In a heat exchanger that involves a tube bank, the tubes are usually placed in a *shell* (and thus the *name shell-and-tube heat exchanger*), especially when the fluid is a liquid, and the fluid flows through the space between the tubes and the shell. There are numerous types of shell-and-tube heat exchangers.

Because many heat-exchanger arrangements involve multiple rows of tubes, the heat transfer characteristics for tube banks are of important practical interest. The heat-transfer characteristics of staggered and in-line tube banks were studied by Grimson.

Determination of Maximum Flow Velocity

For flows normal to in-line tube banks the maximum flow velocity will occur through the minimum frontal area $(Sn - d)$ presented to the incoming free stream velocity u_∞. Thus,

$$u_{max} = u_\infty \left[\frac{s_n}{(s_n - d)}\right] \quad \text{(in-line arrangement)} \quad 5.89$$

For staggered

If $\left\{\left[\left(\frac{S_n}{2}\right)^2 + S_p^2\right]^{\frac{1}{2}} - d\right\} * 2 < (S_n - d)$

Then

$$u_{max} = \frac{\frac{1}{2} s_n u_\infty}{\left[\left(\frac{S_n}{2}\right)^2 + S_p^2\right]^{\frac{1}{2}} - d} \quad \text{(staggered arrangement)} \quad 5.90$$

If $\left\{\left[\left(\frac{S_n}{2}\right)^2 + S_p^2\right]^{\frac{1}{2}} - d\right\} * 2 > (S_n - d)$

$$u_{max} = u_\infty \left[\frac{s_n}{(s_n - d)}\right]$$

The nomenclature for use with Table 5.3 is shown in Figure 5.14. The data of Table 5.3 pertain to tube banks having 10 or more rows of tubes in the direction of flow. For fewer rows the ratio of *h* for *N* rows deep to that for 10 rows is given in Table 5.4.

$$Nu_{df} = \frac{hd}{k_f} = C\left(\frac{u_\infty d}{v_f}\right)^n Pr_f^{\frac{1}{3}} \quad \textbf{(5.80)}$$

Table 5.3 Modified correlation of Grimson for heat transfer in tube banks of 10 rows or more, , for use with Equation (5.80).

	$\frac{S_n}{d}$							
	1.25		1.5		2.0		3.0	
$\frac{S_p}{d}$	*C*	*n*	*C*	*n*	*C*	*n*	*C*	*n*
In line								
1.25	0.386	0.592	0.305	0.608	0.111	0.704	0.0703	0.752
1.5	0.407	0.586	0.278	0.620	0.112	0.702	0.0753	0.744
2.0	0.464	0.570	0.332	0.602	0.254	0.632	0.220	0.648
3.0	0.322	0.601	0.396	0.584	0.415	0.581	0.317	0.608
Staggered								
0.6	—	—	—	—	—	—	0.236	0.636
0.9	—	—	—	—	0.495	0.571	0.445	0.581
1.0	—	—	0.552	0.558	—	—	—	—
1.125	—	—	—	—	0.531	0.565	0.575	0.560
1.25	0.575	0.556	0.561	0.554	0.576	0.556	0.579	0.562
1.5	0.501	0.568	0.511	0.562	0.502	0.568	0.542	0.568
2.0	0.448	0.572	0.462	0.568	0.535	0.556	0.498	0.570
3.0	0.344	0.592	0.395	0.580	0.488	0.562	0.467	0.574

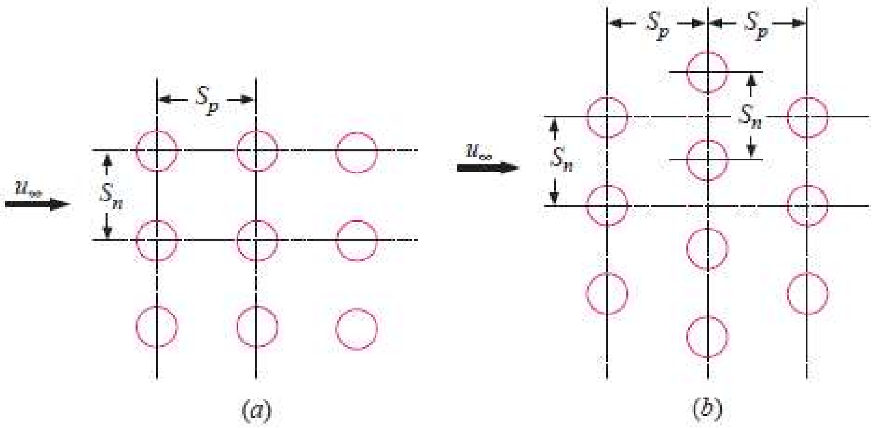

Figure 5.14 Nomenclature for use with Table 5.3: (*a*) in-line tube rows; (*b*) staggered tube rows.

