Process safety in cooling and heating: Conditions for successfully competing internationally

Designing Safe and Reproducible Temperature-Control Processes

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Entering a new business area had seemed easier to the processor with decades of experience in injection moulding of technical parts. But when validating his processes, it became obvious where he and many other plastic processors had considerable shortcomings. There was sufficient know-how in processing thermo plastics, the machinery was state-of-the-art, but proof of process safety was hard to come by. Most of all, there were flaws in mould temperature-control, which were considered normal and common to the industry. Only when entering into an area of (as yet) unusually high customer requirements were these flaws revealed.
Process safety in temperature-control is of course connected with temperature-control appliances. However, the means and methods used to measure, evaluate and safely reproduce temperature-control results are far more important. Therefore this document is also concerned with this ever-more important topic.

Importance of the temperature profile

Producing high-quality products at a high rate of reproducibility requires exact knowledge of the processes involved. Although it is well known that the mould wall temperature influences cooling time as well as the quality of the moulded part considerably, few plastic processors think about what the actual temperature profile over the full surface of a newly produced moulded part looks like.
The question of the mould wall temperature used during production is frequently answered by pointing at the display of the controls of the temperature-control appliance. However, this value represents the actual temperature only at one single position in the mould cavity, where a sensor happens to be installed.
The complex correlations between the geometry of the moulded part, the structural arrangement of the temperature-control channels in the mould, the connected temperature-control appliances, their operating temperatures and the water quality are often overlooked in practice. Or, even worse, they are subordinated to different priorities.

Temperature-control decisive for quality of moulded parts

Important features of the moulded part such as mechanical firmness, surface quality, dimensional accuracy and warping are determined by the quality of mould temperature-control. At the same time, temperature-control is, due to its influence on cooling time, a decisive factor for the cycle time, thus for the economy of the injection moulding process.
The condition is a temperature profile that is as even as possible over the whole surface of the moulded part. How is it possible to determine the actual temperature distribution, and are there any means to visualize and record them? Process safety on the one hand means determining important parameters; but on the other hand it must be possible to control and document these parameters.
A proven and meanwhile frequently used method is thermography. The just ejected plastic part is photographed by means of an infrared camera. It is important to record the cooling behaviour over a longer period of time,

rather than taking just one shot. Modern, high-end infrared cameras have a video function which allows documenting the cooling process of the moulded part in real time. Another very important feature is the corresponding software to evaluate and process the data. Several different types of representation can be used for optimal visualization of the temperature differences.

Identification using a thermo-camera

The general result of a thermography is that there is no absolutely even temperature distribution over the component. Two factors are responsible for this behaviour. The first one is that moulded parts rarely have uniform wall thickness over their whole geometry. Openings, thin wall areas and strengthening ribs cause partially varying heat input into the mould. In the mould, the heat is not adequately dissipated, due to the structurally possible arrangement and dimensioning of the temperature channels. If there is a large bolting mandrel that enables high heat input, there is normally an ejector pin for ejection, so that there is no space for a sufficiently dimensioned cooling channel. Narrow, deep areas in the moulded part are tricky for the mould maker if he wants to ensure adequate temperature-control with conventional methods. Using a thermo-camera helps identifying problem areas with certainty.

Arranging cooling channels in three dimensions and close-to-cavity

The next important step is testing the mould drawing. Are there cooling channels in critical areas, and, if this is the case, what is their position with regards to the moulded part? Do dimensioning and circuitry of the channels allow sufficient heat dissipation? If the answer is positive, all current operating parameters must be compared with the thermal calculation. If the answer is negative, a structural modification must be considered.

Since the geometry of the moulded part and the mechanical structure of the mould often do not allow a thermally favourable placement of the cooling channels produced by drill technology, further optimization happens by arranging the channel geometry close-to-cavity by means of milling and joining technology, by using Laser-sintered mould components and by combining both of them.

These special manufacturing methods allow bypassing openings, ejector pins and other installations, thus creating a heat-exchanging surface that is on average three times as large as what is achieved by conventional drill technology. The even distribution of the cooling channels in different levels around the moulded part ensures a homogenous temperature profile and optimal process quality. Mean cooling time reductions of 30% and decreased piece costs by up to 15% make using these three-dimensional temperature-control technologies absolutely worthwhile.

Solution by surface cooling

For moulded parts with high requirements in terms of surface used either immediately after injection moulding within the field of vision, or used after further upgrading, as well as for transparent components with special visual requirements, the moulding process of the mould cavity is crucial. The various procedures of dynamic mould temperature-control used for these applications - also called vario-thermal cooling - can only be used successfully without increasing cooling time considerably if prior to production the thermal conditions are laid out in the injection mould. There have been numerous solutions recently. An example is surface cooling produced by Laser cusing.

Segmented mould cooling

In the next step the selection of temperature-control appliances is made. Optimal cooling results are achieved by considering the different heat input per surface element from the moulded part into the injection mould with temperature-control systems especially constructed for segmented mould cooling. Each temperature circuit has an individual flow rate and temperature regulation.

