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Solutions Manual

to accompany

Heat Transfer

tenth edition

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Chapter 1

1-1

$$\Delta T = \frac{(3000)(0.025)}{(0.2)(0.6)} = 625^\circ\text{C}$$

1-2

$$\begin{aligned}\frac{q}{A} &= \frac{(0.035)(85)}{0.13} = 22.885 \text{ J/s} \cdot \text{m}^2 \\ &= 82,386 \text{ J/h} \cdot \text{m}^2\end{aligned}$$

1-3

$$q = -kA \frac{dT}{dx} \quad \frac{dx}{\pi r^2} = -k \frac{dT}{q}$$

$$r = ax + b; \quad x = 0; \quad r = 0.0375$$

$$x = 0.3, \quad r = 0.0625$$

$$r = 0.0833x + 0.0375$$

$$\begin{aligned}\int \frac{dx}{\pi(0.0833x + 0.0375)^2} &= -\frac{(204)(93 - 540)}{q} \\ \frac{-1}{\pi(0.0833)} \left(\frac{1}{0.0833x + 0.0375} \right) \Bigg|_{x=0}^{x=0.3} &= -\frac{(204)(-447)}{q} \\ q &= 2238 \text{ W}\end{aligned}$$

1-4

$$\frac{q}{A} = \frac{(0.78)(375 - 85)}{0.15} = 1508 \text{ W/m}^2$$

1-5

$$A = \pi r^2 \quad q = -k4\pi r^2 \frac{dT}{dr} \quad q = \frac{-4\pi k(T_0 - T_i)}{\frac{1}{r_i} - \frac{1}{r_0}}$$

$$q = \frac{-4\pi(2 \times 10^{-4})(21 + 196)}{\frac{1}{0.26} - \frac{1}{0.285}} = 1.617 \text{ W}$$

$$\begin{aligned}\text{mass evaporated} &= \frac{1.617}{199,000} = 0.813 \times 10^{-5} \text{ kg/s} \\ &= 0.702 \text{ kg/day}\end{aligned}$$

Chapter 1

1-7

$$\frac{q}{L} = \frac{T_i - T_\infty}{\frac{\ln(r_0/r_i)}{2\pi k} + \frac{1}{h\pi d_0}} = \frac{30 + 20}{\frac{\ln(\frac{30}{25})}{2\pi(7)(10^{-3})} + \frac{1}{9\pi(0.6)}} = 11.89 \text{ W/m}$$

1-8

Like many kinds of homespun advice, this is bad advice. *All* types of heat transfer; conduction, convection, and radiation vary directly with area. The surface area of the head is much less than that of the other portion of the body and thus will lose less heat. This may be shown experimentally by comparing exposure in cold weather wearing heavy clothing and no hat, to that wearing a heavy hat and only undergarments!

1-9

$$\frac{q}{A} = \frac{(0.161)(200 - 100)}{0.05} = 322 \text{ W/m}^2$$

1-10

$$\begin{aligned} \Delta x &= \frac{kA\Delta T}{q} \\ &= \frac{(10 \times 10^{-3} \frac{\text{W}}{\text{m}\cdot\text{C}})(500)}{400 \frac{\text{W}}{\text{m}^2}} \\ &= 0.0125 \text{ m} = 1.25 \text{ cm} \end{aligned}$$

1-11

$$2.158 = (2.7)(4\pi)\left(\frac{13}{12}\right)(0.3048)^2 \Delta T$$
$$\Delta T = 0.632^\circ\text{C}$$

1-12

$$\frac{q}{A} = (5.669 \times 10^{-8})[(1073)^4 - (523)^4] = 70.9 \frac{\text{kW}}{\text{m}^2}$$

1-13

$$\frac{q}{A} = (5.669 \times 10^{-8})[(1373)^4 - (698)^4] = 188 \frac{\text{kW}}{\text{m}^2}$$

1-14

$$q = (5.669 \times 10^{-8})(4\pi)(0.35)^2[(300)^4 - (70)^4] = 704.8 \text{ W}$$

1-15

a. $q = (5.669 \times 10^{-8})[(773)^4 - (373)^4] = 1.914 \times 10^4 \text{ W/m}^2$

b. $q = (5.669 \times 10^{-8})[(773)^4 - (T_p)^4]$
 $= (5.669 \times 10^{-8})[(T_p)^4 - (373)^4]$

$$T_p = 641 \text{ K}$$

$$q = 8474.3 \text{ W/m}^2$$

Reduced by 44.3%

1-16

$$q = hA(T_w - T_{fluid})$$

$$\text{From Table 1-2} \quad h = 3500 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (3500)\pi dL(40) = (3500)\pi(0.025)(3)(40) = 32987 \text{ W}$$

$$q = mc_p \Delta T_{fluid}$$

$$32,987 \text{ W} = (0.5 \text{ kg/s})(4180 \text{ J/kg} \cdot ^\circ\text{C})\Delta T$$

$$\Delta T = 15.78^\circ\text{C}$$

1-17

$$h_{fg} = 2257 \text{ kJ/kg}$$

$$q = \dot{m}h_{fg} = (3.78 \text{ kg/hr})(2257 \text{ kJ/kg}) = 8531 \frac{\text{kJ}}{\text{hr}} = 2.37 \frac{\text{kJ}}{\text{s}} = 2.37 \text{ kW}$$

$$\text{From Table 1-2} \quad h \sim 7500 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - T_{fluid})$$

$$2370 \text{ W} = (7500)(0.3)^2(T_w - 100)$$

$$T_w \approx 96.5^\circ\text{C}$$

1-18

$$q = hA\Delta T$$

$$3 \times 10^4 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} = h(232 - 212)^\circ\text{F}$$

$$h = 1500 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} = 8517 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

1-19

$$q = \sigma \varepsilon A [(T_1)^4 - (T_2)^4]$$

$$2000 \text{ W} = (5.669 \times 10^{-8})(0.85)(0.006)(3)[(T_1)^4 - (298)^4]$$

$$T_1 = 1233 \text{ K}$$

1-20

$$\frac{q}{A} = \sigma T^4 = (5.669 \times 10^{-8})(1000 + 273)^4 = 1.489 \times 10^5 \frac{\text{W}}{\text{m}^2}$$

1-21

$$\frac{q}{A} = \sigma T^4$$

$$54 \times 10^6 = (5.669 \times 10^{-8})T^4$$

$$T = 5556 \text{ K}$$

Chapter 1

1-22

$$q = \sigma \varepsilon A_1 (T_1^4 - T_2^4) = (5.669 \times 10^{-8})(0.6)(4\pi)(0.04)^2(473^4 - 293^4) = 29.19 \text{ W}$$

1-23

$$q = kA \frac{\Delta T}{\Delta x} = hA(T_0 - T_\infty)$$

$$\frac{(1.4)(315 - 41)}{0.025} = h(41 - 38)$$

$$h = 5114 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

1-25

$$q = (1.6) \frac{100 - T_{w_2}}{0.4} = 10(T_{w_2} - 10)$$

$$T_{w_2} = 35.7^\circ\text{C}$$

$$q = 10(35.7 - 10) = 257 \frac{\text{W}}{\text{m}^2}$$

1-26

From Table 1-2 $h = 4.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$ for $\Delta T = 30^\circ\text{C}$

$$q = hA\Delta T = (4.5)(0.3)^2(30) = 12.15 \text{ W}$$

Conduction

$$q = kA \frac{\Delta T}{\Delta x}$$

$$k \text{ for air} = 0.03 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$q = \frac{(0.03)(0.3)^2(30)}{0.025} = 3.24 \text{ W}$$

1-27

$$\Delta T = \frac{(1500) \left(\frac{0.25}{12} \right)}{25} = 1.25^\circ\text{F}$$

$$T = 100 - 1.25 = 98.75^\circ\text{F}$$

1-28

$$700 = (11)(T_w - 30)$$

$$T_w = 93.6^\circ\text{C}$$

1-29

$$q = q_{\text{conv}} + q_{\text{rad}}$$

$$q_{\text{conv}} = hA(T_w - T_\infty)$$

From Table 1-2 $h = 180 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$

$$q_{\text{conv}} = (180)\pi(0.05)(1)(200 - 30) = 4807 \frac{\text{W}}{\text{m}} \text{ length}$$

$$q_{\text{rad}} = \sigma \varepsilon A_1 (T_1^4 - T_2^4)$$

$$= (5.669 \times 10^{-8})(0.7)\pi(0.05)(1)(473^4 - 283^4)$$

$$= 272 \frac{\text{W}}{\text{m}} \text{ length}$$

$$q_{\text{total}} = 4807 + 272 = 5079 \frac{\text{W}}{\text{m}}$$

Most heat transfer is by convection.

1-30

$$q = q_{\text{conv}} + q_{\text{rad}}$$

$$q_{\text{conv}} = hA(T_w - T_\infty)$$

From Table 1-2 $h = 4.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$

$$q_{\text{conv}} = (4.5)(0.3)^2(50 - 20) \quad (2 \text{ sides})$$

$$= 24.3 \text{ W}$$

$$q_{\text{rad}} = \sigma \varepsilon A_1 (T_1^4 - T_2^4) = (5.669 \times 10^{-8})(0.8)(0.3^2)(323^4 - 293^4) \quad (2 \text{ sides})$$

$$= 28.7 \text{ W}$$

$$q_{\text{total}} = 24.3 \text{ W} + 28.7 \text{ W} = 53 \text{ W}$$

Convection and radiation are about the same magnitude.

1-31

$$q = q_{\text{conv}} + q_{\text{rad}} = 0 \quad (\text{insulated})$$

$$q_{\text{conv}} = hA(T_w - T_\infty)$$

From Table 1-2 $h = 12 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$

$$q_{\text{rad}} = \sigma \varepsilon A_1 (T_1^4 - T_2^4), \quad \varepsilon = 1.0, \quad T_2 = 35^\circ\text{C} = 308 \text{ K}$$

$$0 = hA_1(T_1 - T_\infty) + \sigma \varepsilon A_1 (T_1^4 - T_2^4)$$

$$0 = (12)(T_1 - 273) + (5.669 \times 10^{-8})(1.0)(T_1^4 - 308^4)$$

Solution by iteration:

$$T_1 = T_w = 285 \text{ K} = 12^\circ\text{C}$$

Chapter 1

1-32

$$(100)(353 - T_{w_1}) = (5.669 \times 10^{-8})(T_{w_1}^4 - T_{w_2}^4) = 15(T_{w_2} - 293)$$

$$15(T_{w_2} - 293) - (5.669 \times 10^{-8})[(397 - 0.15T_{w_2})^4 - (T_{w_2})^4] = 0 = f(T_{w_2})$$

$$T_{w_2} \quad f(T_{w_2})$$

$$320 \quad 158.41$$

$$350 \quad 907.22$$

$$310 \quad -77.03$$

$$313.3 \quad 0.058$$

$$T_{w_1} = 397 - (0.15)(313.3) = 350 \text{ K}$$

1-36

$$h = 4.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \text{ (plate)}$$

$$h = 6.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \text{ (cylinder)}$$

$$T_\infty = 20^\circ\text{C} = 293 \text{ K}$$

$$hA(T - T_\infty) = \sigma \varepsilon A(T^4 - T_\infty^4)$$

Plate

$$(4.5)(T - 293) = (5.668 \times 10^{-8})(T^4 - 293^4)$$

$T =$ no realistic value ($T = 247 \text{ K}$, heat gained)

Cylinder

$$(6.5)(T - 293) = (5.668 \times 10^{-8})(T^4 - 293^4)$$

$$T = 320 \text{ K} = 47^\circ\text{C}$$

1-37

The woman is probably correct. Her perceived comfort is based on both radiation and convection exchange with the surroundings. Even though a fan does not blow cool air on her from the refrigerator, her body will radiate to the cold interior and thereby contribute to her feeling of "coolness."

1-38

This is an old story. All things being equal, hot water does not freeze faster than cold water. The only explanation for the observed faster cooling is that the refrigerator might be a non-self defrost model which accumulated an ice layer on the freezing coils. Then, when the hot water tray was placed on the ice layer, it melted and reduced the thermal insulation between the cooling coil and the ice tray.

1-39

As in problem 1-36, it must be observed that a person's comfort depends on total heat exchange with the surroundings by both radiation and convection. In the winter the walls of the room will presumably be cooler than the room air and increase the heat loss from the bodies. In the summer the walls are probably hotter than the room air temperature and thereby increase the heat gain or reduce the heat loss from the people in the room.

1-40

$$q = q_{\text{conv}} + q_{\text{rad}}$$

$$q_{\text{conv}} = hA(T_w - T_{\infty}) = (2)\pi(1)(6)(78 - 68) = 377 \text{ Btu/hr}$$

$$\text{For } T_2 = 45^\circ\text{F} = 505^\circ\text{R}$$

$$\begin{aligned} q_{\text{rad}} &= \sigma \epsilon A_1 (T_1^4 - T_2^4) \\ &= (0.1714 \times 10^{-8})(0.9)\pi(1)(6)(538^4 - 505^4) \\ &= 544 \text{ Btu/hr} \end{aligned}$$

$$q_{\text{total}} = 377 + 544 = 921 \text{ Btu/hr}$$

$$\text{For } T_2 = 80^\circ\text{F} = 540^\circ\text{R}$$

$$q_{\text{rad}} = (0.1714 \times 10^{-8})(0.9)\pi(1)(6)(538^4 - 540^4) = -36.4 \text{ Btu/hr}$$

$$q_{\text{total}} = 377 - 36.4 = 340.6 \text{ Btu/hr}$$

Conclusion: Radiation plays a very important role in "thermal comfort."

1-41

$$T_i = 0^\circ\text{C} = 273 \text{ K} \quad \epsilon_{\text{ice}} = 0.95$$

$$A = (12)(40) = 480 \text{ m}^2 \quad T_s = 25^\circ\text{C} = 298 \text{ K} \quad T_a = 22^\circ\text{C}$$

$$q_{\text{rad}} = \sigma \epsilon A_1 (T_s^4 - T_i^4) = (5.668 \times 10^{-8})(0.95)(480)(298^4 - 273^4) = 60262 \text{ W}$$

$$q_{\text{conv}} = hA(T_a - T_i) = (10)(480)(22 - 0) = 105,600 \text{ W}$$

$$q_{\text{total}} = 60,262 + 105,600 = 165,862 \text{ W}$$

$$\text{For ice } i_{fg} = 80 \text{ cal/g} = 3.348 \times 10^5 \text{ J/kg}$$

$$\text{Mass rate melted} = \frac{165,862}{3.348 \times 10^5} = 0.495 \text{ kg/sec}$$

$$\text{density of ice} \sim 1000 \text{ kg/m}^3$$

$$\text{volume rate melted} = \frac{0.495}{1000} = 4.95 \times 10^{-4} \text{ m}^3/\text{s}$$

$$\text{Volume} = A \times \text{thk} = (480)(0.003) = 1.44 \text{ m}^3$$

$$\text{Time to melt} = \frac{1.44 \text{ m}^3}{4.95 \times 10^{-4} \text{ m}^3/\text{s}} = 2909 \text{ sec} = 0.808 \text{ hr}$$

1-42

The price of fuel and electric energy varies widely with time of year and location throughout the world, so individual answers can differ substantially for this problem.

