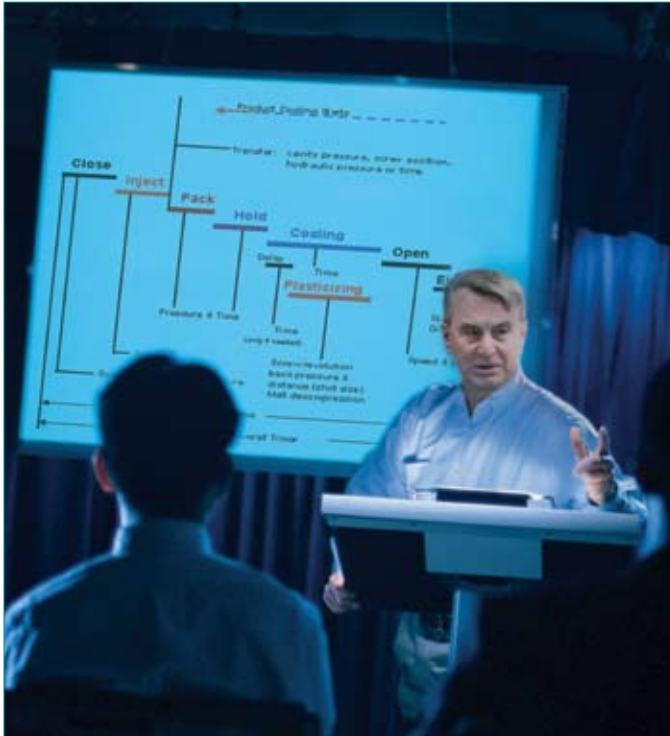




sharing the knowledge

Mold-Masters understands the importance of sharing knowledge. A knowledgeable workforce, having a good understanding of the technology they are working with, is a distinct competitive advantage in today's injection molding industry. We want to assist our customers in the pursuit of knowledge.

This portion of the "knowledge section" discusses some of the basic principles pertaining to the application and use of hot runner systems. It also deals with topics of general interest to the hot runner user.



Mold-Masters also hosts seminars throughout the year at the *Mold-Masters Academy* in Georgetown, Ontario, Canada and at other locations throughout the world. Visit us online at www.moldmasters.com for more information on upcoming seminars.



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polymer structure

heat and temperature are two different things

A mixture of ice and water has a temperature of 0°C (32°F). Heat must be applied to increase the water temperature. As heat is applied, the ice melts, but it is noticed that the temperature does not rise. The temperature of the water will not rise until all the ice has melted. What happens to the heat if it was not converted into a temperature change?

This example shows that it takes energy to change the structure of a material. In this case, changing the structure of ice to water.

As plastic materials are heated, they also go through changes in structure. The temperatures that these changes occur at are called transition points. Plastic materials can be divided into two broad categories according to their structure. These are amorphous materials and crystalline materials.

amorphous materials

Amorphous materials have their molecular chains in a random tangle. As heat is applied to amorphous material, it becomes gradually softer. An amorphous material will show a gradual transition as it is transformed from a solid to a rubbery material. This behavior can be compared to that of butter, becoming gradually softer as it is heated.

The temperature at which this occurs is called the material's Glass Transition Temperature (T_g). As the material is heated further, it will become softer, allowing it to be molded. Amorphous material does not show sharp changes in properties as it's heated and typically has a broad processing range.

crystalline materials

What we call crystalline materials are in fact semi-crystalline. That is, they have small regions of crystalline material, surrounded by amorphous material. In the crystalline regions, the polymer chains have taken up a tight, orderly, arranged structure. As a crystalline material

is heated up, a change in the mechanical properties will be witnessed as the amorphous regions encounter a glass transition phase. The crystalline regions remain intact, preventing the material from flowing. Considerably more heat must be applied before the crystalline regions break apart. This is a sharp transition point, occurring at a specific temperature for that material. This temperature is called the Melting Temperature (T_m). Below the T_m , the material is a solid. Above the T_m , the material is a melt, and can be processed. The behavior of crystalline material can be compared to that of ice and water, having a sharp transition between being solid and being liquid.

materials

General classification of materials into amorphous and crystalline groups, as outlined in the following table, gives a practical guideline of processing characteristics. Both groups are subdivided according to temperature difference (ΔT) between the processing temperature and the temperature at which the material solidifies.

In general, crystalline polymers are characterized by (ΔT) less than 50°C/122°F:

PA 66: melt temp. 285°C - solidification temp. 255°C = ΔT 30°C

In order to achieve the required temperature drop (ΔT) in the melt at the gate within the same cooling time, the cooling rate in the gate area must be many times higher for amorphous than for crystalline polymers. To some extent, the temperature of the nozzle tip can also influence the cooling rate. The amount of this influence depends on the method used to provide thermal separation between the nozzle tip and the gate steel. It also depends on the gate seal itself.

POM: melt temp. 200°C - solidification temp. 180°C = ΔT 20°C

For amorphous polymers ΔT is usually greater than 100°C / 212°F

ABS : melt temp. 250°C -



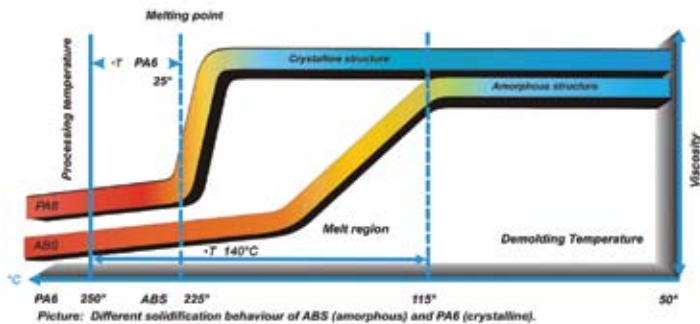


solidification temp. $110^{\circ}\text{C} = \Delta T\ 140^{\circ}\text{C}$

PC : melt temp. 300°C -

solidification temp. $150^{\circ}\text{C} = \Delta T\ 150^{\circ}\text{C}$

processing



An understanding of the complex relationship between polymer structure and its processability in hot runner injection molding is essential for the correct selection and application of hot runner systems.

The thermal and rheological characteristics of a polymer are set by its specific macromolecular structure. Processability is influenced by the chemical structure, the molecular weight and form, the flexibility of the molecule, and the intermolecular bonding.

rheology

Polypropylene	$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- \\ & & & & & \\ \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 \end{array}$
Polystyrene	$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- \\ & & & & & \\ \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 \end{array}$
Polymethyl Methacrylate	$\begin{array}{ccccccc} \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 \\ & & & & & \\ -\text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- \\ & & & & & \\ \text{H} & \text{C}=\text{O} & \text{H} & \text{C}=\text{O} & \text{H} & \text{C}=\text{O} \\ & & & & & \\ & \text{CH}_3 & & \text{CH}_3 & & \text{CH}_3 \end{array}$
Polysulphone®	$\begin{array}{c} \text{CH}_3 \\ \\ \text{C}_6\text{H}_4-\text{C}-\text{C}_6\text{H}_4-\text{O}-\text{C}_6\text{H}_4-\text{S}-\text{O} \\ \\ \text{CH}_3 \end{array}$

structural formulas of various unrelated polymers.

Even within a particular thermoplastic family, significant processing differences can be found despite a similar basic structure. For example, HDPE has an

even, simple carbon-hydrogen chain structure ($\text{CH}_2 - \text{CH}_2$) with almost no side groups (1 per 10,000 carbon atoms), whereas LDPE has a less organized chain structure with approximately 150 to 230 side groups. This means that HDPE can attain a high crystallinity (70-90%), whereas LDPE, due to its unorganized structure, achieves less crystallinity (20-60%). As a result, HDPE has a melt temperature of 110°C as compared to that of LDPE at 120°C . The viscosity of an unorganized chain structure with many side groups is also higher. The longer chains in larger macro-molecules (greater molecular weight) also increase the viscosity. The normal molecular weight of polyethylene lies between 50,000 and 300,000 whereas with ultra-high molecular PE that flows extremely poorly, it can be up to 5,000,000.

Polyethylene (few side branches)	$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- \\ & & & & & \\ \text{H} & \text{CH}_3 & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$
Polyethylene (many side branches)	$\begin{array}{ccccccc} & & & & \text{CH}_3 & & \\ & & & & & & \\ & & & & \text{CH}_2 & & \\ & & & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- & \text{C}- \\ & & & & & \\ \text{H} & \text{CH}_3 & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ & \text{CH}_3 & & & & \end{array}$

different structural formulas within the polyethylene family.





flow properties

Rheology is the study of how a material flows under different conditions. Viscosity is a measurement of how well a liquid flows. We are familiar with different viscosity motor oils being specified for different applications. Treacle or molasses has a higher viscosity than water.

Water has some specific flow characteristics. Hot water does not flow much better than cold water. Its viscosity does not change significantly with temperature.

Water is a Newtonian fluid. This means that if the force (pressure) making it flow is, for example, increased by 50%, then you will get 50% more output. The flow rate is proportional to the pressure acting on it.

The flow behavior of plastic materials is a little more complex than that of water. Plastic materials have Non-Newtonian behavior. Most plastics encountered for injection molding applications will exhibit what can be described as “shear thinning”. The more these materials are forced to flow, the easier they flow. For example, if the pressure making a material flow is increased by 50%, there will be more than a 50% increase in output.

A common indicator of how a material flows is the Melt Flow Index, or MFI. The MFI is a useful method to compare one grade of material with another. However MFI tests are conducted at a single temperature, and at a very low flow rate. They do not give the full picture of the flow properties of a material.

To understand how a material will behave under injection molding conditions, the material is tested using an apparatus that measures the pressure needed to make the material flow through a bore whose diameter and length is known. This is done at a range of flow rates, and at several temperatures. The flow rate Q (m³/sec.) and bore size are used to calculate the shear rate:

$$\text{Shear Rate} = 4Q/\pi r^3$$

The pressure required to flow through the bore (of

known radius r , and length L) allows the shear stress to be calculated:

$$\text{Shear Stress} = \Delta P r / 2L$$

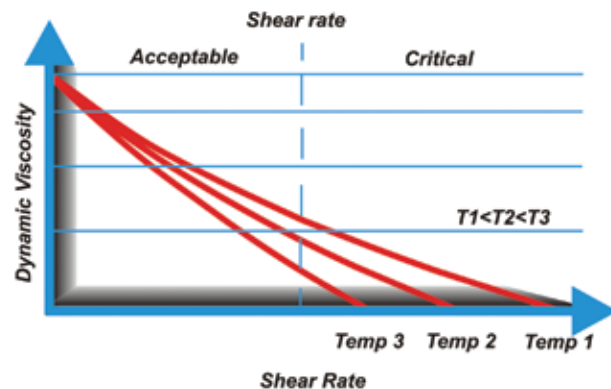
Finally, the viscosity that the material is showing (apparent viscosity) can be calculated:

$$\text{Viscosity} = \text{Shear Stress} / \text{Shear Rate}.$$

The results are typically presented in the form of a table, or as a graph of Shear Rate vs. Viscosity. This graph is sometimes referred to as a flow curve. Material suppliers typically provide results for three different temperatures.

