate or both create excessive shear conditions through the gate. The second type affects semi-crystalline engineering resins, especially POM. Larger and thicker skinned, this type of shear blister will be located ran-

domly around the part but always in the cross-sectional center of the part wall. Blisters in semi-crystalline materials are also a function of shear through the gate. Yet in this case, they form because shear causes a rapid crystallization of the skin layer and forces the SCF to over-saturate the molten core. Shear-induced blisters of both kinds present themselves in every shot or almost every shot.



There are two varieties of shear-induced blister. Above are small blisters that occur around the gate. At left are larger blisters that affect semi-crystalline engineering materials

**Solutions**:

- *Reduce injection velocity.* Profile injection speed such that a slow speed is used until the flow front forms in the mold cavity. Then increase the speed to complete the filling.
- *Redesign or resize the gate***.** This strategy can be used in case the process adjustments do not solve the problem.

### Blisters: Out of Solution

Though they can look similar to the larger shear-induced or flow-induced blisters, out-of-solution blisters will occur randomly in the part. And out-of-solution blisters will not be affected by injection velocity. In addition, while flow blisters and shear induced blisters can occur in 50 percent or more of the parts, out-of-solution blisters typically occur in cyclical clusters. For example, blisters may occur in clusters of 3 or 4 sequential shots separated by 20 or more blister-free shots. The number of parts between clusters of blisters is typically consistent. In one application, for instance, the clusters occurred every 350 parts or so. The cause of the defect is an SCF bubble in the injection barrel, brought on by improper SCF dosing. With each dose of SCF, the bubble grows larger until it reaches a size where it moves out the barrel and into the mold. The cycle in which the bubble exits the barrel depends on the process conditions. The formation of blisters tends to be more likely as the impact modifier (rubber) level of a material increases. Examples of this are that a high impact polystyrene (HIPS) is more prevalent to out of solution blisters than a general purpose polystyrene (GPPS). Consequently, the MPP setpoint for a HIPS is typically 500 to 750 psi higher than for GPPS.

**Solutions:**

- *Increase MPP:* The setting for MPP is a function of the material type, filler level and amount of SCF being added. If the MPP value is set too low, the SCF will not be fully dissolved in the polymer therefore single phase solution will not be created.
- *Reduce SCF levels*. The amount of SCF is a function of the material type and the filler level. If the SCF level is too high then a single- phase solution will not be created.
- *Confirm that the start of SCF dosing is not set to occur as soon as the screw start rotating.* If it is, the start position must be increased. Typically the start of SCF dosing should be 10 to 15 mm.

After making changes for an out-of-solution condition, purge back to solid and then reintroduce the SCF. When restart, set the SCF dosing conditions such that the *% SCF* setting is at 70 percent of the previous level.

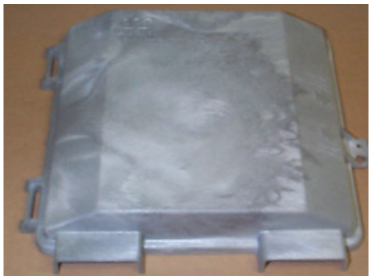
### Surface Swirl

It should be noted here that the appearance of a foamed part will in almost all cases be different from a solid part. Typically the surface appearance is lower in gloss and lighter in color. The uniformity of the surface finish can be affected by process conditions, material and tool texture. The objective of these guidelines are to provide the most uniform surface possible. To create a "perfect" surface, it is typically required to combine the MuCell process with other technologies such as gas counterpressure or variotherm technologies.

Swirl marks that interfere with the normally uniform appearance of the part surface are usually caused by excessive shear through the gate.

