

Do Not Forget the Cooling

Measures for More Energy Efficiency in Thin-Wall Injection Molding

Notwithstanding the oil-price fluctuations, in the long term, energy prices are moving in only one direction: upwards. It will therefore be even more important in future for manufacturers to keep an eye on their energy balance. The injection molding machine manufacturer Engel is concentrating its development work not only on the drive technology, but also on, e.g., the mold cooling. This holds great savings potential, particularly in the manufacture of thin-wall packaging.

As regards production performance data, the packaging industry plays in the Champions League. Whether it makes a profit or loss depends on the cycle times. To be among the winners, it is necessary to make adjustments at two points: first, the velocity of the machine movements, for example during opening and closing the mold halves or during ejection of the parts and, second, the cooling time. The latter is obtained from the part shape and the temperatures of the melt and mold surface. The mold cooling thus becomes a fundamental efficiency factor.

The heat transfer from the melt through the mold into the cooling medium [1] results in three parameters that determine the temperature at the cavity surface:

- The thermal resistance in the mold,
- the heat transfer resistance from the mold to the coolant, and
- the chosen level of the coolant temperature.

These parameters are mathematically related to one another:

$$k = 1 / \left(\frac{1}{\alpha_M} + \frac{\delta}{\lambda} + \frac{1}{\alpha_{TM}} \right) \quad (1)$$

k : Heat transfer coefficient [kJ/m²hK]

δ : Distance from the cooling channel to mold cavity [m]

α_M : Heat transition coefficient melt/mold [kJ/m²hK]

λ : Thermal conductivity [kJ/mhK]

α_{TM} : Heat transition coefficient mold/cooling medium [kJ/m²hK]

As regards the thermal resistance in the mold, the closer the cooling channel is to the cavity, the smaller is the thermal resistance. Conformal cooling can be achieved with laser-sintered mold inserts ("laser-curing" or comparable processes), even with complex mold geometries. The thermal conductivity also plays a major role here. There are advantages in using inserts made of highly conductive materials such as bronze or copper-beryllium alloy (CuBe), however these materials are only suitable for exposed areas because of their restricted strength.

The heat transfer from the mold into the heat-transfer medium is determined not only by the cooling channel geometry, but also by the throughflow of the coolant. As is generally known, turbulent flow in the cooling channel is necessary for optimum heat transfer. Turbulence develops at Reynolds numbers above 2,300; the ideal values are between 10,000 and 20,000 (Fig. 1). At even higher Reynolds numbers, the heat transfer only changes marginally and therefore does not achieve a further improvement. From an energetic point of view, a higher throughflow should therefore be avoided [2].



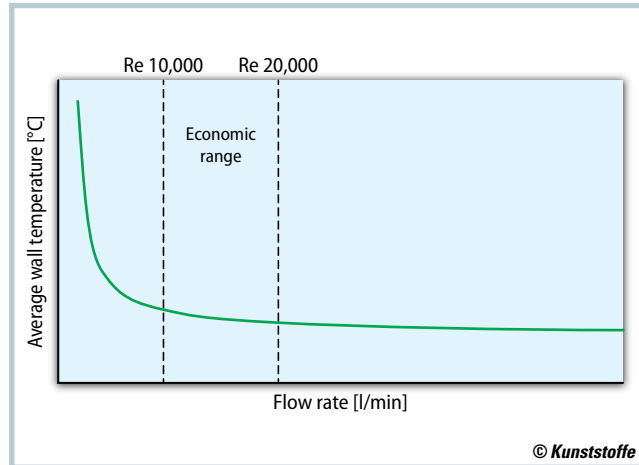
In the production of thin-wall packaging, the available energy saving potential is often not completely utilized (figure: Fotolia.com/euthymia)

Physical Principles Are Not Paid Enough Attention in Practice

The medium supply temperature also influences the heat transition – not only via the temperature of the cooling channel but also via the wall temperature of the cavity. The greater the temperature difference, the greater the amount of heat that needs to be removed. However, there are only drastic changes in the heat flow if the coolant temperature changes very greatly, which hardly occurs in practice.

In the injection molding of technical parts, the coolant temperature is »

Fig. 1. Mold wall temperature as a function of the flow rate: The Reynolds number should ideally lie between 10,000 and 20,000 (figure: Engel)



adapted to the requirements of the material. In thin-wall injection molding, the bandwidth may be wider, however in this case, too, the temperature usually remains below 20°C. Since the temperature of the cooling channel surface does not change significantly in this area, the supply temperature of the coolant is only of minor importance for the heat transfer in thin-wall technology.

In practice, these physical principles have so far received too little attention in thin-wall applications in the packaging industry. Though the exposed regions in the mold, such as the core bases of cup or pail molds are correctly made of highly conductive materials, conformal cooling is only rarely to be found.

In addition, there is a widespread opinion that a higher coolant throughflow can achieve greater heat removal and therefore a shorter cooling time. As mentioned above, however, with turbulent flow an increase of the Reynolds number to over 20,000 no longer has a significant effect on the heat removal. This should be taken into account in the cooling water flow rate that is used.

