Corrosion comparison between a coated (left) and non-coated heating/cooling channel (right): each layer of deposits costs the processor money (figs.: gwk)

Cost Factor Corrosion

Heating/Cooling. Producing high-quality injection moldings not only reproducibly but also on a cost-efficient basis requires precise knowledge of the processes involved. Of particular importance here are the thermal processes that take place in the mold. Anyone who does not bear this in mind will have to pay a high price for ignoring it.

HELMUT GRIES

Although a large number of converters are sufficiently familiar with the fact that the "mold temperature" influences not only the cooling time but also the quality of the molded part, they do not realize that this means the mold wall temperature, i.e. the temperature profile over the entire surface area of a part that has just been produced, rather than the temperature value that is shown on the display of the heating/cooling unit **(Fig. 1)**.

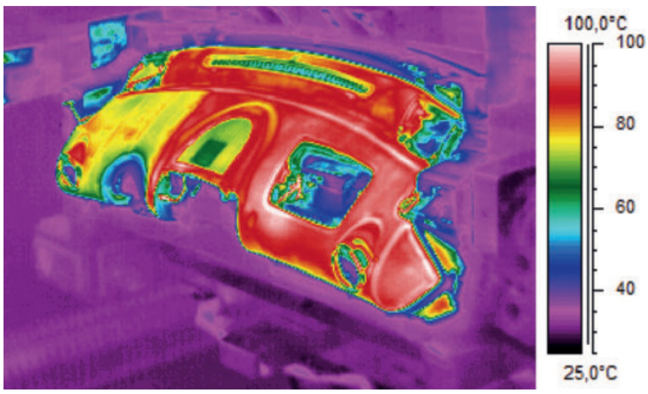

Fig. 1. The thermograph shows an uneven temperature distribution over the molded part. Only a uniform temperature profile over the entire surface will guarantee a high process quality

The Decisive Factor for Cost-Efficiency

Key molded part properties, such as mechanical strength, surface quality, dimensional stability and warpage are a direct function of the mold wall temperature. At the same time, this temperature is a decisive factor for the cooling time and hence for the attainable cycle time and the cost-efficiency of the injection molding process. As a rough guide, increasing the mold wall temperature by 1°C will increase the cooling time by 2 % **(Equation 1)**.

The injection mold not only serves to shape the molded part but also has the

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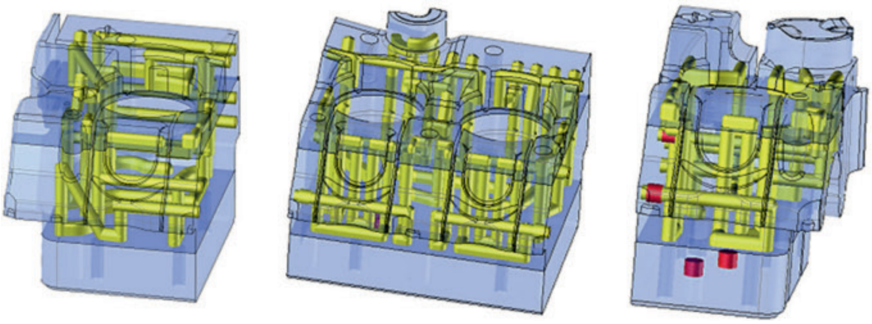

Fig. 2. Positioning the heating/cooling channels close to the cavity in the injection mold permits an ideal heat flow profile

function of a heat exchanger. The correct arrangement of the cooling channels is a prerequisite for the rapid and uniform exchange of heat. The converter can essentially expect to obtain an optimum heat flow profile if the heating/cooling channels are located close to the cavity and follow the contours of the molded part **(Fig. 2)**.

The heat transfer medium flowing through the heating/cooling channels absorbs the necessary amount of heat introduced into the mold by the melt to cool the molded part and eliminates this via a heat exchanger in the heating/cooling unit or directly to the cooling system. Water is the main circulating medium employed on account of its excellent heat transfer properties. The quantity of heat that can be transferred per time unit depends not only on the heat-exchange surface and the temperature differential but also on the coefficient of heat transfer k. The k value includes the material values of the plastic and the water as well as the thermal conductivities of the materials involved in the heat exchange process **(Table 1, Equation 2)**.

