for horizontal cylinders,

$$h = 0.27(\Delta T/D)^{1/4}$$

In these, h is in Btu/(h)(ft^2)(°F), ΔT is in °F, and L and D are in feet.

7.18 HEAT-TRANSFER COEFFICIENTS FOR FLUIDS FLOWING INSIDE TUBES: FORCED CONVECTION, SENSIBLE HEAT

Calculate the heat-transfer coefficient for a fluid with the properties listed below flowing through a tube 20 ft (6.1 m) long and of 0.62-in (0.016-m) inside diameter. The bulk fluid temperature is 212°F (373 K), and the tube surface temperature is 122°F (323 K). Calculate the heat-transfer coefficient if the fluid is flowing at a rate of 2000 lb/h (907.2 kg/h). Also calculate the heat-transfer coefficient if the flow rate is reduced to 100 lb/h (45.36 kg/h).

Physical Properties of the Fluid

c = specific heat = 0.65 Btu/(lb)(°F) [2.72 kJ/(kg)(K)]
k = thermal conductivity = 0.085 Btu/(h)(ft)(°F) [0.147 W/(m)(K)]
μ_w = viscosity at 122°F = 4.0 lb/(ft)(h) (1.65 cP)
μ_b = viscosity at 212°F = 1.95 lb/(ft)(h) (0.806 cP)

Calculation Procedure

1. Select the appropriate heat-transfer coefficient equation. Heat-transfer coefficients for fluids flowing inside tubes or ducts can be calculated using these equations:

a. For Reynolds numbers (DG/μ) greater than 8000,

$$\frac{h}{cG} = \frac{0.023}{(c\mu/k)^{2/3}(D_iG/\mu)^{0.2}(\mu_w/\mu_b)^{0.14}}$$

b. For Reynolds numbers (DG/μ) less than 2100,

$$\frac{h}{cG} = \frac{1.86}{(c\mu/k)^{2/3}(D_iG/\mu)^{2/3}(L/D_i)^{1/3}(\mu_w/\mu_b)^{0.14}}$$

In these equations,

h = heat-transfer coefficient
c = specific heat
G = mass velocity (mass flow rate divided by cross-sectional area)
μ = viscosity
μ_w = viscosity at the surface temperature
μ_b = viscosity at the bulk fluid temperature
k = thermal conductivity
D_i = inside diameter
L = length

2. Calculate D_iG/μ for a 2000 lb/h flow rate.

$$\frac{D_iG}{\mu} = \frac{0.62}{12}\frac{2000}{(0.62/12)^2(\pi/4)}\frac{1}{1.95}$$
$$= 25{,}275$$

3. Calculate h for the 2000 lb/h flow rate. Because DG/μ is greater than 8000,

$$\frac{h}{cG} = \frac{0.023}{(c\mu/k)^{2/3}(D_iG/\mu)^{0.2}(\mu_w/\mu_b)^{0.14}}$$
$$= \frac{0.023(0.65)[2000/(0.62/12)^2(\pi/4)]}{[0.65(1.95)/0.085]^{2/3}25{,}275^{0.2}(4.0/1.95)^{0.14}}$$
$$= 280.3\ \text{Btu/(h)(ft}^2\text{)(K)[1592 W/(m}^2\text{)(K)]}$$

4. Calculate DG/μ for a 100 lb/h flow rate.

$$D_iG/\mu = 25{,}275(100/2000) = 1263.8$$

5. Calculate h for the 100 lb/h flow rate. Because DG/μ is less than 2100,

$$\frac{h}{cG} = \frac{1.86}{(c\mu/k)^{2/3}(DG/\mu)^{2/3}(L/D)^{1/3}(\mu_w/\mu_b)^{0.14}}$$
$$= \frac{1.86(0.65)\{100/[(0.62/12)^2(\pi/4)]\}}{\left[\frac{0.65(1.95)}{0.085}\right]^{2/3}1263.8^{2/3}\left[\frac{20}{(0.62/12)}\right]^{1/3}\left(\frac{4.0}{1.95}\right)^{0.14}}$$
$$= 10.1\ \text{Btu/(h)(ft}^2\text{)(}^\circ\text{F)[57.4 W/(m}^2\text{)(K)].}$$

Related Calculations. Heat transfer for fluids with Reynolds numbers between 2100 and 8000 is not stable, and the heat-transfer coefficients in this region cannot be predicted with certainty. Equations have been presented in many of the references. The heat-transfer coefficients in this region can be bracketed by calculating the values using both the preceding equations for the Reynolds number in question.