1-43

$$k_{\text{glass wool}} = 0.038 \quad \text{thickness} = 0.15 \text{ m}$$

$$A = 144 + (4)(5)(12) = 384 \text{ m}^2$$

$$T \text{ (inside building surface)} = -10 + 30 = 20^\circ\text{C}$$

$$q \text{ lost (without insulation)} = hA\Delta T = (13)(384)(30) = 149,760 \text{ W}$$

$$q \text{ lost (with insulation)} = A\Delta T / [\Delta x/k + 1/h]$$

$$= (384)(30) / [0.15/0.038 + 1/13] = 2862 \text{ W}$$

$$\text{Energy saving by installing insulation} = 146,897 \text{ W}$$

This number must be combined with the energy costs obtained in Problem 1-42 to obtain the cost saving per hour (or per day, etc).

1-44

This problem is quite open-ended and the answers will strongly depend on the assumptions cot/bunk materials etc.

Chapter 2

2-1

$$q = \frac{T_i - T_o}{\left(\frac{\Delta x}{kA}\right)_w + \left(\frac{\Delta x}{kA}\right)_{ins}} \quad 1830 = \frac{1300 - 30}{\frac{0.02}{1.3} + \frac{\Delta x}{0.35}}$$

$$\Delta x = 0.238 \text{ m}$$

2-2

Assume Linear variation: $k = k_0(1 + \beta T)$

$$q = -\frac{k_0 A}{\Delta x} \left[T_3 - T_1 + \frac{\beta}{2} (T_3^2 - T_1^2) \right] = -\frac{k_0 A}{\Delta x / 2} \left[T_2 - T_1 + \frac{\beta}{2} (T_2^2 - T_1^2) \right]$$

$$T_3 = 95^\circ\text{C}, T_2 = 62^\circ\text{C}, T_1 = 35^\circ\text{C}, \Delta x = 0.025$$

$$2 \left[62 - 35 + \frac{\beta}{2} (62^2 - 35^2) \right] = \left[95 - 35 + \frac{\beta}{2} (95^2 - 35^2) \right]$$

$$\beta = -4.68 \times 10^{-3}$$

$$1000 = q = \frac{k_0(0.1)}{0.025} \left[95 - 35 - \frac{4.68 \times 10^{-3}}{2} (95^2 - 35^2) \right]$$

$$k_0 = 5.988$$

$$k = 5.988(1 - 4.68 \times 10^{-3} T) \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

2-3

$$\frac{q}{A} = \frac{560}{\frac{0.025}{386} + \frac{3.2 \times 10^{-3}}{0.16} + \frac{0.05}{0.038}} = 419 \frac{\text{W}}{\text{m}^2}$$

2-4

$$R = \frac{\Delta x}{kA}$$

$$R_A = \frac{0.025}{(150)(0.1)} = 1.667 \times 10^{-3}$$

$$R_B = \frac{0.075}{(30)(0.05)} = 0.05$$

$$R_C = \frac{0.05}{(50)(0.1)} = 0.01$$

$$R_D = \frac{0.075}{(70)(0.05)} = 0.02143$$

$$R = R_A + R_C + \frac{1}{\frac{1}{R_B} + \frac{1}{R_D}} = 2.667 \times 10^{-2}$$

$$q = \frac{\Delta T}{R} = \frac{370 - 66}{2.667 \times 10^{-2}} = 11,400 \text{ W}$$

2-5

$$\frac{44,000}{A} = \frac{250 - 35}{\frac{0.05}{386} + \frac{0.025}{0.038}} \quad A = 134.7 \text{ m}^2$$

2-6

$$\frac{q}{A} = \frac{75}{\frac{0.10}{0.69} + \frac{0.025}{0.05}} = 38.76 \text{ W/m}^2$$

2-7

$$\frac{q}{A} = \frac{\Delta T}{R}$$

$$\frac{300}{A} = \frac{175 - 80}{\frac{0.04}{386} + \frac{0.015}{0.038}}$$

$$A = 1.247 \text{ m}^2$$

2-8

Assume one directional no heat sources

$$q = -kA \frac{dT}{dx} = -k_0 A [1 + \beta T^2] \frac{dT}{dx} = -k_0 A \frac{dT}{dx} - k_0 \beta A T^2 \frac{dT}{dx}$$

$$\text{Integrating: } q \Delta x = -k_0 A \int_{T_1}^{T_2} dT - A k_0 \beta \int_{T_1}^{T_2} T^2 dT$$

$$q = -\frac{k_0 A}{\Delta x} \left[(T_2 - T_1) + \frac{\beta}{3} (T_2^3 - T_1^3) \right]$$

Chapter 2

2-9

$$\frac{1}{h_i A_i} = \frac{1}{(1500)\pi(0.03)} = 0.00709 \quad r_0 = 0.015 + 0.002 = 0.017$$

$$\frac{\ln(r_0/r_i)}{2\pi k} = \frac{\ln(0.017/0.015)}{2\pi(46)} = 0.000433$$

$$\frac{1}{h_o A_o} = \frac{1}{(197)\pi(0.034)} = 0.0475$$

$$\sum R = 0.05502 \frac{^\circ\text{C} \cdot \text{m}}{\text{W}}$$

$$\frac{q}{L} = \frac{223 - 57}{0.05502} = 3017 \text{ W/m}$$

2-10

$$\frac{\partial T}{\partial x} = 300x - 30$$

$$\frac{\partial^2 T}{\partial x^2} = 300 = \frac{1}{\alpha} \frac{\partial T}{\partial \tau} \text{ heating up}$$

$$\frac{\partial T}{\partial x} = -30 \text{ at } x = 0$$

$$\frac{\partial T}{\partial x} = 60 \text{ at } x = 0.3$$

$$\frac{q}{A} = -(0.04)(-30) = +1.2 \frac{\text{W}}{\text{m}^2} \text{ at } x = 0$$

$$\frac{q}{A} = -(0.04)(60) = -2.4 \frac{\text{W}}{\text{m}^2} \text{ at } x = 0.3$$

2-11

$$d = 0.000025; \quad k = 16; \quad L = 0.8\text{m}; \quad h = 500; \quad T_\infty = 20^\circ\text{C}; \quad T_o = T_L = 200^\circ\text{C}$$

$$m = [(500)(4)/(16)(0.000025)]^{1/2} = 2236$$

$$\theta'_o = \theta'_L = 200 - 20 = 180$$

$$q = -2kA(\partial\theta'/\partial x)_o = -2kA(-m\theta'_o)$$

$$= (2)(16)\pi(0.000025)^2(2236)(180)/4 = 0.0063 \text{ W}$$

2-12

$$R_{Cu} = \frac{0.02}{374} = 5.35 \times 10^{-5}$$

$$R_{As} = \frac{0.003}{0.166} = 0.0181$$

$$R_{Fi} = \frac{0.06}{0.038} = 1.579$$

$$\frac{q}{A} = \frac{500}{\sum R} = 313 \frac{\text{W}}{\text{m}^2}$$

2-13

$$R_c = \frac{\frac{6}{12}}{(1.2)(0.5778)} = 0.721$$

$$R_f = \frac{\frac{2}{12}}{(0.038)(0.5778)} = 7.59$$

$$R_g = \frac{\frac{0.375}{12}}{(0.05)(0.5778)} = 1.082$$

$$R_i = \frac{1}{2.0} = 0.5 \quad R_o = \frac{1}{7} = 0.143$$

$$\frac{q}{A} = \frac{72 - 20}{\sum R} = 5.18 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2}$$

$$U = \frac{1}{\sum R} = 0.0996$$

2-14

$$R_{ss} = \frac{\Delta x}{k} = \frac{0.004}{16} = 0.0025$$

$$R_{\text{overall}} = \frac{1}{U} = \frac{1}{120} = 0.00833$$

$$\frac{\Delta T_{ss}}{\Delta T_{\text{overall}}} = \frac{R_{ss}}{R_{\text{overall}}} = \frac{0.0025}{0.00833} = 0.3$$

$$\Delta T_{ss} = (0.3)(60) = 18^\circ\text{C}$$

Chapter 2

2-15

$$\text{Ice at } 0^\circ\text{C} \quad \rho = 999.8 \text{ kg/m}^3$$

$$V = (0.25)(0.4)(1.0) = 0.1 \text{ m}^3$$

$$m = 100 \text{ kg}$$

$$q = (100)(330 \times 10^3) = 3.3 \times 10^7 \text{ J}$$

$$A_i = (2)(0.25)(0.4) + (2)(0.4)(1.0) + (2)(0.25)(1.0) = 1.5 \text{ m}^2$$

$$A_0 = (2)(0.35)(0.5) + (2)(0.5)(1.1) + (2)(0.35)(1.1) = 2.22 \text{ m}^2$$

$$A_m = 1.86 \text{ m}^2$$

$$R_s = \frac{\Delta x}{kA} = \frac{0.05}{(0.033)(1.86)} = 0.8146$$

$$R_0 = \frac{1}{hA_0} = 0.045$$

$$R = 0.8596$$

$$\frac{Q}{\Delta T} = \frac{3.3 \times 10^7}{\Delta T} = \frac{25 - 0}{0.8596}$$

$$\Delta\tau = 1.135 \times 10^6 \text{ sec}$$

$$= 315 \text{ hr}$$

$$= 13 \text{ days}$$

2-16

$$q \text{ (no ins.)} = hA(T_w - T_\infty) = (25)(4\pi)(0.5)^2(120 - 15) = 8247 \text{ W}$$

$$k_{\text{foam}} = \frac{18 \text{ mW}}{\text{m} \cdot ^\circ\text{C}}$$

$$q = \frac{4\pi k(T_i - T_0)}{\frac{1}{r_i} - \frac{1}{r_0}} = h4\pi r_0^2(T_0 - T_\infty)$$

$$\frac{(0.018)(120 - 40)}{\frac{1}{0.5} - \frac{1}{r_0}} = (25)r_0^2(40 - 15)$$

$$r_0 = 0.5023 \text{ m}$$

$$\text{thk} = r_0 - r_i = 0.023 \text{ m}$$

$$q \text{ (w/ ins.)} = (25)(4\pi)(0.5023)^2(40 - 15) = 1982 \text{ W}$$

2-17

$$q = \frac{4\pi k(T_i - T_0)}{\frac{1}{r_i} - \frac{1}{r_0}} \quad k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$= \frac{(4)\pi(204)(100 - 50)}{\frac{1}{0.02} - \frac{1}{0.04}} = 5127 \text{ W}$$

2-18

$$q = \frac{\Delta T}{\sum R}$$

$$R_{\text{alum}} = \frac{\frac{1}{0.02} - \frac{1}{0.04}}{4\pi(204)} = 9.752 \times 10^{-3}$$

$$R_{\text{ins}} = \frac{\frac{1}{0.04} - \frac{1}{0.05}}{4\pi(0.05)} = 7.958$$

$$R_{\text{conv}} = \frac{1}{hA} = \frac{1}{(20)(4\pi)(0.05)^2} = 1.592$$

$$q = \frac{100 - 10}{0.00975 + 7.958 + 1.592} = 9.41 \text{ W}$$

2-19

$$d_i = 2.90 \text{ in.} \quad d_o = 3.50 \text{ in.} \quad k = 43 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$R_{\text{steel}} = \frac{\ln(3.5/2.9)}{(2\pi)(43)(1)} = 6.96 \times 10^{-4}$$

$$R_{\text{ins}} = \frac{\ln(5.5/3.5)}{(2\pi)(0.06)(1)} = 1.1999$$

$$R_{\text{conv}} = \frac{1}{hA_o} = \frac{1}{(10)\pi(5.5)(0.0254)} = 0.2278$$

$$R_{\text{tot}} = 1.427$$

$$q = \frac{\Delta T}{R} = \frac{250 - 20}{1.427} = 161.1 \frac{\text{W}}{\text{m}}$$

2-20

$$k_A = 0.166 \quad k_f = 0.0485 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\frac{315 - T_i}{\frac{\ln(31.4/25)}{0.166}} = \frac{T_i - 38}{\frac{\ln(56.4/31.4)}{0.0485}}$$

$$0.7283(315 - T_i) = 0.0828(T_i - 38)$$

$$T_i = 286.7^\circ\text{C}$$

Chapter 2

2-21

$$q_r = -k4\pi r^2 \frac{dT}{dr}$$
$$q_r \int_{r_i}^{r_0} \frac{1}{r^2} dr = -k4\pi \int_{T_i}^{T_0} dT$$
$$q_r \left(\frac{1}{r_0} - \frac{1}{r_i} \right) = -4\pi k (T_0 - T_i)$$
$$q = \frac{-4\pi k (T_0 - T_i)}{\left(\frac{1}{r_0} - \frac{1}{r_i} \right)}$$
$$R_{th} = \frac{\left(\frac{1}{r_i} - \frac{1}{r_0} \right)}{4\pi k}$$

2-22

$$r_i = 0.5 \text{ mm} = 5 \times 10^{-4} \text{ m}$$
$$r_0 = \frac{k}{h} = 5 \times 10^{-4} + 2 \times 10^{-4} = 7 \times 10^{-4}$$
$$k = (7 \times 10^{-4})(120) = 0.084 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$
$$q(\text{bare wire}) = \pi(0.001)(120)(400 - 40) = 135.7 \text{ W/m}$$
$$q(\text{insulated}) = (135.7)(0.25) = 33.93 \text{ W/m}$$
$$q = \frac{400 - 40}{\frac{\ln(r_0/5 \times 10^{-4})}{2\pi(0.084)} + \frac{1}{\pi(2)(120)r_0}} = 33.93$$

By iteration: $r_0 = 135 \text{ mm}$
thickness = 134.5 mm

2-23

$$R_i = \frac{(1)(12)}{(30)\pi(2.067)} = 6.16 \times 10^{-2}$$
$$R_p = \frac{\ln(2.375/2.067)}{2\pi(27)} = 8.188 \times 10^{-4}$$
$$R_i = \frac{\ln(3.375/2.375)}{2\pi(0.023)} = 2.432$$
$$R_0 = \frac{(1)(12)}{2\pi(3.375)} = 5.659 \times 10^{-1}$$
$$\frac{q}{L} = \frac{320 - 70}{\sum R} = 81.7 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}}$$

2-24

$$q = -k4\pi r^2 \frac{dT}{dr} = \frac{k4\pi(T_0 - T_i)}{\frac{1}{r_0} - \frac{1}{r_i}} = k4\pi r_0^2 (T_0 - T_\infty)$$

$$q = \frac{T_i - T_\infty}{\frac{1}{4\pi k} \left(\frac{1}{r_i} - \frac{1}{r_0} \right) + \frac{1}{4\pi r_0^2 h}}$$

