Leveraging Hidden Potential

Mold Temperature Control. Reduced cycle time, minimized rejects and increased process reliability are significant competitive advantages in injection molding. Companies are therefore increasingly relying on high-precision injection molding machines – often in combination with appropriate process monitoring systems. An important factor that is often overlooked is mold temperature control.

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To maintain high rates of repeatability even over long periods, it is necessary to keep the key manufacturing parameters constant. Modern injection molding machines offer processors the option of monitoring and documenting a wide variety of process parameters. However, there is generally not a lot of information available about the current temperature status in the current process. This is all the more surprising since the temperature exerts a strong influence on the product quality as well as being at the source of a range of malfunctions and influencing factors **(Fig. 1)**. It is therefore understandable that, according to a study, 24 % of rejects on average can be attributed to defects in mold temperature control [1].

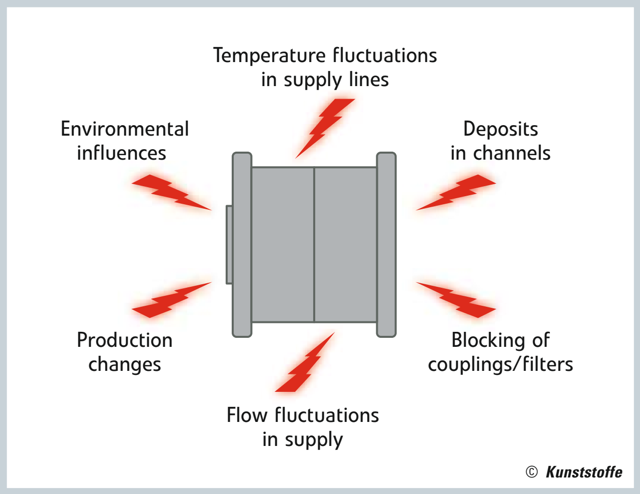

Fig. 1. Mold heating/cooling is subject to a range of malfunctions and influencing factors (figures: Engel).

To eliminate these influences, the flow rates through the individual heating/cooling circuits and the supply and return temperature should be measured, monitored and, if necessary, corrected. However, the manual flow meters that are widely used for this purpose are often not up to the job. Engel Austria GmbH, Schwertberg, Austria, has therefore developed and launched a cooling water distribution system with electronic sensor, which can be integrated into the machine control.

Modern Distribution Systems Increase Process Reliability

If multiple temperature control circuits are operated with the same water or oil temperature, the question arises at the latest on mold set-up of whether to connect up the operating media supply serially or in parallel with the mold heating/cooling circuits. Generally, the parallel circuit favors a high overall through-flow and the temperature differences between the mold input and output are smaller because of the shorter heating/cooling channel length. This in turn can benefit the mold quality – for example due to lower warpage. However, this major advantage of the parallel circuit should not blind us to the fact that the media distribution is uncontrolled. There is a strong risk of the individual circuits becoming blocked unnoticed [2].

With the Engel Flow Monitoring System **(Fig. 2)** – Engel flomo for short – it is possible to combine the advantages of the parallel circuit with high process reliability. The compact, manually adjustable water distribution system, whose integrated sensors can register flow rates, temperatures and pressures, is mounted directly on the injection molding machine – including the direct vicinity of the mold if desired and space permits. The measurements are transmitted to the machine control, so that they can be visualized, monitored and documented. Integration into the machine control also makes it convenient to operate.

Water distribution systems of this kind are more expensive than conventional flow meters, due to their electronics, but in practice, their purchase pays off very quickly. An automotive supplier that now uses Engel flomo produces PA parts in a two-cavity mold. The five cooling circuits

Fig. 2. Engel flomo is a compact sized cooling water distributor/manifold with electronic monitoring