**Solutions:**

- *Increase gate size if possible.*
- *Decrease injection velocity to minimize shear through the gate.* In some instances, it is possible to profile the injection, increasing velocity once a flow front has been established in the mold cavity.
- *Change SCF level/ according the material type*. When processing glass-filled, semi-crystalline engineering resins, reducing SCF level can improve appearance. The SCF level can be decreased to as little as 0.1 percent. When running all other materials, higher SCF levels will yield a more uniform, but low gloss, appearance. If the surface appears to have streaks of high gloss and low gloss areas, increasing SCF level will eliminate the high gloss areas.
- *Add mold texture*: The addition of a grain to the mold surface will create vent channel for the SCF and also impart a roughness to the part surface which obscures some of the surface roughness normally seen on parts produced with the MuCell process.



These parts are identical in weight reduction, but the swirled part above was run using a flat fast injection speed while the uniform part on the bottom was run with profiled injection speed that started slow until the flow front is established.

### Dimples

These small depression in the surface of the part usually measure 2 to 3 mm in diameter. They are typically caused by and found over larger cells, often near the gate area. They occur most often in softer materials, most commonly with unfilled PP but also with other unfilled materials and filled PP.

**Solutions:**

- *Increase SCF level.* Low SCF levels result in low cell density and, therefore, larger cells.

# Typical Nitrogen Levels and MPP Settings By Material

| Material | Nitrogen, % | MPP, bar (psi) | Comments |
|---|---|---|---|
| *Polyolefins* | | | |
| HDPE | 0.6 – 1 | 172 (2500) | Highly susceptible to voids. |
| Unfilled PP | 0.6 – 1 | 172 (2500) | Nitrogen can reach 2 percent at high length-to-thickness ratios |
| Talc-filled PP | 0.4 - 0.6 | 117 - 159<br>(1700 - 2300) | |
| Glass-filled PP | 0.3 - 0.5 | 100 - 120<br>(1450 - 1740) | Glass promotes cell growth more effectively than talc. |
| *Amorphous* | | | |
| PS and PC | 0.25 - 0.5 | 172 - 207<br>(2500 -3000) | Very good foamability. |
| HIPS, ABS and Impact-modified PC | 0.2 – 0.4 | 193 - 228<br>(2800 - 3300) | Impact modifiers adversely affect cell structure. |
| Glass-filled amorphous resins | 0.2 - 0.4 | 138 (2000) | Independent of impact modifiers. |
| *Semi-Crystalline Engineering Resins* | | | |
| Unfilled PA | 0.3 - 0.6 | 172 (2500) | |
| Glass-filled PA, PBT and PET | 0.2 - 0.4 | 69 - 103<br>(1000 - 1500) | Excellent cell structure control. |
| *High-heat Resins* | | | |
| Unfilled polysulphone, PEEK and similar | 0.5 - 0.7 | 172 (2500) | |
| Glass-filled polysulphone, PEEK and similar | 0.3 - 0.4 | 172  (2500) | Excellent cell structure control. |

# Startup and Shutdown Procedures

**Short-term Shutdown**

1. Cut off the plastic material (close the feed throat of the barrel).
2. Run production parts just before running out of plastic material.
3. Disable SCF injector.
4. Change the operation of the injection molding machine to "manual."
5. Turn off the hot runner (if any) heat zones.
6. Turn off the cooling water supply to the hot runner.
7. Turn off the cooling water/hot water supply to the mold (sometimes, it is necessary to turn off the cooling water supply to the core side earlier to avoid water condensation on the mold surface).
8. Close the mold without the clamping pressure.
9. Retract the nozzle from the mold.
10. Empty the barrel (see *Note C*).
11. Disable MPP.
12. Perform the SCF injector purging as per Trexel procedure.
13. Retract the screw to about 1/3 of the full shot stroke.
14. Put the barrel temperatures in standby mode/reduce the barrel temperatures.
15. Shut down the motor of the injection molding machine.

