HANSER

Hot Runner Technology

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2 Basic Aspects of Heat Technology

Heat sources must be installed in the hot runner system in order to melt the thermoplastic resin during setup of the mold and to keep it molten during production. The heat source has to compensate for thermal energy lost by dissipation. It should be aimed for a balanced temperature level without temperature peaks within the hot runner system. However, unavoidable heat dissipation makes this a difficult task. Since the amount of heat dissipation can be influenced, within a relatively wide range, by design as well as by appropriate material selection, technically quite simple solutions can be implemented as long as the basic aspects of heat transfer are considered.

Insulating runners capitalize on the low thermal conductivity of thermoplastic resins to sustain a liquid center in the melt channel for the plastic to flow through during the injection phase. The melt also serves as a heat source. Often, insulated runners are heated to achieve a higher degree of processing safety, see Section 3.1.3.

There are three principal methods of heat transfer:

- Conduction
- Convection
- Radiation

In a hot runner system, conduction is responsible for most of the heat transferred. The dimensional stability of moldings is influenced by heat: increasing temperature leads to changes in volume and length. If thermal expansion is not accommodated, deformation or material failure may occur in extreme cases. The basic aspects of heat technology, as explained in the following sections, will provide a better understanding of hot runner-specific characteristic features.

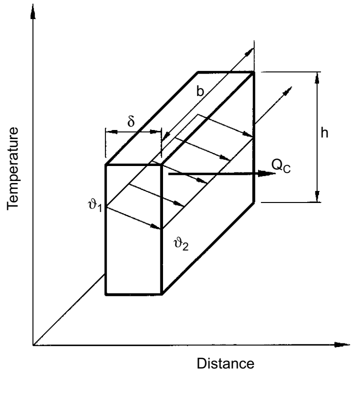
2.1 Heat Transfer

Heat can be transferred by two different physical principles:

- *Heat conduction and convection* are carried out with the help of a medium. During conduction, energy is transferred between atoms and molecules. Convection occurs through macroscopic particle movement, which is only possible in fluid agents, such as air, water, or oil. (Remark: For example, heat in a combustion engine is transferred via the cooling ribs (conduction) and together with air delivered to the environment (convection)).
- *Heat radiation* is performed with the help of electromagnetic oscillations, which are sent by solid or gaseous bodies. On the other hand, absorbed radiation can be converted into heat. Heat transfer by means of radiation does not require solid or fluid media (Remark: The earth receives energy in form of heat by means of radiation from the sun, even though the surrounding space is free from solid or gaseous substances).

2.1.1 Heat Conduction

According to Fourier, a certain amount of heat Q_C streams through a single-layer, flat wall, if there is a temperature gradient $\Delta\vartheta = \vartheta_1 - \vartheta_2$.

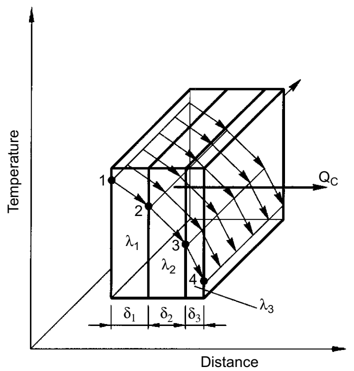


$$Q_C = \frac{\lambda}{\delta} \cdot A \cdot (\vartheta_1 - \vartheta_2) \tag{2.1}$$

where	Q_C	Heat flow [W]
	λ	Thermal conductivity [W/mK]
	A	Wall area = b · h [m²]
	δ	Wall thickness [m]
	$\vartheta_1 - \vartheta_2$	Temperature gradient [K]

We define *stationary* heat transfer, when the temperature gradient between ϑ_1 and ϑ_2 remains unchanged in the wall over time. This condition is reached in a mold, when the temperatures in the hot runner system and in the cavity wall have reached constant values. Heat transfer will change to a non-stationary state, if the driving potential changes as a function of time. This process, which will not be described in more detail, occurs particularly during the heating and cooling phases in the mold.

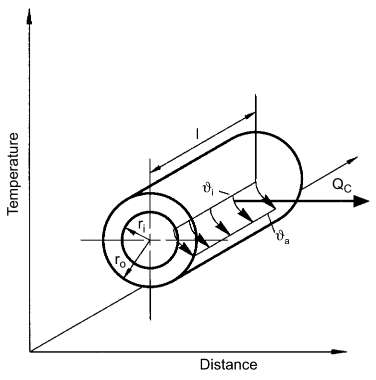
The amount of heat transferred through a multi-layer, flat wall is calculated according to Eq. 2.2:



$$Q_C = \frac{1}{\frac{\delta_1}{\lambda_2} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}} \cdot A \cdot (\vartheta_1 - \vartheta_{i+1}) \tag{2.2}$$

where i is the number of walls.

