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10. Heating and cooling of fluids in forced convection outside tubes :

Cross-flow over a cylinder

$T_\infty = 30\ °C, \ \ T_w = 324\ °C$

$$T_f = \frac{T_w + T_\infty}{2} = \frac{324 + 30}{2} = 177°C = 450\ K$$

Physical properties of air at 450 K (Table 5) : $\rho = 0.7833\ kg/m^3$

$\mu = 2.484 \times 10^{-5}\ kg/ms$

$k = 0.03707\ W/m°C$

$Pr = 0.683$

$$\frac{hD}{k} = c\left(\frac{D_o V_\infty \rho_f}{\mu_f}\right)^n Pr^{1/3}$$

$$Re_f = \frac{D_o V_\infty \rho_f}{\mu_f} = \frac{3\ \times 10^{-3} m \times 6\ m/s \times 0.7833\ kg/m^3}{2.484 \times 10^{-5}\ kg/ms} = 567$$

$Re_f = 567$ (range $40 - 4000$) c=0.683 n=0.466 (from Table 12)

$$\frac{h \times 3\ \times 10^{-3} m}{0.03707\ W/m°C} = 0.683\ (567)^{0.466}(0.683)^{1/3} = 11.54 \rightarrow h = 142.66 \frac{W}{m^2°C}$$

$$q = h * A * (T_w - T_\infty)$$

$$q = h * \pi\ D\ L * (T_w - T_\infty)$$

$$\frac{q}{L} = h * \pi\ D * (T_w - T_\infty) = \ 142.66 \frac{W}{m^2°C} * \pi * 3\ \times 10^{-3} m * (324 - 30)°C$$

$$\frac{q}{L} = 395.3\ \frac{W}{m}$$

Example:

An in-line arrangement cross flow heat exchanger is set up 6 rows parallel to the flow and 4 rows normal to the flow. L = 15.24 m D= 0.0064 m and Sn=Sp=0.0192 m. Tw= 93.3 ℃. Atmospheric air, velocity of 4.57 m/s, is heated in the system

$$\overline{T} = 21.1°C$$

$$T_f = \frac{T_w + \overline{T}}{2} = \frac{93.3+21.1}{2} = 57.2\ ℃ = 330.2\ K$$

The properties of air at 330.2 K by interpolation:

$\rho_f = 1.0656\ kg/m^3$

$\mu_f = 1.9844 \text{ x } 10^{-5}\ kg/m.s$

$k_f = 0.02853\ W/m.℃$

$C_p = 1.0077\ kj/kg.℃$

$Pr = 0.701$

$$\vartheta_{max} = \vartheta_{\infty}\frac{S_n}{S_n - D} = 4.57\frac{0.0192}{0.0192-0.0064} = 6.86\ m/s$$

$$Re = \frac{D\vartheta_{max}\rho}{\mu} = \frac{0.0064 \text{ x } 6.86 \text{ x } 1.0656}{1.9844 \text{ x } 10^{-5}} = 2357.6$$

$$Nu = c\left(\frac{D\vartheta_{max}\rho}{\mu}\right)^n Pr^{1/3}$$

The constants (c and n) are obtained from Table 13, using

$$\frac{S_p}{D} = \frac{S_n}{D} = \frac{0.0192}{0.0064} = 3$$

c = 0.317

n = 0.608

$$\frac{h \text{ x } 0.0064}{0.02853} = 0.317 \text{ x } (2357.6)^{0.608} \text{ x } (0.701)^{\frac{1}{3}}$$

$$h = 141\ W/m^2°C$$

This h is for ten rows. There are only 6 rows in this system. This value must be multiplied by the factor 0.94, as determined from Table 14.

$$h = 141 \text{ x } 0.94 = 132.54\ W/m^2℃$$

$$A = \pi DL \text{ x } N = \pi \text{ x } 0.0064 \text{ x } 15.24 \text{ x } 24 = 7.354\ m^2$$

$$q = hA(T_w - \overline{T}) = 132.54 \text{ x } 7.354 \text{ x } 72.2 = 70373.3\ W$$