CONVECTIVE COEFFICIENT (h) CALCULATIONS
Chapter 7: External Flow

For a flat plate: $Nu_x \equiv \frac{hx}{k}$ $\qquad \overline{Nu}_L \equiv \frac{\bar{h}L}{k}$

For a cylinder or sphere: $\overline{Nu}_D \equiv \frac{\bar{h}D}{k}$

For a flat plate: $Re_x \equiv \frac{\rho V x}{\mu} = \frac{Vx}{\nu}$ $\qquad Re_L \equiv \frac{\rho V L}{\mu} = \frac{VL}{\nu}$

For a cylinder or sphere: $Re_D \equiv \frac{\rho V D}{\mu} = \frac{VD}{\nu}$ where V is the upstream velocity.

FLAT PLATE

For a flat plate, transition to turbulent flow occurs at Re $\sim 10^5 - 3 \times 10^6$

Isothermal

Laminar flow:	$Nu_x = 0.332 Re_x^{1/2} Pr^{1/3}$	Valid for $Pr \geq 0.6$
	$\overline{Nu}_L = 0.664 Re_L^{1/2} Pr^{1/3}$	Valid for $Pr \geq 0.6$
Turbulent Flow:	$Nu_x = 0.0296 Re_x^{4/5} Pr^{1/3}$	Valid for $0.6 \leq Pr \leq 60$
Mixed Flow:	$\overline{Nu}_L = \left(0.037 Re_L^{4/5} - A\right) Pr^{1/3}$ $A = 0.037 Re_{x,c}^{4/5} - 0.664 Re_{x,c}^{1/2}$	Valid for $0.6 \leq Pr \leq 60$ $Re_{x,c} \leq Re_L \leq 10^8$
Evaluate properties at film temperature $T_f \equiv \frac{T_s + T_\infty}{2}$		

Constant Heat Flux

Laminar flow:	$Nu_x = 0.453 Re_x^{1/2} Pr^{1/3}$	Valid for $Pr \geq 0.6$
	$\overline{Nu}_L = 0.680 Re_L^{1/2} Pr^{1/3}$	Valid for $Pr \geq 0.6$
Turbulent Flow:	$Nu_x = 0.0308 Re_x^{4/5} Pr^{1/3}$	Valid for $0.6 \leq Pr \leq 60$
	$\overline{Nu}_L = 0.664 Re_L^{1/2} Pr^{1/3}$	Valid for $0.6 \leq Pr \leq 60$
Evaluate properties at film temperature $T_f \equiv \frac{T_s + T_\infty}{2}$		

CYLINDERS IN CROSS FLOW

Hilpert Correlation:

$\overline{Nu}_D = C\,\mathrm{Re}_D^m\,\mathrm{Pr}^{1/3}$	Valid for $\mathrm{Pr} \geq 0.7$
• C and m are evaluated using Table 7.2. • May be used for non-circular cylinders in cross flow of a gas (see Table 7.3 for characteristic length D, C and m values). • Evaluate properties at T_f.	

Zukauskas Correlation:

$\overline{\mathrm{Nu}}_D = C\,\mathrm{Re}_D^m\,\mathrm{Pr}^n\left(\frac{\mathrm{Pr}}{\mathrm{Pr}_s}\right)^{1/4}$	Valid for $0.7 \leq \mathrm{Pr} \leq 500$ $1 \leq \mathrm{Re}_D \leq 10^6$
• C and m are evaluated using Table 7.4. • n=0.37 for Pr≤10 and n=0.36 for Pr>10 • Evaluate properties at T_∞ except Pr_s, which is evaluated at T_s.	

Churchill and Bernstein Correlation:

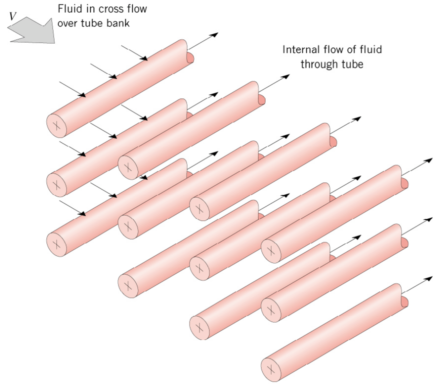
$\overline{Nu}_D = 0.3 + \frac{0.62\,Re_D^{1/2}\,Pr^{1/3}}{\left[1+\left(0.4/Pr\right)^{2/3}\right]^{1/4}}\left[1+\left(\frac{Re_D}{282{,}000}\right)^{5/8}\right]^{4/5}$	Valid for $\mathrm{Re}_D\mathrm{Pr} > 0.2$
Evaluate properties at T_f.	

SPHERE

Whitaker correlation:

$\overline{\mathrm{Nu}}_D = 2 + \left(0.4\,\mathrm{Re}_D^{1/2} + 0.06\,\mathrm{Re}_D^{2/3}\right)\mathrm{Pr}^{0.4}\left(\frac{\mu}{\mu_s}\right)^{1/4}$	Valid for $0.71 \leq \mathrm{Pr} \leq 380$ $3.5 \leq \mathrm{Re}_D \leq 7.6\mathrm{x}10^4$ $1.0 \leq (\mu/\mu_s) \leq 3.2$
Evaluate properties at T_∞ except μ_s, which is evaluated at T_s	

SPECIAL GEOMETRIES: FLOW ACROSS BANKS OF TUBES



A row of tubes is in the transverse direction to the flow. In the schematic above there are 4 rows (N_L=4) and 3 tubes in each row (N_T=3). N is the total number of tubes in the bank (N=12).

Aligned	Staggered
$V_{max} = \frac{S_T}{S_T - D} V$	If $S_D = \left[S_L^2 + \left(\frac{S_T}{2} \right)^2 \right]^{1/2} < \frac{S_T + D}{2}$ $V_{max} = \frac{S_T}{2(S_D - D)} V$ Otherwise use equation for aligned
$Re_{D,max} \equiv \frac{\rho V_{max} D}{\mu}$	

$$\overline{Nu}_D = C_1 Re_{D,max}^m Pr^{0.36} \left(\frac{Pr}{Pr_s} \right)^{1/4}$$

C_1 and m are obtained from Table 7.5
Valid for $N_L \geq 20$; $1000 < Re_{D,max} < 2 \times 10^6$; $0.7 < Pr < 500$
Evaluate properties at the arithmetic mean of the inlet and outlet temperatures except Pr_s, which is evaluated at T_s.

For $N_L < 20$, use $\overline{Nu}_D \Big|_{(N_L < 20)} = C_2 \overline{Nu}_D \Big|_{(N_L \geq 20)}$ (C_2 from Table 7.6)

Equations for flow across a band of tubes:

$$\Delta T_{lm} = \frac{(T_s - T_i) - (T_s - T_o)}{\ln\left(\frac{T_s - T_i}{T_s - T_o}\right)} \qquad \text{where, } T_o = T_s - (T_s - T_i)\exp\left(-\frac{\pi D N \bar{h}}{\rho V N_T S_T c_p}\right)$$

$$q' = N(\bar{h}\pi D \Delta T_{lm}) \qquad \Delta p = N_L \chi \left(\frac{\rho V_{\max}^2}{2}\right) f$$