Heat transfer to ambient air / Simu-Therm 8.0

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Contents

Structure of this tutorial

This tutorial gives an introduction about **heat transfer coefficients towards ambient air** in heat loss calculations with Simu-Therm.
In Simu-Therm the convective share of the outside heat transfer coefficient can be calculated by different formulas. You learn on which different mathematical approaches the formulas are based on and get examples for the different results.
Finally you get a recommendation how to select a suitable formula for your application.

Typical heat transfer coefficients for water, air/gas, metal

for flowing water

500 to 10000 $\frac{W}{m^2K}$ (increases with increasing temperature)

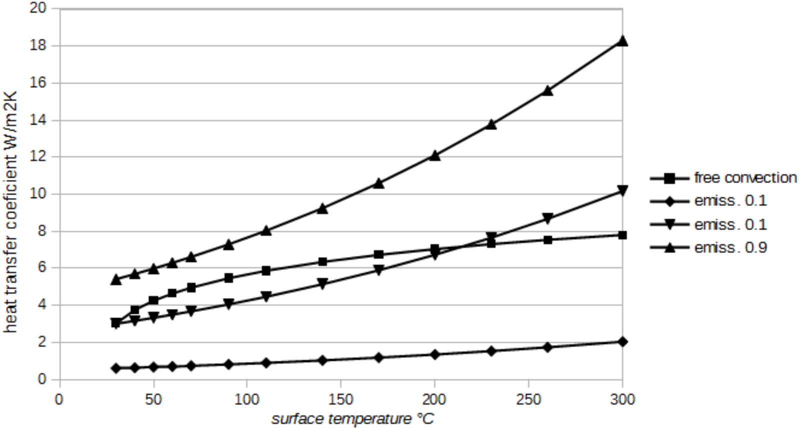
for air and flue gases

the convective portion is on the order of 3 to 30 $\frac{W}{m^2K}$
(decreases with increasing temperature)
In the case of hot flue gases, the radiation share predominates (typically 80 to 300 $\frac{W}{m^2K}$). It grows rapidly with the temperature.

in the case of liquid metals

the heat transfer coeffiient in thermal calculations is commonly assumed to be infinite. Thus a very large value (e.g. 9999. $\frac{W}{m^2K}$) is manually entered.

Heat transfer to ambient air - radiative and convective portion over surface temperature



Example: Free convection at a vertical wall. Heat transfer over surface temperature by convection and by radiation for three emissivities

Calculation formulas for convective heat transfer to ambient air

Simu-Therm 8 provides formulas from ASTM and VDI to compute the convective heat transfer to ambient air.

Each formula is based on a different approach. Especially when wind speed is considered, the **formulas yield different results**. The formulas are no exact computations, but just recommendations of ASTM and VDI how to proceed with heat flow calculations. E.g. the formulas **do not consider the direction of the wind**. There is no distinction between a wind perpendicular or lateral to the wall.

In case of free convection (no wind), the prediction of the convective heat transfer coefficient is much more reliable. As it also represents the worst case, **calculation without wind should be preferred** if possible.

All formulas provide **mean values** of the heat transfer coefficient. The heat transfer (and thus the surface temperature) varies over the area.

Similitude theory for free and forced convection

The dimensionless calculation approaches of ASTM and VDI are based on the similitude theory. There the heat transfer coefficient h follows from a relationship of the type:

$Nu = f(Re, Pr)$ (forced convection = wind driven) or

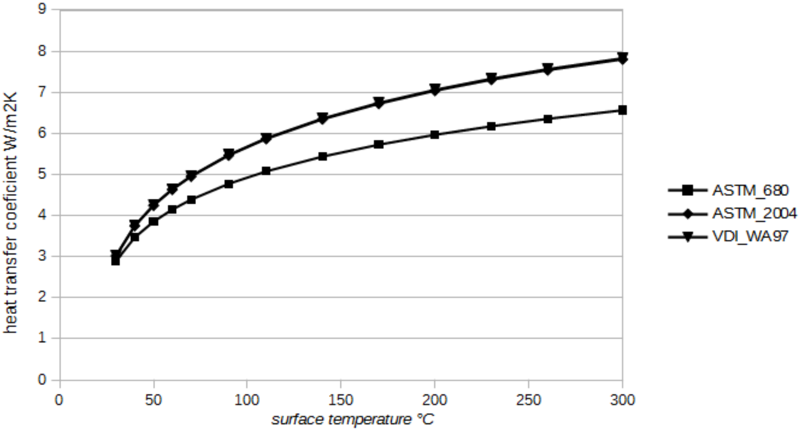
$Nu = f(Gr, Pr)$ (free convection) and $h = \frac{Nu*k}{L}$

Nu, Re, Gr, Pr are the dimensionless numbers of Nusselt, Reynolds, Grashof, Prandtl. L is a characteristic length, k is the thermal conductivity of air. The function $f(Re, Pr)$,or $f(Gr, Pr)$ is determined by experiments.