See the accompanying Shear Rate chart. This data can then be used to predict how the material behaves, and the pressures that will be required to make it flow at different rates and temperatures, through different sized flow channels.

It can be seen that there is a wide range of flow proper-



ties, which have to be catered to. In evaluating any application, the flow length and wall section of the part are considered to give an indication of the pressures required to fill the part. When filling a cavity, the additional complexity of the material cooling and solidifying as it makes contact with the cavity wall must be considered. This can be evaluated using finite element flow analysis.

In addition to the pressure required to fill the part, the pressure to flow through the hot runner system needs to be considered. It is important to ensure that the





total pressure required is within the capability of the intended injection molding machine. Some allowance should be made for the machine nozzle and such factors as filter nozzles, or shut off nozzles, which could further add to the pressure loss experienced. The pressure that will be required to make material flow through the hot runner system is not just a function of the hot runner system. It also depends on the material to be molded and the rate at which the cavity has to be filled.

In designing the hot runner system, there is often some flexibility with regard to the bore sizes selected within the manifolds, and the nozzles, which make up the system. If the pressure losses through the system are a concern, larger bores may be selected to reduce the pressure loss. As larger bores are used, the volume of plastic in the system obviously increases. If the volume of the material in the hot runner system becomes too great, this can result in slower color change performance. Some materials can only withstand a limited time period at processing temperature. These materials will show signs of degradation and poor mechanical properties if exposed to an extended residence time within the hot runner system.

The ability of a thermoplastic to flow at processing temperature depends on its macromolecular structure. A linear polymer structure with few or no side groups flows easier than a polymer with many or large side groups. A thermoplastic with a low molecular weight or short polymer chain flows easier than one with a high molecular weight or long chain.

Normally, the polymer producer supplies all the necessary flow data, such as viscosity, for each individual

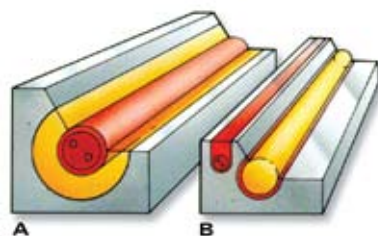


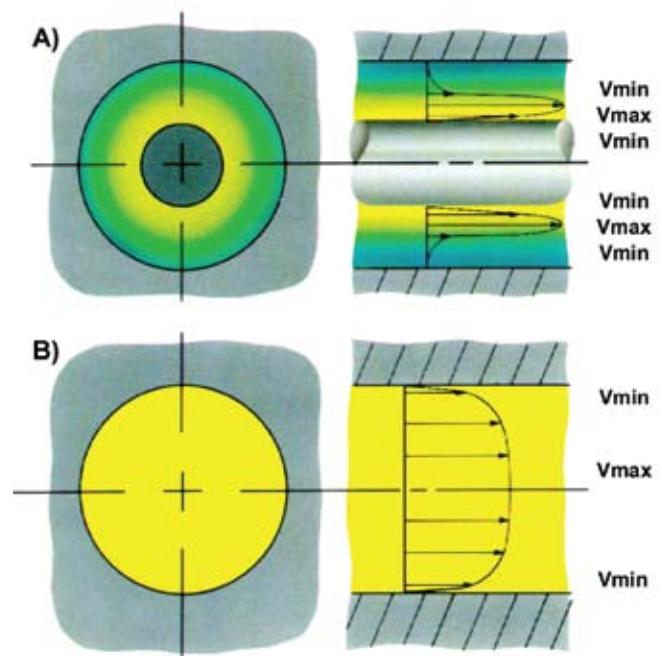
image A: Internally heated annular flow channel, rheologically disadvantageous, leads to higher melt shear and pressure drop.

image B: Cylindrical flow channel provides the best rheological conditions for guiding the melt to the cavity.

polymer it sells. It is absolutely necessary to consider this flow data, because it determines runner size and gate geometry. This is why material, part, and process have to be specified when choosing a hot runner.

As the melt is forced along the hot runner channel under pressure, it is subject to shear stress. The melt can only tolerate shear up to a certain level, known as the maximum shear rate, beyond which the macromolecules are damaged and the polymer's intended properties are changed. Runner diameters too small or flow lengths too long can cause damage to the polymer or its additives by bringing it past this limit, especially with shear sensitive or highly viscous polymers. This would in turn reduce the quality of the part.

Most of the shear on the material occurs along the melt



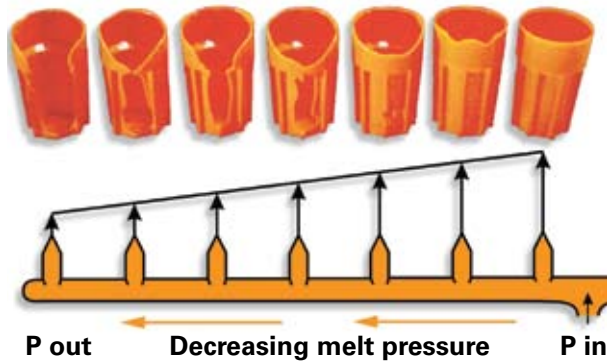
To produce the same average flow speed, annular hot runner channels must have a greater maximum flow speed and thus greater flow shear than cylindrical hot runner channels.

channel wall. Across the core of the melt stream, the melt velocity is fairly constant and therefore very little shearing or friction occurs. Heating elements within the melt channel (internally heated) should be avoided





since the increased surface area (annular flow) subjects the melt to much greater shearing. Pressure drop is an indication of the amount of shear that the melt is subjected to. Therefore, the lower the pressure drop between the machine nozzle and the mold cavity, the better the conditions for processing.

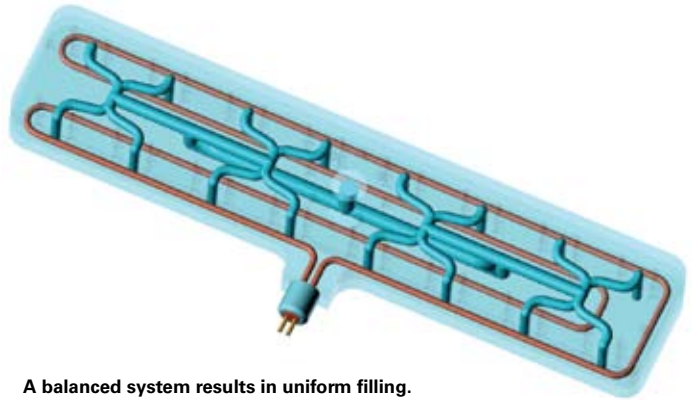


Unbalanced systems result in cavity-to-cavity inconsistencies. Another important rheological objective in hot runner design is to “balance” the flow. Unbalanced hot runner systems are only used to fill cavities of different sizes, or when aiming for a specific fill pattern of a multi-gated part.

Natural flow balance means the same flow length, the same channel diameter, and the same number of turns from the machine nozzle to each mold cavity. This leads to uniform filling and back pressure conditions in each cavity, and therefore uniform part quality. A hot runner can also be balanced using artificial rheological balancing. This is achieved by combining various channels and gate geometries for each cavity.

A naturally balanced hot runner is superior to an artificially balanced system. In a naturally balanced hot runner, uniform conditions will continue to exist in each cavity even when flow properties change due to changing material, differences in molecular weights, or changing injection parameters like temperature, time, or pressure. In an artificially balanced system, these changes would cause quality problems, such as poor weight consistency in the molded parts.

A naturally, rheologically balanced hot runner system



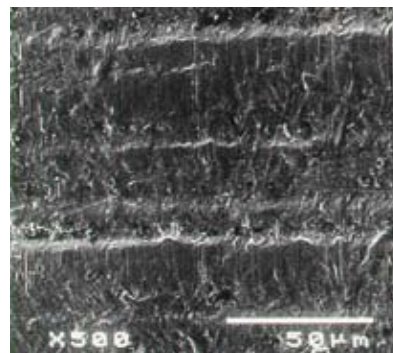
A balanced system results in uniform filling.

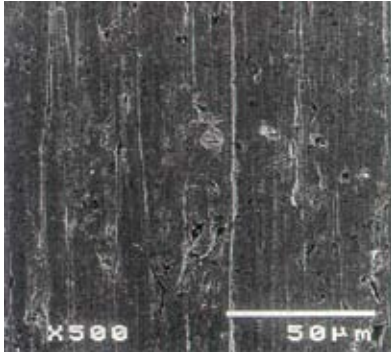
provides the injection molder with the widest processing window on multi-cavity molds with the same cavity sizes, and guarantees consistent high quality results.

The detailed design of the melt channel within the manifold has a major influence on the processing of thermally sensitive thermoplastics, additives and pigments. Highly polished channel walls reduce pressure drop, and rounded curves eliminate dead zones or flow shadows where the melt can sit and degrade. When processing extremely critical thermoplastics, the quality of the melt channels should be checked using fiber optics.

Small shot weights and long cycle times greatly increase the residence time of the melt. In such cases it is best to consult a material specialist to determine the critical residence time. This time is highly dependent on temperature. Increasing the processing temperature causes the maximum residence time to drop exponentially.

The *Master-Series* nozzle follows ideal rheological principles. Channel surface magnified 500x using an electron microscope.





Channel created by
Mold-Masters,
gun-drilled and
polished in the
direction of
flow.

ciples. The runner in the nozzle is a round melt channel extending down to the gate. This is not the case in most other hot runner mini-nozzles where limited size forces the use of a torpedo in the center of the melt channel. A torpedo results in many disadvantages such as higher shear, longer residence time of the melt, and more difficult material and color changes. The design of the *Master-Series* not only eliminates these disadvantages, but offers a better relationship between flow channel and nozzle body diameter than any other existing nozzle - a relatively large internal runner diameter for a very small external body diameter.

For low and medium viscosity materials and small shot weights, this compact nozzle offers a large variety of gating techniques. The result is a range of totally new application areas made possible.





balancing

the effect of hot runners on improving injection mold balancing

When more than one gate is required within a system, the question of balance is raised. When running multi-cavity molds, it's important that all the gates perform identically. This is especially true when molding highly toleranced and thin wall components. If the gates do not all behave in the same manner, the mold is said to be unbalanced. Serious imbalance can result in some cavities being over packed and sticking in the mold, while other cavities remain under packed and retain poor dimensional stability.

In recent years, the construction of higher cavity tools and demand for better quality parts has put an increased emphasis on mold fill balancing. Since the majority of these tools incorporate hot runners, at times the hot runner has been falsely accused of being the direct cause for the imbalanced filling of cavities. A poorly constructed hot runner system can cause imbalance. However, a well-built hot runner system, monitored by a top-quality temperature controller, can be a valuable tool to assist the processor in fine-tuning the seven key issues that can lead to mold fill balance. These seven key phenomena that contribute to mold fill balance are.