Harmful Deposits with a Low Thermal Conductivity

By comparison to the standard metal materials used in mold building, deposits such as those caused by reactions of the substances contained in the cooling water, have considerably lower thermal conductivity values. At points with low flow velocities, in particular, layers build up on the walls of the heating/cooling channels in the form of mineral deposits and corrosion coatings which sooner or later (as a function of the temperature) have the effect of obstructing the heat transition. If injection molds are operated via heating/cooling units running at high temperatures on account of the molding compound being processed, then they are at particular risk of corrosion, especially if the heating/cooling medium has a high oxygen content and a high concentration of dissolved salts **(Fig. 3)**.

As a result, the k value falls, the mold wall temperature rises, and the cooling time undergoes a considerable increase. As the layer becomes thicker and thicker, this also has a negative influence on the quality of the molded part. Both effects together have an enormous impact on the energy and process costs, since considerably more operating hours elapse before the requisite number of molded parts has been produced, and the entire manufacturing cell is affected. Cooling times up to 60 % longer than for new production equipment and operating costs more than 30 % higher are not uncommon.

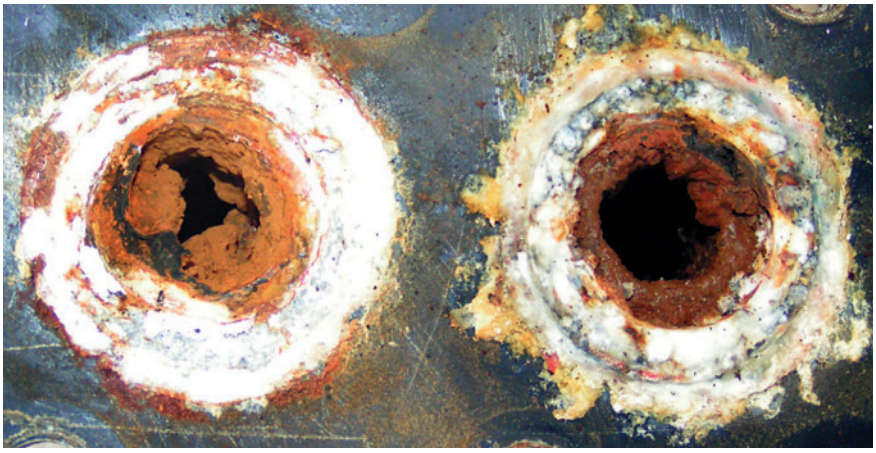

Fig. 3. Corrosion in the heating/cooling channels increases the cooling time and impairs the quality of the molded part over time

! Equations

(1) Approximation formula for calculating the theoretical cooling time of a flat plate

$$t_K = \frac{s^2}{\pi^2 \cdot a_{eff}} \ln\left(\frac{8}{\pi^2} \cdot \frac{\vartheta_M - \bar{\vartheta}_W}{\bar{\vartheta}_E - \bar{\vartheta}_W}\right)$$

s = Wall thickness

$\bar{\vartheta}_W$ = Mold wall temperature

ϑ_M = Compound temperature when injecting

$\bar{\vartheta}_E$ = Mean demolding temperature

a_{eff} = Effective thermal conductivity

(2) Calculation formula for the heat exchange in the injection mold

$\dot{Q} = A \cdot k \cdot \Delta\vartheta_m$ with

$k = \dfrac{1}{\frac{1}{\alpha_1} + \sum_{i=1}^{n} \frac{s_i}{\lambda_i} + \frac{1}{\alpha_2}}$ with

$\frac{s_i}{\lambda_i}$ = Quotient of the layer thickness and the thermal conductivity of the heat-conducting layers