**Short-term Startup**

1. Increase barrel temperatures to the required settings.
2. Turn on any hot runner heat zones with the required temperature settings, and turn on the cooling water supply to the hot runner.
3. Turn on the mold temperature controller with the required temperature setting (for cooling water, this can be done later).
4. When the temperatures and soak time are reached (important!), switch on the motor of the injection molding machine (injection molding machine in manual mode operation).
5. Check for the normal operation of the SON by toggling the MuCell on/off (or Solid off/on) switch on the SCF delivery unit.
6. With the MuCell On mode enabled and without adding the plastic material (barrel is still empty), set the injection pressure limit to 550 bar (~8000 psi, absolute pressure), air purge the barrel (empty) for 2-3 times to seat the check ring against the seat of the NRV( i.e. rotate the screw for about 5 seconds and then move the screw forward to seat the ring of the screw tip, retract the screw to 1/3 to 1/2 of the full shot stroke and then repeat the process for 2 more times).
7. Perform the SCF injector purging as per Trexel procedure to check for its normal operation.

**For cold runner mold**

1. Add the plastic material (open the feed throat of the barrel) and set the injection pressure limit to 550 bar (8000 psi, absolute pressure), perform air shots with the plastic melt material until the residual purging material is completely purged out of the barrel (see *Note C*). Skip to Step 15.

**For valve-gated hot runner mold**

2. Add the plastic material (open the feed throat of the barrel) and set the injection pressure limit to 550 bar (8000 psi, absolute pressure), perform air shots with the plastic melt material until the residual purging material is completely purged out of the barrel (*Note C*).
3. Ensure the mold plates are closed, and then move the nozzle to the mold.
4. Open the mold plates and place a piece of wooden board/cardboard between them to protect the core side.
5. Check for the normal operation of the valve gates.
6. Purge the hot runner (see *Note C*) until the residual purging material is completely purged out.
7. Take away the wooden board/cardboard from the mold.
8. Based on the predefined molding parameters, reduce the shot size to ~90% of the predefined shot size setting (beware of part sticking and note if the part can be ejected) OR increase the switch over position by ~10 mm while keep the injection pressure limit be 550 bar (8000 psi, absolute pressure).

9. Check for the correctness of the predefined MuCell related parameters (e.g. SCF delivery pressure, SCF start position, Shot Weight, %SCF) on the SCF delivery unit.
10. Enable SCF injector
11. Perform 2-3 shots with this setting (the injection molding machine is in semi-automatic mode).
12. Change the injection pressure limit from 550 bar (8000 psi, absolute pressure) back to the predefined setting.
13. Change the shot size/switch over position back to the predefined setting and start the molding operation

**Long-term Shutdown**
1. Cut off the plastic material (close the feed throat of the barrel).
2. Run production parts just before running out of plastic material.
3. Disable SCF injector.
4. Change the operation of the injection molding machine to manual mode.
5. Open the mold plates and place a piece of wooden board/cardboard between them to protect the core side.
6. Add the purging material (open feed throat of the barrel)
7. Purge the barrel, SON and hot runner with the purging material.
8. Cut off the purging material (close the feed throat of the barrel).
9. Take away the wooden board/cupboard from the mold.
10. Turn off the hot runner heat zones.
11. Turn off the cooling water supply to the hot runner.
12. Turn off the cooling water/hot water supply to the mold (sometimes, it is necessary to turn off the cooling water supply to the core side earlier to avoid water condensation on the mold surface).
13. Retract the nozzle from the mold.
14. Empty the barrel (see *Note* C).
15. Disable MPP.
16. Perform the SCF injector purging as per Trexel procedure.
17. Retract the screw to about 1/3 of the full shot stroke.
18. Turn off the barrel heat zones.
19. If necessary, clean the mold surface and spray the mold anti-rust agent on the mold surface.
20. Close the mold without the clamping pressure.
21. Shut down the SCF delivery unit as per Trexel procedure (if the system will be started up again for the molding operation in a short time, this step and step 23 may be omitted).
22. Shut down the motor of the injection molding machine.
23. Turn off the power of the injection molding machine.