1. **venting uniformity**
2. **uniform wall sections**
3. **uniform mold temperatures**
4. **effects of shear on melt viscosity**
5. **uniform heat profile**
6. **naturally balanced manifold design**
7. **injection profile and velocities**
8. **proper temperature control**

1. venting uniformity

Non-uniform venting is the number one cause of mold fill in-balance. A common misperception is that venting is acceptable so long as there is no evidence of burning on a part. However, poor venting can lead to

significant backpressure in the cavity and the end result is poor fill balance.

The volume of air in the cavity needs to be displaced by the molten plastic. In the example of a syringe barrel, the size of the syringe orifice will determine how fast the plunger can move forward and how much pressure is required to push the plunger. If a mold exhibits poor venting, it will require more pressure and time to displace the air in the cavity in order for the plastic to fill the volume.

Ironically, the depth and size of vents is often determined by how easy the resin flashes and not by how quickly the cavity fills. By having insufficient venting, the cavity backpressure makes it more difficult to fill. If all the cavities exhibit the same level of venting, poor or acceptable, fill balance is not impacted. If the venting characteristics across the cavities vary, then the mold fill will be imbalanced.

The best way to check for vent uniformity from cavity to cavity is to do a pressure leak-down test. By fabricating a fixture specific to your mold cavity or core, you can check venting at the parting line. The fixture needs to be machined flat and cover the cavity parting line. This fixture also requires a pressure gauge and valve shut off. Clamp the fixture to the parting surface. Apply air pressure, then close the valve and measure the time required for the air to leak out through the vents. Do this for every cavity on the tool. This won't tell you if you have a general venting problem, however it will tell you if your venting is consistent from cavity to cavity.

2. uniform wall sections

Uniform wall sections are not only critical for dimensional stability of the part, but also affect how fast the cavity fills. An unbalanced fill can be directly attributed to dissimilar wall sections from cavity to cavity. Even very small differences in steel dimensions can yield a large change in part volume. Clearly, a high cavity mold with different part volumes across the cavities will not fill in a balanced fashion.





The following chart is based on a small part (test strip) measuring 1.00" x 2.00" x .080"

Applying the same logic to the gate diameter, we can

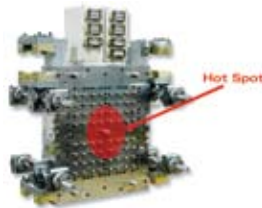
cavity type		plate A	plate B	
part thickness	inch	0.079	0.081	0.002 difference in part thickness
max flow length	inch	2.000	2.000	0.000 difference in part length
part width	inch	1.000	1.000	0.000 difference in part width
part volume	cm ³	2.589	2.654	2.5% difference in part volume
gate diameter	inch	0.029	0.031	6.9% difference in gate diameter
gate area	square inches	0.00066	0.00075	14.3% difference in gate area

With a variance of only .002 inches in thickness, the part volume changes 2.5%.

see an almost 7% change in gate diameter, however the flow volume or cross sectional area changes 14%. As you can see, very subtle changes in wall sections and gate diameters can have a severe effect on cavity balancing.

3. uniform mold temperatures

Non-uniform mold temperatures adversely affect how resin flows throughout the mold, especially when you introduce a hot runner in the mold base. The extra heat from the hot runner that is built up in the center of the tool needs to be addressed by introducing good water circuit designs and turbulent flow. Proper cooling at



the right portion of the mold becomes paramount to maintain consistency - not only from cavity to cavity but also within the same cavity from shot to shot. A key factor in proper cooling design is facilitating the correct amount of turbulence in the water flow. A highly turbulent flow dramatically improves the efficiency of cooling circuits - in some cases by as much as 10 times more. Using the following chart you can apply the GPM requirements for any water circuit to achieve turbulent flow. This chart drastically simplifies applying Reynolds numbers to achieve turbulent flow.

4. effects of shear on melt viscosity

In order for a hot runner manifold system to be naturally balanced, the melt distances to each gate must exhibit the same flow length and flow diameters.

temperature (°F)		40°F	60°F	80°F	100°F	120°F	140°F	160°F	180°F	200°F
viscosity (centistokes)		1.54	1.12	0.86	0.69	0.56	0.47	0.4	0.35	0.31
diameter (inches)		GPM flow required for Reynolds number equal to 5000 using water with no additives.								
0.188	3/16	0.46	0.33	0.26	0.21	0.17	0.14	0.12	0.10	0.09
0.250	1/4	0.61	0.44	0.34	0.27	0.22	0.19	0.16	0.14	0.12
0.313	5/16	0.76	0.55	0.43	0.34	0.28	0.23	0.20	0.17	0.15
0.375	3/8	0.91	0.66	0.51	0.41	0.33	0.28	0.24	0.21	0.18
0.438	7/16	1.07	0.78	0.60	0.48	0.39	0.33	0.28	0.24	0.21
0.500	1/2	1.22	0.89	0.68	0.55	0.44	0.37	0.32	0.28	0.25
0.563	9/16	1.37	1.00	0.77	0.61	0.50	0.42	0.36	0.31	0.28
0.625	5/8	1.52	1.11	0.85	0.68	0.55	0.46	0.40	0.35	0.31
0.750	3/4	1.83	1.33	1.02	0.82	0.66	0.56	0.47	0.42	0.37
0.875	7/8	2.13	1.55	1.19	0.96	0.78	0.65	0.55	0.48	0.43
1.000	1	2.44	1.77	1.36	1.09	0.89	0.74	0.63	0.55	0.49





When considering polymer rheology - as the melt flows through the channels and changes direction - the melt can be subjected to shearing thus changing the melt viscosity. On many manifold configurations, this phenomenon can result in the center cavities filling much faster than the outer cavities. This will be more pronounced on manifold systems that are designed on a single level.

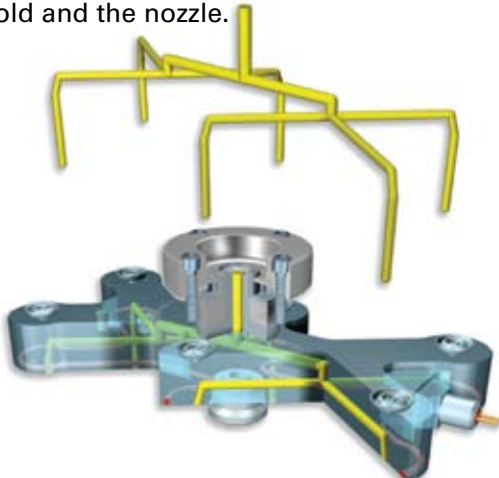
Two ways to counteract this phenomenon are:

1. to provide level changes within the manifold
2. stack one manifold on top of another creating a level change



5. uniform heat profile

Mold-Masters integral heating technology is profiled to provide heat where it's needed and to compensate for thermal losses. This provides a uniform heat profile in the manifold and the nozzle.



By comparison, conventional nozzles employ heater bands that provide heat to a relatively isolated portion of the nozzle. A conventional nozzle with isolated heat must add additional energy into the polymer in the area of the heater band to achieve a condition where material will flow in the non-directly heated areas of

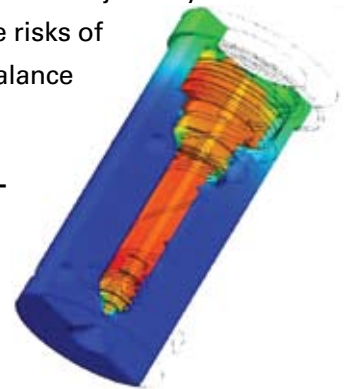
the nozzle. This added heat energy must be removed during the hold portion of the cycle.

The *Master-Series* nozzle with its uniform heat profile maintains a consistent melt temperature over the entire length of the nozzle. Thus the average melt temperature is lower, resulting in improvements in cycle time. *Master-Series* line of nozzles also incorporates *CIC* technology that further equalizes the temperature gradient across the nozzle, delivering the best heat profile in the business.

When the melt for each cavity has experienced the same, constant heat throughout its journey from the manifold and to the gate, the risks of experiencing mold in-fill imbalance are greatly reduced.

6. naturally balanced manifold design

When designing hot runner manifolds, *Mold-Masters* has always maintained the principle of Natural Balance.



In order to achieve natural balance, the material must flow through identical geometry from the machine nozzle to each of the gates. This means not just the same flow distance, but the same bore diameters and the same number of turns along the flow path. This ensures that every gate receives material that has experienced exactly the same shear history in its path to the gate. Natural balance provides the greatest flexibility when processing. With natural balance, the balance is inherent in the design, and is not based on a specific material or processing temperature.

The study of rheology shows that the flow properties of a polymer melt are dependent on both the temperature and the shear that the melt is subjected to. In addition to rheological balance, it is essential that the system is thermally balanced and that the gate sizes are all dimensionally accurate so that all aspects of the

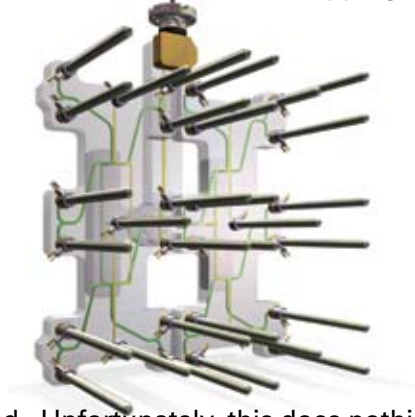




system are balanced.

7. injection profile and velocities

Another big contributor to filling imbalances is not utilizing a proper injection profile for maintaining consistent melt front velocities. When filling a moderately sized part, most injection processors run a straight injection profile (constant velocity) while stepping the

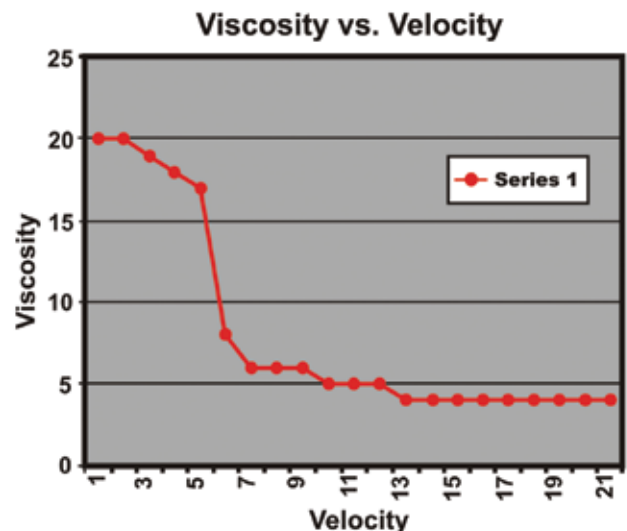


pressure as needed. Unfortunately, this does nothing to improve the cavity fill, and in most cases has an opposite effect.

When filling a multi-cavity mold, the goal is to keep a consistent melt viscosity. The challenge lies in the properties of the resin and two issues that change the melt viscosity during the injection process. One issue is the effect of shear on melt viscosity. As the melt flows through the channels and changes direction, the melt can be subjected to shearing thus decreasing the melt viscosity. The second issue is that all resins exhibit an increase in viscosity in response to an increase in velocity.