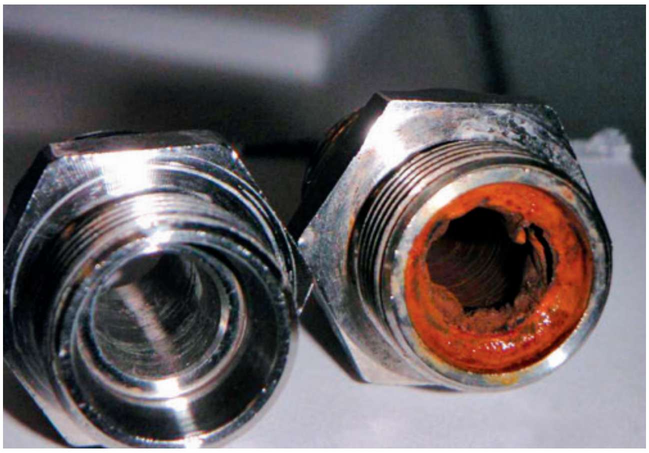

Fig. 5. The cross-section of a screw fitting made narrower by corrosion deposits considerably reduces the amount of water flowing through

There is potential for further danger when valves or slides are opened or heating/cooling units started up. Deposits that have formed are dissolved and rinsed into the circuit, and the particles now circulating inside the system can clog up lines, fittings and heating/cooling channels. At all events, the transition of heat is impeded in two ways, since not only is heat transfer obstructed, but the pressure loss in the cooling channels rises as a result of the reduced flow cross-section. This, in turn, leads to a considerable reduction in the quantity of water flowing through **(Figs. 4 and 5)**.

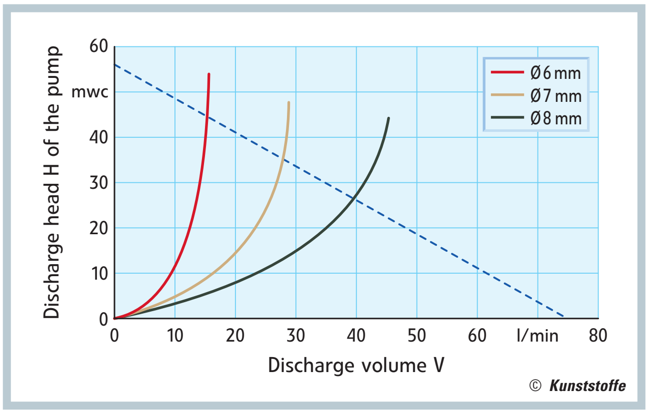

Fig. 4. Effective pumping capacity with different heating/cooling channel diameters and pressure losses: clogged lines obstruct the transfer of heat in two ways (mwc: meter water column)

Additional Costs Running into Seven Figures

Under certain circumstances, a company will have to purchase additional injection molding cells with molds and peripheral units in order to fulfill its production obligations. A study commissioned by one manufacturer of engineering parts showed that, with a corrosion layer of no more than 1 mm in the heating/cooling channels, the additional costs incurred through the deposits can be more than EUR 3 million per year. The company has 20 injection molding machines on which it produces molded parts in ABS for the electrical industry, which are subject to stringent requirements in terms of surface quality.

With a 1 mm deposit, the thermal conductivity λ in the mold falls from 34 to 14 W/mK – corresponding to a 56 % increase in the cooling time. The results of the study were as follows:

- Clean mold: rejects 5 %, cycle time 22.5 s with a cooling time of 12.5 s;
- soiled mold with a 1 mm deposit: rejects up to 20 %, cycle time 29.5 s with a cooling time of 19.5 s –

putting the additional costs per machine due to a soiled mold at between EUR 57,500 and 143,400 per year. Added to this comes EUR 90,000 for the greater amount of energy consumed by the cooling system due to its reduced efficiency and EUR 230,000 for machine downtime and cleaning. Transposed to 20 machines, the theoretical spread of the additional annual costs, as referred to above, is between EUR 1.47 million and 3.19 million and the mean value per machine EUR 116,450.

The costs of the available preventive measures appear low by comparison, starting with the use of corrosion-resistant steel and going via the coating of heating/cooling channels through to the use of closed heating and cooling circuits with the appropriate form of water treatment.