Even greater saving potential is provided by the cooling channel diameters. Though, with the use of interfering elements [3], turbulent flow can be achieved even at relatively small Reynolds numbers, the cooling channel diameters used are often dimensioned too large. The reasons for this are that production managers often want to limit the pressure loss in the channels, which are usually connected in series, and assume that a larger cooling channel surface area also provides greater cooling performance.

Water Throughflow Can Be Drastically Reduced for the Same Cooling Effect

On the other hand, it is correct that the effective cooling channel surface area is derived from the surface area facing the cavity. If a larger cooling channel is then replaced by two channels, each with half the diameter, the effective cooling channel surface area remains unchanged. However, a considerably smaller throughflow is enough to obtain the same Reynolds number. At the same time, the pressure loss can be compensated by changing from series to parallel arrangement of the cooling channels. This allows the water throughflow to be drastically reduced for the same cooling effect. The energy consumption and the cost are consequently reduced.

Lower Energy Demand despite Higher Melt Temperature

Besides these simple measures for optimizing mold cooling, other, less obvious potentials are also available. Observing the minimum cooling time is essential in thin-wall technology. In the wall-thickness range below 0.5 mm, this behaves a little differently than is generally assumed. The minimum cooling time results not only from the wall thickness and the material properties, such as effective thermal conductivity and maximum permissible demolding temperature, but also from the melt temperature and mold wall temperature. However, with these small wall thicknesses, both of these parameters only have a negligible effect (Fig. 2). That means that, with a change of these parameters, the cooling time only varies in the range of hundredths of a second, and therefore only has a marginal effect on the cycle time.

For optimizing the energy consumption, this finding opens up new potential. Though an increase in the melt temperature requires more energy for heating due to the larger enthalpy difference, the filling pressure required for these small wall thicknesses is reduced (Fig. 3). In the end effect, the overall energy demand for production of the packaging parts is reduced.

A further approach to saving energy in the coolant supply is to increase the mold wall temperature. It makes a difference whether one works with supply tempera-

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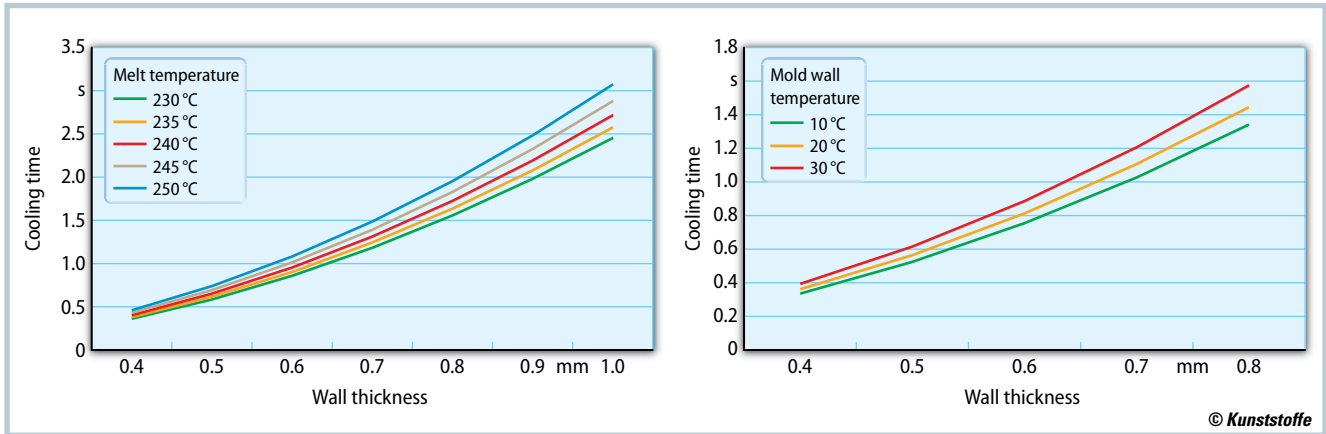


Fig. 2. In the range of very small wall thicknesses below 0.5 mm, the melt temperature and mold wall temperature do not have a significant influence on the cooling time. The graph left shows the dependency of the cooling time on the wall thickness and melt temperature; the graph right takes into account the mold wall temperature instead of the melt temperature (figure: Engel)

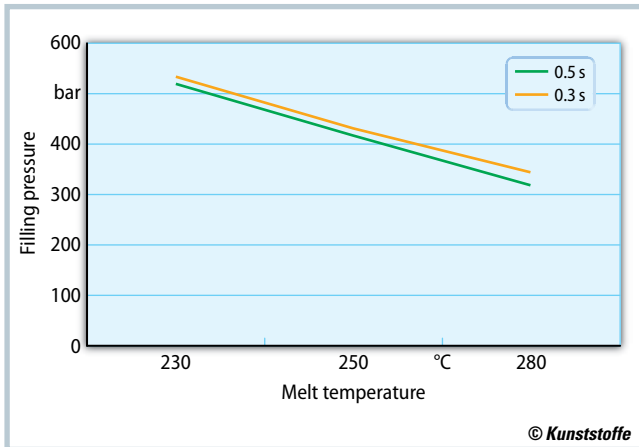


Fig. 3. The required filling pressure is reduced with increasing melt temperature. This opens up further possibilities for improving the overall energy balance. The diagram shows two different filling times (figure: Engel)