Take $\frac{dq}{dr_0} = 0$

Result is: $r_0 = 2 \frac{k}{h}$

2-25

$$M_w \text{ at } 90\% \text{ full} = (0.9)(970)\pi(0.8)^2(2) = 3511 \text{ kg}$$

$$\text{at } 2^\circ\text{C/hr } q = \frac{(3511)(4191)(2)}{3600} = 8174 \text{ W}$$

$$A = 2\pi(0.8)^2 + \pi(0.8)(2) = 9.048 \text{ m}^2$$

Fiberglass boards with $k = 40 \text{ mW/m} \cdot ^\circ\text{C}$

$$\Delta x = \frac{(40 \times 10^{-3})(9.048)(80 - 20)}{8174} = 2.66 \times 10^{-3} \text{ m}$$

2-26

for 1 m length

$$R(\text{pipe}) = \frac{\ln(9.1/8)}{2\pi(47)} = 4.363 \times 10^{-4}$$

$$R(\text{ins}(1)) = \frac{\ln(27.1/9.1)}{2\pi(0.5)} = 0.3474$$

$$R(\text{ins}(2)) = \frac{\ln(35.1/27.1)}{2\pi(0.25)} = 0.8246$$

$$R(\text{tot}) = 1.172$$

$$q = \frac{\Delta T}{R} = \frac{250 - 20}{1.172} = 196.2 \frac{\text{W}}{\text{m}}$$

2-27

Fiberglass $k = 0.038$ $\Delta x = 1.2 \text{ cm} \times 2$

Asbestos $k = 0.154$ $\Delta x = 8.0 \text{ cm}$

brick $k = 0.69$ $\Delta x = 10.0 \text{ cm}$

$$h = 15 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \times 2$$

$$U = \frac{1}{\frac{2}{12} + \frac{(2)(0.012)}{0.038} + \frac{0.08}{0.154} + \frac{0.1}{0.69}} = 0.684 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

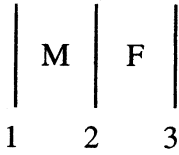
Chapter 2

2-28

$$R = \frac{1}{k}$$

	k	R
Fiberglass	0.046	21.74
Urethane	0.018	55.6
Mineral Wool	0.091	11.0
Calcium Silicate	0.058	17.2

2-29



$$T_1 = 1000^\circ\text{C}$$

$$T_2 = 400^\circ\text{C}$$

$$T_3 = 55^\circ\text{C}$$

$$k_m = 90 \frac{\text{mW}}{\text{m} \cdot ^\circ\text{C}}$$

$$h = 15 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$k_F = 42 \frac{\text{mW}}{\text{m} \cdot ^\circ\text{C}}$$

$$T_\infty = 40^\circ\text{C}$$

$$\frac{q}{A} = h(T_3 - T_\infty) = (15)(55 - 40) = 225 \frac{\text{W}}{\text{m}^2}$$

$$\frac{q}{A} = k_m \frac{(1000 - 400)}{\Delta x_m} \quad \Delta x_m = 0.24 \text{ m}$$

$$\frac{q}{A} = k_F \frac{(400 - 55)}{\Delta x_F} \quad \Delta x_F = 0.0644 \text{ m}$$

2-30

Uniformly distributed heat sources

$$\frac{d^2T}{dx^2} + \frac{\dot{q}}{k} = 0 \quad T = T_1 \quad \text{at} \quad x = -L$$

$$T = T_2 \quad \text{at} \quad x = +L$$

$$T = -\frac{\dot{q}x^2}{2k} + c_1x + c_2$$

$$T_1 = -\frac{\dot{q}L^2}{2k} - c_1L + c_2$$

$$T_2 = -\frac{\dot{q}L^2}{2k} + c_1L + c_2$$

$$T = \frac{\dot{q}}{2k}(L^2 - x^2) + \frac{T_2 - T_1}{2L}x + \frac{T_1 + T_2}{2}$$

2-31

$$r_1 = 2.5 \quad r_2 = 3.5 \quad r_3 = 6.5$$

$$R_1 = \frac{\ln(r_2/r_1)}{0.22(2\pi)} = \frac{\ln(3.5/2.5)}{0.22(2\pi)} = 0.2433$$

$$R_2 = \frac{\ln(r_3/r_2)}{0.06(2\pi)} = 1.642$$

$$R_\infty = \frac{1}{hA} = \frac{1}{(60)\pi(2)(0.065)} = 0.0408$$

$$\sum R = 1.9262 \quad \frac{^\circ\text{C} \cdot \text{m}}{\text{W}}$$

$$q = \frac{L\Delta T}{R} = \frac{(20)(400 - 15)}{1.9262} = 3997 \text{ W}$$

2-32

$$\frac{d^2T}{dx^2} + \frac{\dot{q}}{k} = 0 \quad \dot{q} = \dot{q}_w[1 + \beta(T - T_w)]$$

$$T = T_w \text{ at } x = \pm L$$

General solution

$$T - T_w = c_1 \left[\cos \left(\sqrt{\frac{\dot{q}_w \beta}{k}} x \right) \right] + c_2 \left[\sin \left(\sqrt{\frac{\dot{q}_w \beta}{k}} x \right) \right] - \frac{1}{\beta}$$

From boundary conditions

$$c_2 = 0 \quad c_1 = \frac{1}{\beta \cos \left(\sqrt{\frac{\dot{q}_w \beta}{k}} L \right)}$$

$$T - T_w = \frac{\cos \sqrt{\frac{\dot{q}_w \beta}{k}} x}{\beta \cos \sqrt{\frac{\dot{q}_w \beta}{k}} L}$$

2-33

$$k = 43; \quad r_1 = 0.015; \quad r_2 = 0.04; \quad T_0 = 250^\circ\text{C}; \quad T_\infty = 35^\circ\text{C}; \quad h = 43$$

$$L = 0.025$$

$$L_c = 0.0255$$

$$r_{2c} = 0.0405$$

$$r_{2c}/r_1 = 2.7$$

$$L_c^{3/2} (h/kA_m)^{1/2} = 0.825$$

$$\text{Fig. 2-12 } \eta_f = 0.59$$

$$q = (45)(2)\pi(0.0405^2 - 0.015^2)(250 - 35)(0.59) = 5.08 \text{ W}$$

2-34

$$\dot{q} = 0.30 \frac{\text{MW}}{\text{m}^3} \quad \text{Same as half of wall 15 cm thick with convection on each side.}$$

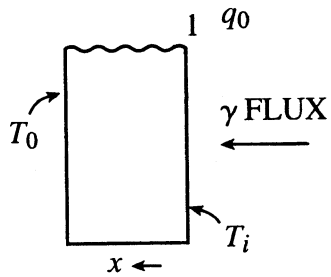
$$T_0 - T_w = \frac{\dot{q}L^2}{2k} = \frac{(0.30 \times 10^6)(0.060)^2}{(2)(21)} = 25.7^\circ\text{C}$$

$$\dot{q}LA = hA(T_w - T_\infty) \quad T_w - T_\infty = \frac{(0.30 \times 10^6)(0.060)}{570} = 31.6^\circ\text{C}$$

$$T_0 = T_{\text{max}} = 93 + 25.7 + 31.6 = 150.3^\circ\text{C}$$

30

2-35



$$\dot{q}_x = \dot{q}_0 e^{-ax} \quad \frac{d^2 T}{dx^2} = \frac{-\dot{q}_0 e^{-ax}}{k}$$

$$T = c_1 + c_2 x - \frac{\dot{q}_0}{a^2 k} e^{-ax}$$

Boundary conditions:

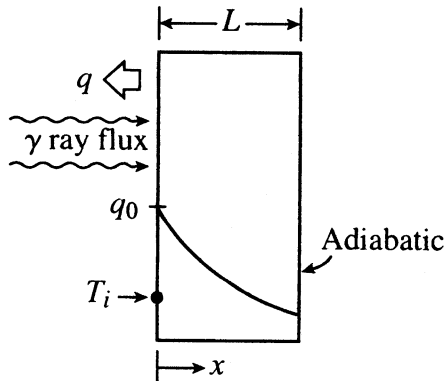
- (1) $T = T_i$ at $x = 0$
- (2) $T = T_0$ at $x = L$

$$c_1 = T_i + \frac{\dot{q}_0}{a^2 k} \quad c_2 = \frac{T_0 - T_i - \frac{\dot{q}_0}{a^2 k} (1 - e^{-aL})}{L}$$

$$T = T_i + \frac{\dot{q}_0}{a^2 k} + \frac{T_0 - T_i - \frac{\dot{q}_0}{a^2 k} (1 - e^{-aL})}{L} x + \frac{-\dot{q}_0}{a^2 k} e^{-ax}$$

Chapter 2

2-36



$$\dot{q} = \dot{q}_0 e^{-ax} \quad \frac{d^2 T}{dx^2} = \frac{-\dot{q}_0}{k} e^{-ax}$$

$$T = c_1 + c_2 x - \frac{\dot{q}_0}{a^2 k} e^{-ax}$$

Boundary conditions:

(1) at $x = L$ $\frac{dT}{dx} = 0$ (adiabatic)

(2) at $x = 0$ $T = T_i$

$$c_1 = T_i + \frac{\dot{q}_0}{a^2 k} \quad c_2 = -\frac{\dot{q}_0}{ak} e^{-aL}$$

$$T = T_i + \frac{\dot{q}_0}{a^2 k} - \frac{\dot{q}_0 e^{-aL}}{ak} x - \frac{\dot{q}_0}{a^2 k} e^{-ax}$$

2-37

$$T - T_w = c_1 \cos \sqrt{q_w \frac{\beta}{k}} x + c_2 \sin \sqrt{q_w \frac{\beta}{k}} x - \frac{1}{\beta}$$

$$T = T_1 \text{ at } x = \pm L \quad c_2 = 0$$

$$-kA \frac{\partial T}{\partial x} \Big|_{x=L} = hA(T_1 - T_\infty) \quad c_1 = \frac{T_1 - T_w + \frac{1}{\beta}}{\cos \sqrt{q_w \frac{\beta}{k}} L}$$

$$T = T_w + \frac{T_1 - T_w + \frac{1}{\beta}}{\cos \sqrt{q_w \frac{\beta}{k}} L} \cos \sqrt{q_w \frac{\beta}{k}} x - \frac{1}{\beta}$$

Solving for $\frac{\partial T}{\partial x} \Big|_{x=L}$ and substituting in above equation:

$$T_1 = \frac{1}{1-h} \left[T_w - \frac{1}{\beta} - \frac{hT_\infty}{k \sqrt{q_w \frac{\beta}{k}} \tan \sqrt{q_w \frac{\beta}{k}} L} \right]$$

2-38

$$\dot{q}AL = hPL(T_w - T_\infty)$$

$$(35.3 \times 10^6)(0.025)^2 = (4000)(4)(0.025)(T_w - 20)$$

$$T_w = 75.16^\circ\text{C}$$

2-39

$$\frac{d^2T}{dx^2} + \frac{\dot{q}_0 \cos(ax)}{k} = 0 \quad \frac{dT}{dx} = \frac{-\dot{q}_0}{ak} \sin(ax) + c_1$$

$$T = T_w \text{ at } x = \pm L \quad \therefore c_1 = 0 \quad T = \frac{\dot{q}_0}{a^2k} \cos(ax) + c_1x + c_2$$

$$T_w = \frac{\dot{q}_0}{a^2k} \cos(aL) + c_2 \quad T - T_w = \frac{\dot{q}_0}{a^2k} [\cos(ax) - \cos(aL)]$$

$$\frac{q}{A} = -2k \frac{dT}{dx} \Big|_{x=L} = -2k \frac{\dot{q}_0}{ak} [-\sin(aL)] = \frac{2k\dot{q}_0}{ak} \sin(aL)$$

Chapter 2

2-40

$$k = 0.0124 \frac{\text{W}}{\text{cm} \cdot ^\circ\text{C}} = 1.24 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\rho = 1.5 \times 10^{-3} \Omega \cdot \text{cm}$$

$$R = (1.5 \times 10^{-3}) \left(\frac{3}{1} \right) = 4.5 \times 10^{-3}$$

$$q = I^2 R = (50)^2 (4.5 \times 10^{-3}) = 11.25 \text{ W}$$

$$q = \frac{q}{V} = \frac{11.25}{3 \times 10^{-6}} = 3.75 \frac{\text{MW}}{\text{m}^3} \quad T = -\frac{\dot{q}}{2k} x^2 + c_1 x + c_2$$

$$L = 1.5 \text{ cm} = 0.015 \text{ m} \quad T = 300 \text{ at } x = -0.015$$

$$T = 100 \text{ at } x = +0.015$$

$$300 - 100 = c_1(-0.015 - 0.015) \quad c_1 = -6667$$

$$300 = \frac{(-3.75 \times 10^6)(0.015)^2}{(2)(1.24)} - (6667)(-0.015) + c_2 \quad c_2 = 540.2$$

$$\text{at } x = 0 \quad T = c_2 = 540.2^\circ\text{C}$$

2-41

$k = \text{constant}$ $\dot{q} = \dot{q}_0$ at $x = 0$ Assume one directional with no heat storage.

$$\frac{d^2 T}{dx^2} + \frac{\dot{q}}{k} = 0 \quad T - T_1 = (T_2 - T_1)(c_1 + c_2 x^2 + c_3 x^3)$$

$$T = T_1 + (T_2 - T_1)(c_1 + c_2 x^2 + c_3 x^3)$$

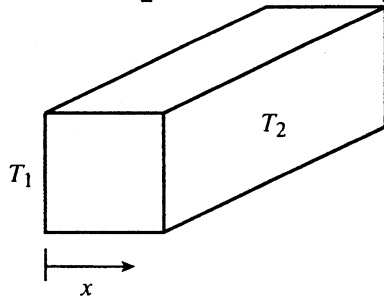
$$\frac{d^2 T}{dx^2} = (T_2 - T_1)(2c_2 + 3c_3 x)$$

$$T = T_1 \text{ at } x = 0 \quad T = T_2 \text{ at } x = L \quad \dot{q} = \dot{q}_0 \text{ at } x = 0$$

$$q = -k(T_2 - T_1)(2c_2 + 3c_3 x)$$

$$\text{so: } c_1 = 0 \quad c_2 = -\frac{\dot{q}_0}{2k(T_2 - T_1)} \quad c_3 = \frac{1}{L^3} + \frac{\dot{q}_0}{2kL(T_2 - T_1)}$$

$$\dot{q}_x = \dot{q}_0 - \left[\frac{3k}{L^3}(T_2 - T_1) + \frac{3\dot{q}_0}{2L} \right] x$$



