HEAT TRANSFER

EXTERNAL FORCED CONVECTION

Through experimental methods convection correlations were developed. These correlations have a general form:

$$Nu_L = C \,\mathrm{Re}_L^m \,\mathrm{Pr}^n$$

where C, m and n are constants.

Heat transfer correlations according to geometry can be found in Table 1 below.

To solve Nu, fluid properties such as density, kinematic viscosity, specific heat capacity are taken from tables at the **film temperature, T_f**.

$$T_f = \frac{T_s + T_f}{2}$$

The main objective in convection heat transfer problems is to find the convection heat transfer coefficient using the appropriate correlation. The convection heat transfer coefficient is then used to calculate the heat rate using.

$$q = hA(T_s - T_\infty)$$

Methodology for a Convection Calculation

1. Become immediately cognizant of the flow geometry i.e. flat plate, sphere or cylinder.
2. Specify the appropriate reference temperature and evaluate the pertinent fluid properties at that temperature.
3. Calculate the Reynolds number to determine if the flow is laminar or turbulent.
4. Decide whether a local or surface average coefficient is required.
5. Select the appropriate correlation.

Table 1: Summary of convection heat transfer correlations for external flow.		
Correlation	**Geometry**	**Conditions**
1. $Nu_x = 0.332\,\mathrm{Re}_x^{1/2}\,\mathrm{Pr}^{1/3}$	Flat plate	Laminar, local, T_f, $0.6 \le \mathrm{Pr} \le 50$
2. $\delta = 5x/\mathrm{Re}_x^{1/2}$	Flat plate	Laminar, T_f
3. $C_f = 0.664\,\mathrm{Re}_x^{-1/2}$	Flat plate	Laminar, local, T_f
4. $\overline{Nu_x} = 0.664\,\mathrm{Re}_x^{1/2}\,\mathrm{Pr}^{1/3}$	Flat plate	Laminar, average, T_f, $0.6 \le \mathrm{Pr} \le 50$
5. $Nu_x = 0.0296\,\mathrm{Re}_x^{4/5}\,\mathrm{Pr}^{1/3}$	Flat plate	Turbulent, local T_f, $\mathrm{Re}_x \le 10^8$, $0.6 \le \mathrm{Pr} \le 50$
6. $\delta = 0.37x/\mathrm{Re}_x^{1/5}$	Flat plate	Turbulent, local T_f, $\mathrm{Re}_x \le 10^8$
7. $C_f = 0.0592\,\mathrm{Re}_x^{-1/5}$	Flat plate	Turbulent, local T_f, $\mathrm{Re}_x \le 10^8$
8. $\overline{Nu_x} = \left(0.037\,\mathrm{Re}_L^{4/5} - 871\right)\mathrm{Pr}^{1/3}$	Flat plate	Mixed , average, T_f, $\mathrm{Re}_{x,c} = 5 \times 10_5$, $\mathrm{Re}_L \le 10^8$, $0.6 \le \mathrm{Pr} \le 50$
9. $\overline{Nu_x} = C\,\mathrm{Re}_D^m\,\mathrm{Pr}^{1/3}$ *(Table 2)*	Cylinder	Average, T_f, $0.4 \le \mathrm{Re}_D \le 4 \times 10^5$, $\mathrm{Pr} \ge 0.7$
10. $\overline{Nu_x} = C\,\mathrm{Re}_D^m\,\mathrm{Pr}^n\left(\mathrm{Pr}/\mathrm{Pr}_s\right)^{1/4}$ *Zhukauskas correlation* *(Table 3)*	Cylinder	Average, T_∞, $1 \le \mathrm{Re}_D \le 10^6$, $0.7 \le \mathrm{Pr} \le 500$ If $\mathrm{Pr} \le 10$, n = 0.37, If $\mathrm{Pr} > 10$, n = 0.36

Table 2		
Re_D	**C**	**m**
0.4 – 4	0.988	0.330
4 – 40	0.911	0.385
40 – 4000	0.683	0.466
4000 – 40,000	0.193	0.618
40,000 – 400,000	0.027	0.805

