11 FACTORS FOR EFFICIENT MOLD COOLING

Balancing speed and quality to reduce cycle time

AUTODESK.

INTRODUCTION

How cool is that?

In every minute of cycle time, cooling consumes the vast majority of clock-ticks. That makes it an important factor in determining the profitability of a part. Mold and part designers understand the implications, relying on some combination of expertise, experience, intuition, prototyping and CAE analysis to develop trusted cooling system designs.

This approach helps practicing engineers maximize productivity. In other words, when you create a cooling system that works well and performs reliably for your application, you can spend more time designing high-quality molds as quickly as possible.

But pressures to reduce cycle time and increase cost-efficiency are growing more intense by the day. If you can find new ways to shorten cycle time or minimize piece part cost – without sacrificing your quality standards – it's a clear opportunity to build valuable competitive advantage.

How cool is that?

Cooling is a critical part of this dynamic, because even small changes in cooling can have a huge impact on cycle time. This ebook offers a few simple ideas you can use to refresh your thinking about cooling systems, maximize the efficiency of traditional cooling systems, produce higher-quality parts more rapidly, and ultimately strengthen your company's bottom line.

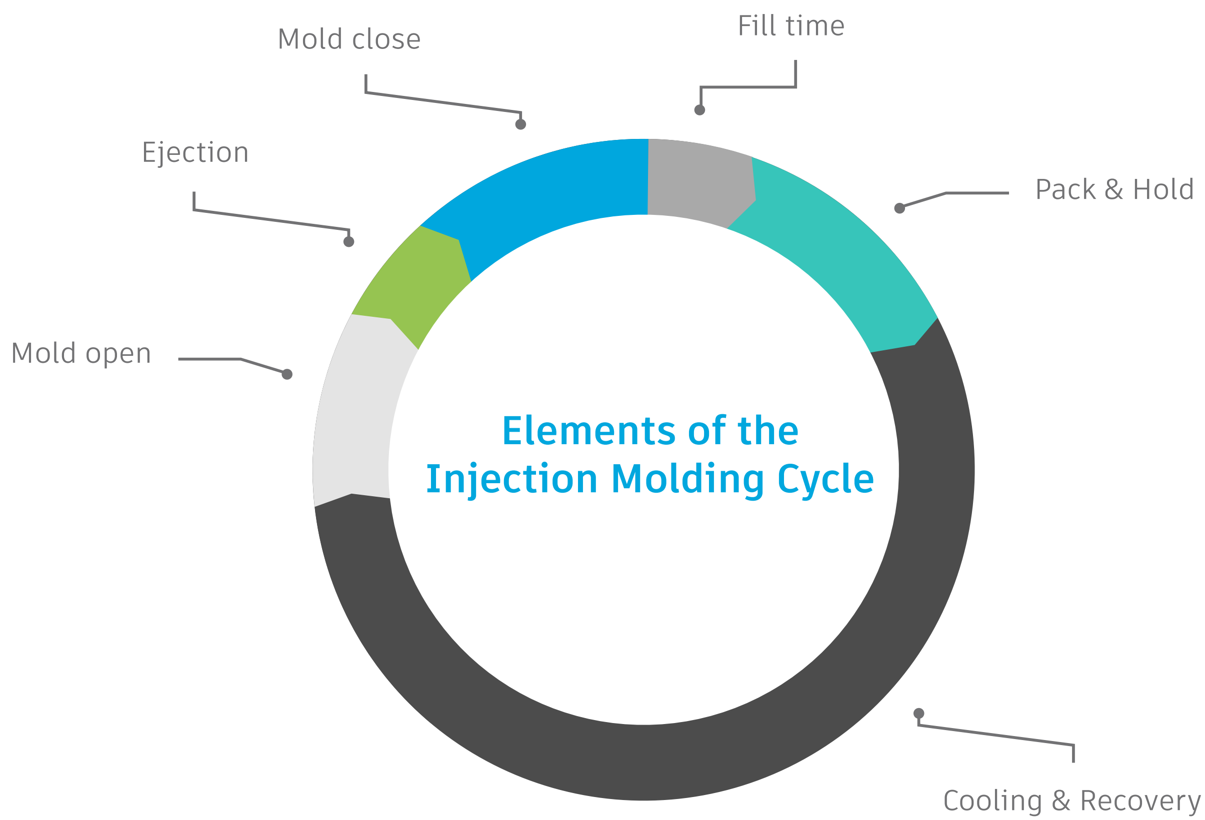

Figure 1: Mold cooling can account for more than two-thirds of the total cycle time in the production of injection-molded thermoplastic parts.

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COOLING OBJECTIVES

Elevating cooling system performance to an elite level hinges on the mold designer's ability to achieve the ideal balance of temperature and pressure.

COOLING OBJECTIVES

Finding your balance

Think about the perfect injection molding scenario: the ram moves forward, plastic flows into a mold at the glass transition temperature of the polymer, the mold comes up to pressure and fills, and the hot polymer cools instantaneously to proper ejection temperature in a uniform manner.

This, of course, never happens. Physics gets in the way.