Thus, in order to achieve consistent cavity filling velocity and viscosity, the injection velocity needs to continue to increase through the injection cycle.

Failure to have an increasing velocity causes the melt to go through huge viscosity changes and the cavity filling velocity to decrease. This has a very direct effect on overall balance of the mold.



8. proper temperature control

Accurate and stable temperature control of the hot runner nozzles is crucial for balanced fill of the cavities, especially on multi-cavity tooling. On hot tip runnerless systems the hot runner nozzle tip and cavity steel land area determine the amount of material solidification that takes place directly in the gate area.

At the point in time when injection of the resin takes place, it is ideal for all the gates to open simultaneously. Now we all know in the real world this doesn't happen because of all the variables that can occur in the molding process. One of the advantages of having a hot runner system with individual tip control, is that the controller will automatically compensate for subtle gate to gate variations by adjusting the amount of power each tip receives and so maintains a consistent set temperature. Furthermore, you can adjust the individual set temperatures to compensate for varying material solidification from gate-to-gate and achieve better gate opening balance.

Most temperature controllers on the market today do a reasonable job of controlling temperature. However





when it comes to controlling high-wattage, low-mass hot runner nozzles, the field of sufficiently advanced temperature controllers is drastically reduced.

High-wattage, low-mass hot runner nozzles heat up very fast and cool down very fast. If you don't have a high performance temperature controller, the hot runner nozzle will experience undesirable temperature swings. Those temperature swings will cause non-uniform solidification of material in the gate area, and will result in an un-balanced fill pattern.

Because of the fast response of the nozzle heater, the controllers logic needs to act even faster than the nozzle in order to achieve a stable and consistent temperature.

Mold-Masters TempMaster-Series temperature controllers are equipped to do just that. Through proprietary programming the controller is able to identify the type of heater being controlled and automatically apply the correct algorithms to achieve precise and stable temperature to the hot runner nozzles, thus resulting in a more balanced fill of cavities.

summary

The hot runner is a terrific tool to assist in fine-tuning mold balance, but it too has its limitations. So in order to achieve perfect balance, it's imperative to make sure all these items concerning imbalance fill of cavities are addressed.





thermodynamics

cooling

A mold is a heat transfer device. Its purpose is to transfer the heat out of the plastic after it has been injected into the mold, and to do this as quickly as possible. The faster that a mold achieves this, the more efficient it is considered. Efficiency of a mold will also be related to how well it achieves certain mechanical functions, but the cooling portion of a molding cycle represents a significant portion of the cycle in most applications.

Based on this, a newcomer to the industry might be forgiven for thinking that molds should always be run with chilled water. Those who have witnessed a variety of materials running will know that it is not that simple. General practice is to run the mold “as cold as possible” in order to speed up the cycle as much as possible. What are the limitations on what is “as cold as possible”?

who decides this?

The answer is that the physical properties of the material will decide how cold the mold can be. Each different plastic material will have different thermal properties. Many materials will have a ‘solidification’ temperature, which is significantly higher than room temperature. This means that the mold will be hot to touch, and actually has to be heated. The function of the mold is still the same. It is cooling the plastic melt.

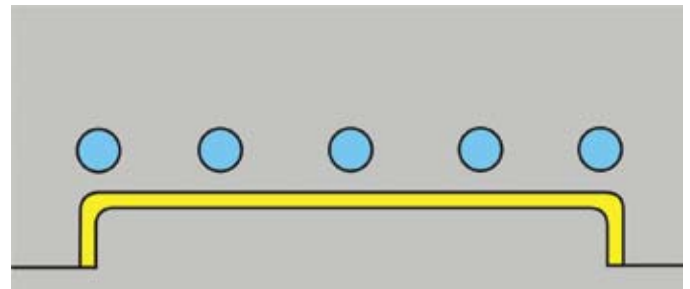
If the mold temperature is too low, the polymer may solidify before the cavity has been filled. The thinner the part, the faster it will solidify and the greater the challenge to fill the part. Clearly a relationship exists between the wall thickness and flow length of the part, as well as the fill time required, and the injection pressure that will be needed. This relationship will be different for each polymer used.

gate cooling

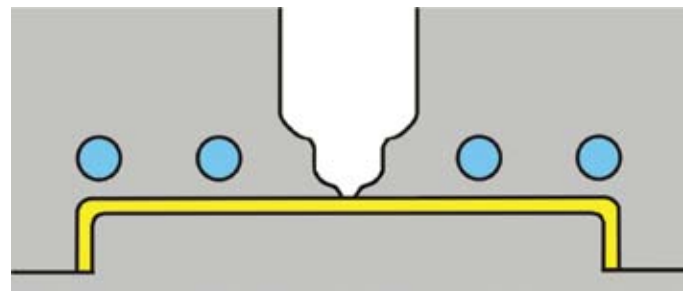
When designing cooling into a cavity insert, (around the part), the cooling should be as uniform as possible. The positioning of the hot runner nozzle disturbs the ability to maintain this uniformity. In addition to this, the hot runner nozzle adds a heat source to the heat balance equation and the gate is a source of heat generated through friction during injection.

The cooling of the gate area is therefore of prime importance. If the gate area is too hot, this can result in poor gate performance such as gate stringing with Tip or sprue gates, and a hot spot visible around valve gates.

Frequently tip gates are required to be recessed below the part surface. There may be several reasons for this:



uniform cooling of cavity



positioning of the hot runner interrupts cooling uniformity

- The application is sensitive to any gate remnant being felt on the surface of the part when the part is being handled.
- The application has a mechanical function, which





requires that nothing sticks up above the part surface.

If the dimple is not designed correctly, it can actually cause the gate to string and give a poor gate performance. Gating onto a flat surface will provide uniform cooling around the gate. As the gate becomes recessed, the cooling is less effective. The cooling of the gate becomes more restricted as the depth of the dimple is increased and the diameter of the dimple on the part is decreased.

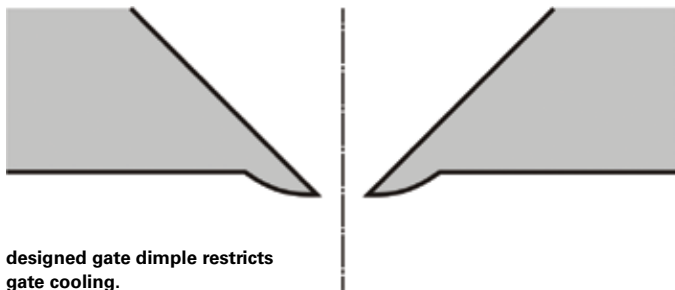
The following is an example of a recessed gate design used for a closure application. This provides a reason-



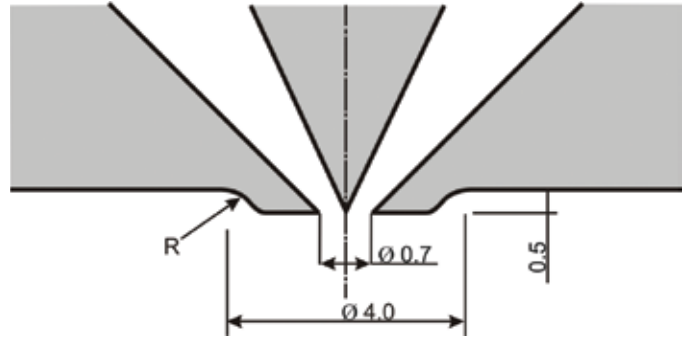
Valve gating example: Gate appearance is excellent - no vestige able dimple to contain any gate remnant, while still maintaining cooling to the gate. Note that the dimple has a flat bottom, which is preferred.

steel selection

The selection of the gate steel can have a significant influence on the performance of a gating method.



Stainless steel is attractive as a cavity steel for its corrosion resistance properties and for ease of polishing. While it's successfully used in many tip applications, it does have lower thermal conductivity than H13. This makes the cooling issues much more critical. With a stainless steel, it becomes more difficult to absorb the



Example of a gate dimple used for a closure application.

heat generated in the gate and to transfer it to the cooling channels. Poor gate performance such as high vestige or gate stringing can result. H13 is recommended for its overall properties in order to provide optimum cooling and gate performance.

Cooling is an important consideration for any hot runner gating application. In discussing cooling, emphasis has been placed on the performance of the tip type style gates. This is due to the demanding performance typically required from tip applications. Cooling is just as important a consideration for the performance of **Sprue** gates, however this gating method is not typically used for applications having critical gate appearance requirements. The performance of stainless steel in the gate area of a sprue gate is more likely to give an acceptable performance.

Edge gates rely on the solidification of the plastic in the gate to provide a clean gate appearance. If the gate has not cooled sufficiently, it will not shear properly. This condition can either lead to extended cycle times, or unsatisfactory gates. In conjunction with a close examination of the cooling circuit around an edge gate nozzle, it is critical that the steel have sufficient thermal conductivity.

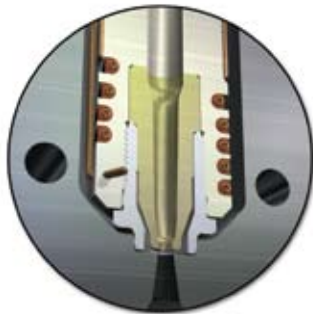
Stainless steels are not recommended for edge gate applications for this reason. In addition, the design of the edge gate typically features a thin steel section



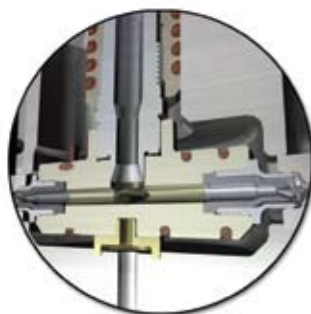


in the gate area. This is subjected to cyclical thermal loading with each molding cycle. H13 is recommended for this type of application due to its superior thermal shock resistance properties.

Valve gating is perhaps the gating method that is most tolerant of poor gate cooling. That is not to say that cooling is not required, just that the cooling does not need to be as intense. The function of cooling in a valve



Bi-Metallic C-Sprue



Melt Disk

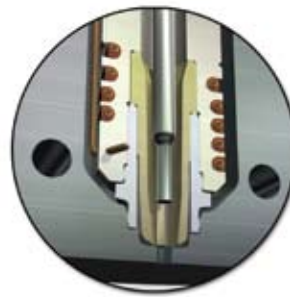
gate application, in addition to cooling the plastic in the cavity, is to cool the valve pin. The valve pin provides a mechanical shut off with the cavity steel. However, the plastic, which filled the cavity, flowed around the pin when it was in the open position. This put shear heat into the pin immediately before it closed. The pin relies on the contact with the cavity to dissipate this heat from its front surface.

If the pin is too hot, the plastic will stick to the surface of the pin. Amorphous materials are more susceptible to this behavior than crystalline materials.