Table 5.4 Ratio of *h* for *N* rows deep to that for 10 rows deep, for use with Equation (5.80).

N	1	2	3	4	5	6	7	8	9	10
Ratio for staggered tubes	0.68	0.75	0.83	0.89	0.92	0.95	0.97	0.98	0.99	1.0
Ratio for in-line tubes	0.64	0.80	0.87	0.90	0.92	0.94	0.96	0.98	0.99	1.0

Zukauskas has presented additional information for tube bundles that takes into account wide ranges of Reynolds numbers and property variations. The correlating equation takes the form

$$Nu = \frac{\bar{h}d}{k} = CRe_{d,max}^{n}Pr^{0.36}\left(\frac{Pr}{Pr_w}\right)^{\frac{1}{4}} \quad \begin{cases} 10 < Re_{d,max} < 10^6 \\ 0.7 < Pr < 500 \end{cases} \qquad 5.91$$

where all properties except Pr_w are evaluated at T_∞ and the values of the constants are given in Table 5.5 for greater than 20 rows of tubes. For gases the Prandtl number ratio has little influence and is dropped. Once again, note that the Reynolds number is based on the maximum velocity in the tube bundle. For less than 20 rows in the direction of flow the correction factor in Table 5.6 should be applied. It is essentially the same as for the Grimson correlation.

Table 5.5 Constants for Zukauskas correlation [Equation (5.91)] for heat transfer in tube banks of 20 rows or more.

Geometry	$Re_{d,max}$	C	n
In-line	10–100	0.8	0.4
	$100–10^3$	Treat as individual tubes	
	$10^3 - 2\times10^5$	0.27	0.63
	$>2\times10^5$	0.21	0.84
Staggered	10–100	0.9	0.4
	$100–10^3$	Treat as individual tubes	
	$10^3 - 2\times10^5$	$0.35\left(\frac{S_n}{S_L}\right)^{0.2}$ for $\frac{S_n}{S_L} < 2$	0.60
	$10^3 - 2\times10^5$	0.40 for $\frac{S_n}{S_L} > 2$	0.60
	$>2\times10^5$	0.022	0.84

Table 5.6 Ratio of *h* for *N* rows deep to that for 20 rows deep for use with Equation (5.91).

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

Example 5.13: Heating of Air with In-Line Tube Bank

Air at 1 atm and 10◦C flows across a bank of tubes 15 rows high and 5 rows deep at a velocity of 7 m/s measured at a point in the flow before the air enters the tube bank. The surfaces of the tubes are maintained at 65◦C. The diameter of the tubes is 1 in [2.54 cm]; they are arranged in an in-line manner so that the spacing in both the normal and parallel directions to the flow is 1.5 in [3.81 cm]. Calculate the total heat transfer per unit length for the tube bank and the exit air temperature.

Solution

The constants for use with Equation (5.80) may be obtained from Table 5.3, using

$$\frac{S_p}{d} = \frac{3.81}{2.54} = 1.5 \qquad \frac{S_n}{d} = \frac{3.81}{2.54} = 1.5$$

$$C = 0.278 \qquad n = 0.620$$

The properties of air are evaluated at the film temperature, which at entrance to the tube bank is

$$T_{f_1} = \frac{T_w + T_\infty}{2} = \frac{65+10}{2} = 37.5°\text{C} = 310.5\text{ K}$$

$$\rho_f = \frac{p}{RT} = \frac{1.0132 \times 10^5}{(287)(310.5)} = 1.137\text{ kg/m}^3$$
$$\mu_f = 1.894 \times 10^{-5}\text{ kg/m}\cdot\text{s}$$
$$k_f = 0.027\text{ W/m}\cdot°\text{C} \quad [0.0156\text{ Btu/h}\cdot\text{ft}\cdot°\text{F}]$$
$$c_p = 1007\text{ J/kg}\cdot°\text{C} \quad [0.24\text{ Btu/lb}_m\cdot°\text{F}]$$
$$\text{Pr} = 0.706$$

$$u_{max} = u_\infty \frac{S_n}{S_n - d} = \frac{(7)(3.81)}{3.81 - 2.54} = 21\text{ m/s}$$