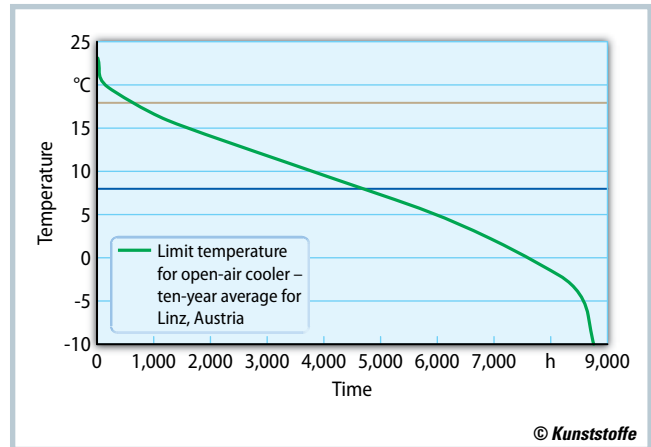


Fig. 4. A typical theoretical limit of cooling can be shown for every place on Earth. The graph shows the values for Linz in Upper Austria, which are also approximately valid for South Germany (figure: Engel, source: ZAMG)

tures of 5 or 20 °C. It depends on whether production must work with refrigeration units or can use open-air coolers.

Check Options for Using Open-Air Coolers to Reduce Costs

There is a theoretical limit of cooling for every place on Earth. It records the climatic situation of the place in the ten-year average and, for the chosen coolant supply temperature, indicates how long this temperature can be achieved with an open-air cooler, or after how many operating hours a refrigeration unit is required.

The graph (Fig. 4), which is valid for Upper Austria and Southern Germany, shows that, in these latitudes, a coolant temperature of over 20 °C can be covered 100 % by an open-air cooler. At a coolant temperature of 8 °C (blue line), this is only

possible to an extent of 50 %, and at 5 °C – i.e. principally in winter – to an extent of 25 %. For the remaining cooling performance, a refrigeration unit is unavoidable. While the type of back-cooling does not have any influence on the production of the parts, there is a large different with respect to the energy consumption and operating costs.

Both the coolant flow rate and the temperature difference between the supply and return determine the energy required for back-cooling, and this is precisely the difference between the refrigeration machine and open-air cooler. For assessing the energy efficiency of the two systems, the so-called annual coefficient of performance (CoP) is used. This indicates the ratio between the electrical energy output and consumption.

The annual CoP is about 3 for refrigeration machines and about 15 for open-air coolers. Correspondingly, when a refrigeration machine is used for cooling a cubic meter of water by 1K, an energy requirement of 0.40 kWh must be reckoned with, while, with an open-air cooler, 0.08 kWh is sufficient for the same task. If the supply temperature can be raised for the application at hand, open-air cooling represents a very effective energy-saving measure [4].

Practical Example: Cup Production

The following example illustrates the difference between the use of a refrigeration machine and that of an open-air cooler, and therefore the potential within the latter for optimizing the energy consumption and the costs for mold »

cooling. In a 4-cavity mold, cups of polypropylene are molded with a cycle time of 5 s and a shot weight of 65 g. With a melt temperature of 230 °C ($H = 680 \text{ kJ/kg}$) and a demolding temperature of 60 °C ($H = 100 \text{ kJ/kg}$), there is an enthalpy difference ΔH of 580 kJ/kg.

Since the heat exchange of the mold with the environment can be neglected, the thermal energy Q_{TM} to be removed by the cooling medium has a value of 7.54 kW:

$$\begin{aligned} Q_{TM} &= (m \cdot \Delta H) \cdot 3,600 / t_z = \\ (0.065 \cdot 580 \cdot 3,600 / 5) &= \\ 27,144 \text{ kJ/h} &= 7.54 \text{ kW} \end{aligned} \quad (2)$$

m = melt throughflow [kg/h]
 t_z = cycle time [s]

The power output of the hot runner to the cooling water (Q_{HR}) is assumed to have a value of 5 kW. This results in a total power ($Q_{TM} + Q_{HR}$) of 12.54 kW to be removed.

For the power consumption of the two systems for back cooling, this thus results in the following values:

- Open-air cooler (total power/annual CoP): 0.84 kW,
- Refrigeration machine cooler (total power/annual CoP): 4.18 kW.

The result is a large difference in energy consumption between the use of an open-air cooler and a refrigeration machine. The open-air cooler leads to a significantly better energy balance.

Summary

In the field of thin-wall injection molding, in this case in the packaging industry, there is a large saving potential available regarding both the water consumption and energy requirement. With correctly dimensioned cooling channels, not only is the efficiency of the mold cooling improved but the water consumption is also reduced. Since in this case, too, very low coolant temperatures do not significantly shorten the cooling time, it is advisable to look at using refrigeration machines based on the local conditions. It may be possible to obtain significant savings for coolant back-cooling with the use of an open-air cooler. ■