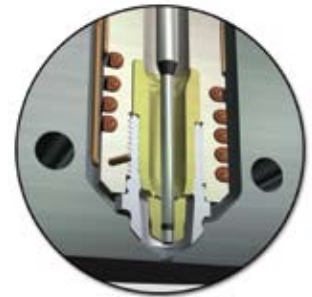
The cooling in the gate must also dissipate the shear heat that is developed in the gate during injection. This heat will be greater for more viscous materials, larger shot sizes, and smaller gates. These are aspects that must be considered in conjunction with the cooling design when selecting the gating method and the gate size.

plate cooling

The hot runner system relies on the mold plates for mechanical support. The design of the hot runner system will minimize heat transfer into the mold plates, but some heat will transfer into the plates through both conduction and radiation. Cooling channels are needed in the manifold



Bi-Metallic C-Valve



Accu-Valve CX

plate and in the top clamp plate to remove this heat. The purpose of the cooling is to maintain a consistent temperature. Variations in temperature will cause dimensional fluctuations due to thermal expansion. This can lead to wear of leader pins and interlocks, especially on large plates.

mechanics

Although the mold and hot runner system appears to be a static assembly, it is in fact subjected to high dynamic forces during the injection molding cycle.

Cyclical bending forces on the mold plates are partially transmitted into the hot runner system. In addition, the heating and cooling of the mold and hot runner system result in high forces through heat expansion.

These forces have to be considered in the mechanical layout of the mold and hot runner. Insufficient mold strength will cause melt leakage in the hot runner and flashing of the part. Mechanical stability calculations through methods such as finite element analysis can be made.

The number of mold plate screws has to be sufficient to handle the internal forces caused by heat expansion and



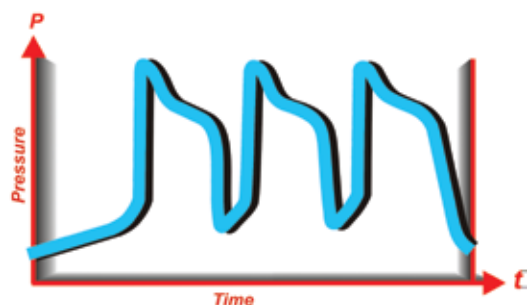


melt pressure. Preload on these screws prevents plate separation. Positioning should be as close as possible to the gating points, and evenly spread around.

For gating methods where the nozzle well is filled with plastic for insulation purposes (hot-tip, hot-edge, multi-tip), an extremely high force of up to 6 tons per nozzle may occur due to melt pressure. This force acts on the nozzle tip as well as the gate land of the cavity plate, and can damage an insufficiently strong mold.

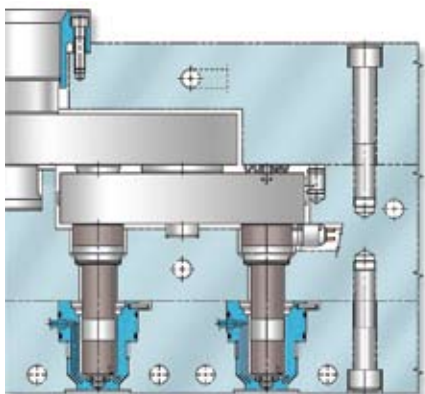
The mold cutout for the hot runner system must be minimized in order to allow enough support areas for the cavity plates, and to provide sufficient mold rigidity.

The contact load of the machine nozzle transmits high



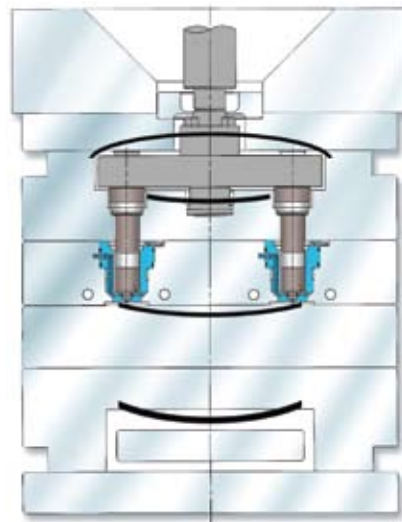
A hot runner experiences cyclical loading during the normal injection process.

forces into the hot runner system. The machine nozzle should stay in permanent contact with the hot runner, and provide only the force necessary to prevent leakage between machine nozzle and backplate (melt bore cross-section $\times$ max. injection pressure $\times$ 1.5). The melt should be decompressed by internal screw suck



back, and not by physically moving the injection unit carriage every cycle.

Deep plunging machine nozzles often create transverse forces, which they can transmit into the hot runner system due to inaccurate centering of the injection unit. Machine nozzle forces are transmitted to the manifold through the locating ring, and are supported by the mold plate. Sufficient support, and exact fit-



The schematic cross section shows possible deformations of the mold plates. Maximum deflection of the mold plates should not exceed 0.02mm; otherwise flashing of crystalline thermoplastics can occur.

ting along with sufficient plate thickness and hardness are required to prevent the manifold from excessive deflection.

Stress optics using polarized lenses can be used on a model of the mold to show the internal stress in the hot runner manifold. The lines emphasize the stress patterns caused by external forces, which are transmitted into the hot runner.

Another principle of sound hot runner design is unhindered and stress-free heat expansion. With the *Master-Series* line, the hot runner manifold (which can consist of a main manifold and sub-manifolds) is rigidly centered in the mold





by a locating ring on the injection side of the mold. This center is the fixed point from which the main manifold expands in all directions. Sub-manifolds and nozzles are allowed to slide under a pressure seal relative to the main manifold. This method ensures that each nozzle remains perfectly centered in the nozzle cutout, which is paramount for consistent gate geometry.

Optimum gate function is guaranteed by:

- A concentric gate opening aligned with the nozzle center



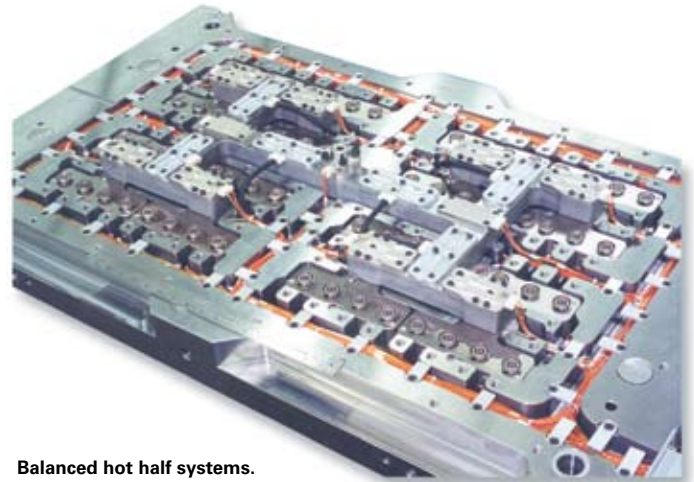
Machine nozzle.

- An accurately ground bore for the nozzle seat
- Even nozzle head height

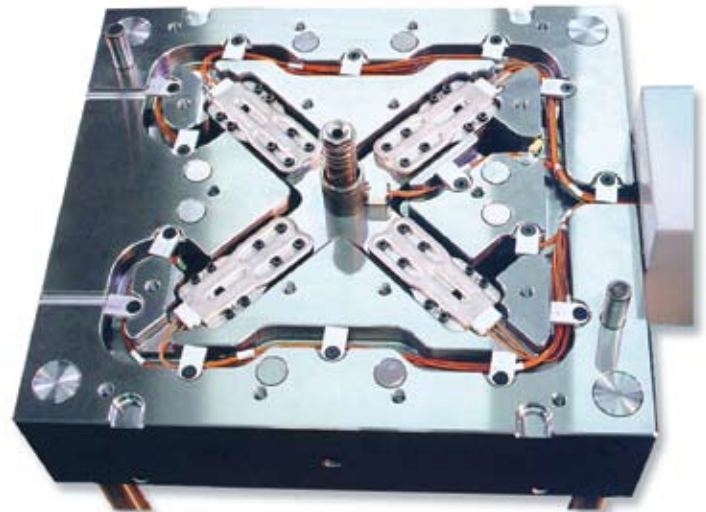
For custom-built systems, the manifolds are dimensioned so that the manifold/sub-manifold/nozzle melt channels are perfectly aligned at the specified process-



Stress optics photo shows force (F) created during molding.



Balanced hot half systems.



ing temperature.

The splitting of the hot runner system into main manifold and sub-manifolds, also divides the heat expansion into smaller sections. A sliding pressure seal between main and sub-manifolds in effect reduces the heat expansion of the overall system, minimizing dimensional changes in the hot runner due to changes in processing temperature.

The origin for the bi-directional heat expansion of the nozzle is in the plane where the nozzle seat is located. This is the origin for the calculation of the axial expansion towards the cavity on one side and the clamping





plate on the other side. A small portion of this elongation is used for preloading the sealing surfaces in the nozzle/manifold transition area. The exact preload for a given processing temperature should be calculated and included in the dimensions of the mold cutout.

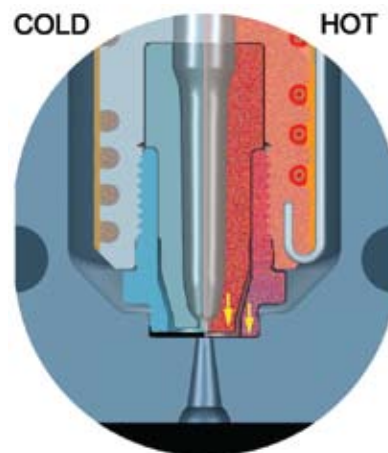
The supporting components (valve support bushings, gate seals) show gaps in cold conditions. These gaps are determined using the relevant processing temperature.

The thermoplastic melt cannot be considered inert material; since in many cases it will react with the metal it comes in contact with. Therefore, it is important to provide the hot runner with sufficient corrosion resistance.

It would not make sense to provide different hot runner systems for aggressive and non-aggressive processing applications. To require exact prior knowledge by the injection molder of all the thermoplastic materials and additives to be used in the future with each hot runner would be unreasonable. It is therefore the mandate of the hot runner manufacturer to design standard components capable of withstanding the toughest processing conditions to be encountered today and in the foreseeable future.

Chemically aggressive constituents in the melt can ap-

pear as by-products of the polymer. This is exemplified by the splitting off of halogens during PVC processing, formaldehydes from POM, and acetaldehydes from PET.



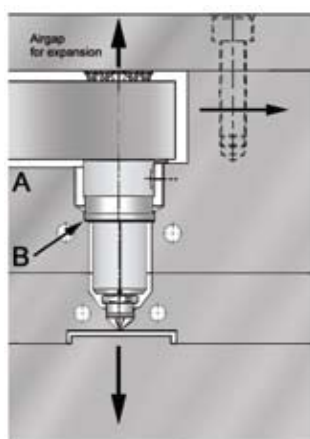
Heat expansion of a Sprue Gate
Air gap for expansion

Some melt additives can have a corrosive effect if they separate from the polymer during processing. Such melt additives are becoming increasingly common. A typical example is the creation of halogens such as Bromine when flame-retardants degrade due to overheating.

