SUMMARY – EXTERNAL FORCED CONVECTION HEAT TRANSFER

Convection heat transfer is expressed by Newton's law of cooling as

$$q_{conv} = h.A_s.(T_s - T_\infty)$$

Where

h is the convection heat transfer coefficient,
T_s is the surface temperature, and
T_∞ is the free-stream temperature.

The convection coefficient is also expressed as

$$h = \frac{-k_{fluid}.(\frac{\partial T}{\partial y})_{y=0}}{(T_s - T_\infty)}$$

The dimensionless heat transfer coefficient, called the ***Nusselt number*** (***Nu***), is defined as

$$Nu = \frac{h.L_c}{k}$$

Where

k is the thermal conductivity of the fluid,
L_c is the characteristic length.

The friction force per unit area is called ***shear stress***(τ_s), and the ***shear stress*** at the wall surface is expressed as

$$\tau_s = \mu.\frac{\partial u}{\partial y}\bigg|_{y=0} \qquad \text{or} \qquad \tau_s = C_f.\frac{\rho.V^2}{2}$$

Where

μ is the dynamic viscosity,
V is the upstream velocity, and
C_f is the dimensionless friction coefficient.

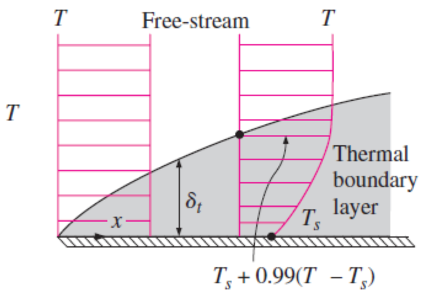
The property ($\nu = {}^{\mu}/_{\rho}$) is the kinematic viscosity.

The friction force over the entire surface is determined from

$$F_f = C_f.A_s.\frac{\rho.V^2}{2}$$

The flow region over the surface in which the temperature variation in the direction normal to the surface is significant is the **thermal boundary layer**(δ_t).

The thickness of the thermal boundary layer δ_t at any location along the surface is the distance from the surface at which the temperature difference $T - T_s$ equals $0.99(T_\infty - T_s)$.



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The relative thickness of the velocity and the thermal boundary layers, ($\boldsymbol{\delta}$) and ($\boldsymbol{\delta_t}$) respectively, is best described by the dimensionless ***Prandtl number*** (**Pr**), defined as

$$Pr = \frac{\nu}{\alpha} = \frac{\mu . C_p}{k}$$

For external flow, the dimensionless **Reynolds number** (**Re**) is expressed as

$$Re = \frac{V . L_c}{\nu} = \frac{\rho . V . L_c}{\mu}$$

For a flat plate, the characteristic length is the distance (**x**) from the leading edge. The Reynolds number at which the flow becomes turbulent is called the **critical Reynolds number**. For flow over a flat plate, its value is taken to be

$$Re_{cr} = \frac{V . x_{cr}}{\nu} = 5 \times 10^5$$

The **drag coefficient** ($\boldsymbol{C_D}$) is a dimensionless number that represents the drag characteristics of a body, and is defined as

$$C_D = \frac{F_D}{\frac{1}{2} . \rho . V^2 . A}$$

Where

A is the frontal area for blunt bodies, and surface area for parallel flow over flat plates or thin airfoils.

For flow over a flat plate, the Reynolds number is

$$Re = \frac{V . x}{\nu} = \frac{\rho . V . x}{\mu}$$

Transition from laminar to turbulent occurs at the *critical Reynolds number* of

$$Re_{x,cr} = \frac{V . x_{cr}}{\nu} = 5 \times 10^5$$

FOR PARALLEL FLOW OVER A FLAT PLATE

The local friction coefficient ($\boldsymbol{C_{f,x}}$) and convection coefficient ($\boldsymbol{Nu_x}$) are

Regime flow	Correlation	Condition
Laminar	$C_{f,x} = \frac{0.664}{Re_x^{1/2}}$	$Re_x < 5 \times 10^5$ $\mathrm{Pr} > 0.6$
	$Nu_x = \frac{h_x . x}{k} = 0.332 Re_x^{0.5} Pr^{\frac{1}{3}}$	
Turbulent	$C_{f,x} = \frac{0.059}{Re_x^{1/5}}$	$5 \times 10^5 \le Re_x \le 10^7$ $0.6 \le \mathrm{Pr} \le 60$
	$Nu_x = \frac{h_x . x}{k} = 0.0296 \mathrm{Re}_x^{0.8} \mathrm{Pr}^{\frac{1}{3}}$	