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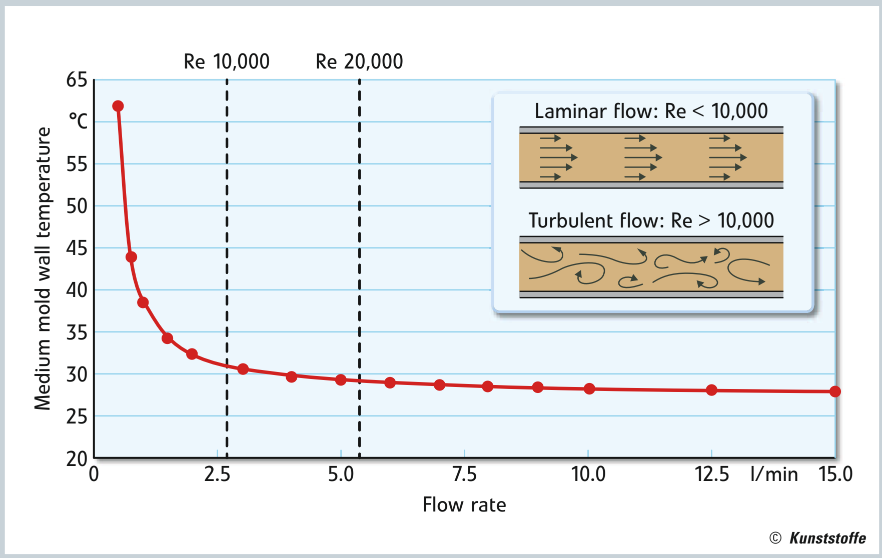

Fig. 3. The mold wall temperature depends on the flow rate of the cooling water (cooling water temperature in the illustrated process: 20 °C)

were previously supplied via flow meters. During production, contaminants in the cooling water had become deposited on a quick-connection coupling, and completely interrupted the supply to the cooling circuit without anyone noticing.

The part geometry was still OK before shipping; off-spec dimensional deviations were only recognized in the customers' incoming goods control. As a consequence, the entire delivery was rejected. It was only after a long search that technicians identified the lack of flow as the cause. This defect, which caused post-shrinkage of the parts was expensive. The overall cost the automotive supplier almost EUR 30,000.

Turbulent Flow in Demand

Modern distribution systems offer the opportunity to identify and counteract defects of this kind at an early stage before the defective parts are shipped. At the same time, the systems provide the user with new parameters that can be used for process optimization, for example the flow rate.

The thermal balance of an injection mold is significantly influenced by the volume flow rates in the individual cooling circuits. But who knows the ideal flow rates for their process? In essence, the greater the flow rate, the better the heat exchange between the mold and heat-exchange medium, and the lower the temperature difference between the mold inlet and outlet. In many companies, to be on the safe side, it should be ensured that the flow controllers of all circuits are completely open. It remains a mystery whether the individual flow rates are then too low, unnecessarily high or just right.

Engel's developers have investigated the question of optimum flow rate in cooling circuits in depth and performed a wide range of simulations and experiments. In principle, the minimum required flow rate is principally determined by two factors:

- The temperature increase between mold inlet and mold outlet,
- Reynolds number.

The maximum permissible temperature increase should not be exceeded. According to [3], this is between 3 and 5 K for standard injection molding and between 1 and 3 K for precision injection molding. To determine the actual influence of the temperature increase on the thermal homogeneity of a part during cooling, it is advisable in many cases to employ injection molding simulation for the application.

Reynolds number Re characterizes the turbulence of flow. This must be so clearly developed that the system-dependent flow fluctuations do not significantly affect the mold wall temperature. From a Reynolds number of 10,000, turbulent flow is completely developed. To a first approximation, this value serves for definition of the minimum required flow rate. How does the average mold wall temperature depend on the flow rate? While the temperature change is very significant at low flow rates (Reynolds number Re < 10,000), only a very small effect on the mold wall temperature can be seen at high flow rates (**Fig. 3**). Reynolds numbers Re < 10,000 denote somewhat uneconomic process because of the reduced heat exchange. In addition, the steep drop of the curve shows that the mold wall temperature responds sensitively to low flow fluctuations. For this reason, it is recommended to choose the flow rate such →