In many cases the presence and effects of fillers and reinforcing additives (i.e. glass fibers, ceramics) amplify damaging influences during processing. Such situations demand that hot runner components are protected with the use of corrosion resistant steels and alloys containing Chromium, Nickel, Titanium, Wolfram, etc. In addition, surface hardening methods (Nitriding, Titanium-Nitriding), high-speed steel inserts, surface upgrading (Nickel flashing, Nickel plating) help provide protection.

controlling the heat in hot runners

It is a known fact that hot runner systems should act as an extension of the injection machine nozzle. The temperature of the melt should remain the same throughout the system. However, in practice, tempera-



Heat expansion in a hot-tip system
A - Datum for manifold B - Datum for nozzle

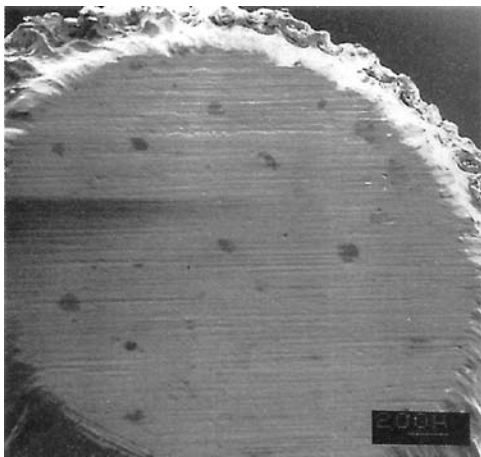




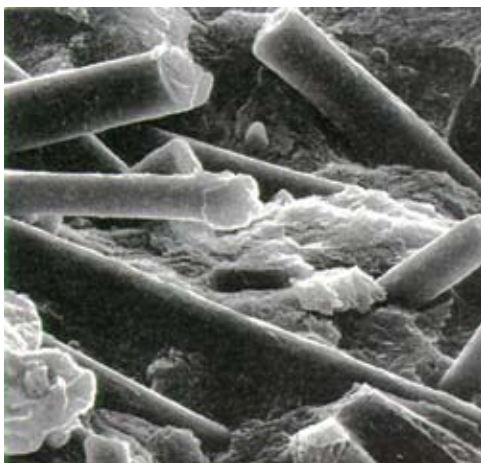
ture variations in the melt are normal and expected. For example, the shear heat produced in the gate area is significant and can negatively affect the melt conditions if not controlled. The good hot runner systems prepare for these variations by providing distributed heat input; powerful watt densities for quick heating and adequate heat dissipation to remove shear generated, excess heat.

nozzle heat

The figure below shows a hot runner nozzle with a tubular heater element metallurgically fused inside a profiled groove. The tubular heater element extends from the nozzle base (also called flange) to the tip (gate area). The varying nozzle geometry coupled with the mold contact areas suggest that the heater element



Corrosion and Abrasion damage on valve pin.



Glass fiber reinforced POM

requires profiling around the nozzle. In the flange area, a larger concentration of heat is required to compensate for the larger mass. At the contact area with the mold cavity, high heat losses are expected. Higher concentration of heat in this area is therefore required. The nozzle body, on the other hand, has no contact with the mold, therefore less heat is needed.

Another source of heat to the plastic is termed shear heat. This heat results from chain interaction due to the profiled flow velocity in the runner as illustrated in the figure below. If the runner diameter is decreased, more heat is generated. Most of this heat will, however, be localized at the runner walls where the change in velocity is greatest. To minimize this heat generation, the hot runner should have good surface finish, open pipeline structure, and sufficiently large diameter runners.

runner diameter

However, due to the constraints on runner diameter regarding plastic flow, flow length and shot size, the designer is faced with the fact that to guarantee good parts and fast cycles, shear heat has to be controlled.

heat dissipation

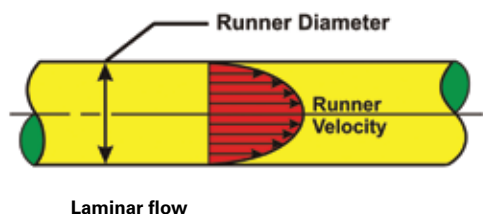
Shear heat as mentioned above is a cyclic phenomenon. The hot runner must account for this heat source in its design. By the same token, when excess heat is produced, heat dissipation to the cooled mold cavity (such as through radiation) should not be impeded.

However, there is a wide misconception in the hot runner community stating that a hot runner should

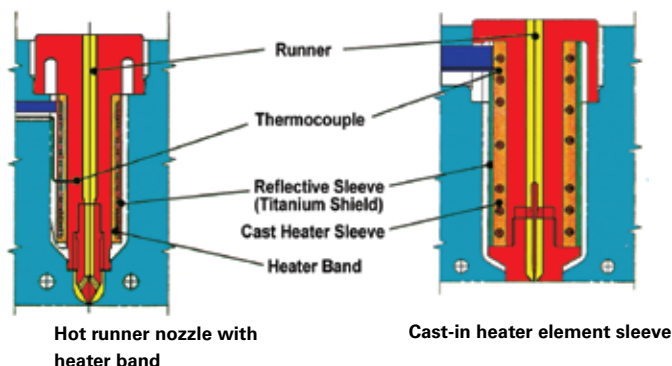




function like a “thermos.” The above figures show two similar hot runner designs. The first shows a band heater wrapped around the nozzle and then enclosed in a low thermal conductivity heat shield. As implied by its designation, the heat shield reflects any radiated heat back to the hot runner. In essence, the hot runner operates like a thermos bottle with minimum heat loss to the surrounding water cooled plates and cavity.



In the figure on the right, the heater is cast into a copper alloy band. In this case, the heater band not only retains heat but acts like a heat sink. Also, the thermal expansion of the band is typically greater than the thermal expansion of the nozzle. In effect, control of the process will worsen as the heater band separates from the nozzle during heating and during process conditions.



Consider a molding cycle during plastic injection to the cavity. Shear heat is generated in the runner and especially in the gate. Depending on thermocouple location, the controller will decrease the power input after shear heat has accumulated and reached the thermocouple position. A hot runner acting like a thermos will not lose heat as fast as needed.

Accordingly, the controller continues to decrease the power input. By the time the thermocouple has sensed

the shear heat and has lowered power input, tens of cycles might have evolved. Until this excess heat is dissipated, material degradation, stringing, and/or longer cycles may have resulted.

One might suggest that to avoid the problem of overheating, the nozzle temperature should be decreased to account for shear heat. Ironically, this seems to work during start up, but after a certain number of cycles, the same problem occurs. To solve this problem, longer processing cycles are required due to the slow heat loss provided by the thermos design. Consequently, one of the possible advantages of using a hot runner to cut cycle time is defeated.

thermocouple location

Along with the thermos design, there are claims that some hot runners may operate at lower temperature settings than others. Did the plastics processing temperature suddenly change for that material or has something been modified in the temperature control unit? In most cases, it's the thermocouple location that is responsible for this 'misbehavior'. In fact, the processing temperature of the plastic at steady state is a material property.

For example, a certain grade of polypropylene is processed in a temperature range of 230°C to 250°C. Unless a different grade material is employed or additives used, we should expect polypropylene to be processed in the same temperature range.

What would then explain the fact that the temperature controller outputs a low reading? It's the thermocouple location that dictates this behavior. When the thermocouple is located close to the melt stream, a recording of the true processing temperature is registered. By the same token, the thermocouple should also be close to the heaters to ensure fast temperature control. Therefore the location of the thermocouple should be optimized near both the gate and the heater source.





In the case of the metallurgically fused heater element, the thermocouple can easily be introduced between the heater and the melt stream close to the gate area. The heater band systems vary to some degree in their construction, but the design similarity is that a heating band is affixed and centered on the nozzle body. The temperature is frequently controlled in or near the heater band itself and well removed from the conditions of the material in the runner and gate.

conclusion

An ideal hot runner provides a medium of material transfer from the machine nozzle to the cavity with no effects on its rheology. Unwanted changes in temperature should be quickly rectified through profiled heat input, optimum thermocouple location, and adequate heat dissipation.

Any molder who extensively uses hot runners will know that you must have sufficient and balanced heat for quick start-ups. You must also be able to control the gate area to avoid sputtering and oozing out of the gate. The thermocouple should therefore be located near this area, in close proximity to the nozzle interface and the mold. That is precisely where the critical function and control of any hot runner system must be, and that is also where we want and need radiation of the nozzle into the cooled mold.

the science of gating

The success of any hot runner application is dependent on numerous factors. With selection of the most appropriate polymer a given, incorporating good part and mold design practices, and a correctly sized machine/screw are also critical factors. Of equal importance is the selection of the most appropriate gate location on the part and the correct gating method for the application.

In the part conception stages, consideration should be given to the preferred gate location. It should be chosen by taking into account the part filling characteristics (a mold flow program is useful here) and knowing that the

gate will be the weakest point in the molded part. The gate area is the weakest section due to the orientation of the molecular chains in the injection-molded part. As the material flows into the part, the molecular chains are oriented longitudinally (radially if the gate is in the part center). It is strongest in the direction of flow and weakest at right angles to the flow.





Once the preferred location is determined, a choice is made between the broad range of hot runner gating types. They can be classified as either Tip (pin-point), Sprue, Edge or Valve gates. Since each method has both advantages and disadvantages, the selection of the most appropriate gate is always a compromise. When selecting the type of gate (and later the gate size), first consider the material suitability with the gating method.

tip gating

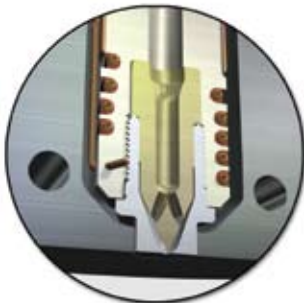
This is the most common gating method. Generally acceptable for crystalline and amorphous materials, this method relies on gate diameter, gate area cooling, and temperature control at the tip to optimize part quality.

Tip gating leaves a small mark on the molded part surface (gate vestige). The size of this mark is in direct relation to the gate geometry and material properties. The less notch sensitive the thermoplastic, or the larger the gate diameter, the more the vestige will protrude. For this reason, the gate is often sunk into a spherical depression or dimple ('technical gate') so that the mark does not protrude above the part surface.

Tip gating is generally not suited to shear sensitive and filled materials due to the high temperature and high shear effects of the relatively small gate openings.

sprue gating

Sprue gates use an 'open' gate, characterized by a small cold sprue which remains on the surface of the molded part. The relatively large gates, although not suitable for very 'stringy' materials, permit good packing with reduced shear stresses.



Applications include technical components where gate appearance is not critical, and

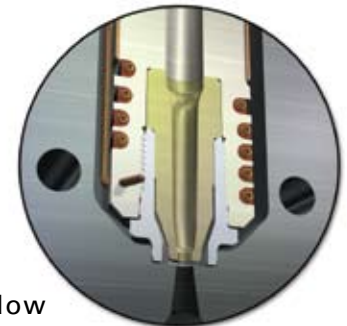
when part packing and minimum part stress is important. This gating method is also the most common approach when gating onto cold sub runners.

valve gating

With this method, a valve pin closes the gate on completion of the holding pressure time. Since pin closing occurs before gate solidification, valve gates frequently offer decreased cycle times when compared to open gating methods.

