Cross Flow Heat Exchanger (CFHX)

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ME 307: Heat Transfer Equipment Design
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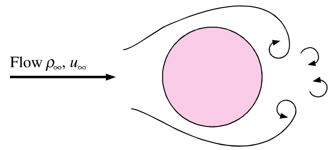
Cylinder in Cross Flow



T649

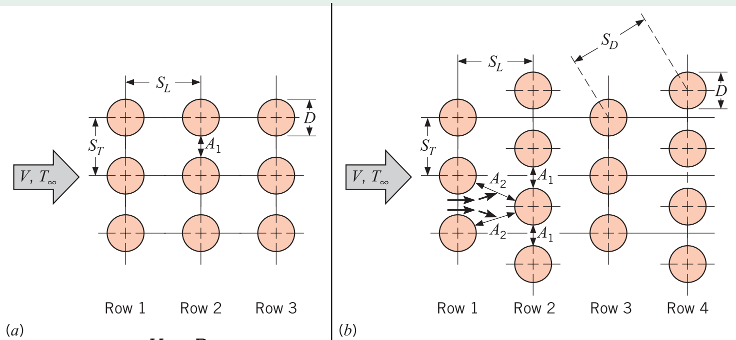
Whitaker: [gas & liquid]

$$Nu_m \equiv \frac{h_m D}{k} = (0.4 Re^{1/2} + 0.06 Re^{2/3}) Pr^{0.4} \left(\frac{\mu_\infty}{\mu_w}\right)^{0.25}$$

$40 < Re < 10^5,\ 0.67 < Pr < 300,\ 0.25 < \frac{\mu_\infty}{\mu_w} < 5.2$

- properties are evaluated at free-stream temperature, except μ_w.
- $u_\infty \equiv$ free stream velocity
- $h_m \equiv$ average heat transfer coefficient.
- Agrees experimental values within $\pm$ 25%.

Flow Across Tube Banks



T653

- $Re_{D,max} = \frac{V_{max} D}{\nu}$

(a) in-line rows, $V_{max} = u_\infty \left[\frac{S_T}{S_T - D}\right]$

(b) staggered row, $V_{max} = max\left(u_\infty \left[\frac{S_T}{S_T - D}\right],\ u_\infty \left[\frac{S_T}{2(S_D - D)}\right]\right)$

$S_D = \sqrt{S_L^2 + (S_T/2)^2}$

Zukauskas: $N_L \geqslant 20$

$$Nu_m \equiv \frac{h_m D}{k} = C_1 Re^m_{D,max} Pr^{0.36} \left(\frac{Pr}{Pr_w}\right)^n$$

$0.7 < Pr < 500;\ 1000 < Re_{D,max} < 2 \times 10^6$

Zukauskas: $N_L < 20$

$$Nu_m|_{(N<20)} = C_2 Nu_m|_{(N\geqslant 20)}$$

- $n = \begin{cases} 0.25 & \text{for liquids} \\ 0 & \text{for gases} \end{cases}$
- Fluid properties are evaluated at arithmetic mean temperature of inlet and outlet fluid.
- $\bar{h} = C_2 h_m$

Configuratio	$Re_{D,\max}$	C_1	m
Aligned	10–10^2	0.80	0.40
Staggered	10–10^2	0.90	0.40
Aligned	10^2–10^3	Approximate as a single (isolated) cylinder	
Staggered	10^2–10^3		
Aligned ($S_T/S_L > 0.7$)[a]	10^3–2×10^5	0.27	0.63
Staggered ($S_T/S_L < 2$)	10^3–2×10^5	$0.35(S_T/S_L)^{1/5}$	0.60
Staggered ($S_T/S_L > 2$)	10^3–2×10^5	0.40	0.60
Aligned	2×10^5–2×10^6	0.021	0.84
Staggered	2×10^5–2×10^6	0.022	0.84

T651 [a]For $S_T/S_L < 0.7$, heat transfer is inefficient and aligned tubes should not be used.