There is always some variation in melt temperature coming from the barrel of the injection machine. Complex parts feature thinner and thicker sections, asymmetries, and cores, all of which make it difficult to ensure consistent heat transfer and even cooling. Coolant pressure affects flow rates and turbulence, creating hot spots. The mold material has a profound impact on heat exchange. And even if everything worked perfectly six weeks ago, the system may perform differently due to a new batch of material, a different chiller, corrosion, scale, or leaks in the mold itself.

Efficient cooling systems help overcome these realities, enabling mold designers to balance tradeoffs of temperature, pressure and time to meet the ultimate objective: lower cycle time. Here are three factors to consider in your designs.

COOLING OBJECTIVES

Uniform temperature

Cycle time is most influenced by changes in mold temperature. This is why maintaining a uniform temperature is so important to mold designers. One challenge in this respect is the temperature differential between the core and the cavity.

As the polymer melt cools, it tends to shrink toward the core side. Because more material is in contact with the core side, more heat will escape through the core than the cavity, which is why the core side requires more efficient cooling. If the gradient is too high, warpage is the inevitable result.

Mold designers should strive for a differential of no more than 5ºC between the core and cavity. This depends on many factors, but material selection tops the list. When the thermal conductivity of the mold changes, so does temperature uniformity and differential.

The two factors engineers must consider are speed and consistency. Shorter cycle times increase part warpage with less expensive mold materials like H13 and grade 420 stainless steel (see Fig. 2). Longer cycle times reduce warpage for all materials, but add to total manufacturing costs.

COOLING OBJECTIVES

Uniform temperature

In applications with higher tolerances, mold designers can safely specify more affordable materials, knowing that the temperature differential will likely exceed 5ºC and a predictable amount of warpage will occur. Applications with tighter tolerances or higher overall volume will need extended cycle time or a more expensive material, such as copper alloy, to stay within the 5ºC limit.

