

CONVECTION

Formulae & Parameters for the derivation of Convective Heat Transfer Coefficient h

Reynolds number

$$Re = \frac{u \cdot l \cdot \rho}{\mu} = \frac{u \cdot l}{\nu}$$

Prandtl number

$$Pr = \frac{\mu \cdot c_p}{k}$$

Grashof number

$$Gr = \frac{g \cdot \beta \cdot \Delta T \cdot l^3}{\nu^2}$$

Nusselt number

$$Nu = \frac{h \cdot l}{k}$$

where:

u : velocity (m/s)

l : significant length (m)

ρ : density (kg/m³)

μ : dynamic viscosity (kg/m.s)

ν : kinematic viscosity (m²/s)

k : thermal conductivity (W/m.K)

c_p : specific heat at constant pressure (J/kg.K)

h : convective heat transfer coefficient (W/m².K)

g : acceleration due to gravity (m/s²)

ΔT : temperature difference between the surface and the free steam (K or °C)

β : coefficient of cubic expansion (K⁻¹ or °C⁻¹)

The formula expressing the relationship between the various dimensionless groups may be written in one of the following forms:

- For forced convection:

$$Nu = A \cdot Re^a \cdot Pr^b$$

- For free convection:

$$Nu = B \cdot Gr^c \cdot Pr^d$$

Typical formulae and their areas of validity are listed in the following TABLE 1 which provides values for the factors A, B, a, b, c and d.

TABLE 1

TYPE OF FLOW	EQUATION	VALIDITY
<u>Forced Convection</u>		
1. Heating of a fluid in turbulent flow inside a circular tube	$Nu = 0.023 \cdot Re^{0.8} \cdot Pr^{0.4}$	$Re > 2300$
2. Cooling of a fluid in turbulent flow inside a circular tube	$Nu = 0.023 \cdot Re^{0.8} \cdot Pr^{0.3}$	$Re > 2300$
3. Heating or cooling of a fluid in laminar flow inside a circular duct	$Nu = 0.664 \cdot Re^{0.5} \cdot Pr^{0.3} \cdot \left(\frac{d}{l}\right)^{0.5}$	$Re < 2300$
4. Heating or cooling of a fluid in turbulent flow along a plate	$Nu = 0.036 \cdot Re^{0.8} \cdot Pr^{0.3}$	$Re > 50,000$
5. Heating or cooling of a fluid in laminar flow along a plate	$Nu = 0.664 \cdot Re^{0.5} \cdot Pr^{0.3}$	$Re < 50,000$
6. Heating or cooling of a fluid in cross-flow over the outside of a tube	$Nu = 0.38 \cdot Re^{0.56} \cdot Pr^{0.3}$	$Re > 100$ (significant length is the diameter)
<u>Free Convection</u>		
7. Heating or cooling of a fluid outside a vertical plate or cylinder	$Nu = 0.555 \cdot (Gr \cdot Pr)^{0.25}$	Laminar region $Gr < 10^9$
	$Nu = 0.021 \cdot (Gr \cdot Pr)^{0.4}$	Turbulent region $Gr > 10^9$
8. Heated horizontal rectangular plate facing upwards, or cooled horizontal rectangular plate facing downwards.	$Nu = 0.54 \cdot (Gr \cdot Pr)^{0.25}$	Laminar region $10^5 < Gr < 2.7 \times 10^7$
	$Nu = 0.14 \cdot (Gr \cdot Pr)^{0.33}$	Turbulent region $2.7 \times 10^7 < Gr < 3 \times 10^{10}$
For circular plates, Equation 8 may be used with $l = 0.9 \cdot d$		
9. Heating or cooling of a fluid outside a horizontal tube or rod	$Nu = 0.53 \cdot (Gr \cdot Pr)^{0.25}$	$10^3 < Gr < 10^9$ (not applicable to heated wires; significant length is the diameter)