$$\text{Re} = \frac{\rho u_{max} d}{\mu} = \frac{(1.137)(21)(0.0254)}{1.894 \times 10^{-5}} = 32{,}020$$

$$Nu_{Df} = \frac{hD}{k_f} = C\left(\frac{u_\infty D}{v_f}\right)^n Pr_f^{\frac{1}{3}} \qquad \textbf{(5.80)}$$

$$\frac{hd}{k_f} = (0.278)(32{,}020)^{0.62}(0.706)^{1/3} = 153.8$$

$$h = \frac{(153.8)(0.027)}{0.0254} = 164\text{ W/m}^2\cdot°\text{C}$$

Because there are only 5 rows deep, this value must be multiplied by the factor 0.92, as determined from Table 5.4.

The total surface area for heat transfer, considering unit length of tubes, is

$$A = N\pi d(1) = (15)(5)\pi(0.0254) = 5.985\text{ m}^2/\text{m}$$

$$q = hA\left(T_w - \frac{T_{\infty,1} + T_{\infty,2}}{2}\right) = \dot{m}c_p(T_{\infty,2} - T_{\infty,1})$$

$$\dot{m} = \rho_\infty u_\infty (15) S_n$$

$$\rho_\infty = \frac{p}{RT_\infty} = \frac{1.0132 \times 10^5}{(287)(283)} = 1.246\ \text{kg/m}^3$$

$$\dot{m} = (1.246)(7)(15)(0.0381) = 4.99\ \text{kg/s}$$

$$(0.92)(164)(5.985)\left(65 - \frac{10 + T_{\infty,2}}{2}\right) = (4.99)(1006)(T_{\infty,2} - 10)$$

$$T_{\infty,2} = 19.08^\circ\text{C}$$

$$q = (4.99)(1006)(19.08 - 10) = 45.6\ \text{kW/m}$$

H.W force convection

5-14 For water flowing over a flat plate at 15 ◦C and 3 m/s, calculate the mass flow through the boundary layer at a distance of 5 cm from the leading edge of the plate.

5-15 Air at 90 ◦C and 1 atm flows over a flat plate at a velocity of 30 m/s. How thick is the boundary layer at a distance of 2.5 cm from the leading edge of the plate?

5-16 Air flows over a flat plate at a constant velocity of 20 m/s and ambient conditions of 20 kPa and 20◦C. The plate is heated to a constant temperature of 75◦C, starting at a distance of 7.5 cm from the leading edge. What is the total heat transfer from the leading edge to a point 35 cm from the leading edge?

$$h_x = 0.332k\,Pr^{1/3}\left(\frac{u_\infty}{\nu x}\right)^{1/2}\left[1 - \left(\frac{x_o}{x}\right)^{3/4}\right]^{-1/3}$$

5-17 Water at 15 ◦C flows between two large parallel plates at a velocity of 1.5 m/s. The plates are separated by a distance of 15 mm. Estimate the distance from the leading edge where the flow becomes fully developed.

$$\delta = \frac{4.64x}{Re_x^{1/2}}$$

$$\delta = 7.5 \text{ mm} = 0.0075 \text{ m} \qquad \rho = 1000 \qquad \mu = 1.5\times10^{-3} \ \frac{\text{kg}}{\text{m}\cdot\text{sec}}$$

$$x = \frac{\rho u_\infty}{\mu}\left(\frac{\delta}{4.64}\right)^2 = \frac{(1000)(1.5)}{1.5\times10^{-3}}\left(\frac{0.0075}{4.64}\right)^2 = 2.61 \text{ m}$$

5-18 Air at standard conditions of 1 atm and 27◦C flows over a flat plate at 20 m/s. The plate is 60 cm square and is maintained at 97◦C. Calculate the heat transfer from the plate.

$$\overline{Nu_L} = \frac{hL}{k} = Pr^{\frac{1}{3}}(0.037Re_L^{0.8} - 871)$$

$$\bar{h} == \frac{k}{L}Pr^{\frac{1}{3}}(0.037Re_L^{0.8} - 871)$$

$$Re_L = \frac{u_\infty L}{\upsilon}$$

$$T_f = \frac{90+30}{2} = 60°\text{C} = 333 \text{ K} \qquad \nu = 19.09\times10^{-6} \qquad k = 0.0288$$

$$\text{Pr} = 0.7 \qquad \text{Re} = \frac{(20)(0.6)}{19.09\times10^{-6}} = 6.29\times10^5$$

$$\bar{h} = \frac{0.0288}{0.6}(0.7)^{1/3}[(0.037)(6.29\times10^5)^{0.8} - 871] = 31.5 \ \frac{\text{W}}{\text{m}^2\cdot°\text{C}}$$

$$q = (31.5)(0.6)^2(90-30) = 681.3 \text{ W}$$

5-19 Air at 7 kPa and 35◦C flows across a 30-cm-square flat plate at 7.5 m/s. The plate is maintained at 65◦C. Estimate the heat lost from the plate.