Valve gating creates no gate vestige, generally leaving only a barely visible ring. It is the best solution when surface quality is critical.

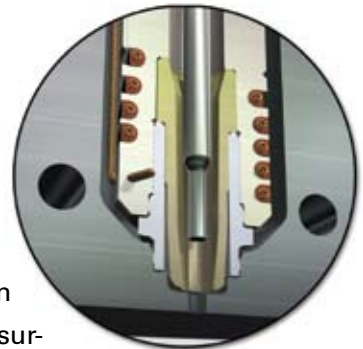
Due to the relatively large gate openings, reduced shear heat and pressure drop is realized. Valve gates impart a lower mold filling stress and give a wider processing window suitable for the more difficult to process thermoplastics. With any material, the possibility of 'drooling' is eliminated.



edge gating

Side or edge gating is normally accomplished on vertical part walls or ribs to prevent the polymer from flowing long distances in open air ('jetting'), and appearing as a visible (often serpentine) surface defect. The gate mark and filling characteristics are similar that of tunnel gating, encountered in two plate molds.

The preferred gate location is on a corner or curved surface of the rib/core, which ensures adequate steel in the gate area for both strength and for adequate heat dissipation. Avoid gating onto a thick rib





or wall since the part shrinkage will prove detrimental to gate shearing and good gate vestiges.

gating method selection

When choosing between the various vertical gating styles (Edge gating being the exception), one must compare the suitability of each gating method with the critical factors of the application. Mold features (most importantly gate cooling) will also influence the results with a particular gating method. Your hot runner supplier should be able to verify that your gate cooling, steel selection, and other mold design features are acceptable with the selected gating method. The chart below is a general guide on vertical gating methods. One must decide which factors are the most important in the application before selecting the gating method.



Once the general gating method is determined, one must choose between the various styles available with that gating method based on the rate of heat dissipation in the gate.

Crystalline materials will solidify more rapidly than amorphous materials. The gate area must be kept warmer to prevent premature solidification, and therefore inadequate part packing. Filled materials tend to possess a higher thermal conductivity and frequently behave like crystalline materials. They also should employ a gating arrangement that will maintain a warmer gate. Generally, the fast solidifying materials will also require a larger gate opening.

The gate area is commonly kept warmer for fast solidifying materials by increasing the mold contact with the hot runner nozzle. This will transfer heat into the gate area of the mold to prolong gate solidification. Nozzles that utilize a material insulation area in the gate are normally not suited to the fast solidifying polymers

vertical gating method suitability

critical factors	tip	sprue	valve
avoiding material shear	poor	good	good
avoiding part stress	poor	good	good
fast cycle needed	good	poor	best
good cosmetics critical	good	poor	best
avoiding high mold costs	good	good	poor
avoiding drooling	good	poor	best
large shot size	poor	good	good
packing important	poor	good	good
tight processing window required	poor	good	good

since the gate area is too well insulated from the hot runner.

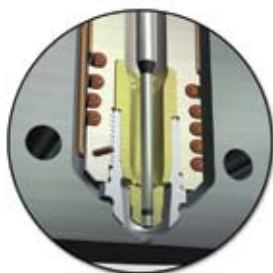
color change

During a production run of plastic injection molded components, a number of different colored components may be required. The variety of colors offered to the product designer, coupled with "Just in time" manufacturing principles have increased the frequency with which color changes are required during a production run.

In order to change from one color to another, it's necessary to remove all traces of the first color from the injection molding system. This is normally achieved by introducing the new color to the system in order to "push out" the old color. The efficiency with which the change over from one color to the next can be achieved can be a critical cost factor.

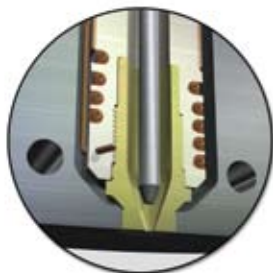
Injection molding machine manufacturers offer machine options, which minimize the interruption to production needed to achieve a color change. For example, machines are available with two injection barrels





Accu-Valve™ CX

The gating method shown utilizes a material insulation layer to thermally separate the gate from the heated nozzle. This keeps the gate area cooler as required for amorphous materials.



Hot Valve

This gating method has no material insulation area but actually conducts heat into the gate through the nozzle. This arrangement maintains a warmer gate area as needed by crystalline materials.

gate appearance, this will not always work to your advantage. Smaller gates increase the pressure loss, add to part stress, and can create other part blemishes due to the excessive shear heat created. If cosmetics are not an issue (e.g. Gate area is hidden in the final product assembly), do not choose a small opening, which will unnecessarily shear the material and put stress in the part.

Each gating method will have a range of possible gate diameters and the selection of a gate diameter will hinge on a variety of factors. The chart on the following page will help in narrowing down the optimum gate size.

With amorphous materials, the solidification rate is much slower. There must be a sharp thermal separation between the hot runner system and the mold in the gate area to prevent long cycles and the possibility of drooling. The sharper the thermal separation, the better suited the nozzle is for amorphous materials.

Frequently, a solidified material insulation layer is used to insulate the hot runner from the mold. Although this provides good thermal conditions for amorphous polymers, it is not well suited to residence time sensitive materials and for frequent color change applications. A nozzle such as the one shown on the left combines the excellent thermal insulation provided by a material insulation area with open pipeline design for use with residence sensitive materials and in frequent color change applications. The semi crystalline materials PP and PS require the same gate conditions as the amorphous materials.

gate size selection

Once the gating method and style is known, the final step is to determine the gate size. Although the tendency is to make a smaller gate so as to improve the





	gate sizing		
	small	medium	large
material consideration			
structure	amorphous	part crystalline	crystalline
molecular weight	low	medium	high
melt flow index	high, lubricants	medium	low
reinforcements, fillers	none	low percentage	high
additives, flame retardants	without		with
heat, shear sensitivity	not feasible	acceptable	feasible
solidification rate of material	slow	medium	fast
part consideration			
shot weight	low	medium	high
wall thickness / flow length	small	medium	large
tolerances	wide	average	tight
gate mark, gate vestige	excellent	good	fair
end use	consumer-cosmetic		technical
proces considerations			
temperature window	wide	medium	narrow
injection speed	low	medium	high
pressure drop created	high	normal	low
effect of holding pressure	less		more

At present, there is no sure substitute for experience. Selecting the best gating location, gating method, and gate size is still frequently based on past applications. On new applications, it may not be a clear-cut matter at all. Numerous gate sizes may perform adequately and, on occasion, a few different gating styles would be acceptable. On the other hand, certain gating methods would be completely unacceptable.

The science of gating is based primarily on the heat transfer requirements of the material in the gate area. An understanding of the material structure (amorphous or crystalline) will help you prevent disasters in selection of the gating method. The gate size is also instrumental to the success of the project. In choosing a gate size, analyze the material, part, and process before settling on a gate diameter.

Only after the preferred gate location is determined should one begin to spec out the hot runner system. Changing gate locations to accommodate one particular hot runner design might be compromising the performance of the finished part. If purchasing standard off the shelf products, ensure that the selected nozzle has the appropriate heat transfer in the gate area for your selected resin. If unsure, an experienced supplier can assist you in selecting the most appropriate gate location.





allowing production to be continued with one barrel while the color change is effected on the other.

The hot runner system is an integral part of the mold, which can contain a sizable quantity of polymer in relation to the part. The design of the hot runner system therefore has a significant influence on the color change efficiency ultimately realized.

If frequent color changes are required, the hot runner manufacturer should be made aware upfront. There are several measures that can be taken to improve color change performance. The runner volume in the manifold system can be reduced in order to reduce the quantity of material resident in the system. This will serve to reduce the number of shots required to purge it out. By reducing the bore sizes within the hot runner system, the velocity of the material passing through is increased which further improves the color change performance. There is of course a limit to the amount in which the bore sizes can be reduced since this also increases the pressure drop through the hot runner system.

Consider what is happening within a bore when one material tries to push out already resident material. Those who have witnessed a color change will know that it is not simply a matter of pushing out resident material. Some mixing also occurs. The first material may still come out even after a considerable volume



Velocity profile. Material moves faster in the center of a bore.

of the second material has passed through the system. Understanding why this is so, and understanding the factors surrounding this behavior will help to optimize the color change process.

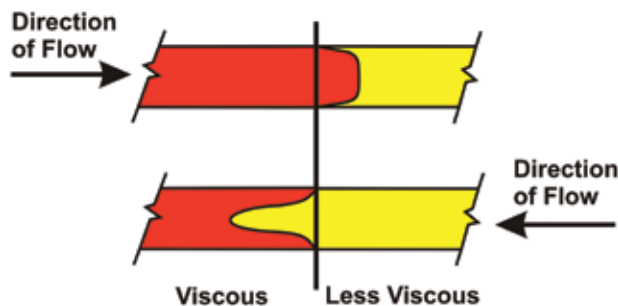
A polymer melt does not flow like water. Different polymers, or different grades of the same polymer will

have different viscosity. The viscosity of the melt results in the polymer moving at different speeds at various positions within the bore. Melt close to the manifold steel tends to 'cling' to the runner wall and does not move as quickly as the melt in the center. This can be described by a 'velocity profile'.

Since the material close to the wall of the bore moves at a slower speed, it naturally takes longer to purge. Purging at higher speeds can minimize this effect.

It is interesting to consider what happens when two materials of different viscosity meet.

The top runner in Figure 1 illustrates a viscous material pushing a less viscous material. This provides the more effective removal of the first material. The bottom runner depicts the effect of a less viscous material attempting to push out a more viscous material. The less viscous material tends to push through the center of the viscous material, leaving a thick layer of the old



Effect of viscosity on color change

material on the wall of the bore. This will continue to contaminate the flow as the thick layer is eroded away at a very slow pace. It is therefore always preferable to introduce a more viscous material to remove a less viscous material.

The viscosity of a polymer melt is highly dependent on the temperature of the melt. The figure below shows the viscosity versus shear rate for the same grade of polypropylene at three different temperatures. This shows that temperature has a significant effect on viscosity and therefore in the effectiveness of color changes. If material exists within the hot runner system, which is colder than the material being intro-





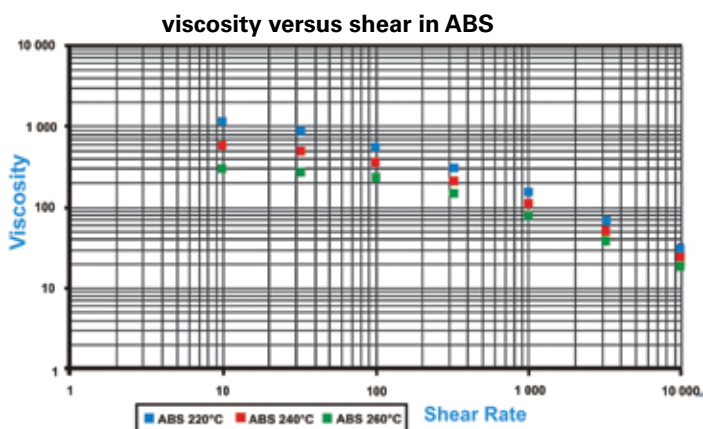
duced, it will be very difficult to push the cold material out. For this reason it is essential that the hot runner system have an even heat profile.