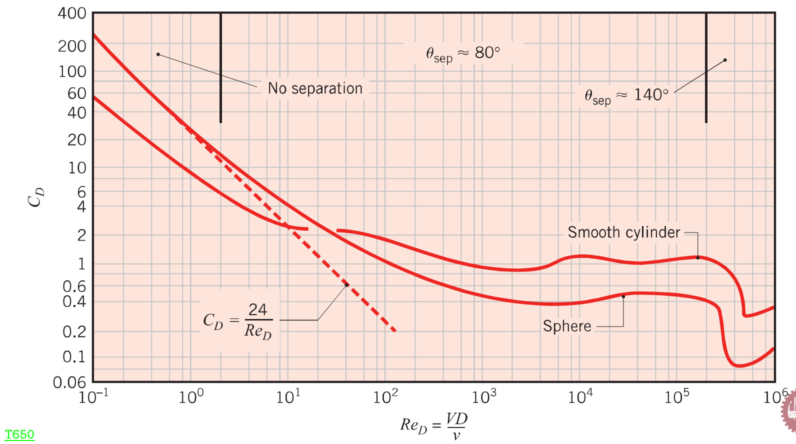
Correction factor, C_2

N	2	3	4	5	6	8	10	16	20
Staggered	0.77	0.84	0.89	0.92	0.94	0.97	0.98	0.99	1.0
In-line	0.70	0.80	0.90	0.92	0.94	0.97	0.98	0.99	1.0

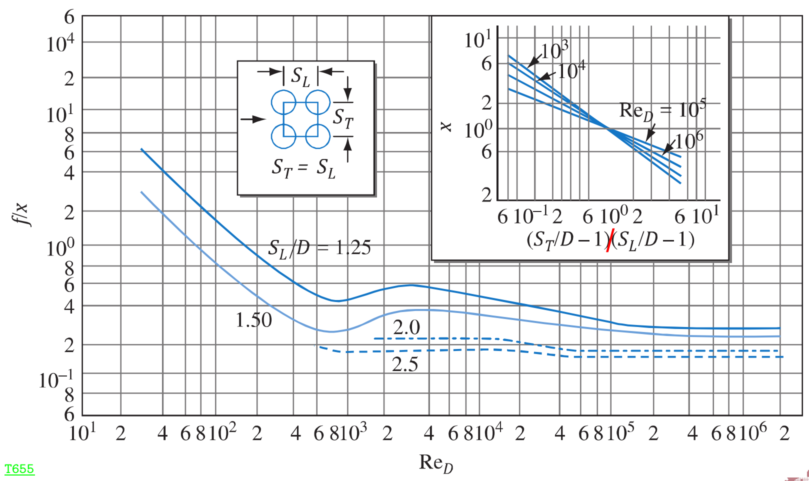
T652

- $\Delta T_{LM} = \dfrac{(T_s - T_i) - (T_s - T_e)}{\ln\left(\frac{T_s - T_i}{T_s - T_e}\right)}$
- Fluid exit temperature, $T_e = T_s - (T_s - T_i)\exp\left[-\frac{A_s \bar{h}}{\dot{m} c_p}\right]$
- Heat transfer, $\dot{Q} = \bar{h} A_s \Delta T_{LM} = \dot{m} c_p (T_e - T_i)$
- Heat transfer area, $A_s = N(\pi D L)$
- Fluid mass flow rate, $\dot{m} = \rho u_\infty (N_T S_T L)$
- Total number of tubes in a bank, $N = N_L N_T$
- $N_T \equiv$ number of tubes in a row
- $N_L \equiv$ number or rows in the bank
- $u_\infty \equiv$ free stream velocity
- Pressure drop, $\Delta P = f\left(\frac{1}{2}\rho V_{max}^2\right) N_L$
- Pumping work, $\dot{W}_p = \dot{V}\Delta P = V_{av} A \Delta P$
- Motor power, $\dot{W}_{motor} = \dfrac{\dot{W}_p}{\eta_{pump}}$
- $\dot{V} \equiv$ volume flow rate
- $\eta_{pump} \equiv$ pump efficiency