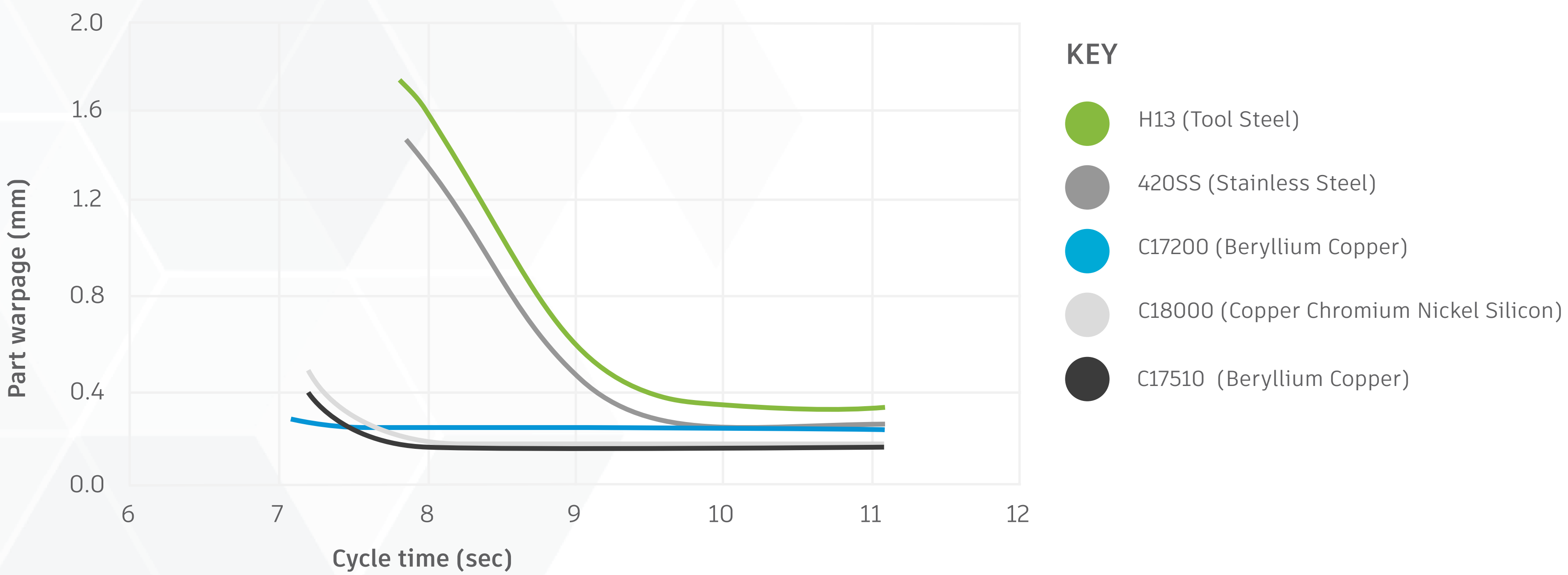

Figure 2: Core materials have a significant effect on part warpage in the first 10 seconds of cooling time.

COOLING OBJECTIVES

Uniform pressure

Like temperature, pressure within cooling lines should be kept as uniform as possible. Ideally, mold designers should aim for a maximum pressure drop of 5 psi across the mold. With uniform pressure in all branches of the cooling system, coolant will flow with sufficient turbulence and blockages will be easier to detect. If pressure drops more than 5 psi, the Reynolds number will fall below the desired level, creating hot spots that compromise thermal balance.

Turbulent flow is critical for efficient cooling. Unlike laminar flow, which transfers heat only through conduction, turbulent flow transfers heat by both conduction and convection, which increases efficiency dramatically.

The critical point to reach is a Reynolds number greater than 10,000. Once this level of turbulence is achieved, the increase of heat transfer will diminish as coolant flow becomes greater, so there is no need to expend any energy to exceed it. In other words, any small improvement in heat transfer will be offset by a higher pressure drop across the cooling channels, along with more pumping expense.

Achieving a Reynolds number greater than 10,000 requires a flow rate of 2.35 GPM for 3/8" NPT pipe. Note that for a 50% glycol mix, this flow rate needs to be doubled. Of course, the required flow rate in any application will depend on the coolant temperature and pipe size.

Inlets should be sized consistently with cooling lines to maintain uniform pressure. Within complex part geometries, baffles and bubblers may be used to achieve uniform temperature in the mold. These also need to have the same diameter as cooling lines, as alternative cooling devices that are too small will cause pressure drops and affect flow rates.

COOLING OBJECTIVES

Mold temperature

The temperature differential between hot polymer filling the mold and the mold itself is another factor to consider when designing an efficient cooling system.

Ideally, mold designers should plan for a difference of no more than 25%. The closer the temperature of the mold is to the melt, the better the finish quality you can expect in the part—and a gap greater than 25% will typically result in unacceptable finish quality.