This phenomenon can also be used to our advantage in reducing the time needed to conduct a color change. If the material being introduced into the system is colder, it will be more viscous and will be more effective in achieving a color change. The material in the machine barrel should therefore be as low as the material can tolerate. Elevating the hot runner system temperature also assists as this reduces the viscosity of the old material and makes it easier to push out.

Selecting the right type of hot runner system can reduce a 4-hour (or at times impossible) color change to minutes. The following figure shows a system with annular flow in which the heater is in the center of the runner.

The frozen layer of material near the walls makes this type of system particularly ill suited for color change applications.

Similarly the valve pin arrangement shown in Figure 2 will also make color changes difficult due to the dead

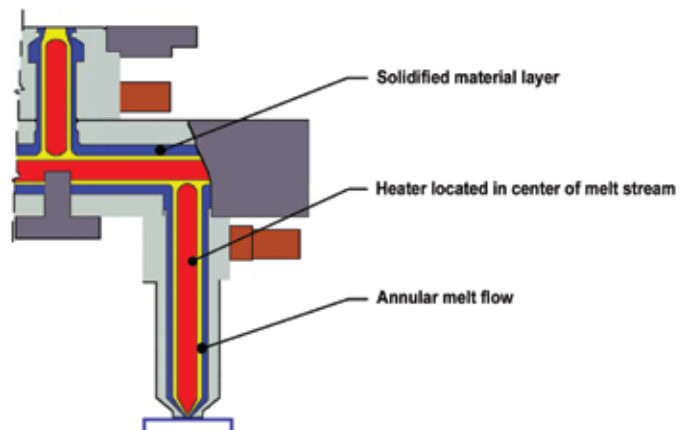


spot created behind the pin. Figure 3 shows a far superior arrangement in which the runner system features no stagnant material in the manifold runner and the elimination of the dead spot behind the pin.

In the same way in which different material/part combinations require different set ups on the injection molding machine, a color change procedure must also be tailored to some extent to each application. It is not possible to make a generic color change procedure that will give the best performance in all circumstances. However, the following points are generally true:

design

- Minimize hot runner volume



Annular flow hot runner with solidified material layers

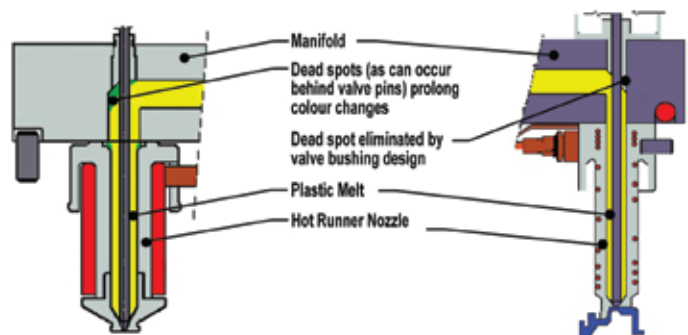


Figure 2
Hot runner system
with dead spots
behind valve pin

Figure 3
Hot runner system
with dead spots
behind valve pin

- Ensure even temperature profile
- Use open pipeline design
- Avoid designs using the polymer as an insulation layer
- Design molds so that any insulation materials





can be accessed and removed

- Avoid obstructions or stagnant areas in the melt channel
- In valve gate systems, avoid dead spots behind the pin where the melt first enters

processing

Use a viscous material to push out less viscous material. Reducing the temperature of the machine barrel and elevating the temperature of the hot runner system can achieve this. Increase injection speed if possible.

materials

Some materials will be easier to change than others. Some colorants will have a lubricating effect on the polymer, reducing the viscosity and thereby making a certain color difficult to change.

Not all hot runner systems are designed with color changes in mind, and certainly, not all systems are compatible with frequent color changes. Knowing that the application involves frequent color changes is essential in selecting and designing an acceptable hot runner system.

temperature control

In hot runner systems, the most commonly used heating method features series-wound electrical heaters. The heater elements contain one continuous wire that produces thermal energy whenever electrical energy is applied to the ends of the wire. Typically, this wound element has a uniform electrical resistance, thereby producing uniform heating over the entire length. The heating element is contained by, and insulated from, the outer sheathing by an insulating material, usually magnesium oxide (MgO). MgO provides excellent electrical insulation properties and is also a good heat conductor. These properties are critical to this discussion since the life of the wire greatly depends on the insulating efficiency and the prevention of any localized overheating.

Unfortunately MgO also has a tendency to absorb moisture. If an element is not heated for a period of time,

the MgO in the element can absorb moisture from the air. The possibility of this happening will be greater in more humid climates, and the longer the element is out of service. Absorbed moisture contaminates the MgO and reduces the insulating efficiency, thereby creating a new current path between the heating element and the outer sheathing. This new shorter length 'heater' becomes a localized hot spot on the wire.

Generally, high wattage, long length heater elements are less susceptible to this localized heating. Short, high wattage elements (with their thin gauge wires) tend to be more sensitive to this condition. Local overheating of the wire causes a breakdown of the heater wire material, resulting in further contamination of the MgO. A vicious cycle develops whereby the current



path increases in strength and further contaminates the MgO, ultimately resulting in the failure of the heater wire.

An effective "Softstart" feature on the temperature controller (to eliminate the moisture present in the MgO) is critical in order to maximize the life of the heating element. However, there are numerous methods available on the market, some of which are actually





damaging the heating element while drying the MgO. It is important then, to understand the Softstart method that is used on the temperature controller.

time proportioning of the supply voltage

This Softstart method applies full line voltage for a predefined time period. When a section of the heating circuit contains moisture, the application of full AC power cycles can result in a power surge to that portion of the heater element, momentarily overloading it at the ground fault.

Most applications with multiple heaters make use of a 3-phase power supply, which further compounds the problem. The triac used in this method is located on only one side of the power line resulting in a direct, unswitched path to ground on one side of the heater. This method may be adequate for high power, long length heater elements, which can endure the stress applied to the heater wire, but small high power elements are easily damaged. Although the simplest and least expensive of Softstarts to implement, this method is potentially the most harmful due to the high ground currents present.



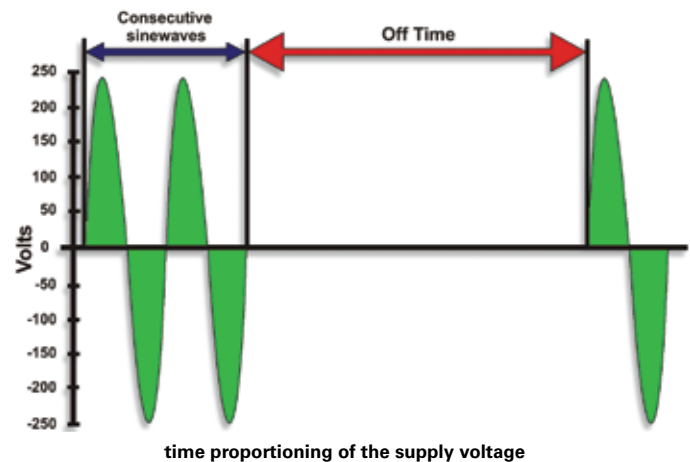
Low Cavity TempMaster-Series XL-II Controller

phase fire proportioning of the supply voltage

This method waits a predetermined time period after the zero voltage point of the AC supply until the voltage level has been reduced below critical levels. Due to the closer spacing of the power pulses, this method, when correctly implemented, provides a greater degree of protection than the time proportioning method. In most cases however, the input power supply is of a three-phase configuration that results in a triac turn-on

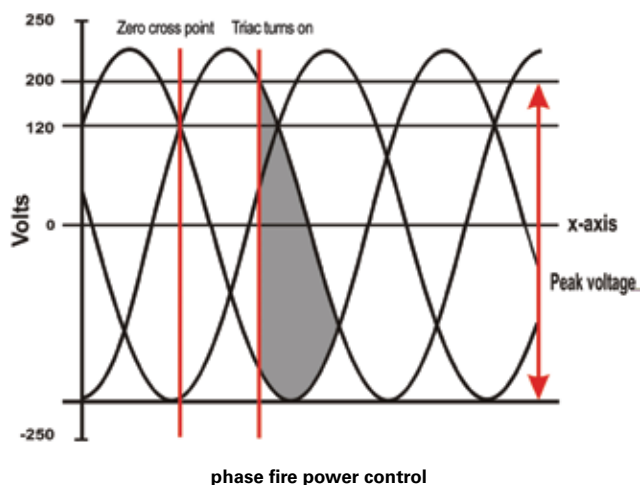
point with a substantial voltage above ground level. The resulting line voltage creates an unusually high ground fault current even if the voltage level has been set low. The gray shaded area bordered by the black curved line of the 3-phase diagram illustrates the high voltage potential. The x-axis of the graph indicates the ground level.

Softstart also generates significantly more Radio Frequency Interference (RFI) than the previous method.

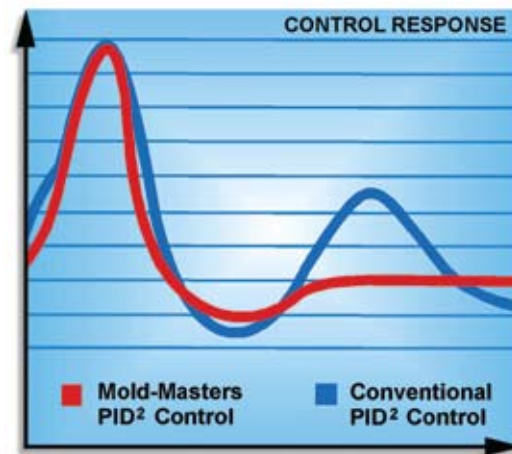


This is due to the non-zero turn on characteristic of this switching method and can also produce large ground fault currents as a result of utilizing phase angle firing. In the case of a Delta three phase power system, the zero cross point can be well over 100 volts from the true ground potential.





This method also eliminates the possibility of an uncontrolled ground fault. Uncontrolled ground faults can occur if the leakage current is of sufficient magnitude close to the unswitched supply line.



Mold-Master Softstart profile

isolated low voltage supply voltage (Softstart PID² Control)

This method, used on *Mold-Masters* temperature controllers, steadily increases the temperature by applying a safe, low voltage power supply to the heating element. By limiting the power to the heater through a mechanical relay, the heater element is completely isolated from the high voltage supply. On initial startup, the relay connects the low voltage supply for a predetermined time period. A moisture detection circuit measures the resistance between the heater wire and the outside sheath of the heater. If the moisture is within a safe range (resistance is greater than 500k ohms) the relay connects the 220 volt supply to the heater element. The power level is then maintained at a potential that is insufficient to damage the heater wire, but sufficient to evenly warm the wire and release residual moisture from the MgO.

The most complex of soft start methods, this system completely isolates the heater load from any high voltage supply.

By referencing a separate supply to the ground level, ground fault currents can be held to a manageable level until such time as all the moisture has been removed from the heating element.