2-42

$$k = 2.5 \quad h_1 = 75 \text{ (left)} \quad h_2 = 50 \text{ (right)}$$

$$T_{1\infty} = 50^\circ\text{C} \quad T_{2\infty} = 30^\circ\text{C}$$

$$T = -\frac{\dot{q}x^2}{2k} + c_1x + c_2$$

$$T = T_1 \text{ at } x = -0.04; \quad T = T_2 \text{ at } x = +0.04$$

$$\frac{\partial T}{\partial x} = -\frac{\dot{q}x}{k} + c_1$$

$$T = T_{\max} = 300 \text{ at } x = c_1 \frac{k}{\dot{q}} \quad (1)$$

$$h_1(T_{1\infty} - T_1) = -k \left. \frac{\partial T}{\partial x} \right|_{x=-0.04} \quad (2)$$

$$-k \left. \frac{\partial T}{\partial x} \right|_{x=+0.04} = h_2(T_2 - T_{2\infty}) \quad (3)$$

$$300 = -\frac{\dot{q}}{2k} \left[c_1 \frac{k}{\dot{q}} \right]^2 + c_1 \left[c_1 \frac{k}{\dot{q}} \right] + c_2 \quad (1)$$

$$75 \left[50 + \frac{\dot{q}}{2k} (0.04)^2 + c_1(0.04) - c_2 \right] = -k \left(\frac{+\dot{q}(0.04)}{2k} \right) \quad (2)$$

$$-k \left[\frac{-\dot{q}(0.04)}{2k} \right] = 50 \left[\frac{-\dot{q}(0.04)^2}{2k} + c_1(0.04) + c_2 - 30 \right] \quad (3)$$

3 Equations, 3 Unknowns, c_1 , c_2 , \dot{q}

Solve for $\dot{q} = 2.46 \times 10^5 \text{ W/m}^3$

2-43

$$d = 0.05; \quad L = 0.02; \quad \Delta T = 200^\circ\text{C}; \quad k = 204$$

$$\text{shim } 0.025 \text{ mm} = 0.001 \text{ inch}$$

$$\text{Table 2-3 ; } 1/h_c = 3.52 \times 10^{-4}$$

$$\text{Bars: } \Delta x/kA = (4)(0.02)/\pi(0.05)^2 = 10.19$$

$$\text{Joint: } 1/h_cA = 0.179$$

$$\Sigma R = (2)(10.19) + 0.179 = 20.559$$

$$\Delta T_{\text{joint}} = (200)(0.179/20.559) = 1.74^\circ\text{C}$$

2-44

Use solution from Prob. 2-28

$T = T_0$ at $x = 0$

$$T_0 = \frac{\dot{q}}{2k} L^2 + \frac{T_1 + T_2}{2} = \frac{(5 \times 10^5)(0.015)^2}{(2)(16)} + \frac{220 + 45}{2} = 136^\circ\text{C}$$

2-45

Use solution from Prob. 2-28

$$T_0 = \frac{\dot{q}}{2k} L^2 + \frac{T_1 + T_2}{2} = \frac{(500 \times 10^6)(0.005)^2}{(2)(20)} + \frac{100 + 200}{2} = 462.5^\circ\text{C}$$

Chapter 2

2-46

Behaves like half a plate having a thickness of 8 mm. Max Temp is at $x = 0$

$$T_0 = \frac{\dot{q}L^2}{2k} + T_w$$

$$L = 0.004 \text{ m} \quad T_w = 100^\circ\text{C}$$

$$T_0 = \frac{(200 \times 10^6)(0.004)}{(2)(25)} + 100 = 164^\circ\text{C}$$

2-47

$$\dot{q}\pi r^2 L = \frac{E^2}{R} = \frac{(10)^2 \pi (0.16)^2}{(7 \times 10^{-6})(30)}$$

$$\dot{q} = \frac{(10)^2 \pi (0.16)^2}{(7 \times 10^{-6})(30)(0.3)\pi (1.6 \times 10^{-3})^2} = 1587 \frac{\text{MW}}{\text{m}^3}$$

$$T_0 = \frac{\dot{q}r^2}{4k} + T_w = \frac{(1.587 \times 10^9)(1.6 \times 10^{-3})^2}{(4)(22.5)} + 93 = 138.1^\circ\text{C}$$

2-48

$$(200)^2 (0.099) = (5700)\pi (3 \times 10^{-3})(1)(T_w - 93)$$

$$T_w = 166.7^\circ\text{C} \quad T_0 = 16.6 + 166.7 = 183.3^\circ\text{C}$$

2-49

$$q = EI = \dot{q}\pi(r_0^2 - r_i^2)L = h2\pi rL(T_i - T_f)$$

$$\frac{d^2T}{dr^2} + \frac{1}{r} \frac{dT}{dr} + \frac{\dot{q}}{k} = 0 \quad T = \frac{-\dot{q}r}{4k} + c_1 \ln r + c_2$$

$$T = T_0 \text{ at } r = r_0 \quad \frac{dT}{dr} = 0 \text{ at } r = r_0 \quad T_0 = \frac{-\dot{q}r}{4k} + c_1 \ln r_0 + c_2$$

$$\frac{dT}{dr} = 0 = \frac{-\dot{q}r}{2k} + \frac{c_1}{r_0} \quad c_1 = \frac{\dot{q}r_0^2}{2k} \quad T_i = \frac{-\dot{q}r}{4k} + \frac{\dot{q}r_0^2}{2k} \ln r_1 + c_2$$

$$T_0 = \frac{-\dot{q}r_0^2}{4k} + \frac{\dot{q}r_0^2}{2k} \ln r_0 + c_2 \quad T_i = T_0 - \frac{\dot{q}}{4k}(r_1^2 - r_0^2) + \frac{\dot{q}r_0^2}{2k} \ln\left(\frac{r_1}{r_0}\right) \quad (\text{a})$$

$$\dot{q} = \frac{EI}{\pi(r_0^2 - r_i^2)L} \quad (\text{b})$$

Insert (a) and (b) in $EI = 2\pi rLh(T_i - T_f)$ and solve for h .

2-50

\dot{q} uniform $T = T_w$ at $r = R$ steady state, T varies only with r .

$$\frac{1}{r} \frac{\partial^2(rT)}{\partial r^2} + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial T}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 T}{\partial \theta^2} + \frac{\dot{q}}{k} = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

this reduces to:

$$\frac{1}{r} \frac{\partial^2(rT)}{\partial r^2} + \frac{\dot{q}}{k} = 0 \quad \frac{\partial^2(rT)}{\partial r^2} = \frac{-\dot{q}r}{k} \quad \text{Integrating } T = \frac{-\dot{q}r^2}{6k} + c_1 + \frac{c_2}{r}$$

$$\text{Boundary conditions: } \dot{q} \frac{4}{3} \pi R^3 = -k4\pi R^2 \frac{dT}{dr} \Big|_{r=R}$$

$$(1) \quad \frac{dT}{dr} = -\frac{\dot{q}r}{3k} \quad (2) \quad T = T_w \text{ at } r = R$$

$$(3) \quad \frac{dT}{dr} \Big|_{r=R} = 0 \text{ then } c_1 = T_w + \frac{\dot{q}R^2}{6k} \quad c_2 = 0$$

$$T - T_w = \frac{\dot{q}}{6k} (R^2 - r^2)$$

2-51

From Prob. 2-47⁵⁰

$$T - T_w = \frac{\dot{q}}{6k} (R^2 - r^2)$$

$$T_0 - T_w = \frac{(1 \times 10^6)(0.02)^2}{(6)(16)} = 4.17^\circ\text{C}$$

$$q = \dot{q}V = \dot{q} \frac{4}{3} \pi R^3 = h4\pi r^2 (T_w - T_\infty)$$

$$T_w - T_\infty = \frac{(1 \times 10^6)(0.02)}{(3)(15)} = 444.4^\circ\text{C}$$

$$T_0 - T_\infty = 444.4 + 4.17 = 448.6^\circ\text{C}$$

$$T_0 = 448.6 + 20 = 468.6^\circ\text{C}$$

2-52

$$\frac{R}{L} = \frac{\rho}{\pi r_0^2} = \frac{2.9 \times 10^{-6}}{\pi(1.5)^2} = 4.1 \times 10^{-7} \frac{\Omega}{\text{cm}} = 4.1 \times 10^{-5} \frac{\Omega}{\text{m}}$$

$$\dot{q} = \frac{I^2 R}{V} = \frac{(230)^2 (4.1 \times 10^{-5})}{\pi(0.015)^2} = 3.07 \times 10^3 \frac{\text{W}}{\text{m}^3}$$

$$T_0 = \frac{(3.07 \times 10^3)(0.015)^2}{(4)(190)} + 180 = 180.0009^\circ\text{C}$$

Chapter 2

2-53

$$\dot{q} = a + br \quad \frac{d}{dr} \left(r \frac{dT}{dr} \right) = -\frac{\dot{q}r}{k} = -\frac{ar + br^2}{k}$$

$$r \frac{dT}{dr} = -\frac{1}{k} \left(\frac{ar^2}{2} + \frac{br^3}{3} \right) + c_1 \quad T = -\frac{1}{k} \left(\frac{ar^2}{4} + \frac{br^3}{9} \right) + c_1 \ln r + c_2$$

$$\frac{dT}{dr} = -\frac{1}{k} \left(\frac{ar}{2} + \frac{br^2}{3} \right) + \frac{c_1}{r}$$

$$T = T_i \text{ at } r = r_i \quad T = T_0 \text{ at } r = r_0$$

Solving for constants gives:

$$c_1 = \frac{T_i - T_0 - \frac{1}{k} \left[\frac{a(r_0^2 - r_i^2)}{4} + \frac{b(r_0^3 - r_i^3)}{9} \right]}{\ln \left(\frac{r_i}{r_0} \right)}$$

$$c_2 = T_0 + \frac{1}{k} \left(\frac{ar_0^2}{4} + \frac{br_0^3}{9} \right) + \frac{T_i - T_0 - \frac{1}{k} \left[\frac{a(r_0^2 - r_i^2)}{4} + \frac{b(r_0^3 - r_i^3)}{9} \right]}{\ln r_0}$$

$$\text{Also } \dot{q} = \dot{q}_i \text{ at } r = r_i = a + br_i$$

2-54

$$d = 2 \text{ mm} \quad T_\infty = 100^\circ\text{C} \quad h = 5000 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$T_0 = 150^\circ\text{C} \quad \rho_e = 1.67 \mu\Omega \cdot \text{cm} \quad k = 386 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$T_0 - T_w = \frac{\dot{q}R^2}{4k}$$

$$q = \dot{q}(\pi R^2)L = h(2\pi RL)(T_w - T_\infty)$$

$$T_w - T_\infty = \frac{\dot{q}R^2}{2h}$$

$$T_0 - T_\infty = \frac{\dot{q}R^2}{4k} + \frac{\dot{q}R}{2h}$$

$$150 - 100 = \dot{q} \left[\frac{0.001^2}{(4)(386)} + \frac{0.001}{(2)(5000)} \right] \quad \dot{q} = 4.97 \times 10^8 \frac{\text{W}}{\text{m}^3}$$

$$q = I^2 \rho_e \frac{L}{A} = \dot{q}AL$$

$$I^2 = \frac{\dot{q}A^2}{\rho_e} = \frac{(4.97 \times 10^8)(\pi)^2(0.001)^4}{1.67 \times 10^{-8}}$$

$$I = 542 \text{ amp}$$

2-55

$$r_i = 0.0125 \text{ m} \quad r_0 = 0.0129 \text{ m}$$

Assume inner surface is insulated

$$\frac{dT}{dr} = -\frac{\dot{q}r}{2k} + \frac{c_1}{r} = 0 \text{ at } r = r_i$$

$$c_1 = \frac{\dot{q}r_i^2}{2k} \quad (\text{a})$$

$$T = \frac{-\dot{q}r^2}{4k} + c_1 \ln r + c_2 \quad T_i = \frac{-\dot{q}r_i^2}{4k} c_1 \ln r_i + c_2$$

$$T_0 = \frac{-\dot{q}r_0^2}{4k} c_1 \ln r_0 + c_2$$

$$T_i - T_0 = \frac{-\dot{q}}{4k} (r_0^2 - r_i^2) + c_1 \ln \left(\frac{r_i}{r_0} \right) \quad (\text{b})$$

Heat Transfer is:

$$q = \dot{q}V = \dot{q}\pi(r_0^2 - r_i^2) = h\pi(2r_0)(T_0 - T_\infty) \quad (\text{c})$$

Inserting (a) in (b) gives

$$T_i - T_0 = \frac{q}{4k} (r_0^2 - r_i^2) + \frac{\dot{q}r_i^2}{2k} \ln \left(\frac{r_i}{r_0} \right) \quad (\text{d})$$

$$\text{We take: } T_i = 250^\circ\text{C} \quad h = 100 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad T_\infty = 40^\circ\text{C} \quad k = 24 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

Inserting the numerical values in Equations (c) and (d) and solving gives:

$$\dot{q} = 53.26 \frac{\text{MW}}{\text{m}^3}$$

$$T_0 = 249.76^\circ\text{C}$$

2-56

$$k = 43 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$U_i = \frac{1}{\frac{1}{500} + \frac{\ln(1.45/1.25)\pi(0.025)}{(2\pi)(43)} + \frac{0.025}{0.029} \left(\frac{1}{12} \right)} = \frac{1}{2 \times 10^{-3} + 4.31 \times 10^{-5} + 71.84 \times 10^{-3}}$$

$$= 13.54 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

2-57

$$r_0 = \frac{k}{h} = \frac{0.18}{12} = 0.015 \text{ m} = 1.5 \text{ cm}$$

$$\text{(a) } r_0 = 1.25 + 0.05 = 1.3 \text{ cm} \quad \text{Increased}$$

$$\text{(b) } r_0 = 1.25 + 1.0 = 2.25 \text{ cm} \quad \text{Decreased}$$

Chapter 2

2-58

$$U = \frac{1}{R} = \frac{1}{3.114 \times 10^{-2}} = 32.11 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

2-59

$$A = 130.4 \text{ m}^2$$
$$U = \frac{q}{A\Delta T} = \frac{44,000}{(130.4)(260 - 38)} = 1.52 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