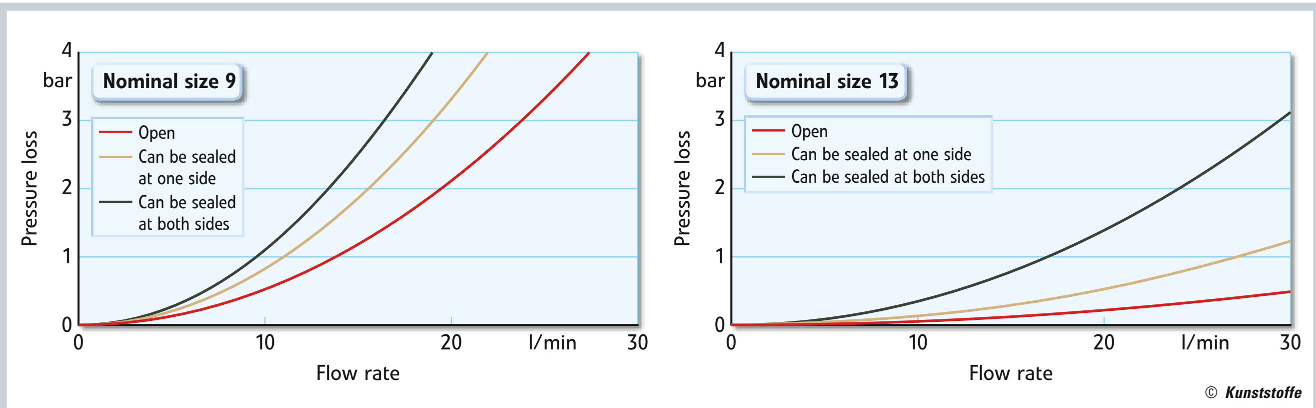

Fig. 5. Rapid couplings cause pressure loss – to different degrees depending on the design and nominal size. At a nominal size 13 (right) the design that can be sealed at one side causes about 2.5 times greater the pressure loss compared to an open model, while the model that can be sealed at both sides has over 6 times greater the pressure loss. At nominal size 9 (left), the model that can be sealed at one side has about 1.5 times greater the pressure loss compared to the open design, while the version that can be sealed at both sides has over twice the pressure loss

that Re > 20,000. The characteristic curve profile is generally applicable for injection molding processes.

Reynolds number in turn depends on three factors:

- The flow rate,
- the bore diameter and
- the viscosity, which in turn is strongly influenced by the temperature.

The flow rates that allow the recommended Reynolds number Re = 20,000 to be reached can be read from the graph **(Fig. 4)**. If, for example, water can pass with a supply temperature of 60 °C through a bore with a diameter of 10 mm, a flow rate of 4.5 l/min is necessary (black arrows in the graph).

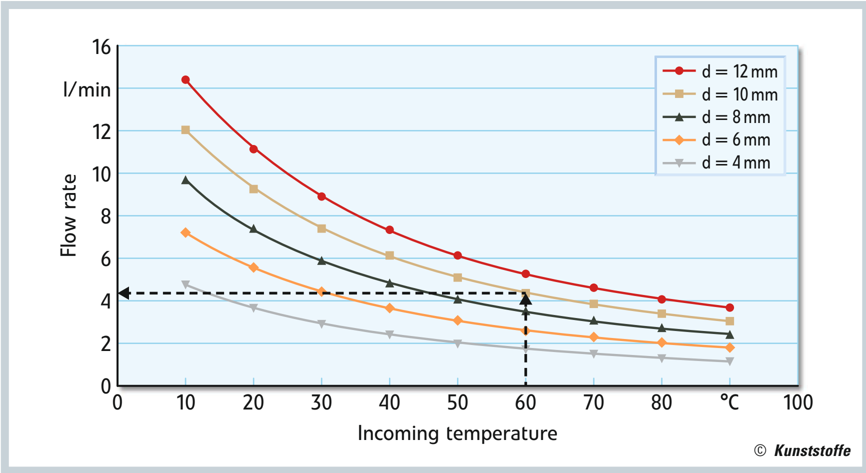

Fig. 4. The flow rate necessary for reaching the optimum Reynolds number (Re = 20,000) is calculated from the supply temperature and bore diameter (d) of the cooling channels

Do Not Underestimate Hydraulic Connections

The necessary flow rates can often not be reached straightaway. This may be because the pumps are not dimensioned powerfully enough or are worn. A simple way of still reaching the flow rates consists in optimizing the hydraulic mold connections. Long hoses between the heat-exchange medium supply and mold, small hose diameters and a wide variety of pressure-reducing quick-connection couplings are only one characteristic of the hydraulic mold connections that are to be found in many injection molding companies. Each of these components causes pressure losses and is therefore partly responsible for reducing the flow rate.