**Long-term Startup**
1. Turn on the injection molding machine.
2. Turn on the barrel heat zones with the required temperature settings.
3. Turn on the hot runner (if any) heat zones with the required temperature settings and turn on the cooling water supply to the hot runner.
4. Turn on the mold temperature controller with the required temperature setting (for cooling water, this can be done later).
5. Start up the SCF delivery unit as per Trexel procedure.
6. When the temperatures and soak time are reached (important!), switch on the motor of the injection molding machine (injection molding machine in manual mode operation).
7. Check for the normal operation of the SON by toggling the MuCell on/off (or Solid off/on) switch on the SCF delivery unit.
8. With the MuCell On mode enabled on the SCF delivery unit and without adding the plastic material (barrel is still empty), set the injection pressure limit to 550 bar (~8000 psi, absolute pressure), air purge the barrel (empty) for 2-3 times to seat the check ring against the seat of the NRV (i.e. rotate the screw for about 5s and then move the screw forward to seat the ring of the screw tip, retract the screw to 1/3 to 1/2 of the full shot stroke and then repeat the process for 2 more times).
9. Perform the SCF injector purging as per Trexel procedure to check for its normal operation.

**For cold runner mold**

10. Add the plastic material (open the feed throat of the barrel) and set the injection pressure limit to 550 bar (8000 psi, absolute pressure), perform air shots with the plastic melt material until the residual purging material is completely purged out of the barrel (see *Note c* below). Skip to Step 16.

**For valve-gated hot runner mold**

11. Add the plastic material (open the feed throat of the barrel) and set the injection pressure limit to 550 bar (8000 psi, absolute pressure), perform air shots with the plastic melt material until the residual purging material is completely purged out of the barrel (see *Note* c below).
12. Ensure the mold plates are closed, and then move the nozzle to the mold.
13. Open the mold plates and place a piece of wooden board/cardboard between them to protect the core side
14. Check for the normal operation of the valve gates.
15. Purge the hot runner (see *Note C*) until the residual purging material is completely purged out
16. Take away the wooden board/cardboard from the mold.
17. Based on the predefined molding parameters, reduce the shot size to ~90% of the predefined shot size setting (beware of part sticking) OR increase the switch over position by ~10 mm while keep the injection pressure limit be 550 bar (8000 psi, absolute pressure).
18. Check for the correctness of the predefined MuCell related parameters (e.g. SCF delivery pressure, SCF start position, Shot Weight, %SCF) on the SCF delivery unit.
19. Enable SCF injector.
20. Perform 2-3 shots with this setting (the injection molding machine is in semi-automatic mode).
21. Change the injection pressure limit from 550 bar (8000 psi, absolute pressure) back to the predefined setting.

# Glossary of Terms

**Barrel Plug**
A plug that can be installed into the barrel port in place of the SCF injector and sleeve.

**Blocker Valve**
The valve inserted into the hydraulic loop to prevent the oil behind the screw from draining to tank at the end of screw recovery.

**Cell Growth**
The expansion of cells due to the pressure of the gas in the polymer.

**Cell Structure**
The cell size, cell density and cell-size distribution.

**Electrical-to-Pneumatic (E/P)**
A piece of hardware that receives an electrical signal from the PLC and converts it to pneumatic pressure that is used to adjust the pre-metering pressure regulator.

**Human-Machine Interface (HMI)**
The touch screen used to make changes to the process and which displays the process status.

**Injection Request Signal**
Signal from the injection molding machine to the SCF Delivery System indicating the molding machine is ready to inject plastic. Part of the MMU sequencing.

**Injection Permit Signal**
The signal returned by the SCF Delivery System to the injection molding machine in response to the Injection Request Signal when the SCF Delivery System is ready for the machine to inject plastic.

**Injector Sleeve**
The outer housing into which the SCF injector mounts.

**Mass Flow Element (MFE)**
The calibrated, replaceable orifice across which the SCF is metered. The MFE allows the PLC to very accurately calculate the required pressure drop across the opening to achieve the requested mass flow rate.