2-60

$$\text{For } L = 1 \text{ m} \quad \frac{1}{h_i A_i} = \frac{1}{(65)\pi(0.025)} = 0.1959$$

$$\frac{\ln(r_0/r_i)}{2\pi k} = \frac{\ln(2.58/2.5)}{2\pi(18)} = 2.79 \times 10^{-4}$$

$$\frac{1}{h_o A_o} = \frac{1}{(6.5)\pi(0.0258)} = 1.898$$

$$UA = \frac{1}{\sum R} = 2.094$$

$$\frac{q}{L} = (2.094)(120 - 15) = 219.9 \frac{\text{W}}{\text{m}}$$

2-61

$$A = 1 \text{ m}^2 \quad R_{\text{glass}} = \frac{\Delta x}{k} = \frac{0.005}{0.78} = 6.41 \times 10^{-3}$$

$$R_{\text{air}} = \frac{\Delta x}{k} = \frac{0.004}{0.026} = 0.1538$$

$$R_{\text{conv}_1} = \frac{1}{h} = \frac{1}{12} = 0.0833$$

$$R_{\text{conv}_2} = \frac{1}{50} = 0.02$$

$$U = \frac{1}{(2)(6.41 \times 10^{-3}) + 0.1538 + 0.0833 + 0.02} = \frac{1}{0.2699} = 3.705 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$R = 0.2699$$

$$\text{single glass plate: } R = 6.41 \times 10^{-3} + 0.0833 + 0.02 = 0.1097$$

$$U = \frac{1}{R} = 9.11 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

2-62

$$R_{Cu} = \frac{0.001}{386} = 2.59 \times 10^{-6} \quad \Delta T_{Cu} = (52)(2.59 \times 10^{-6}) = 1.35 \times 10^{-4} \text{°C}$$

$$R_{St} = \frac{0.004}{43} = 9.3 \times 10^{-5} \quad \Delta T_{St} = (52)(9.3 \times 10^{-5}) = 4.84 \times 10^{-3} \text{°C}$$

$$R_{As} = \frac{0.01}{0.166} = 0.0602 \quad \Delta T_{As} = (52)(0.0602) = 3.13 \text{°C}$$

$$R_F = \frac{0.1}{0.038} = 2.632 \quad \Delta T_F = (52)(2.632) = 136.9 \text{°C}$$

$$\sum R = 2.692 \quad U = \frac{1}{R} = 0.371 \frac{\text{W}}{\text{m}^2 \cdot \text{°C}}$$

$$q = U\Delta T = (0.371)(150 - 10) = 52 \frac{\text{W}}{\text{m}^2}$$

Inside of copper = 150°C

2-63

$$r_1 = 0.015 \quad L_c = 0.02 + 0.00035 = 0.02035$$

$$r_{2c} = 0.03535 \quad r_{2c}/r_1 = 2.357$$

$$L_c^{3/2} \left[\frac{h}{kA_m} \right]^{1/2} = (0.02035)^{3/2} \left[\frac{524}{(386)(0.0007)(0.02035)} \right]^{1/2} = 0.896$$

$$\eta_f = 0.55$$

$$q = \eta_f h A \theta_0 = (0.55)\pi(0.03535^2 - 0.015^2)(2)(524)(200 - 100) = 186 \text{ W}$$

Chapter 2

2-64

The general solution of eq. 2-19 (b) is:

$$\theta = T - T_{\infty} = c_1 e^{-mx} + c_2 e^{mx} \quad (1)$$

boundary conditions:

$$(1) \quad \text{at } x = 0 \quad \theta = \theta_1 = T_1 - T_{\infty}$$

$$(2) \quad \text{at } x = L \quad \theta = \theta_2 = T_2 - T_{\infty}$$

from:

$$(1) \quad \theta_1 = c_1 + c_2 \quad c_1 = \theta_1 - c_2$$

$$(2) \quad \theta_2 = c_1 e^{-mL} + c_2 e^{mL}$$

$$\theta_2 = (\theta_1 - c_2) e^{-mL} + c_2 e^{mL} = \theta_1 e^{-mL} - c_2 (e^{-mL} - e^{mL})$$

$$c_2 = \frac{\theta_2 - \theta_1 e^{-mL}}{e^{mL} - e^{-mL}} \quad (2)$$

$$c_1 = \theta_1 - c_2 = \theta_1 - \frac{\theta_2 - \theta_1 e^{-mL}}{e^{mL} - e^{-mL}}$$

$$c_1 = \frac{\theta_2 - \theta_1 e^{mL}}{e^{-mL} - e^{mL}} \quad (3)$$

Then eq. (1) becomes

$$\theta = \frac{\theta_2 - \theta_1 e^{mL}}{e^{-mL} - e^{mL}} e^{-mx} + \frac{\theta_2 - \theta_1 e^{-mL}}{e^{mL} - e^{-mL}} e^{mx}$$

$$\theta = \frac{e^{-mx}(\theta_2 - \theta_1 e^{mL}) + e^{mx}(\theta_1 e^{-mL} - \theta_2)}{e^{-mL} - e^{mL}}$$

Part heat lost by rod:

$$q = -kA \left. \frac{d\theta}{dx} \right|_{x=0} + kA \left. \frac{d\theta}{dx} \right|_{x=L}$$

$$\frac{d\theta}{dx} = m \left[\frac{-e^{-mx}(\theta_2 - \theta_1 e^{mL}) + e^{mx}(\theta_1 e^{-mL} - \theta_2)}{e^{-mL} - e^{mL}} \right]$$

$$q = \frac{kAm[-e^{-mL}(\theta_2 - \theta_1 e^{mL}) + e^{mL}(\theta_1 e^{-mL} - \theta_2)]}{e^{-mL} - e^{mL}}$$

$$+ \frac{kAm[-(\theta_2 - \theta_1 e^{mL}) + (\theta_1 e^{-mL} - \theta_2)]}{e^{-mL} - e^{mL}}$$

$$q = \frac{kAm[(\theta_2 - \theta_1 e^{mL})(1 - e^{-mL}) + (\theta_2 - \theta_1 e^{-mL})(1 - e^{mL})]}{e^{-mL} - e^{mL}}$$

2-64

Part A:

$$\dot{q}A = -kA \frac{d^2T}{dx^2} + hP(T - T_\infty)$$

$$\frac{d^2T}{dx^2} - \frac{hP}{kA}(T - T_\infty) + \frac{\dot{q}}{k} = 0$$

let $\theta = T - T_\infty$

$$\left(D^2 - \frac{hP}{kA}\right)\theta = -\frac{\dot{q}}{k}$$

$$\theta = c_1 e^{\sqrt{hP/kA}x} + c_2 e^{-\sqrt{hP/kA}x} + \frac{\dot{q}A}{hP}$$

$$\text{let } \sqrt{\frac{hP}{kA}} = m$$

$$\theta = \theta_0 \text{ at } x = 0 \quad \therefore c_1 = \theta_0 - \frac{\dot{q}A}{hP} - c_2$$

$$-kA \frac{dT}{dx} \Big|_{x=L} = hA(T - T_\infty) \Big|_{x=L} = hA\theta_L$$

$$\theta = \frac{\left[e^{-mL} \left(\theta_0 - \frac{\dot{q}A}{hP} \right) - \frac{h\theta_L}{km} \right] e^{mx}}{e^{mL} + e^{-mL}} + \frac{\left[e^{mL} \left(\theta_0 - \frac{\dot{q}A}{hP} \right) + \frac{h\theta_L}{km} \right] e^{-mx}}{e^{mL} + e^{-mL}} + \frac{\dot{q}A}{hP}$$

Part B:

$$q = \int_0^L [hP(T - T_\infty)] dx + hA\theta_L$$

$$q = \frac{hP}{m} \left\{ -\frac{h\theta_L}{kL} + \frac{\left(\theta_0 - \frac{\dot{q}A}{hP} \right) (e^{mL} - e^{-mL}) + \frac{2h\theta_L}{km}}{e^{mL} + e^{-mL}} \right\} + \dot{q}AL + hA\theta_L$$

Part C:

$$-kA \frac{dT}{dx} \Big|_{x=0} = 0 = q_0$$

$$0 = [c_1 m e^{mx} - c_2 m e^{-mx}]_{x=0}$$

$$\therefore c_1 = c_2$$

$$2c_1 = \theta_0 - \frac{\dot{q}A}{hP}$$

$$\dot{q} = \frac{hP}{A} \left[\theta_0 + \frac{2h\theta_L}{km(e^{mL} - e^{-mL})} \right]$$

Chapter 2

2-66

$$\frac{d^2\theta}{dx^2} - \frac{hP}{kA}\theta = 0 \text{ let } m = \sqrt{\frac{hP}{kA}}$$

$$T_\infty = 38 \quad d = 12.5 \text{ mm} \quad L = 30 \text{ cm} \quad h = 17$$

$$\theta = c_1 e^{mx} + c_2 e^{-mx} \text{ at } x = 0 \quad \theta = 200 - 38 = 162 \quad k = 386$$

$$P = \pi d \quad A = \frac{\pi d^2}{4} \quad x = 0.3 \quad \theta = 93 - 38 = 55$$

$$m = \left[\frac{(17)\pi(0.0125)(4)}{(386)\pi(0.0125)^2} \right]^{1/2} = 3.754 \quad 162 = c_1 + c_2$$

$$55 = 3.084c_1 + 0.324c_2 \quad c_1 = 0.91 \quad c_2 = 161.09$$

$$\theta = 0.91e^{mx} + 161.09e^{-mx}$$

$$\begin{aligned} q \int_0^L hP\theta dx &= hP \frac{1}{m} [0.91e^{mx} - 161.09e^{-mx}]_0^L = \sqrt{hPkA} [0.91e^{mx} - 161.09e^{-mx}]_0^{0.3} \\ &= [(17)\pi(0.0125)(386)\pi(0.0125)^2]^{1/2} \times [0.91e^{mx} - 161.09e^{-mx}]_0^{0.3} \\ &= 122.7 \text{ W} \end{aligned}$$

2-68

$$k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad L_c = L + \frac{d}{4} = 12 + \frac{2}{4} = 12.5 \quad T_0 = 250^\circ\text{C} \quad T_\infty = 15^\circ\text{C}$$

$$h = 12 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad A = \frac{\pi d^2}{4} \quad P = \pi d$$

$$m = \sqrt{\frac{hP}{kA}} = \left[\frac{(12)\pi(0.02)(4)}{(204)\pi(0.02)^2} \right]^{1/2} = 3.43$$

$$mL_c = (3.43)(0.125) = 0.429 \quad q = \sqrt{hPkA}\theta_0 \tanh(mL_c)$$

$$q = \left[(12)\pi(0.02)(204)\pi \frac{(0.02)^2}{4} \right]^{1/2} (250 - 15) \tanh(0.429) = 20.89 \text{ W}$$

2-69

$$q = \int_0^\infty hP(T - T_\infty) dx = \int_0^\infty hP\theta dx = hP \int_0^\infty e^{-mx} dx = \frac{hP\theta_0}{-m} [e^{-mx}]_0^\infty = \sqrt{hPkA}\theta_0$$

$$= \frac{hP\theta_0}{-\sqrt{\frac{hP}{kA}}} \left[e^{-\sqrt{\frac{hP}{kA}}L} - 1 \right]$$

$$q = \frac{hP\theta_0}{\sqrt{\frac{hP}{kA}}} = \sqrt{hPkA}\theta_0$$

2-70

$\theta = c_1 e^{-mx} + c_2 e^{mx}$ In case II the end of the fin is insulated.

$\left. \frac{dT}{dx} \right|_{x=L} = 0$ the boundary conditions are $\theta = \theta_0$ at $x = 0$

$\frac{d\theta}{dx} = 0$ at $x = L$ then $\theta = \theta_0 \frac{\cosh[m(L-x)]}{\cosh(mL)}$

$dq_{\text{conv}} = hP dx(T - T_\infty)$ or $hP dx \theta$

$$q_{\text{conv}} = \int_0^L hP dx = \int_0^L \frac{hP \theta \cosh[m(L-x)] dx}{\cosh(mL)}$$

$$q_{\text{conv}} = \frac{hP \theta_0}{\cosh(mL)} \frac{1}{m} [\sinh(m(L-x))]_0^L = \sqrt{hPkA} \theta_0 \tanh(mL)$$

2-71

$$q = \sqrt{hPkA} \theta_0 = \left[\frac{(20)\pi(0.0005)(372)\pi(0.0005)^2}{4} \right]^{1/2} (120 - 20) = 0.152 \text{ W}$$

2-72

$$q = \sqrt{hPkA} \theta_0 = \left[\frac{(3.5)\pi(0.025)(372)\pi(0.025)^2}{4} \right]^{1/2} (90 - 40) = 11.2 \text{ W}$$

2-73

$T_0 = 150^\circ\text{C}$ $T_\infty = 15^\circ\text{C}$ $r_1 = 1.35 \text{ cm}$ $L = 6.0 \text{ mm}$ $t = 1.5 \text{ mm}$

$h = 20 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$ $k = 210 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$

$$L_c = L + \frac{t}{2} = 6.0 + 0.75 = 6.75 \text{ mm}$$

$$r_{2e} = r_1 + L_c = 1.35 + 0.675 = 2.025 \text{ cm} \quad \frac{r_{2e}}{r_1} = 1.50$$

$$A_m = t(r_{2e} - r_1) = (0.0015)(0.00675) = 1.012 \times 10^{-5} \text{ m}^2$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.00675)^{3/2} \left[\frac{20}{(210)(1.012 \times 10^{-5})} \right]^{1/2} = 0.0538$$

From Fig. 2-11 $\eta_f = 97\%$

$$q_{\text{max}} = 2h\pi(r_{2e}^2 - r_1^2)(T_0 - T_\infty) = 3.86 \text{ W}$$

$$q = (0.97)(3.86) = 3.75 \text{ W}$$

Chapter 2

2-74

$$L_c = 23 + 1 = 24 \text{ mm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.024)^{3/2} \left[\frac{25}{(14)(0.002)(0.024)} \right]^{1/2} = 0.717$$

$$\eta_f = 0.77$$

$$q = \eta_f h A \theta_0 = (0.77)(25)(0.024)(2)(220 - 23) = 182 \text{ W/m}$$

2-75

$$L_c = 3 + 0.1 = 3.1 \text{ cm}$$

$$r_{2c} = 1.5 + 3.1 = 4.6 \text{ cm}$$

$$r_1 = 1.5 \quad \frac{r_{2c}}{r_1} = 3.067$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.031)^{3/2} \left[\frac{68}{(55)(0.002)(0.031)} \right]^{1/2} = 0.77$$

$$\eta_f = 0.58$$

$$q = \eta_f h A \theta_0 = (0.58)(68)(2\pi)[0.046^2 - 0.015^2](100 - 20) = 37.49 \text{ W}$$

2-76

η = total efficiency A_f = surface area of all fins η_f = fin efficiency

A = total heat transfer area including fins and exposed tube or other surface.