Prevention Pays for Itself

Even circuits that were clean to begin with frequently become soiled again when the

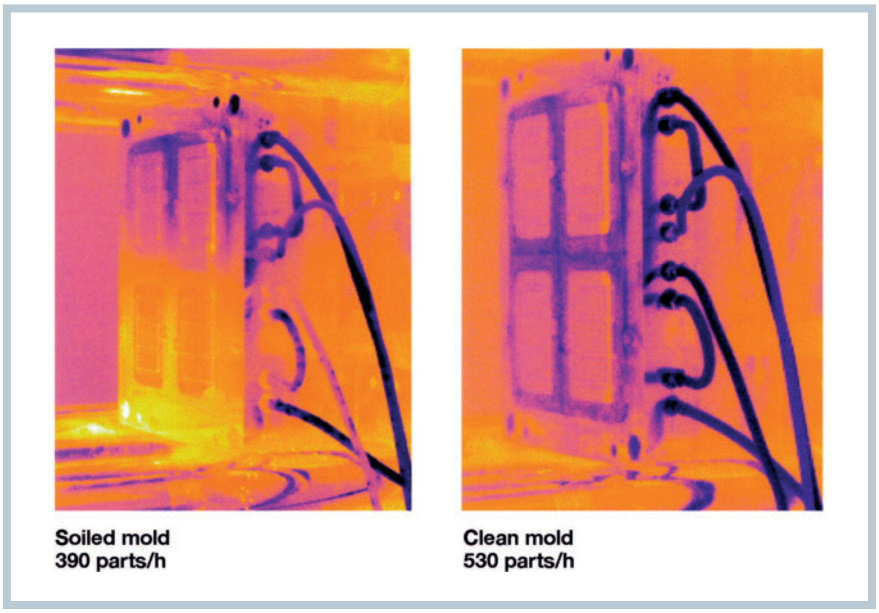

Fig. 6. Thermographs of a mold with soiled and cleaned heating/cooling channels: preventive cleaning measures are worthwhile

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Material	Thermal conductivity λ [W/m × K]
Iron	67
Steel (0.6 % C)	46
High-alloyed tool steel	14–40
Aluminum	221
Copper	393
Scale deposit	0.08–2.2
Oxidized steel	1–5
Polystyrene	0.17
Polyamide	0.25–0.27
Polyethylene	0.35–0.45
Mineral fiber insulating materials	0.04

Table 1. The thermal conductivity of the materials involved in the heat-exchange process in the mold has a decisive effect on the cooling time

mold is changed. To stop this from happening, all the heating/cooling channels ought to be cleaned before the molds are put into storage or before they are mounted on the machine. Special cleaning units can provide valuable assistance here. The longer a company waits before performing the cleaning, however, the more difficult it will be to remove highly encrusted deposits. Under some circumstances, the employees in charge will have to have recourse to additional mechanical cleaning methods for particularly stubborn deposits. If the units are used regularly, however, with chemical cleaning based on the flow-through principle and subsequent neutralization of the surface, a good and lasting cleaning result will be achieved **(Fig. 6)**.

The extent to which a corrosion-resistant design of the entire heating/cooling circuit will influence productivity and article costs should not be underestimated. Excessively long cycle times, excessively high reject rates and reduced availability due to broken parts or even entire production plants at a standstill will lead to considerably higher costs and, under certain circumstances, to a reduced capacity to deliver. gwk estimates that rationalization potential of well in excess of two billion euros is available to be tapped in this respect in German injection molding companies each year.

Savings Potential of Two Billion Euros in Germany alone

If the calculations are based on a figure of 50,000 injection molding machines installed in Germany, each clocking up 6,000 operating hours a year, and if a 30 % reduction in cooling time for 15 % of the machines is taken as the optimization potential, then a savings potential of EUR 270 million results from 13.5 million (50,000 × 6,000 × 0.3 × 0.15) wasted production hours (at EUR 20 per hour).

If a second scenario is then pictured in which it is assumed that 15,000 machines, i.e. around one third of the total, require their water quality to be optimized in the manner set out above (mean value per machine: EUR 116,450), then this produces a savings potential of EUR 1,747 million, which, together with the EUR 270 million savings, gives the amazing total of EUR 2 billion.

Don't let anyone say that there is nothing that can be done to alleviate the proverbial cost pressure. ■

THE AUTHOR

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