**Microcellular**
The definition of microcellular varies, but Trexel defines microcellular in injection molding as a foam with an average cell size of less than 100 microns.

**MuCell Modular Upgrade (MMU)**
Hardware supplied by Trexel that converts a standard injection molding machine to a machine equipped to run the MuCell microcellular foam process.

**MuCell Process Pressure (MPP)**
The plastic pressure on the melt during screw recovery and screw idle used to create and maintain the single phase solution.

**Nucleation**
The point at which the cell sites form.

**Original Equipment Manufacturer (OEM)**
A supplier of injection molding machines such as Engel, Nissei and JSW. An OEM MuCell machine is a machine supplied from the machine manufacturer with the MuCell equipment already installed.

**Out Of Solution**
When the SCF is not properly mixed with the molten polymer causing random blisters on the part, screw recover problems and/or loud popping during purging. Typically caused by too much SCF or the MPP set too low.

**Relief Valve**
This is a spring loaded valve which releases the gas pressure at a preset pressure of 415 bar.

**Rupture Disk**
A piece of safety equipment used to protect the barrel and SCF Injector from over pressurization. This disc will be assembled into the barrel at the same position along the barrel of the position of the injector. If the pressure under the injector increases above a set limit, the disc will break and protect the injector.

**Rupture Disk Indicator (RDI)**

A closed loop electrical signal designed to open and signal if the Rupture Disk has failed.

**Screw Recover Delay**

A delay in screw recovery after hold pressure ends.

**Screw Recover Time**

The time from the start of screw rotation until the end of screw rotation.

**Solid Mode**

A mode where the screw position control method is deactivated and SCF dosing is not permitted into the barrel of the injection molding machine.

# Troubleshooting

## PARTS PROBLEMS

**Internal Blisters**
- Decrease SCF Level
- Increase MPP
- Increase Screw Recovery

**Surface Blisters**
- Decrease Screw Recovery
- Check Screw Recovery Profile

**Post Blow**
- Decrease Mold Temperature
- Increase Cooling Time
- Decrease SCF Level
- Decrease Barrel Temperature
- Decrease Injection Speed

**Dimples**
- Increase SCF level
- Decrease weight reduction

**Flow Issues**
- Decrease injection speed
- Profile injection speed
- Raise barrel temperature
- Raise mold temperature

## CELL STRUCTURE PROBLEMS

**Not Enough Cells**
- Increase SCF Level

**Large Cells**
- Increase SCF
- Increase Injection Speed
- Increase Shot Size

**Cells Only In Thick Areas**
- Increase SCF Levels
- Decrease Shot Size
- Increase Mold Temp
- Increase Barrel Temp

**Non-uniform Cells**
- Increase SCF Levels
- Increase Injection Speed
- Increase Shot Size
- Decrease Weight Reduction
- Increase MPP

## PROCESS PROBLEMS

**Short Shots**
*Confirm SCF In solution, then:*
- Increase mold temperature
- Increase barrel temperature
- Increase injection speed
- Increase shot size
- Increase SCF Level
- Decrease Clamp Tonnage

**SCF Out of Solution**
*Check dosage start-end settings, then:*
- Decrease SCF levels
- Increase MPP levels
- Check delivery pressure $\Delta p$
- Increase barrel temperatures

**Variable Recovery Time**
*Confirm SCF is in solution,*
*Confirm dosage start-end settings, then:*
- Decrease SCF level
- Check delivery pressure $\Delta p$
- Increase screw recovery
- Increase MPP
- Increase barrel temperature

**Inconsistent Part Weight**
*Confirm SCF in solution*
*Check dosage start/end setting, then*
- Check delivery pressure $\Delta p$
- Profile screw recovery
- Increase shot size
- Increase MPP
- Profile injection speed
- Increase hold time
- Decrease cooling time
- Reduce cushion
- Increase hold pressure

Key
- Strong influence
- Moderate influence
- Marginal Influence