$$\overline{Nu_L} = \frac{\bar{h}L}{k} = 0.664Re_L^{1/2}Pr^{1/3}$$

$p = 7\ \text{kN/m}^2 \qquad T_\infty = 35°\text{C} \qquad L = 0.3\ \text{m} \qquad u_\infty = 7.5\ \text{m/sec}$

$T_w = 65°\text{C} \qquad T_f = \dfrac{65+35}{2} = 50°\text{C} = 323\ \text{K}$

$\rho = \dfrac{7000}{(287)(323)} = 0.0755\ \text{kg/m}^3 \qquad \mu = 2.025\times10^{-5}\ \dfrac{\text{kg}}{\text{m}\cdot\text{sec}}$

$k = 0.02798\ \dfrac{\text{W}}{\text{m}\cdot°\text{C}} \qquad \text{Pr} = 0.71 \qquad \text{Re} = \dfrac{(0.0755)(7.5)(0.3)}{2.025\times10^{-5}} = 8390$

$\bar{h} = \dfrac{0.02798}{0.3}(0.71)^{1/3}(8390)^{1/2}(0.664) = 5.04\ \dfrac{\text{W}}{\text{m}^2\cdot°\text{C}}$

$q = (5.04)(0.3)^2(65-35) = 13.6\ \text{W}$

5-20 Air at 90◦C and atmospheric pressure flows over a horizontal flat plate at 60 m/s. The plate is 60 cm square and is maintained at a uniform temperature of 10◦C. What is the total heat transfer?

For $Re_{crit} = 5\times10^5$ and $Re_L < 10^7$,

$$\bar{St}\,Pr^{2/3} = 0.037Re_L^{-1/5} - 871Re_L^{-1} \qquad 5.41$$

$$\bar{St} = \frac{\overline{Nu}}{(Re_L \text{Pr})}$$

$$\overline{Nu}_L = \frac{hL}{k} = Pr^{\frac{1}{3}}(0.037Re_L^{0.8} - 871) \qquad 5.42$$

For $10^7 < Re_L < 10^9$ and $Re_{crit} = 5\times10^5$

$$Nu_L = \frac{\bar{h}L}{k} = [0.228Re_L(\log Re_L)^{-2.584} - 871]Pr^{\frac{1}{3}} \qquad 5.43$$

$$\overline{Nu}_L = \frac{hL}{k} = Pr^{\frac{1}{3}}(0.037Re_L^{0.8} - 871)$$

$$\bar{h} == \frac{k}{L}Pr^{\frac{1}{3}}(0.037Re_L^{0.8} - 871)$$

$$Re_L = \frac{u_\infty L}{v}$$

$T_\infty = 90°C \quad u_\infty = 60 \text{ m/sec} \quad L = 60 \text{ cm} \quad T_w = 10°C$

$T_f = 50°C = 323 \text{ K} \quad \rho = \frac{1.0132\times10^5}{(287)(323)} = 1.093 \quad \mu = 1.716\times10^{-5}$

$k = 0.0241 \quad \text{Pr} = 0.71$

$$\text{Re} = \frac{(1.093)(60)(0.6)}{1.716\times10^{-5}} = 2.292\times10^6$$

$$\bar{h} = \frac{0.0241}{0.6}(0.71)^{1/3}[(0.037)(2.29\times10^6)^{0.8} - 871]$$

$\bar{h} = 131.1 \ \frac{\text{W}}{\text{m}^2\cdot°\text{C}} \quad q = (131.1)(0.6)^2(10-90) = 3776$

5-21 Nitrogen at 2 atm and 500 K flows across a 40-cm-square plate at a velocity of 25 m/s. Calculate the cooling required to maintain the plate surface at a constant temperature of 300 K.