This range, however, does give mold designers another lever to pull when designing a mold for efficient cooling. If the application does not require the best possible surface finish quality, starting with a slightly cooler mold may help accelerate the entire cooling process.

BASIC COOLING STRATEGIES

Efficient cooling systems start with a few fundamentals of mold design.

Starting strong

Achieving uniform temperatures and pressures starts with the fundamentals. The following three points will be familiar to many engineers, but they are essential for optimizing cooling performance in a way that delivers the right combination of speed, quality and cost for your application.

BASIC COOLING STRATEGIES

Channel placement

The goal when locating cooling channels in the mold is uniform mold surface temperature, which is determined by cooling channel depth and pitch. Consider the following examples of cooling channel configurations in P20 mold steel with a water line diameter (D) of 11.1mm (7/16"), coolant temperature of 30ºC and cycle time of 17 seconds (see Fig. 3).

With a depth of 1.0D and a pitch of 2.5D, the mold surface temperature is fairly uniform, with a temperature difference of about 1ºC. The average temperature is slightly less than 40ºC, or 10ºC higher than the coolant temperature. When the pitch is increased dramatically (to 10D) but the depth stays the same, the mold surface temperature difference increases to 25ºC with an average of 56ºC. Channels that are further apart cool less efficiently.

With depth and pitch spacing equivalent at 2.5D, the mold surface temperature difference is nearly uniform, but the difference between coolant temperature and the average mold surface temperature increases to just over 20ºC. Deeper channels, even if spaced correctly, affect efficiency as well.

BASIC COOLING STRATEGIES

If the depth is increased to 5D and the pitch to 10D, the mold surface temperature is uniform within 2ºC, but the average temperature is 46ºC hotter than the coolant. Again, uniformity is the goal, but the target is a uniform temperature that is not significantly higher than the coolant temperature.