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The **average friction coefficient** (C_f) relations for flow over a flat plate are:

Regime flow	Correlation	Condition
Laminar	$C_f = \dfrac{1.33}{Re_L^{1/2}}$	$Re_L < 5 \times 10^5$
Turbulent	$C_f = \dfrac{0.074}{Re_L^{1/5}}$	$5 \times 10^5 \leq Re_L \leq 10^7$
Combined	$C_f = \dfrac{0.074}{Re_L^{1/5}} - \dfrac{1742}{Re_L}$	$5 \times 10^5 \leq Re_L \leq 10^7$

The **average Nusselt number** (Nu) relations for flow over a flat plate are:

Regime flow	Correlation	Condition
Laminar	$Nu = \dfrac{h.L}{k} = 0.664 Re_L^{0.5} Pr^{\frac{1}{3}}$	$Re_L < 5 \times 10^5$
Turbulent	$Nu = \dfrac{h.L}{k} = 0.037 Re_L^{0.8} Pr^{\frac{1}{3}}$	$5 \times 10^5 \leq Re_L \leq 10^7$ $0.6 \leq Pr \leq 60$
Combined	$Nu = \dfrac{h.L}{k} = (0.037 Re_L^{0.8} - 871) Pr^{\frac{1}{3}}$	$5 \times 10^5 \leq Re_L \leq 10^7$ $0.6 \leq Pr \leq 60$

FOR ISOTHERMAL SURFACES WITH AN UNHEATED STARTING SECTION OF LENGTH (ξ)

Regime flow	Correlations for local Nusselt Number (Nu_x)
Laminar	$Nu_x = \dfrac{Nu_{x\,(for\ \xi=0)}}{\left[1 - (\xi/x)^{3/4}\right]^{1/3}} = \dfrac{0.332 Re_x^{0.5} Pr^{\frac{1}{3}}}{\left[1 - (\xi/x)^{3/4}\right]^{1/3}}$
Turbulent	$Nu_x = \dfrac{Nu_{x\,(for\ \xi=0)}}{\left[1 - (\xi/x)^{9/10}\right]^{1/9}} = \dfrac{0.0296 Re_x^{0.8} Pr^{\frac{1}{3}}}{\left[1 - (\xi/x)^{9/10}\right]^{1/9}}$

Regime flow	Correlations for the average convection coefficient (h)
Laminar	$h = \dfrac{2\left[1 - (\xi/x)^{3/4}\right]}{1 - \xi/L} h_{x=L}$
Turbulent	$h = \dfrac{5\left[1 - (\xi/x)^{9/10}\right]}{1 - \xi/L} h_{x=L}$

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FOR A UNIFORM HEAT FLUX OVER A FLAT PLATE

Regime flow	Correlations for local Nusselt Number (Nu_x)
Laminar	$Nu_x = 0.453 Re_x^{0.5} Pr^{\frac{1}{3}}$
Turbulent	$Nu_x = 0.0308 Re_x^{0.8} Pr^{\frac{1}{3}}$

FOR CROSS FLOW OVER A CYLINDER AND SPHERE ARE

Regime flow	Correlations for the avarage Nusselt Number (Nu)
Laminar Valid for : $Re.Pr > 0.2$	$Nu_{cyl} = \frac{h.D}{k} = 0.3 + \frac{0.62 Re_x^{0.5} Pr^{\frac{1}{3}}}{\left[1 + \left({0.4}/{Pr}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re}{282\,000}\right)^{5/8}\right]^{4/5}$
Turbulent Valid for : $3.5 \leq Re \leq 80\,000$ $0.7 \leq Pr \leq 380$	$Nu_{sph} = \frac{h.D}{k} = 2 + \left[0.4 Re^{1/2} + 0.06 Re^{2/3}\right] Pr^{0.4} \left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$

The fluid properties are evaluated at the film temperature $T_f = \frac{(T_\infty + T_s)}{2}$ in the case of a cylinder, and at the freestream temperature(T_∞).

Except for μ_s , which is evaluated at the surface temperature (T_s). in the case of a sphere.