For $Re_{crit} = 5\times10^5$ and $Re_L < 10^7$,

$$\bar{St}\, Pr^{2/3} = 0.037 Re_L^{-1/5} - 871 Re_L^{-1} \qquad 5.41$$

$$\bar{St} = \frac{\overline{Nu}}{(Re_L \text{Pr})}$$

$$\overline{Nu}_L = \frac{hL}{k} = Pr^{\frac{1}{3}}(0.037 Re_L^{0.8} - 871) \qquad 5.42$$

For $10^7 < Re_L < 10^9$ and $Re_{crit} = 5\times10^5$

$$Nu_L = \frac{\bar{h}L}{k} = [0.228 Re_L(\log Re_L)^{-2.584} - 871]Pr^{\frac{1}{3}} \qquad 5.43$$

$$\overline{Nu}_L = \frac{hL}{k} = Pr^{\frac{1}{3}}(0.037 Re_L^{0.8} - 871)$$

$$\bar{h} == \frac{k}{L} Pr^{\frac{1}{3}}(0.037 Re_L^{0.8} - 871)$$

$$Re_L = \frac{u_\infty L}{\upsilon}$$

N_2 at 2 atm $\quad T_f = 400 \text{ K} \quad \nu = \frac{25.74\times10^{-6}}{2} \quad k = 0.03335$

$\text{Pr} = 0.691 \quad \text{Re} = \frac{(0.4)(2)(25)}{25.74\times10^{-6}} = 7.78\times10^5$ turbulent

$$\bar{h} = \frac{0.0335}{0.4}[0.037(7.78\times10^5)^{0.8} - 871](0.691)^{1/3} = 76.4 \ \frac{\text{W}}{\text{m}^2\cdot°\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (76.4)(0.4)^2(500-300) = 2446 \text{ W}$$

5-23 Calculate the heat transfer from a 20-cm-square plate over which air flows at 35◦C and 14 kPa. The plate temperature is 250◦C, and the free-stream velocity is 6 m/s.

$$\overline{Nu_L} = \frac{\bar{h}L}{k} = 0.664Re_L^{1/2}Pr^{1/3}$$

$$L = 0.2 \qquad T_\infty = 35°C \qquad p = 14{,}000 \ N/m^2 \qquad T_w = 250°C \qquad u_\infty = 6 \ m/sec$$

$$T_f = \frac{250+35}{2} = 142.5 = 416 \ K \qquad \rho = \frac{14{,}000}{(287)(416)} = 0.117$$

$$\mu = 2.349\times10^{-5} \qquad k = 0.03474 \qquad Pr = 0.685$$

$$Re = \frac{(0.117)(6)(0.2)}{2.349\times10^{-5}} = 5977$$

$$h = \frac{(0.3474)(0.664)}{0.2}(5977)^{1/2}(0.685)^{1/3} = 7.86 \ \frac{W}{m^2\cdot°C}$$

$$q = (7.86)(0.2)^2(250-35) = 676 \ W$$

5-24 Air at 20 kPa and 20◦C flows across a flat plate 60 cm long. The free-stream velocity is 30 m/s, and the plate is heated over its total length to a temperature of 55◦C. For x =30 cm, calculate the value of y for which u will equal 22.5 m/s.

The velocity profile of the stream in x-direction within the boundary layer is given by:

$$\frac{u}{u_\infty} = \frac{3}{2}\frac{y}{\delta} - \frac{1}{2}\left(\frac{y}{\delta}\right)^3 \qquad 5.6$$

$$\delta = \frac{4.64x}{Re_x^{1/2}}$$

$$Re = \frac{u_\infty x}{\upsilon} = \frac{\rho u_\infty x}{\mu}$$

$$T_w = 55°C \qquad T_\infty = 20°C \qquad p = 20{,}000 \ N/m^2 \qquad x = 0.3 \ m$$

$$u_\infty = 30 \ m/sec \qquad u = 22.5 \ m/sec \qquad T_f = \frac{55+20}{2} = 37.5°C = 310 \ K$$

$$\rho = \frac{20{,}000}{(287)(310)} = 0.225 \ kg/m^3 \qquad \mu = 2.001\times10^{-5}$$

$$Re = \frac{(0.225)(30)(0.3)}{2.001\times10^{-5}} = 1.01\times10^5 \qquad \delta = \frac{(0.3)(4.64)}{(1.01\times10^5)^{1/2}} = 4.38\times10^{-3} \ m$$

$$\frac{u}{u_\infty} = \frac{22.5}{30} = \frac{3}{2}\left(\frac{y}{\delta}\right) - \frac{1}{2}\left(\frac{y}{\delta}\right)^3 \qquad \frac{y}{\delta} = 0.56 \qquad y = 2.45\times10^{-3} \ m$$