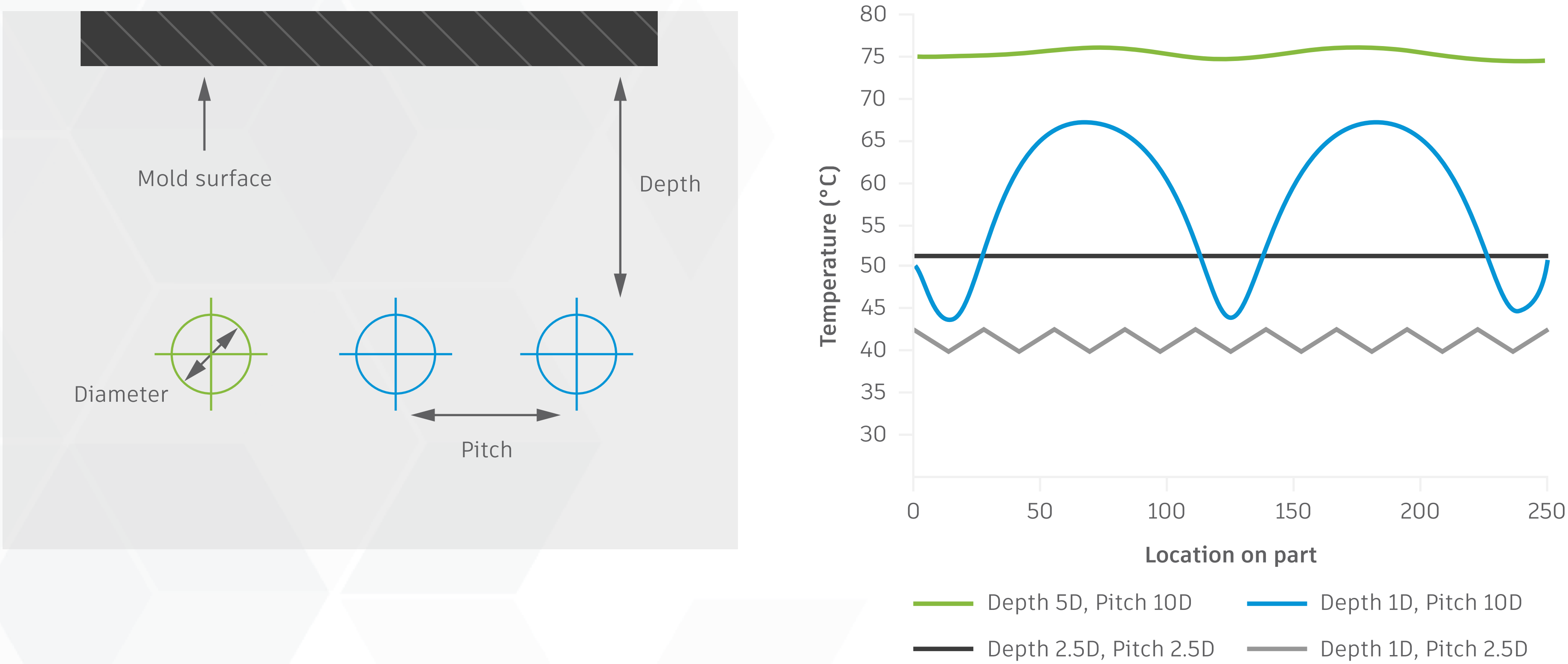

Figure 3: Size and placement of cooling channels have distinct and predictable effects on the difference between mold and coolant temperature.

BASIC COOLING STRATEGIES

Circuit design

Mold designers have two choices for circuit design: parallel or series. Parallel cooling channels are drilled straight through from a supply manifold to a collection manifold. Flow rates vary in parallel channels because each one will have a slightly different flow resistance. This variation causes similar differences in heat transfer efficiency, creating hot spots and making cooling uneven.

Series cooling channels, which are connected in a single loop from the coolant inlet to the outlet, are much more commonly used for this reason. By design, a single cooling channel that is uniform in size maintains the preferred flow rate throughout its entire length.

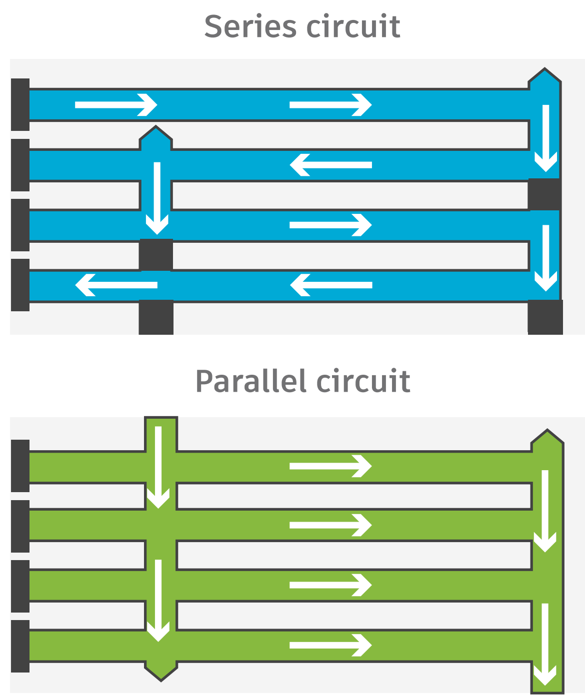

Figure 4: Flow rates and Reynolds numbers differ widely in series and parallel circuits.

BASIC COOLING STRATEGIES

Baffles, bubblers, and thermal pins

Cooling the core side can be especially challenging due to protrusions, extensions, cores and other features that are difficult or impossible to reach with conventional cooling lines. Baffles, bubblers and thermal pins are all cooling devices that can help in this scenario.

A baffle is a cooling channel drilled perpendicular to a main cooling line with a blade separating the passage into two semicircular channels. Coolant flows in one side of the blade from the main cooling line, turns around the tip and flows back. The best baffle designs have a slightly larger diameter than the main channel to make sure the blade completely blocks the channel.