For a single-layer cylindrical wall, we have:



$$Q_C = \frac{\lambda \cdot 2\pi \cdot \ell}{\ln\left(\frac{r_a}{r_i}\right)} \cdot (\vartheta_i - \vartheta_a) \tag{2.3}$$

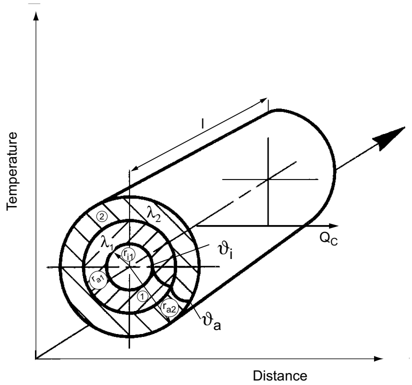
where ℓ length of cylindrical wall [m]

ln natural logarithm

r_o outer radius [m]

r_i internal radius [m]

For a multi-layered cylindrical wall, we have:



$$Q_C = \frac{2 \cdot \pi \cdot \ell}{\frac{\ln\left(\frac{r_{a1}}{r_{i1}}\right)}{\lambda_1} + \frac{\ln\left(\frac{r_{a2}}{r_{i2}}\right)}{\lambda_2}} \cdot (\vartheta_i - \vartheta_a) \tag{2.4}$$

where $r_{i2} = r_{a1}$

The thermal conductivity is a material-specific value, see Table 2.1. The thermal conductivity of solids is higher than the one for liquids or for gasses:

$\lambda_S > \lambda_L > \lambda_G$

where λ_S thermal conductivity of solid substances

λ_L thermal conductivity of liquids

λ_G thermal conductivity of gases

Note: In general, thermal conductivity is temperature-dependent, see Table 2.2.

Table 2.1: Thermal Conductivity of Solids and Gaseous Substances

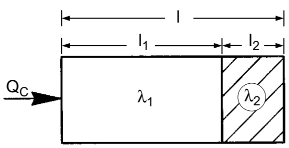
Solid and gaseous substances	**Thermal conductivity λ [W/mK]**
Silver	410
Electrolyte copper 2.0060	395
Elmedur X, Cu-Cr-Zr [2] 2.1293	320
Aluminum	229
Cu-Co-Be 2.1285	197
Dur-aluminum	165
TZM [3]	115
CuBe2 (copper beryllium)	113

Solid and gaseous substances	**Thermal conductivity λ [W/mK]**
Cast iron	58
Steel, depending on chemical analysis	approx. 14–40
Steel, grade[1] "Invar"	17
Thermally conductive cement[2] [5]	≈ 10
Titanium alloy TiAl 6 V 4	6.5
Ceramic	≈ 3
Plastics[3]	0.2–1.2
Heat insulator	0.04–0.14
Air 20 °C 200 °C 300 °C	0.026 0.039 0.046

[1] "Invar" steel composition: 63% Fe, 32% Ni, 5% Co, 0.3% Mn (approx.)
[2] "Prematherm", thermally conductive cement
[3] The higher values are generally for reinforced plastics

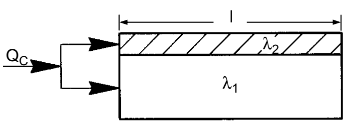
For prismatic parts composed of different materials, (e.g., distance disk for hot runner manifolds, see Section 3.5), the coefficients of thermal conductivity are:

Serial connection λ_S



$$\lambda_S = \frac{1}{\frac{\varphi_1}{\lambda_1} + \frac{\varphi_2}{\lambda_2}} \tag{2.5}$$

Parallel connection λ_P

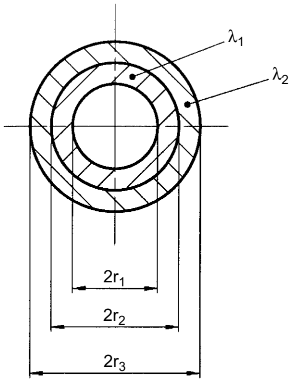


$$\lambda_p = \varphi_1 \cdot \lambda_1 + \varphi_2 \cdot \lambda_2 \tag{2.6}$$

$$\varphi_i = \frac{V_i}{V}; \quad \varphi_1 + \varphi_2 = 1$$

with φ_i Volume percent
V_i Single volumes
V Total volume.

For the *serial connection of a multi-layer cylindrical wall,* λ_{RR}



$$\lambda_{RR=} = \frac{\ln \frac{r_3}{r_1}}{\frac{\ln \frac{r_2}{r_1}}{\lambda_1} + \frac{\ln \frac{r_3}{r_2}}{\lambda_2}} \tag{2.7}$$

Parallel connection will result in the highest possible coefficient of thermal conductivity, while *series connection* will result in the smallest possible coefficient of thermal conductivity (application: distance disk, see Fig. 2.1).