T_0 = base temp T_∞ = environment temp

$$q_{\text{act}} = h(A - A_f)(T_0 - T_\infty) + \eta_f A_f h(T_0 - T_\infty)$$

$$q_{\text{ideal}} = hA(T_0 - T_\infty)$$

$$\eta_t = \frac{q_{\text{act}}}{q_{\text{ideal}}} = \frac{A - A_c + A_f \eta_f}{A} = 1 - \frac{A_f}{A}(1 - \eta_f)$$

2-77

$$l_0 = 460 \quad t = 6.4 \text{ mm} \quad L = 2.5 \text{ cm} \quad T_\infty = 93^\circ\text{C} \quad h = 28$$

$$k = 16.3 \quad A_m = L \left(\frac{t}{2} \right) = 8 \times 10^{-5} \text{ m}^2 \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.579$$

$$\eta_f = 0.85$$

$$q = (0.85)(28)(1)(2)(0.025)(460 - 93) = 437 \text{ W}$$

2-78

$$T_0 = 200^\circ\text{C} \quad T_\infty = 93^\circ\text{C} \quad L = 12.5 \text{ mm} \quad t = 0.8 \text{ mm} \quad r_1 = 1.25 \text{ cm}$$

$$k = 204 \quad L_c = 12.9 \text{ mm} \quad h = 110 \quad r_{2c} = 2.54 \quad \frac{r_{2c}}{r_1} = 2.03$$

$$A_m = 1.03 \times 10^{-5} \text{ m}^2 \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.335 \quad \eta_f = 0.87$$

$$\text{No. of Fins} = \frac{1.0}{0.0095} = 105.3$$

$$\text{Tube surface area} = (105.3)\pi(0.025)(9.5 - 0.8)(10^{-3}) = 0.0719 \text{ m}^2$$

$$\text{Tube heat transfer} = (110)(0.0719)(200 - 93) = 846.6 \text{ W}$$

$$\frac{q}{\text{fin}} = (0.87)(2)\pi(110)(0.0254^2 - 0.0125^2)(200 - 93) = 31.46 \text{ W}$$

$$\text{Total fin heat transfer} = (31.46)(105.3) = 3312 \text{ W}$$

$$\text{Total heat transfer} = 846.6 + 3312 = 4159 \text{ W}$$

2-79

$$r_1 = 1.0 \text{ cm} \quad L = 5 \text{ mm} \quad t = 2.5 \text{ mm} \quad h = 25 \quad T_0 = 260^\circ\text{C}$$

$$T_\infty = 93^\circ\text{C} \quad k = 43 \quad L_c = 5 + 1.25 = 6.25 \text{ mm} \quad r_{2c} = 1.625 \text{ cm}$$

$$\frac{r_{2c}}{r_1} = 1.625 \quad A_m = (0.0025)(0.00625) = 1.56 \times 10^{-5} \text{ m}^2$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.00625^{3/2} \left[\frac{25}{(43)(1.56 \times 10^{-5})} \right]^{1/2} = 0.095 \quad \eta_f = 97\%$$

$$q = (0.97)(25)(2)\pi(0.01625^2 - 0.01^2)(260 - 93) = 4.17 \text{ W}$$

2-80

$$k = 43 \quad t = 2 \text{ cm} \quad h = 20 \quad L_c = 15 \text{ cm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.723 \quad \eta_f = 0.75$$

$$q = (0.75)(20)(2)(0.15)(200 - 15) = 833 \text{ W/m depth}$$

Chapter 2

2-81

$$\begin{aligned}
 t &= 1.6 \text{ mm} & r_1 &= 1.25 \text{ cm} & L &= 12.5 \text{ mm} & T_0 &= 200^\circ\text{C} \\
 T_\infty &= 20^\circ\text{C} & h &= 60 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} & k &= 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} & L_c &= 13.3 \text{ mm} \\
 r_{2c} &= 2.58 \text{ cm} & \frac{r_{2c}}{r_1} &= 2.064 & A_m &= (0.0016)(0.0133) = 2.128 \times 10^{-5} \text{ m}^2
 \end{aligned}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.18 \quad \eta_f = 95\%$$

$$q = (0.95)(60)(2)\pi(0.0258^2 - 0.0125^2)(200 - 20) = 32.84 \text{ W}$$

2-83

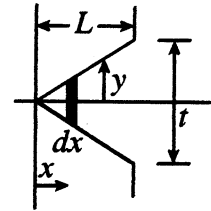
$$A = 2y = \frac{tx}{L} \quad y = \frac{t}{2L}x = \frac{tx}{2L}$$

$$-kA \frac{dT}{dx} = hPdx(T - T_\infty) - \left[kA \frac{dT}{dx} + \frac{d}{dx} \left(kA \frac{dT}{dx} \right) dx \right]$$

$$\frac{d}{dx} \left(kA \frac{dT}{dx} \right) - hP(T - T_\infty) = 0 \quad \theta = T - T_\infty$$

$$\frac{ktx}{L} \frac{d^2\theta}{dx^2} + \frac{kt}{L} \frac{d\theta}{dx} - hP\theta = 0$$

$$x \frac{d^2\theta}{dx^2} + \frac{d\theta}{dx} - \frac{hPL}{kt} \theta = 0$$



2-84

$$\begin{aligned}
 r_1 &= 0.05 & r_2 &= 0.2 & L &= 0.15 \\
 L_c &= 0.1 + 0.001 = 0.101 & r_{2c} &= 0.201
 \end{aligned}$$

$$\frac{r_{2c}}{r_1} = 4$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.101)^{3/2} \left[\frac{60}{(120)(0.101)(0.002)} \right]^{1/2} = 2.388$$

$$\eta_f = 0.16$$

$$q = \eta_f h A \theta_0 = (0.16)(60)\pi(0.201^2 - 0.05^2)(2)(120 - 23) = 222 \text{ W}$$

2-85

$$k = 16 \quad h = 40 \quad T_0 = 250^\circ\text{C} \quad T_\infty = 90^\circ\text{C}$$

$$P = (4)(0.0125) = 0.05 \text{ m} \quad A = (0.0125)^2 = 1.565 \times 10^{-4} \text{ m}^2$$

$$q = \sqrt{hPkA} \theta_0 = [(40)(0.05)(16)(1.565 \times 10^{-4})]^{1/2} (250 - 90) = 11.31 \text{ W}$$

2-86

$$t = 2.1 \text{ mm} \quad L = 17 \text{ mm} \quad h = 75 \quad k = 164 \quad T_0 = 100^\circ\text{C}$$

$$T_\infty = 30^\circ\text{C} \quad L_c = 17 + 1.05 = 18.05 \text{ mm}$$

$$A_m = (0.0021)(0.01805) = 3.79 \times 10^{-5} \text{ m}^2$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.01805)^{3/2} \left[\frac{75}{(164)(3.79 \times 10^{-5})} \right] = 0.266 \quad \eta_f = 94\%$$

$$q = (0.94)(75)(2)(0.01805)(100 - 30) = 178.2 \text{ W}$$

2-87

$$L_c = 0.0574 \text{ ft} \quad r_{2c} = 2.688 \text{ in.}$$

$$A_m = (0.125)(0.688) = 0.081 \text{ in}^2 = 5.97 \times 10^{-4} \text{ ft}^2$$

$$\frac{r_{2c}}{r_1} = 1.34 \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.329 \quad \eta_f = 87\%$$

$$q_{\max} = 2h\pi(r_{2c}^2 - r_1^2)(450 - 100) = 591 \frac{\text{Btu}}{\text{hr}}$$

$$q = (0.87)(591) = 514 \frac{\text{Btu}}{\text{hr}}$$

2-88

Calculate heat lost (not temp. at tip)

$$d = 1.5 \text{ mm} \quad k = 19 \quad L = 12 \text{ mm} \quad T_0 = 45^\circ\text{C} \quad T_\infty = 20^\circ\text{C}$$

$$h = 500$$

Use insulated tip solution

$$L_c = L + \frac{d}{4} = 12 + 0.375 = 12.375 \text{ mm}$$

$$m = \left(\frac{hP}{kA} \right)^{1/2} = \left[\frac{(500)\pi(0.0015)}{(19)\pi(0.0015)^2(4)} \right]^{1/2} = 264.9$$

$$mL_c = (0.012375)(264.9) = 3.278$$

$$q = \sqrt{hPkA}\theta_0 \tanh(mL)$$

$$= \left[(500)\pi(0.0015)(19)\pi(0.0015) \left(\frac{2}{4} \right) \right]^{1/2} (45 - 20) \tanh(3.278) = 0.177 \text{ W}$$

$$\text{For } h = 200 \quad mL_c = 2.073 \quad \tanh(mL_c) = 0.969$$

$$q = \left(\frac{200}{500} \right)^{1/2} (0.177) \left(\frac{0.969}{0.997} \right) = 0.109 \text{ W}$$

$$\text{For } h = 1500 \quad mL_c = 5.677 \quad \tanh(mL_c) = 1.0$$

$$q = \left(\frac{1500}{500} \right)^{1/2} (0.177) \left(\frac{1.0}{0.997} \right) = 0.307 \text{ W}$$

2-89

$$k = 204; \quad T_{\infty} = 20^{\circ}\text{C}; \quad T_0 = 70^{\circ}\text{C}$$

$$L = 25 \text{ mm}$$

$$h = 13.2; \quad d = 2 \text{ mm}; \quad N = 225 \text{ pins}$$

$$m = [(13.2)(4)/(204)(0.002)]^{1/2} = 11.38$$

$$L_c = 0.025 + 0.002/4 = 0.0255$$

$$q/\text{pin} = (hPkA)^{1/2} \theta_0 \tanh(mL_c)$$

$$= [(13.2)\pi(0.002)(204)\pi(0.001)^2]^{1/2} (70 - 20) \tanh[(11.38)(0.0255)]$$

$$= 0.1029 \text{ W/ pin fin}$$

$$\text{total} = (225)(0.1029) = 23.15 \text{ W}$$

2-90

$$k = 204; N = 8; T_0 = 100^\circ\text{C}; T_\infty = 30^\circ\text{C}; h = 15; L = 0.02; t = 0.002$$

$$P = (2)(0.15 + 0.002) = 0.304$$

$$A = (0.002)(0.15) = 0.0003$$

$$m = [(15)(0.304)/(294)(0.0003)]^{1/2} = 8.632$$

$$L_c = 0.02 + 0.001 = 0.021$$

$$\begin{aligned} q/\text{fin} &= (hPkA)^{1/2} \theta_0 \tanh(mL_c) \\ &= [(15)(0.304)(204)(0.0003)]^{1/2} (100 - 30) \tanh[(8.632)(0.021)] \\ &= 6.62 \text{ W/fin} \end{aligned}$$

$$\text{Total} = (8)(6.62) = 53 \text{ W}$$

2-91

$$\text{Surface area from Prob. 2-90} = (8)(0.304)(0.02) = 0.04864$$

$$\text{Area per circular fin} = (2)\pi(0.0325^2 - 0.0125^2) = 0.00565$$

$$\text{Number of circular fins} = 0.04865/0.00565 = 8.6 \text{ Round off to 9 fins}$$

$$r_1 = 0.0125; r_2 = 0.0325; L_c = 0.02 + 0.001 = 0.021$$

$$r_{2c} = 0.0335; r_{2c}/r_1 = 2.68$$

$$L_c^{3/2} (h/kA_m)^{1/2} = 0.1273$$

$$\eta_f = 0.98$$

For 9 fins;

$$\begin{aligned} q &= (9)(0.98)((15)\pi(0.0335^2 - 0.0125^2)(100 - 30)(2) \\ &= 56.2 \text{ W} \end{aligned}$$

Chapter 2

2-92

$$\theta = c_1 e^{-mx} + c_2 e^{+mx}$$

$$\theta = 100 - 20 = 80 \text{ at } x = 0$$

$$\theta = 35 - 20 = 15 \text{ at } x = 0.06$$

$$m = \sqrt{\frac{hP}{kA}}$$

$$80 = c_1 + c_2 \quad (1)$$

$$15 = c_1 e^{-m(0.06)} + c_2 e^{+m(0.06)} \quad (2)$$

$$-k[c_1 e^{-m(0.06)}(-m) + c_2 e^{+m(0.06)}(+m)] = h(15) \quad (3)$$

$$m = \left[\frac{h\pi(0.02)(4)}{k(0.02)^2} \right]^{1/2} \quad (4)$$

4 Equations, 4 unknowns, c_1 , c_2 , m , h .

Solve, and then evaluate q from Eq. (2-37) or (2-36) using L_c

2-93

$$L = 2.5 \text{ cm} \quad t = 1.5 \text{ mm} \quad k = 50 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad T_\infty = 20^\circ\text{C} \quad h = 500$$

$$T_0 = 200^\circ\text{C}$$

$$L_c = 0.025 + 0.00075 = 0.02575$$

$$q_{\max} = (2)(500)(0.02575)(200 - 20) = 4635 \text{ W/m}$$

$$A_m = (0.0015)(0.02575) = 3.863 \times 10^{-5}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right) = (0.02575)^{3/2} \left[\frac{500}{(50)(3.863 \times 10^{-5})} \right]^{1/2} = 2.1$$

$$\eta_f = 0.36$$

$$q = (0.36)(4635) = 1669 \text{ W}$$

2-94

$$L = 3.5 \text{ cm} \quad t = 1.4 \text{ mm} \quad L_c = 3.57 \text{ cm} \quad k = 55$$

$$q_{\max} = hA\theta_0 = (500)(2)(0.0357)(150 - 20) = 4641 \text{ W/m}$$

$$mL_c = \left(\frac{2h}{kA_m} \right)^{1/2} L_c^{3/2} = 4.068$$

$$\eta_f = \frac{\tanh(mL_c)}{mL_c} = 0.246 \quad q_{\text{act}} = (0.246)(4641) = 1140 \text{ W/m}$$

2-95

$$k = 43 \quad h = 100 \quad r_1 = 2.5 \text{ cm} \quad r_2 = 7.5 \text{ cm} \quad L = 5 \text{ cm}$$

$$T_\infty = 20^\circ\text{C} \quad t = 2 \text{ mm} \quad r_{2c} = 7.51 \text{ cm} \quad L_c = 5.1 \text{ cm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 1.74 \quad \frac{r_{2c}}{r_1} \cong 3 \quad \eta_f = 0.27$$

$$q = \eta_f 2h\pi(r_{2c}^2 - r_1^2)\theta_0 = (0.27)(100)(2)\pi(0.0751^2 - 0.025^2)(150 - 20)$$

$$= 110.6 \text{ W}$$

2-96

$$r_1 = 1.5 \text{ cm} \quad L = 2 \text{ cm} \quad r_2 = 3.5 \text{ cm} \quad t = 1 \text{ mm} \quad h = 80$$

$$k = 200 \quad L_c = 2.05 \text{ cm} \quad r_{2c} = 3.55 \text{ cm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.41 \quad \frac{r_{2c}}{r_1} = 2.37 \quad \eta_f = 0.81$$

$$q = (80)\pi(0.0355^2 - 0.015^2)(2)(200 - 20)(0.81) = 75.9 \text{ W}$$

2-97

$$h = 50 \quad k = 20$$

$$m = \left(\frac{hP}{kA} \right)^{1/2} = \left[\frac{(50)\pi(0.01)(4)}{(20)\pi(0.01)^2} \right]^{1/2} = 31.62$$

$$mL = (0.2)(31.62) = 6.324$$

$$e^{mL} = 557.8 \quad e^{-mL} = 0.00179$$

$$e^{mx} = 2362 \quad e^{-mx} = 0.0423$$

$$\theta_1 = 50 - 20 = 30 \quad \theta_2 = 100 - 20 = 80$$

Using solution from Prob 2-61

$$\theta_{(x=10 \text{ cm})} = \frac{(0.0423)[80 - (30)(557.8)] + (23.62)[(30)(0.00179) - 80]}{0.00179 - 557.8}$$

$$= \frac{-704.46 - 1888.33}{-557.8}$$

$$= 4.65^\circ\text{C}$$

$$T = 20 + 4.65 = 24.65^\circ\text{C}$$

Chapter 2

2-98

$$k = 386 \quad r_1 = 0.625 \text{ cm} \quad L = 0.6 \text{ cm} \quad h = 55$$

$$t = 0.3 \text{ mm} \quad L_c = 0.6 + 0.015 = 0.615 \text{ cm}$$

$$r_{2c} = 0.625 + 0.615 = 1.24$$

$$\frac{r_{2c}}{r_1} = \frac{1.24}{0.625} \cong 20$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.00615)^{3/2} \left[\frac{55}{(386)(0.00615)(0.0003)} \right]^{1/2} = 0.134$$

$$\eta_f = 0.95$$

$$q = \eta_f h A \theta_0 = (0.95)(55)\pi(2)(0.0124^2 - 0.00625^2)(100 - 20) = 3.012 \text{ W}$$