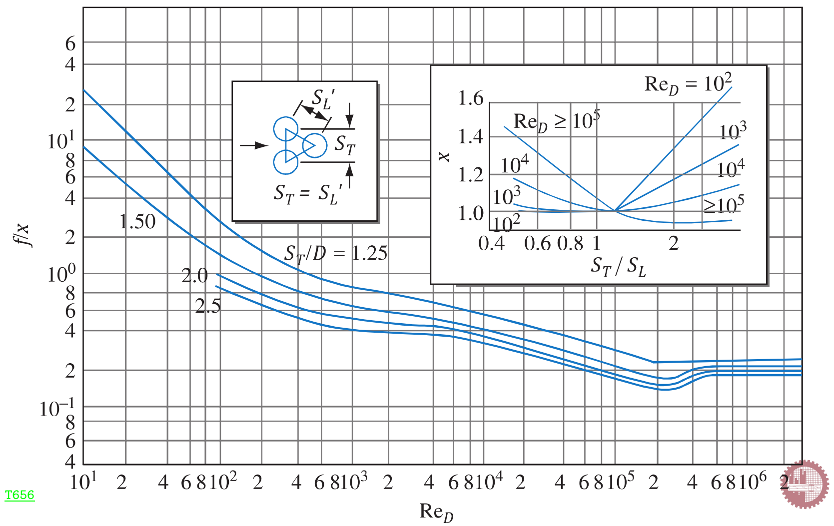
$$F_D = C_D A \left(\frac{1}{2}\rho u_\infty^2\right)$$



T650



T655

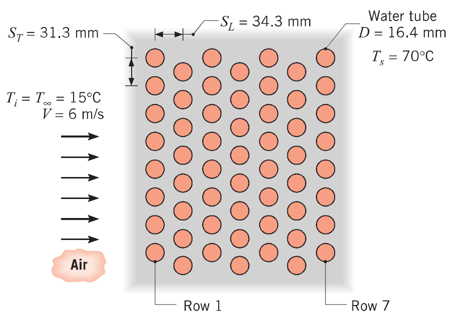


T656

Example: ▷ Water at $T_1 = 24°C$ is to be heated to $T_2 = 74°C$ by passing it through a tube bundle in staggered tube arrangement. Tubes have an outside diameter, $D = 2.5$ cm and are maintained at a uniform surface temperature of $T_s = 100°C$. It is given that: $S_L/D = 1.5$, $S_T/D = 2.0$, $u_\infty = 0.3$ m/s. Estimate:

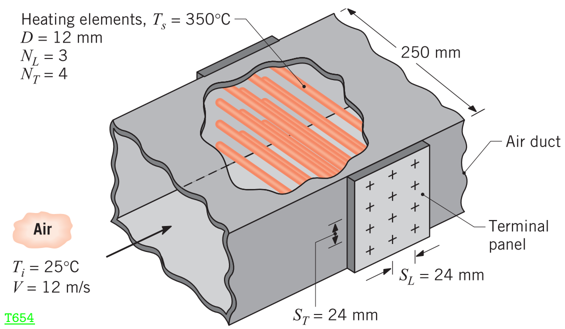
1. average heat transfer coefficient,
2. number of tube rows required to achieve the above temperature rise of water.

Example: ▷ In a staggered cross-flow water heater, water is passed through the tubes, while air is passed in cross flow over the tubes. Consider the tube outside diameter is 16.4 mm and the pitches are S_L= 34.3 mm and S_T= 31.3 mm. There are seven rows of tubes in the airflow direction and eight tubes per row. Under typical operating conditions the cylinder surface temperature is at 70°C, while the air upstream temperature and velocity are 15°C and 6 m/s, respectively. Determine the air-side convection coefficient and the rate of heat transfer for the tube bundle. What is the air-side pressure drop?



T664

Example: ▷ An air duct heater consists of an aligned array of electrical heating elements. Atmospheric air with an upstream velocity of 12 m/s and a temperature of 25°C moves in cross flow over the elements, which have a diameter of 12 mm, a length of 250 mm, and are maintained at a surface temperature of 350°C.



T654