This means: With free convection the flow results solely from the buoyancy, whereas with forced convection buoyancy is neglected. There exists no theory for mixed convection, when heat transfers of both convections are of the same scale (i.e. in case of low wind speed).

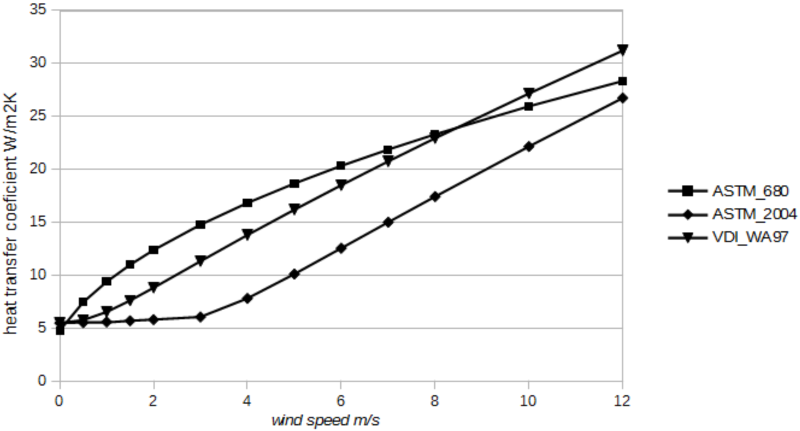
That is why the formulas show large deviations at wind speeds between approx. 0.5 and 6 m/s (see diagram below)

Comparison of 3 formulas: free convection



Free convection example: Comparison of formulas in case of a vertical wall. Here the formulas ASTM_2004 and VDI_WA97 give the same heat transfer coefficient. The curve of the old formula ASTM_680 is lower.

Comparison of 3 formulas: convection with wind



Wind convection example: VDI_WA97 is between ASTM_680 and ASTM_04. The largest difference (in %) occurs at 3 m/s between ASTM_680 (14.77 $\frac{W}{m^2K}$) and ASTM_04 (6.05 $\frac{W}{m^2K}$).

Formula discussion: ASTM680, acc. to ASTM C 680 releases 1968-1986

The calculation according to ASTM in the issues 1968 to 1986 is based on empirical formulas of Langmuir.
Size is not taken into account for plates. With pipes there is a dependency for diameters smaller than 24 inches (approx. 61 cm). Measurements on larger pipes were not made.

Free convection: The temperature dependency for a plate (see diagram) is not in line with the modern dimensionless formulas.

Wind convection: ASTM680 over-estimates the impact of very small wind speed. ($< 2m/s$) This reflects its origin from measurements with small sized objects.

Conclusion ASTM680:
Not recommended, unless required by the customer.

Formula discussion: ASTM_04, according to ASTM C 680 releases 2004-2014

ASTM_04 provides dimensionless formulas for free and forced convection.

Free convection: Formulas are available for horizontal pipes, vertical and horizontal plates.

Wind convection: ASTM680 clearly under-estimates the impact of small wind speed. ($< 6 m/s$)
Laminar flow is assumed for plates up to extremely high Reynolds numbers. That is why the impact of wind speed is very low an why the wind speed is effective from about 3 m/s for pipes and 2 m/s for tubes.

Conclusion ASTM_04:
Highly recommended for free convection (zero wind speed).
Not recommended for calculation with wind.

Formula discussion: VDI_WA98, VDI Heat Atlas 1998

VDI_WA98 provides dimensionless formulas for free and forced convection.

Free convection: Formulas are available for horizontal pipes, vertical plates and horizontal plates with heat flow upward. (Unfortunately, plate with heat flow down is missing). The results for free convection are similar to those of ASTM_04

Wind convection: The impact of the wind speed begins at about $0.5m/s$ and meets outdoor conditions of low wind speed better than the ASTM formulas.

Conclusion VDI_WA98:
Highly recommended for low wind speed ($> 0.5m/s$ and $< 6m/s$).

Recommendations for the use of heat transfer formulas

General recommendation: If surface temperatures have to be guaranteed, the calculations should always be done with free convection (i.e. no wind speed). In particular, wind speeds between 0.5 m/s and 6 m/s should be avoided.

Free convection: The formula **ASTM_04 from 2004-2014 is recommended**. (Do not mix up with ASTM680 from 1968 to 1986)

Wind convection: With wind speeds greater than 0.5 m/s, the heat convective transfer depends of the local wind conditions. Hence there can be deviations between the computational results and the real surface temperatures.

The **best results are obtained with the formula VDI_WA97**