2-99

$$t = 2 \text{ cm} \quad L = 17 \text{ cm} \quad k = 43 \quad h = 23 \quad L_c = 18 \text{ cm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.93 \quad \eta_f = 0.64$$

$$q = (0.64)(2)(23)(0.18)(230 - 25) = 1086 \text{ W/m}$$

2-100

$$L = 5 \text{ cm} \quad L_c = 5 \text{ cm} \quad t = 4 \text{ mm} \quad k = 23 \quad h = 20$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 1.042 \quad \eta_f = 0.68 \quad q = \eta_f h A \theta_0$$

$$A = (2)(0.002^2 + 0.05^2)^{1/2} = 0.10008 \frac{\text{m}^2}{\text{m depth}}$$

$$q = (0.68)(20)(0.10008)(200 - 40) = 217.8 \text{ W/m}$$

2-101

$$t = 1.0 \text{ mm} \quad r_1 = 1.27 \text{ cm} \quad L = 1.27 \text{ cm} \quad L_c = 1.32 \text{ cm} \quad r_2 = 2.54 \text{ cm}$$

$$r_{2c} = 2.59 \text{ cm} \quad h = 56 \quad k = 204 \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.219$$

$$\frac{r_{2c}}{r_1} = 2.04 \quad \eta_f = 0.93$$

$$q = (0.93)(2)\pi(0.0259^2 - 0.0127^2)(56)(125 - 30) = 15.84 \text{ W}$$

2-102

$$t = 2 \text{ mm} \quad r_1 = 2.0 \text{ cm} \quad r_2 = 10.0 \text{ cm} \quad L = 8 \text{ cm} \quad L_c = 8.1 \text{ cm}$$

$$r_{2c} = 10.2 \text{ cm} \quad h = 20 \quad k = 17 \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 1.96$$

$$\frac{r_{2c}}{r_1} = 5.1 \quad \eta_f = 0.19$$

$$q = (0.19)(20)\pi(0.102^2 - 0.02^2)(2)(135 - 15) = 28.7 \text{ W}$$

2-103

$$L = 2.5 \text{ cm} \quad t = 1.1 \text{ mm} \quad k = 55 \quad h = 500 \quad L_c = 2.555 \text{ cm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 2.32 \quad \eta_f = 0.33$$

$$q = (0.33)(2)(0.02555)(500)(125 - 20) = 885 \text{ W/m}$$

2-104

$$t = 1.0 \text{ mm} \quad r_1 = 1.25 \text{ cm} \quad r_2 = 2.5 \text{ cm} \quad r_{2c} = 2.55 \text{ cm}$$

$$h = 25 \quad k = 204 \quad L = 1.25 \text{ cm} \quad L_c = 1.3 \text{ cm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.249 \quad \eta_f = 0.91$$

$$q = (0.91)(2)(75)\pi(0.0255^2 - 0.0125^2)(100 - 30) = 4.94 \text{ W}$$

2-105

$$d = 1 \text{ cm} \quad L = 5 \text{ cm} \quad h = 20 \quad k = 0.78 \quad T_0 = 180$$

$$T_\infty = 20$$

$$L_c = L + \frac{d}{4} = 5 + 0.25 = 5.25 \text{ cm}$$

$$\left(\frac{hP}{kA} \right)^{1/2} = m = \left[\frac{(20)\pi(0.01)(4)}{(0.78)\pi(0.01)^2} \right]^{1/2} = 101.3$$

$$mL_c = (101.3)(0.0525) = 5.317$$

$$\tanh(5.317) = 1.0$$

$$q = (hPkA)^{1/2} \theta_0 \tanh(mL_c) = \left[\frac{(20)\pi(0.01)(0.78)\pi(0.01)^2}{4} \right]^{1/2} (180 - 20)(1.0)$$

$$= 0.993 \text{ W}$$

Chapter 2

2-106

$$A = 1 \times 1 \text{ cm}^2 \quad L = 8 \text{ cm} \quad L_c = 8.5 \text{ cm} \quad m = \left[\frac{hP}{kA} \right]^{1/2} = 31.62$$

$$mL_c = 2.688 \quad \eta_f = \frac{\tanh(mL_c)}{mL_c} = 0.369$$

$$q = (0.369)(45)(0.085)(4)(0.01)(300 - 50) = 14.11 \text{ W}$$

2-107

$$t = 1.0 \text{ mm} \quad r_1 = 1.25 \text{ cm} \quad L = 12 \text{ mm} \quad T_0 = 275^\circ\text{C}$$

$$T_\infty = 25^\circ\text{C} \quad h = 120 \quad k = 386$$

$$L_c = 0.012 + 0.0005 = 0.0125 \quad r_{2c} = 0.025 \quad \frac{r_{2c}}{r_1} = 2.0$$

$$A_m = (0.0125)(0.001) = 1.25 \times 10^{-5}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.0125)^{3/2} \left[\frac{120}{(386)(1.25 \times 10^{-5})} \right]^{1/2} = 0.22$$

$$\eta_f = 0.93$$

$$q = (0.93)(120)\pi(0.025^2 - 0.0125^2)(2)(275 - 25) = 82.12 \text{ W}$$

2-108

$$k = 17 \quad h = 47 \quad L = 5 \text{ cm} \quad t = 2.5 \text{ cm} \quad L_c = 6.25 \text{ cm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.657 \quad \eta_f = 0.8$$

$$q = (0.8)(47)(2)(0.0625)(100 - 20) = 376 \text{ W/m}$$

2-109

$$r_1 = 1.5 \text{ cm} \quad L = 2 \text{ cm} \quad r_2 = 3.5 \text{ cm} \quad t = 1 \text{ mm} \quad r_{2c} = 3.55 \text{ cm}$$

$$h = 80 \quad k = 204 \quad L_c = 2.05 \text{ cm} \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.453$$

$$\frac{r_{2c}}{r_1} = 2.37 \quad \eta_f = 0.79$$

$$q = (0.79)(80)(2)\pi(0.0355^2 - 0.015^2)(200 - 20) = 74 \text{ W}$$

2-110

$$r_1 = 1.5 \text{ cm} \quad r_2 = 4.5 \text{ cm} \quad t = 1.0 \text{ mm} \quad h = 50 \quad r_{2c} = 4.55 \text{ cm}$$

$$L_c = 3.05 \text{ cm} \quad k = 204 \quad \eta_f = 0.6 \quad \frac{r_{2c}}{r_1} = 3$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.78$$

$$k = \frac{1}{(0.001)(0.0305)} (0.0305)^3 \frac{50}{(0.78)^2} = 76.5 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

2-111

$$t = 1.0 \text{ mm} \quad L = 2.0 \text{ cm} \quad r_1 = 1.0 \text{ cm} \quad h = 150 \quad k = 204$$

$$L_c = 2.05 \text{ cm} \quad r_{2c} = 3.05 \text{ cm} \quad \frac{r_{2c}}{r_1} = 3.05 \quad T_0 = 150$$

$$T_\infty = 20$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.0205)^{3/2} \left[\frac{150}{(204)(0.001)(0.0205)} \right]^{1/2} = 0.556$$

$$\eta_f = 0.75$$

$$q = (0.75)(150)(2)\pi(0.0305^2 - 0.01^2)(150 - 20) = 76.3 \text{ W}$$

2-112

$$k_A = k_B = 17 \quad A_c = 0.001 \text{ A} \quad \Delta T = 300^\circ\text{C} \quad A = \frac{\pi d^2}{4} = 5.067 \times 10^{-4} \text{ m}^2$$

$$\frac{L_g}{2} = 1.3 \times 10^{-6} \text{ m} \quad k_f = 0.035 \quad L_A = L_B = 7.5 \text{ cm}$$

$$h_c = \frac{1}{L_g} \left[\frac{A_c}{A} \left(\frac{2k_A k_B}{k_A + k_B} \right) + \frac{A_y}{A} k_f \right] = 19,986 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{1}{h_c A} = \frac{1}{(19,986)(5.067 \times 10^{-4})} = 0.0987 \text{ } ^\circ\text{C/W}$$

$$q = \frac{300}{\frac{(0.075)(2)}{(17)(5.067 \times 10^{-4})} + 0.0987} = 17.31 \text{ W w/no contact resistance}$$

$$q = kA \frac{\Delta T}{\Delta x} = \frac{(17)(5.067 \times 10^{-4})(300)}{0.15} = 17.228 \text{ W}$$

Chapter 2

2-114

$$R_{th} = \frac{\Delta x}{kA} = \frac{5 \times 10^{-3}}{204} = 2.45 \times 10^{-5} \quad R_c = \frac{1}{h_c A} = 0.88 \times 10^{-4}$$

$$\sum R_{th} = (2)(2.45 \times 10^{-5}) + 0.88 \times 10^{-4} = 1.37 \times 10^{-4}$$

$$\Delta T_c = \frac{(80)(0.88 \times 10^{-4})}{1.37 \times 10^{-4}} = 51.4^\circ\text{C}$$

2-115

$$t = 1 \times 10^{-3} \quad r_i = 0.0125 \quad L = 0.0125 \quad L_c = 0.0130$$

$$r_{2c} = 0.0255 \quad \frac{r_0}{r_i} = 2.04 \quad A_m = (0.001)(0.0130) = 1.3 \times 10^{-5} \text{ m}^2$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.322 \quad \eta_f = 0.86 \quad \frac{1}{h_c} = 0.88 \times 10^{-4} \quad T_0 = 200^\circ\text{C}$$

$$T_\infty = 20^\circ\text{C}$$

$$R_{fin} = \frac{1}{2\eta_f \pi (r_{2c}^2 - r_1^2) h} = 2.997 \text{ }^\circ\text{C/W}$$

$$R_c = \frac{1}{h_c A} = 1.1205 \text{ }^\circ\text{C/W}$$

$$q = \frac{\theta_0}{R_{fin} + R_c} = 43.72 \text{ W} \quad \text{w/o contact resistance}$$

$$q = \frac{\theta_0}{R_{fin}} = 60.06 \text{ W} \quad \% \text{ Reduction} = \frac{60.06 - 43.72}{60.06} \times 100\% = 27.2\%$$

2-116

$$\frac{1}{h_c} = 0.9 \times 10^{-4} \quad A_c = 0.5 \text{ cm}^2 \quad q = 300 \text{ mW}$$

Assume fin at 27°C

$$q = (300 \times 10^{-3}) = \frac{1}{0.9 \times 10^{-4}} (0.5)(10^{-4})(T_t - 27)$$

$$T_t = 27.54^\circ\text{C}$$

2-117

$$2L = 20 \text{ cm} = 0.2 \text{ m} \quad T_{\infty} = 50^{\circ}\text{C}$$

$$\frac{q}{A} = \dot{q}(2L) = (2 \times 10^5)(-0.2) = 40,000 \text{ W/m}^2 = 2h(T_w - T_{\infty}) = (400)(T_w - 50)(2)$$

$$T_w = 100^{\circ}\text{C}$$

$$T_0 - T_w = \frac{\dot{q}L^2}{2k} = \frac{(2 \times 10^5)(0.1)^2}{(2)(20)} = 50^{\circ}\text{C}$$

$$T_0 = 150^{\circ}\text{C}$$

2-118

$\frac{1}{2}$ heat generated, max temperature at insulated surface which is the same as in Problem 2-111.