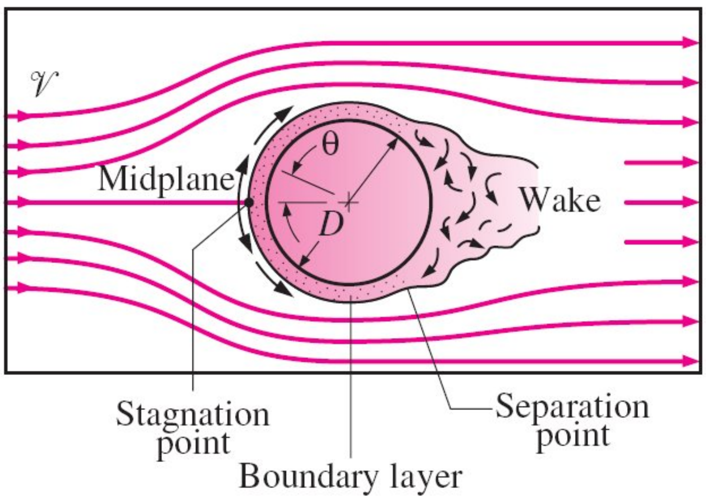
Table 3		
Re_D	**C**	**m**
1 – 40	0.75	0.4
40 – 1000	0.51	0.5
10^3 – 2 x 10^5	0.26	0.6
2 x 10^5 – 10^6	0.076	0.7

Flow across Cylinders and Spheres

The characteristic length for a circular cylinder or sphere is taken to be the *external diameter D.* Thus, the Reynolds number is defined as $\mathrm{Re} = VD/\upsilon$.

The critical Reynolds number for flow across a circular cylinder or sphere is about $\mathrm{Re}_{cr} = 2 \times 10^5$

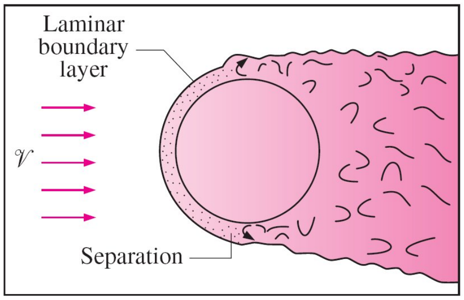
Cross flow over a cylinder exhibits complex flow patterns, as shown in the figure below.



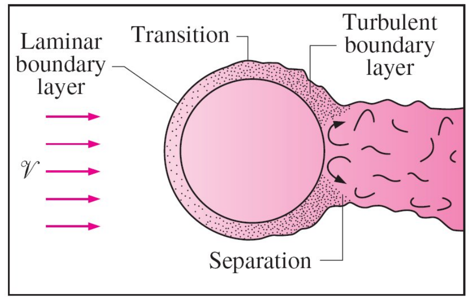
The fluid approaching the cylinder branches out and encircles the cylinder, forming a boundary layer that wraps around the cylinder.

The fluid particles on the midplane strike the cylinder at the stagnation point, bringing the fluid to a complete stop and thus raising the pressure at that point. The pressure decreases in the flow direction while the fluid velocity increases.

At very low upstream velocities, the fluid completely wraps around the cylinder and the two arms of the fluid meet on the rear side of the cylinder in an orderly manner. Thus, the fluid follows the curvature of the cylinder. At higher velocities, the fluid still hugs the cylinder on the frontal side, but it is too fast to remain attached to the surface as it approaches the top of the cylinder. As a result, the boundary layer detaches from the surface, forming a separation region behind the cylinder. Flow in the wake region is characterized by random vortex formation and pressures much lower than the stagnation point pressure.



(a) Laminar flow ($\mathrm{Re} < 2 \times 10^5$)



(b) Turbulence occurs ($\mathrm{Re} > 2 \times 10^5$)

Nevertheless, for cylindrical and spherical evaluation, only the average heat transfer is considered. Local convection heat transfer coefficient is not usually considered.