The biggest pressure consumers generally include, besides the heating/cooling channels in the mold, quick-connection couplings. A distinction is made between quick-action couplings that are open, can be sealed at one side, and those that can be sealed at both sides. The pressure loss functions are different depending on the design **(Fig. 5)**. For nominal size 13 (right) it can be seen that those which can be sealed at one side have about 2.5 times greater the pressure loss, compared to the open model, while those that can be sealed at both sides have over 6 times greater the pressure loss. For nominal size 9 (left) it can be seen that the pressure losses are generally higher than for nominal size 13. The model that can be sealed at one side has a pressure loss about 1.5 times greater the pressure loss of the open design, while the version that can be sealed at both sides has over twice as high a pressure loss. In general, therefore, sealable quick-connection couplings should be avoided in cooling systems or should be adequately dimensioned.

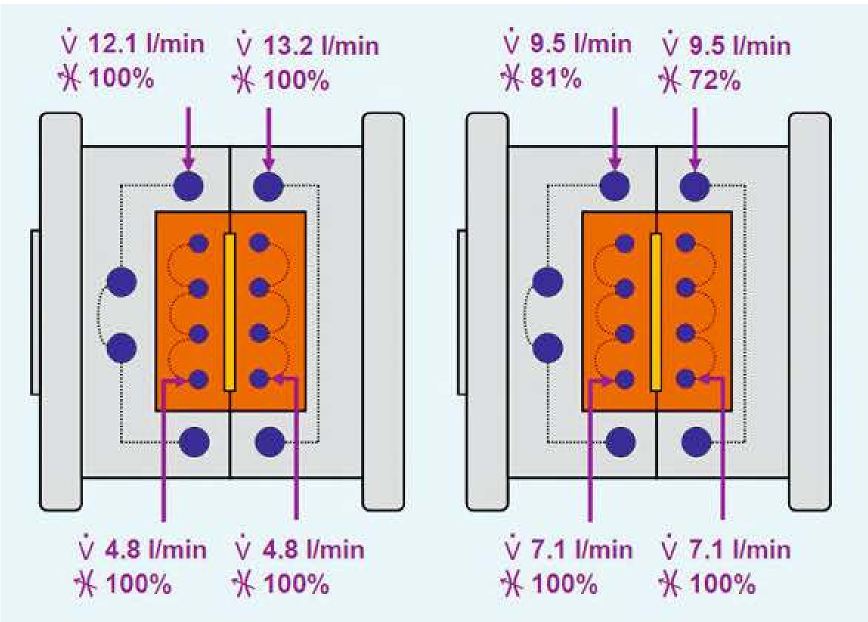

Fig. 6. Natural flow distribution without hydraulic balancing (left) and flow distribution after hydraulic balancing (right). This simple measure increases the heat exchange between the mold and heat-exchange medium.

Process Optimization by Hydraulic Balancing

Despite careful choice of the components, it may be that the flow rate in individual cooling circuits is too low. If the hydraulic resistances of the circuits are very different, the water will choose the path of least resistance. Hydraulic balancing – selective throttling of the flow rates into the individual cooling circuits – may be a remedy here. This can compensate for unbalances in the water distribution. Distribution systems such as the Engel flomo have valves for adjusting the flow rate.

The flow distribution for producing a flat PP part with a wall thickness of 2 mm will illustrate the problem **(Fig. 6)**. In the vicinity of the mold inserts, the temperature-control bores are designed with a diameter of 6 mm, and 10 mm in the main mold. The cooling water temperature is 20 °C. The greater hydraulic resistance in the inserts has the effect that most of the water flows through the main mold, while the greatest heat flow would actually have to be dissipated from the inserts (left). If the hydraulic resistance is increased by the throttling of the flow rates in the main mold, more water flows through the inserts. As a consequence, the flow rate increases from 4.8 to 7.1 l/min (right) and is therefore above the recommended value of 5.7 l/min **(Fig. 4)**. This simple measure increases the heat exchange between the mold and heat-exchange medium; this resulted in a reduction of the cooling time of 7 %. At the same time, the temperature increase between the mold inlet and mold outlet is reduced.

Summary

A demand-optimized control of the flow rates in the mold can significantly contribute to the quality and productivity increase during injection molding. Modern cooling water distributors with flow rates and temperature sensors form the basis for optimization and continuous monitoring of process parameters that have so far often been underestimated. ■

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