A bubbler is similar to a baffle except that the blade is replaced with a small tube. Coolant flows into the bottom of the tube and “bubbles” out of the top, like a fountain, then flows down around the outside of the tube. Bubblers are particularly effective for cooling slender cores and are also useful for cooling flat mold sections that can’t be equipped with drilled or milled channels.

BASIC COOLING STRATEGIES

A thermal pin is a third alternative, which allows mold designers to cool cores and other features without affecting coolant pressure. The pin is a sealed cylinder filled with a fluid. The fluid vaporizes as it draws heat from the mold and then condenses as it releases the heat to the coolant (see Fig. 5). The heat transfer efficiency of a thermal pin is nearly 10 times greater than a copper tube. For good heat conduction, avoid an air gap between the thermal pin and the mold or fill it with a highly conductive sealant.

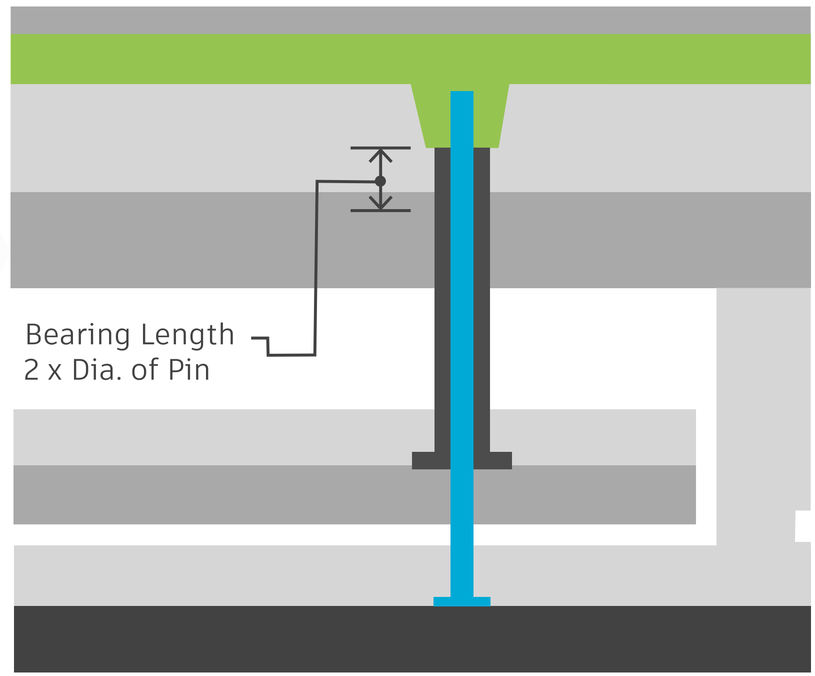

Figure 5: Thermal pins offer a simple, straightforward way to cool cored-out features without affecting coolant pressure.

ADVANCED COOLING STRATEGIES

Once the fundamentals are in place, these strategies can help reduce cooling time even more.

ADVANCED COOLING STRATEGIES

Reaching the next level

If you've already mastered the basics, how can you reduce cooling time even more? By taking a fresh look at some of the nuances in mold design and mold processing. The following factors offer interesting design alternatives. Keep in mind that while they tend to increase the cost of the mold, they may actually lower total operating costs, depending on your application.

CONFORMAL COOLING

Conformal cooling uses cooling channels that curve to follow the geometry of the part, or "conform" to its unique shape (see Fig. 6). While the concept of conformal cooling has been understood for years, creating curved channels has only recently become economically viable due the emergence of mold manufacturing techniques such as laser sintering, among others. Conformal cooling requires a tooled steel mold that is less conductive than copper or aluminum, but the results are impressive. Mold designers can expect cycle time reductions from 10% to 40% with this approach.