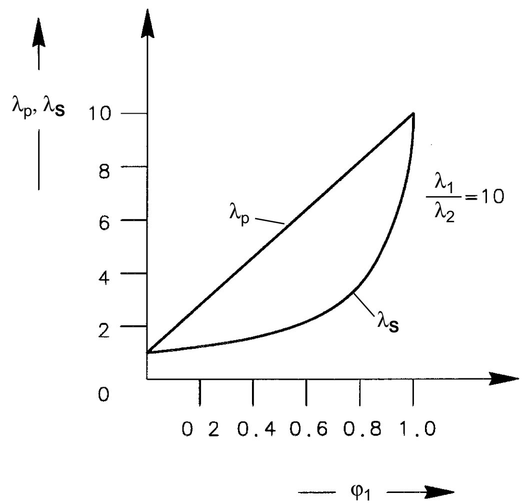


Figure 2.1: Equivalent coefficients of thermal conductivity λ_p and λ_s as a function of volume percent φ_1 of component 1; assumption: $\frac{\lambda_1}{\lambda_2}$ = 10, which corresponds approximately to the ratio of λ_{copper} / λ_{steel}

Table 2.2: Thermal Conductivity of E-Cu as a Function of Temperature [6]

Temperature [°C]	Thermal conductivity [W/mK]
20	395
100	385
200	381
300	377

Figure 2.2 shows heat transfer (arrow direction) within a hot runner system as a result of conduction.

We distinguish between:

- Heat source (supplied energy): heating capacity of hot runner manifold block, heated nozzles, if necessary distributor bushing
- Heat sink (transferred energy, dissipated energy): distance disks, centering elements (air gap)

Note: Heat sinks always lead to a non-uniform temperature distribution (so-called thermal non-homogeneity).

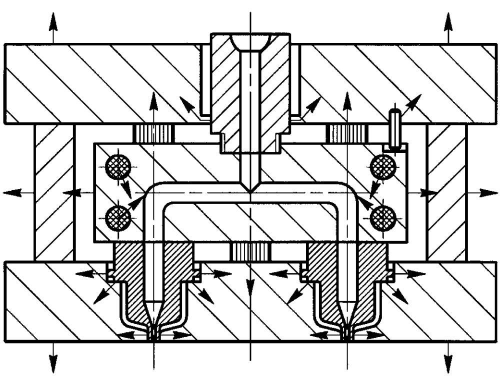


Figure 2.2: Heat transfer as result of conduction within a hot runner system (arrow direction)

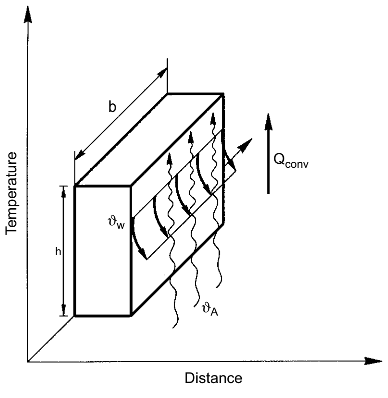
2.1.2 Convection

The heat transfer from a solid wall to a fluid medium (e.g., air, water) is defined as convection. For example, heated air becomes specifically lighter and streams upwards (chimney effect), creating an uplift; also referred to as *free* flow. If air blows at a wall with increased speed, this is referred to as *forced* flow.

The principle of convection is based on the following three steps:

- The fluid absorbs heat
- The heat continues to flow; heat is exchanged within the fluid.
- Heat is released at a place of lower temperature.

The amount of heat transferred by convection is:



$$Q_{conv} = \alpha \cdot A \cdot (\vartheta_W - \vartheta_A) \qquad (2.8)$$

where Q_{conv} heat flow [W]

α heat transfer coefficient [W/m² K]

A wall area = $b \cdot h$ [m²]

ϑ_A temperature of air stream [°C]

ϑ_W wall temperature [°C]

Convective heat transfer depends on the following factors:

- Temperature,
- Pressure,
- Speed,
- Thermal conductivity,
- Density,
- Specific heat,

- Viscosity of fluid,
- Shape and surface of wall.

The values for the heat transfer coefficient α (see Table 2.3) should be considered guide values only; they vary significantly, see also to Table 5.1. An experimental value for air (free flow) is provided in [8] as $\alpha \approx 8$ W/m$^2 \cdot$ K.