Depending on system design the variably adjustable temperatures for each temperature-control circuit are realized via heating installed per circuit, or by a central heating unit and mixing valves. The flow rate is regulated either by installing separate pumps into each circuit, or with a central pump in connection with regulating valves. In connection with close-to-cavity cooling channels it is thus possible to influence the temperature profile in the mould selectively and to achieve an optimal quality of the moulded part while maintaining the shortest possible cycle time.

Process safety at the push of a button

In terms of segmented mould temperature-control, processors are often sceptical: While they are convinced of the process engineering advantages, they fear that the technology would be too complex for their company, not manageable by fitters and machine operators, and would therefore have negative impacts on process safety. To proof their reservation they often quote past bad experiences with systems of that type.

New developments have taken this fact into consideration. A modern multi-circuit temperature-control system is nowadays much easier to operate than a standard temperature-control appliance a few years ago. The central functional element is a single operating button which incorporates all important functions. The rotational function is used to call up and set operating parameters. Pressing the button selects the individual functions and confirms entries. On a large and clearly arranged colour display most functions are graphically displayed.

To monitor the process all quality-relevant parameters are recorded, so that the time-line of the process can be documented later. Temperatures and flow rates have adjustable tolerance bands. If the process deviates from a freely selectable window, the system triggers an alarm. The operating parameters used per mould can be saved in an integrated mould data base. This decreases set-up times and prevents incorrect settings when changing moulds.

Safety gap in the process finally closed

Recording and monitoring of the flow rate is highly important for the process safety. A changed flow rate indicates quality-relevant changes of the temperature-control parameters. It is therefore hard to understand why even today this is the point where one of the fundamental gaps in the process safety of the overall injection moulding process occurs. The crucial item is the “water organ”, which, as a seemingly indispensable component, renders its mainly uncontrolled services. Knowing that the water quantity is crucial for the quality of the temperature-control process, the majority of the processors ignores a basic rule. It should be possible for each quality-relevant parameter to be saved and called up, acknowledged as actual value and captured by a control system, and, within adjustable tolerance limits, to be automatically monitored and adjustable. None of these apply to the water organ!

Often installed in a position outside of the operating person’s range of vision, and once set manually, it distributes water “de gusto“. This is a process gap that a demanding customer might tolerate with a provider from low labour cost countries for the time being. It certainly is the reason why some processors in our latitudes have failed to win – or even worse – have lost an important customer. This situation is not inevitable. Newly developed temperature-control systems have finally closed this gap.

Regulating low rate individually

This does not refer to revolutionary new developments in the flow rate measurement which have been the standard for more than ten years for technically leading manufacturers of temperature-control appliances. Rather, this is about the technically realized possibility to regulate in multi-circuit systems the flow rate per circuit individually – not just impulse-wise, but steadily within programmable quality limits. To do so, the desired water quantity is set electronically on screen on in graphic setting display that represents a water organ. Everything else is done by the control system, even if depositions in the temperature-control circuit reduce the originally set flow rate. After changing the mould, an integrated mould check verifies that the saved data conform to the actual flow rate in order to point out any discrepancies. This way possibly mixed up hoses becomes evident before the first shot from the newly installed mould is made, producing expensive rejects.

Temperature-control systems integrated close-to-mould

Another important advantage of the new systems is that they can be integrated into the processing systems. If traditionally processing happened with long hoses attached to water organs, which especially for large machines and numerous cooling circuits resulted in a hardly understandable tangle of hoses, the ultra-compact construction allows complete close-to-mould integration. To do so, the valve blocks of the temperature-control system are directly mounted to the mounting plates of the injection machine. The hose lengths necessary to connect the mould are reduced to a minimum, and complex hose conducts through the drag chain are completely avoided. The screen with the central operating button for setting and monitoring the parameters is separately placed directly next to the controls of the injection machine. It is also possible to completely integrate the system into the controls of the injection machine.

Bottom line: Check flow rates regularly

Companies that are not using one of these temperature-control systems yet, and in existing temperature-control appliances have no integrated flow rate measuring should opt in favour of a minimum of process monitoring. Slow but constant reductions of the flow rate are not uncommon and will, over time, result in serious problems. The most common cause is deposition of organic and non-organic substances in the cooling channels, which inhibit heat transfer. Pollution in temperature-control circuits considerably influence piece costs. Increased cooling times of up to 60% and increased operating costs of more than 30% as compared to the unpolluted condition are common.

Therefore it is recommended to check the flow rate regularly, ideally when changing the mould, and to record it in the mould log. If temperature-control problems arise during the process checking should happen online. To do so, a mobile measuring device is inserted into the temperature-control circuit, measuring the flow rate as well as the temperatures of the supply and return connections and the pressure loss. This way, the functionality of the connected temperature-control appliance is checked at the same time.

Preventive maintenance prevents interruptions

Temperature-control appliances and moulds should be subject to preventive maintenances, which should include checking and cleaning them before avoidable disruptions occur and process safety is lost. Mobile cleaning appliances are valuable tools. They almost completely control the cleaning process automatically.

It is not so difficult to ensure sufficient process safety in the area of temperature conditioning. All it requires is leaving well-trodden paths and find new ways with the help of temperature-control specialists. Global competition and potentials for rationalizing in the area of mould temperature-control should offer sufficient motivation to do so.