The equations presented here can also be used to predict heat-transfer coefficients for the shell side of shell-and-tube heat exchangers in which the baffles have been designed to produce flow parallel to the axis of the tube. For such cases, the diameter that should be used is the equivalent diameter

$$D_e = \frac{4a}{P}$$

where a = flow area
P = wetted perimeter

Here, $a = (D_s^2 - nD_o^2)(\pi/4)$, where D_s is the shell inside diameter, D_o is the tube outside diameter, and n is the number of tubes; and $P = \pi(D_s + nD_o)$.

For shells with triple or double segmental baffles, the heat-transfer coefficient calculated for turbulent flow (DG/μ greater than 8000) should be multiplied by a value of 1.3.

For gases, the equation for heat transfer in the turbulent region (DG/μ greater than 8000) can be simplified because the Prandtl number ($c\mu/k$) and the viscosity for most gases are approximately constant. Assigning the values $c\mu/k = 0.78$ and $\mu = 0.0426$ lb/(h)(ft) (0.0176 cP) results in the following equation for gases:

$$h = 0.0144 \frac{cG^{0.8}}{D_i^{0.2}}$$

with the variables defined in English units.

7.19 HEAT-TRANSFER COEFFICIENTS FOR FLUIDS FLOWING INSIDE HELICAL COILS

Calculate the heat-transfer coefficient for a fluid with a flow rate of 100 lb/h (45.36 kg/h) and the physical properties outlined in Example 7.18. The inside diameter of the tube is 0.62 in (0.016 m), and the tube is fabricated into a helical coil with a helix diameter of 24 in (0.61 m).

Calculation Procedure

1. Select the appropriate heat-transfer coefficient equation. Heat-transfer coefficients for fluids flowing inside helical coils can be calculated with modifications of the equations for straight tubes. The equations presented in Example 7.18 should be multiplied by the factor $1 + 3.5D_i/D_c$, where D_i is the inside diameter and D_c is the diameter of the helix or coil. In addition, for laminar flow, the term $(D_c/D_i)^{1/6}$ should be substituted for the term $(L/D)^{1/3}$. The Reynolds number required for turbulent flow is $2100[1 + 12(D_i/D_c)^{1/2}]$.

2. Calculate the minimum Reynolds number for turbulent flow. Now,

$$\begin{aligned} DG/\mu)_{\min} &= 2100\left[1 + 12(D_i/D_c)^{1/2}\right] \\ &= 2100\left[1 + 12(0.62/24)^{1/2}\right] \\ &= 6150 \end{aligned}$$

3. Calculate h. From the preceding calculations, $DG/\mu = 1263.8$ at a flow rate of of 100 lb/h. Therefore,

$$\begin{aligned} h &= \frac{1.86cG(1 + 3.5D_i/D_c)}{(c\mu/k)^{2/3}(DG/\mu)^{2/3}(D_c/D_i)^{1/6}(\mu_w/\mu_b)^{0.14}} \\ &= \frac{1.86(0.65)\{100/[(0.62/12)^2(\pi/4)]\}[1 + 3.5(0.62/24)]}{[0.65(1.95)/0.085]^{2/3}1263.8^{2/3}(24/0.62)^{1/6}(4.0/1.95)^{0.14}} \\ &= 43.7\ \text{Btu/(h)(ft}^2\text{)(°F)[248 W/(M}^2\text{)(K)]} \end{aligned}$$

7.20 HEAT-TRANSFER COEFFICIENTS: FLUIDS FLOWING ACROSS BANKS OF TUBES; FORCED CONVECTION, SENSIBLE HEAT

Calculate the heat-transfer coefficient for a fluid with the properties listed in Example 7.18 if the fluid is flowing across a tube bundle with the following geometry. The fluid flows at a rate of 50,000 lb/h (22,679.5 kg/h). Calculate the heat-transfer coefficient for both clean and fouled conditions.