Table 2.3: Heat Transfer Coefficient „α" of Air and Water [7]

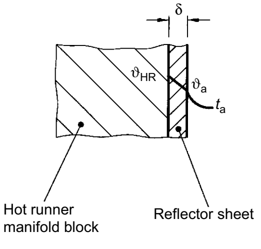
Type of flow	**Heat transfer coefficient α [W/m^{2}K]**
Free flow	
Air	3–20
Water	200–800
Forced flow	
Air	10–100
Water	600–10,000

The heat generated by the heat source in the hot runner block is conducted to the surface, e.g., to the reflector- or thermal insulating plate. Temperature gradients between the hot runner manifold block and the cavity plates lead to an uplift flow (chimney effect), thus convecting heat.

Since the heat input Q_c must be equal to the heat output Q_{conv}, we arrive at the following equation:

$$\frac{\lambda_{is.}}{\delta} \cdot A \cdot (\vartheta_{HR} - \vartheta_a) = \alpha \cdot A \cdot (\vartheta_a - t_a)$$

The wall temperature ϑ_a (see also Section 3.2) is therefore:



$$\vartheta_a = \frac{\vartheta_{HR} \cdot \frac{\lambda_{is.}}{\alpha \cdot \delta} + t_a}{1 + \frac{\lambda_{is.}}{\alpha \cdot \delta}} \quad \text{(see also Chapter 3.2)} \qquad (2.9)$$

Example:

$\vartheta_{HR} = 200\ °C$

$\lambda_{is.} = 0.1\ W/m \cdot K$

α = variable (10–100 W/m^2K)

$\delta = 6\ mm = 6 \cdot 10^{-3}\ m$

$\vartheta_\alpha = 60\ °C$

Table 2.4 and Fig. 2.3 show results of Eq. 2.9: with increasing coefficient of heat transfer α, e.g., as a result of increasing air speed (chimney effect), the surface temperature ϑ_a will decrease and the energy loss by convection increases.

Table 2.4: Surface Temperature ϑ_a and Respective Convective Heat Loss Q_{conv}/A as a Function of Heat Transfer Coefficient (See Fig. 2.3)

Heat transfer coefficient α [$W/m^2 \cdot K$]	Wall temperature ϑ_a [°C]	Q_{conv}/A [W/m^2]
10	147.5	875
20	123.6	1272
50	95	1750
100	80	2000

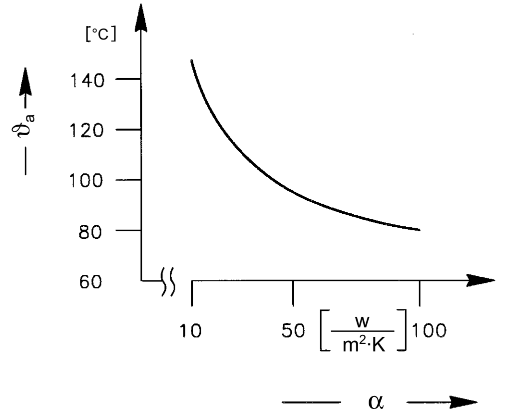


Figure 2.3: Surface temperature dependence on heat transfer coefficient α

Figure 2.4 shows the directions of convective heat flow in the hot runner manifold block. The temperature differences, e.g., between the hot runner block, the clamping plate, cavity plate, and the risers lead to a heat exchange by convection.

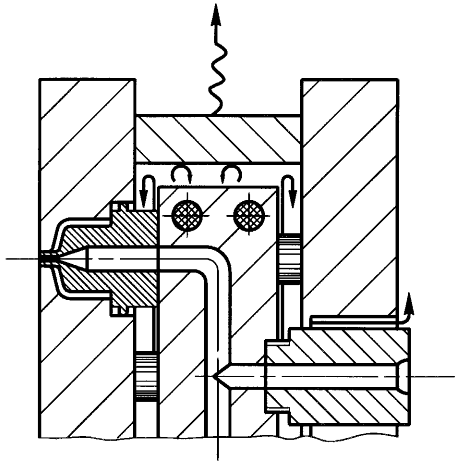


Figure 2.4: Heat flow in the hot runner system by convection (air circulation in direction of arrows)

2.1.3 Radiation

Heat is transferred by radiation between solid bodies – not in direct contact – with different temperatures by means of electromagnetic waves. They are converted into heat because of absorption. A so-called "black body" absorbes the total amount of radiation. As a result, the body also emits a maximum of radiation (Kirchhoff's laws). In comparison, a "gray" body absorbes radiation only partially. For heat transfer by radiation media such as gas, liquids, or solid bodies are not necessary.

For example, radiation energy is exchanged between the hot runner block and the surrounding mold plates. Thermal radiation is partially reflected and partially absorbed by a surface and then again converted into heat.

It should always be a goal to avoid "black bodies" in a hot runner system. This can be achieved by selecting material surfaces whose heat exchange by radiation – and thus heat loss – is minimal, see Table 2.5.