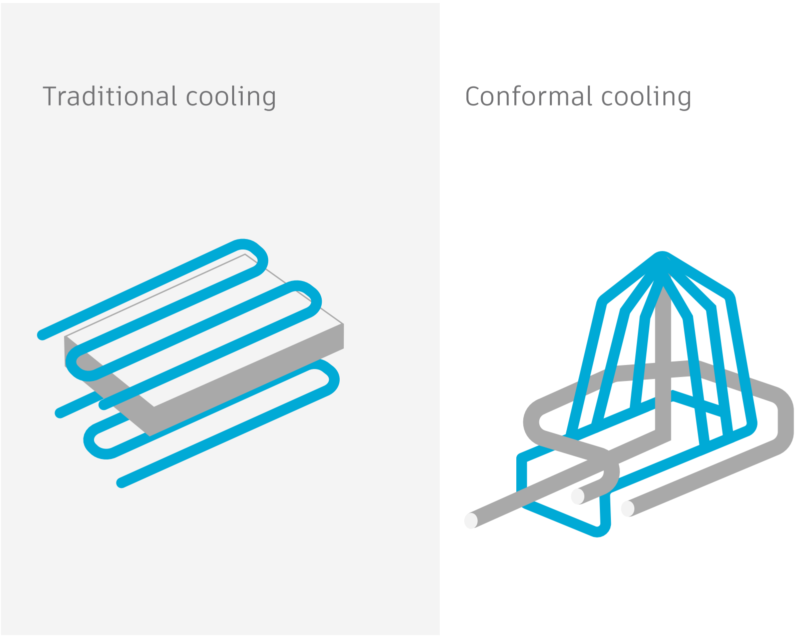

Figure 6: Conformal cooling channels closely follow the geometry of the part, eliminating the need to use alternative devices for cores and other protruding features.

ADVANCED COOLING STRATEGIES

Reaching the next level

HIGH THERMAL CONDUCTIVITY INSERTS

To cool slender cored-out features (5mm in diameter), mold designers can use inserts made from a material with high thermal conductivity. These inserts are typically press-fitted into the core. They extend into the mold base and have a cooling channel that passes through or touches the insert. For large core diameters (40mm and up), mold designers need to ensure a positive transport of coolant with inserts that allow the coolant to reach the tip of the core through a central bore then flow through a spiral to its circumference, then between the core and insert helically to the outlet.

The two most popular choices for inserts are copper alloy and aluminum. The tradeoff has to do with costs. Copper is more durable and will last longer, but is more expensive initially. Aluminum costs less than copper alloy and offers similar thermal conductivity, but it is much softer, more susceptible to wear and generally has a shorter life span.

RAPID HEATING

Rapid heating seeks to quickly pre-heat the mold after each part is ejected, bringing it closer to the polymer's glass transition temperature or higher. This technique helps achieve a high-gloss surface finish as well as stronger weld lines, fewer aesthetic surface defects and lower injection pressures. Depending on the method you choose, rapid heating can create opportunities to reduce cycle time. Heater cartridges, which are placed in the mold block and heat the entire mold, are the most straightforward and least expensive option—but also the slowest.

Injecting pressurized high-temperature steam into the cooling channels, then removing it with compressed air before the coolant flows through, is more efficient. Induction heating, which heats only the surface of the mold instead of the entire tool, is a third option. With this technique, heating is achieved by applying a high-frequency alternating current through an induction coil, which generates a magnetic field that induces eddy currents on surrounding metal objects. These electrical currents flow in a circular path, resulting in Joule heating, or the generation of heat from a current flowing through a conductor, typically a very thin (<1mm) layer of metal on the surface of the mold.

COOLING FACTORS IN PRODUCTION

The realities of the shop floor can compromise cooling in unexpected ways. Mold designers need to account for several production-specific factors to achieve optimal cooling.

COOLING FACTORS IN PRODUCTION

Running into reality

Even if your mold design is perfectly suited to the application, delivering the optimal cooling time for part quality, surface finish and total cost, it's a different story when the injection molding machine starts running. Keep these final three factors in mind to ensure your design fulfills its potential.