5-25 For the flow system in Problem 5-24, calculate the value of the friction coefficient at a distance of 15 cm from the leading edge.

$$\frac{C_{fx}}{2} = 0.332\,\mathrm{Re}_x^{-1/2} \text{ at } x = 15 \text{ cm} \quad \mathrm{Re}_x = 0.5005 \times 10^5 \quad C_{fx} = 2.968 \times 10^{-3}$$

5-26 Air at a pressure of 200 kPa and free-stream temperature of 27◦C flows over a square flat plate at a velocity of 30 m/s. The Reynolds number is 106 at the edge of the plate. Calculate the heat transfer for an isothermal plate maintained at 57◦C.

For $Re_{crit} = 5 \times 10^5$ and $Re_L < 10^7$,

$$\bar{St}\, Pr^{2/3} = 0.037 Re_L^{-1/5} - 871 Re_L^{-1} \qquad 5.41$$

$$\bar{St} = \frac{\overline{Nu}}{(Re_L \mathrm{Pr})}$$

$$\overline{Nu}_L = \frac{hL}{k} = Pr^{\frac{1}{3}}(0.037 Re_L^{0.8} - 871) \qquad 5.42$$

For $10^7 < Re_L < 10^9$ and $Re_{crit} = 5 \times 10^5$

$$Nu_L = \frac{\bar{h}L}{k} = [0.228 Re_L (\log Re_L)^{-2.584} - 871] Pr^{\frac{1}{3}} \qquad 5.43$$

$$\overline{Nu}_L = \frac{hL}{k} = Pr^{\frac{1}{3}}(0.037 Re_L^{0.8} - 871)$$

$$\bar{h} == \frac{k}{L} Pr^{\frac{1}{3}}(0.037 Re_L^{0.8} - 871)$$

$$Re = \frac{u_\infty x}{v} = \frac{\rho u_\infty x}{\mu}$$

$$Re = \frac{u_\infty x}{v} = \frac{\rho u_\infty L}{\mu}$$

$$L = \frac{Re * v}{u_\infty}$$

$T_f = °C = 315\ K$

$\nu = 17.2\times10^{-6}/2 = 8.6\times10^{-6}$

$k = 0.0274; \quad Pr = 0.7$

$L = 10^6(8.6\times10^{-6})/30 = 0.287\ m$

$Nu = (0.7)^{1/3}[(0.037)(10^6)^{0.8} - 871] = 1299$

$h = (1299)(0.0274)/0.287 = 124.1$

$q = (124.1)(0.287)^2(57 - 27) = 307\ W$

5-32 Air flows across a 20-cm-square plate with a velocity of 5 m/s. Free-stream conditions are 10◦C and 0.2 atm. A heater in the plate surface furnishes a constant heat-flux condition at the wall so that the average wall temperature is 100◦C. Calculate the surface heat flux and the value of *h* at an *x* position of 10 cm.

$$\overline{T_w - T_\infty} = \frac{q_w\, L/k}{0.6795 Re_L^{1/2} Pr^{1/3}}$$

$$q_w = \overline{(T_w - T_\infty)} * 0.6795 Re_L^{1/2} Pr^{1/3} * \frac{k}{L}$$

$$T_f = \frac{100+10}{2} = 55°C = 328\ K \qquad \rho = \frac{1.01\times10^5}{(2)(287)(328)} = 0.538$$

$$\mu = 1.974\times10^{-5} \qquad k = 0.0284 \qquad Pr = 0.7$$

$$Re_L = \frac{(0.538)(5)(0.2)}{1.974\times10^{-5}} = 27{,}254 \qquad \text{Re at } x = 10\ \text{cm} = 13{,}627$$

$$\overline{T_w - T_\infty} = \frac{q_w L/k}{0.6795 Re_L^{1/2} Pr^{1/3}}$$

$$q_w = \frac{(100)(0.6795)(27{,}254)^{1/2}(0.7)^{1/3}(0.0284)}{0.2} = 1414\ W/m^2$$

$$\frac{h_x}{k} = 0.453 Re_x^{1/2} Pr^{1/3}$$

$$\text{at } x = 10\ \text{cm} \quad h = \frac{0.0284}{0.1}(0.453)(13{,}627)^{1/2}(0.7)^{1/3} = 13.33\ \frac{W}{m^2\cdot°C}$$