Cooling efficiencey loss over time

Scale Type	Calcium Carbonate Scale	Calcium Sulphate Scale	Calcium Silicate Scale	Organic Sediment	Soot
Conductivity W/mK	0.6 - 6	2.3	0.3	0.1	0.2

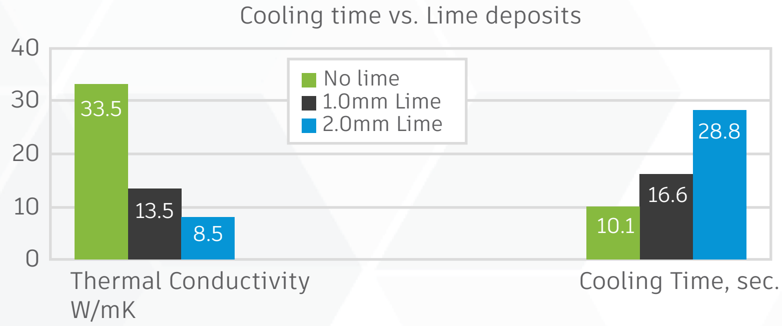

Figure 7: Even a small amount of mineral deposits in cooling lines can have a significant effect on cycle time.

Corrosion and scale

Machine operators know that small changes in injection molding equipment can have a significant cumulative effect on performance. Corrosion and scale, or mineral deposits, are two factors that mold designers need to be aware of when it comes to setting expectations for cooling systems.

Corrosion of cooling lines occurs naturally over time as the material interacts with its environment and oxidation occurs. Mineral deposits are similarly common, developing as cooling lines are exposed to trace minerals in the water supply.

The presence of corrosion or scale in the cooling system can severely compromise thermal diffusivity and radically reduce efficiency, leading to longer than intended cycle time (see Fig. 7). To avoid this situation, make sure to specify non-corroding materials for all circuits, such as copper, Type 420 stainless steel or an electroless nickel-plated aluminum.

Mold designers can also work with machine operators to make sure appropriate steps are taken to treat (filter) the cooling water and clean cooling lines regularly.

COOLING FACTORS IN PRODUCTION

Consistent setup

Not every mold has a finite run. Many complete one production run, get shelved, then re-installed weeks or months later for another run. Even if this gap is one day, the setup process needs to stay consistent from run to run for cooling time to meet expectations.

Placement of inlets and outlets, for example, should stay the same. This is especially important in more complex cooling systems with more than a dozen ports. Changing the placement of inlets and outlets can cause slight deviations in pressure that affect the uniformity of mold temperature. Other factors the mold designers don't control, such as the particular pump or chiller used in a given run, can affect coolant temperature as well. Ideally, the temperature of the coolant should not rise more than 5ºC from the time it enters the mold to the time it leaves.

A best practice for ensuring consistency is mapping the surface temperature during setup. Using a surface temperature gauge, measure temperatures at various locations across the mold. This establishes a benchmark for future runs, one that will help you spot inconsistencies quickly.

CONCLUSION

Staying Cool

Efficient cooling isn't always the first thought on a mold designer's mind. But even practicing engineers who have developed trusted cooling systems can benefit from reconsidering a few key factors in design and production. Taking a fresh look at your current approach to cooling systems may spark new ideas that you can turn into shorter cycle time—and higher profitability.

One way to generate these insights faster is through simulation. Moldflow® plastic injection molding simulation software is specifically designed to help mold and part designers visualize cooling systems and many other features so you can understand tradeoffs more precisely, evaluate the effects of design decisions and optimize cycle time.

Get Started

To explore more information about mold design, cooling systems, and cycle time reduction visit our CAE Analyst resource center.

CAE ANALYST RESOURCE CENTER >

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Figure 2. Source: Engelmann, P. & Dealy B. (2000, Feb.). Injection Mold Design Guidelines. Modern Mold & Tooling.
Figure 3. Shoemaker, J. (2006). Moldflow Design Guide. OH: Hanser Publications.
Figure 5. Source: Engelmann, P. & Dealy B. (2000, Feb.). Injection Mold Design Guidelines. Modern Mold & Tooling.