2-119

$$L_c = 0.03 + 0.001 = 0.031 \quad k = 204 \quad h = 220$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.031)^{3/2} \left[\frac{220}{(204)(0.031)(0.002)} \right]^{1/2} = 0.715$$

$$\eta_f = 0.69$$

$$q = \eta_f h A \theta_0 = (0.69)\pi(0.061^2 - 0.03^2)(2)(220)(120 - 20) = 269 \text{ W}$$

2-120

$$L_c = 0.008 \quad k = 204 \frac{\text{W}}{\text{m} \cdot ^{\circ}\text{C}} \quad h = 45 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.008)^{3/2} \left[\frac{(45)(2)}{(204)(0.008)(0.002)} \right]^{1/2} = 0.119$$

$$\eta_f = 0.97$$

$$q = (2)(0.97)(0.008^2 + 0.001^2)^{1/2}(45)(200 - 25) = 123.2 \text{ W/m}$$

Chapter 2

2-121

$$r_1 = 1.25 \text{ cm} \quad r_2 = 2.25 \text{ cm} \quad t = 2.0 \text{ mm} \quad r_{2c} = 2.35 \text{ cm}$$

$$\frac{r_{2c}}{r_1} = 1.88 \quad L_c = 1.1 \text{ cm} \quad T_0 = 180^\circ\text{C} \quad T_\infty = 20^\circ\text{C}$$

$$h = 50 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$L \text{ of tube} = 1.0 \text{ m}$$

$$\text{bare length} = 1.0 - (100)(0.002) = 0.8 \text{ m}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.011)^{3/2} \left[\frac{50}{(204)(0.002)(0.011)} \right]^{1/2} = 0.122$$

$$\eta_f = 0.95$$

$$q(100 \text{ fins}) = (100)(2)(0.95)\pi(0.0235^2 - 0.0125^2)(50)(180 - 20) = 1869 \text{ W}$$

$$q(\text{bare tube}) = (50)\pi(0.025)(0.8)(180 - 20) = 503 \text{ W}$$

$$q(\text{total}) = 1869 + 503 = 2372 \text{ W}$$

2-122

$$k = 100 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad q = kA \frac{\Delta T}{\Delta x}$$

$$A = (1.7 - 1.5) \text{ cm} = \frac{0.2}{100} = 0.002 \text{ m}^2/\text{m}$$

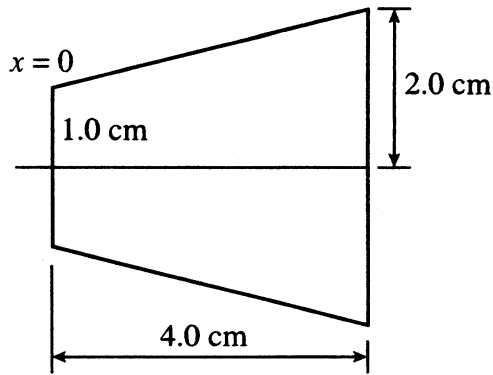
$$\Delta x = \text{circumference at } r = 1.6 \text{ cm for } \frac{\pi}{4}$$

$$\Delta x = (2)(1.6) \left(\frac{\pi}{4} \right) = 2.513 \text{ cm} = 0.02513 \text{ m}$$

$$R = \frac{\Delta x}{kA} = \frac{0.02513}{(100)(0.002)} = 0.1256^\circ\text{C}^{-1}$$

$$\frac{q}{L} = \frac{50}{0.1256} = 398 \text{ W/m}$$

2-123



$$k = 386 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$r = ax + b$$

$$r = 0.01 \quad \text{at} \quad x = 0$$

$$r = 0.02 \quad \text{at} \quad x = 0.04$$

$$0.01 = b \quad a = 0.25$$

$$0.02 = (0.04)a + 0.01$$

$$r = 0.25x + 0.01 \quad A = 2\pi r(0.0005)$$

$$q = -k2\pi(0.25x + 0.01)(0.0005) \frac{dT}{dx}$$

$$\int_0^{0.04} \frac{dx}{0.25x + 0.01} = \int -2\pi k(0.0005) \frac{dT}{q}$$

$$\frac{1}{0.25} \ln \left[\frac{(0.25)(0.04) + 0.01}{0.01} \right] = 2.773 = 2\pi(386)(0.0005) \frac{\Delta T}{q} = 1.213 \frac{\Delta T}{q}$$

$$q = \frac{\Delta T}{2.287} \quad R = 2.287$$

$$\text{For } \Delta T = 300^\circ\text{C} \quad q = \frac{300}{2.287} = 131.2 \text{ W}$$

Chapter 2

2-124

Tube $d_i = 1.25 \text{ cm} = 12.5 \text{ mm}$ $T_{\text{inside}} = 100^\circ\text{C}$ $\text{thk} = 0.8 \text{ mm}$

$d_o = 14.1 \text{ mm}$ $T_\infty = 20^\circ\text{C}$

Fins: $T = 0.3 \text{ mm}$ $L = 3 \text{ mm}$ $L_c = 3 + 0.15 = 3.15 \text{ mm}$

$r_1 = 6.25 + 0.8 = 7.05 \text{ mm}$ $r_{2c} = 7.05 + 3.15 = 10.20 \text{ mm}$

$h = 50 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$ $k = 386 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$

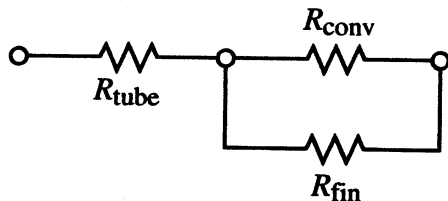
No. of fins $= \frac{300}{6} = 50$ for 30 cm length

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.00315)^{3/2} \left[\frac{50}{(386)(0.00315)(0.0003)} \right]^{1/2} = 0.0654$$

$\frac{r_{2c}}{r_1} = \frac{10.2}{7.05} = 1.447$ $\eta_f = 0.98$

$\frac{R_{\text{tube}}}{L} = \frac{\ln(14.1/12.5)}{2\pi(386)} = 4.97 \times 10^{-5}$

$\frac{R_{\text{conv}}}{L} = \frac{1}{(50)\pi(0.0141)} = 0.4515$



For 6 mm length

$L_{\text{tube}} = 6 - 0.3 = 5.7 \text{ mm}$

$R_{\text{tube}} = \frac{4.97 \times 10^{-5}}{0.0057} = 8.72 \times 10^{-3}$

$R_{\text{conv}} = \frac{0.4515}{0.0057} = 79.2$

$q_{\text{fin}} = \frac{\Delta T}{R_{\text{fin}}} = (0.98)(50)(2\pi)(0.0102^2 - 0.00705^2)\Delta T = 0.01672\Delta T$

$R_{\text{fin}} = 59.78$

$R_{\text{overall}} = 8.72 \times 10^{-3} + \frac{1}{\frac{1}{79.2} + \frac{1}{59.78}} = 34.07$

$q = \frac{100 - 20}{34.07} = 2.348 \text{ W/6 mm length}$

For 30 cm length

$q = (2.348) \left(\frac{300}{6} \right) = 117.4 \text{ W}$

$R = \frac{100 - 20}{117.4} = 0.6814$

For 1 m length

$q = (117.4) \left(\frac{1}{0.3} \right) = 392 \text{ W}$

2-125

For 6 mm length total surface area

$$= A_{\text{tube}} + A_{\text{fin}} = \pi(0.0141)(0.0057) + (2)\pi(0.0102^2 - 0.00705^2) \\ = 5.939 \times 10^{-4} \text{ m}^2$$

$$\frac{q}{A} = \frac{2.348}{5.939 \times 10^{-4}} = 3953 \text{ W/m}^2 \\ = \frac{\Delta T}{R\text{-value}}$$

$$R\text{-value} = \frac{100 - 20}{3953} = 0.0202$$

2-126

$$k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.0654) \left(\frac{386}{204} \right)^{1/2} = 0.09$$

$$\eta_f = 0.96$$

For 6 mm length

$$R_{\text{tube}} = 8.72 \times 10^{-3}$$

$$R_{\text{conv}} = 79.2$$

$$R_{\text{fin}} = (59.78) \left(\frac{0.98}{0.96} \right) = 61.03$$

$$R_{\text{overall}} = 8.72 \times 10^{-3} + \frac{1}{\frac{1}{79.2} + \frac{1}{61.03}} = 34.47$$

$$q = \frac{100 - 20}{34.47} = 2.32 \text{ W/ 6 mm length}$$

For 30 cm length

$$q = (2.32) \left(\frac{300}{6} \right) = 116 \text{ W}$$

$$R = \frac{100 - 20}{116} = 0.6896$$

$$\text{For 1 m length } q = (116) \left(\frac{1}{0.3} \right) = 387 \text{ W}$$

2-127

$$\frac{q}{A} = \frac{2.32}{5.939 \times 10^{-4}} = 3906 \text{ W/m}^2 = \frac{\Delta T}{R\text{-value}}$$

$$R\text{-value} = \frac{110 - 20}{3906} = 0.0205$$

Chapter 2

2-128

$$h = 100 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad d = 2 \text{ mm} \quad T_\infty = 20^\circ\text{C} \quad T_0 = 100^\circ\text{C} \quad L = 10 \text{ cm}$$

$$k = 16 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \theta = c_1 e^{-mx} + c_2 e^{mx}$$

$$m = \left(\frac{hP}{kA} \right)^{1/2} = \left[\frac{(100)\pi(0.002)}{(16)\pi(0.001)^2} \right]^{1/2} = 111.8$$

$$\theta = 100 - 20 = 80 \text{ at } x = 0 \text{ and } x = 0.1$$

$$80 = c_1 + c_2$$

$$80 = 1.395 \times 10^{-5} c_1 + 71,682 c_2$$

$$c_1 = 79.999 \quad c_2 = 1.117 \times 10^{-3}$$

$$q = \sqrt{hPkA} [-c_1 e^{-mx} + c_2 e^{mx}]$$

$$\sqrt{hPkA} = [(100)\pi(0.002)(16)\pi(0.001)^2]^{1/2} = 5.62 \times 10^{-3}$$

$$q_0 = -(5.62 \times 10^{-3})(-79.999 + 1.12 \times 10^{-3}) = 0.45 \text{ W} = -q_L$$

$$q_{\text{total}} = (2)(0.45) = 0.9 \text{ W}$$

2-129

$$T_\infty = 20^\circ\text{C} \quad h = 100 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad k = 16 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad d = 2 \text{ mm}$$

$$T_0 = 100^\circ\text{C}$$

$$\theta = c_1 e^{-mx} + c_2 e^{mx}$$

For very long rod $c_2 = 0$

Acts like two long rods 100°C on each end

$$q = 2\sqrt{hPkA}\theta_0 = (2)[(100)\pi(0.002)(16)\pi(0.001)^2]^{1/2}(100 - 20) = 0.9 \text{ W}$$

2-130

$$A = (0.017 - 0.015)(1) = 0.002 \text{ m}^2/\text{m depth}$$

$$k = 100 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad h = 75 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad T_\infty = 30^\circ\text{C} \quad T_0 = 100^\circ\text{C}$$

$$T_L = 50^\circ\text{C} \quad L = \frac{2\pi}{4}(0.016) = 0.02513 \text{ m}$$

$$\theta = T - T_\infty = c_1 e^{-mx} + c_2 e^{mx}$$

$$m = \left(\frac{hP}{kA} \right)^{1/2} = \left(\frac{2h}{kt} \right)^{1/2} = \left[\frac{(2)(75)}{(100)(0.002)} \right]^{1/2} = 27.39$$

$$mL = 0.6882$$

$$100 - 30 = c_1 + c_2$$

$$50 - 30 = c_1 e^{-0.6882} + c_2 e^{0.6882}$$

$$c_1 = 80.2 \quad c_2 = -10.2$$

$$q_x = -kAm(-c_1e^{-mx} + c_2e^{mx})$$

$$q_{x=0} = -(100)(0.002)(27.39)(-80.2 - 10.2) = 495 \text{ W}$$

$$q_{x=L} = -(100)(0.002)(27.39)[-(80.2)(0.5024) - (10.2)(1.99)] = 332 \text{ W}$$

$$q_{\text{net lost}} = 495 - 332 = 163 \text{ W/m depth}$$

2-131

$$t = 3.0 \text{ mm} \quad k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad h = 50 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \rho = 2707 \text{ kg/m}^3$$

Take $L = 2 \text{ cm}$

$$\text{Rect. Fin} \quad L_c = 2 + 0.15 = 2.15 \text{ cm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.0215)^{3/2} \left[\frac{50}{(204)(0.003)(0.0215)} \right]^{1/2} = 0.1943$$

$$\eta_f = 0.96$$

$$A_{\text{surf}} = (2)L_c = 0.043$$

For same weight $A_m = \text{same}$

$$t(0.0215) = \frac{t}{2} L(\text{triang})$$

$$L(\text{triang}) = 0.043$$

$$(\text{triang})L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.5496$$

$$\eta_f = 0.85$$

$$q \sim A_{\text{surf}} \eta_f$$

$$A_{\text{surf}}(\text{triang}) = 2(4.3^2 + 0.15^2)^{1/2} = 8.6 = 0.086 \text{ m}^2$$

$$A_{\text{surf}} \eta(\text{triangle}) = (0.086)(0.85) = 0.0731$$

$$A_{\text{surf}} \eta(\text{rect}) = (0.043)(0.96) = 0.0413$$

Triangle fin produces more heat transfer for given weight.

Chapter 2

2-132

$$r_1 = 1.0 \quad r_2 = 2.0 \text{ cm} \quad h = 160 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

1.0 mm Fin

$$L_c = 1.05 \text{ cm}$$

$$L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = (0.0105)^{3/2} \left[\frac{160}{(204)(0.001)(0.0105)} \right]^{1/2} = 0.294$$

$$\eta_f = 0.88$$

$$q = (6)(160)\pi(0.0205^2 - 0.01^2)(2)(\Delta T)(0.88) = 1.7\Delta T$$

2.0 mm Fin

$$L_c = 1.1 \text{ cm} \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.218 \quad \eta_f = 0.92$$

$$q = (3)(160)\pi(0.021^2 - 0.01^2)(2)\Delta T(0.92) = 0.95\Delta T$$

3.0 mm Fin

$$L_c = 1.15 \text{ cm} \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.186 \quad \eta_f = 0.95$$

$$q = (2)(160)\pi(0.0215^2 - 0.01^2)(2)\Delta T(0.95) = 0.69\Delta T$$

Conclusion: Several thin fins are better than a few thick fins. More heat transfer for the same weight of fins.

2-133

$$L = 5 \text{ cm} \quad d = 2, 5, 10 \text{ mm} \quad T_\infty = 20^\circ\text{C} \quad h = 40 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad T_0 = 200^\circ\text{C} \quad L_c = L + \frac{d}{4}$$

2 mm pin

$$L_c = 5 + 0.05 = 5.05 \text{ cm} = 0.0505 \text{ m}$$

$$m = \left(\frac{hP}{kA} \right)^{1/2} = \left(\frac{h\pi d}{k\pi \frac{d^2}{4}} \right)^{1/2} = \left(\frac{4h}{kd} \right)^{1/2} = \left[\frac{(4)(40)}{(204)(0.002)} \right]^{1/2} = 19.8$$

$$mL_c = (19.8)(0.0505) = 1.0$$

$$\eta = \frac{\tanh(mL_c)}{mL_c} = 0.762$$

$$q = (0.762)(40)\pi(0.002)(0.0505)(200 - 20) = 1.74 \text{ W}$$

5 mm pin

$$L_c = 5 + 0.125 \text{ cm} = 0.05125 \text{ m} \quad m = 12.52 \quad mL_c = 0.6419$$

$$\eta = \frac{\tanh(mL_c)}{mL_c} = 0.882$$

$$q = (0.882)(40)\pi(0.005)(0.05125)(200 - 20) = 5.11 \text{ W}$$

10 mm pin

$$L_c = 5 + 0.25 \text{ cm} = 0.0525 \text{ m} \quad m = 8.856 \quad mL_c = 0.46495$$

$$\eta = \frac{\tanh(mL_c)}{mL_c} = 0.934$$

$$q = (0.934)(40)\pi(0.01)(0.0525)(200 - 20) = 11.09 \text{ W}$$

d (mm)	q (W)	$\frac{q}{d}$ (mm)	$\frac{q}{d^2}$ (per weight)
2	1.74	0.87	0.435
5	5.11	1.022	0.2044
10	11.09	1.109	0.1109

Conclusion: Smaller pins produce more heat transfer per unit weight.

2-134 :

See conclusion at end of Problem 2-1⁵³~~27~~.

2-137

Once an insulation material is selected for this problem a commercial vendor must be consulted to determine the cost, as no cost figures are given in the problem statement. Cost figures will also have to be determined for the material with reflective coating. When the reflective material is installed it may have an emissivity of 0.1, but after a period of time the surface may oxidize or become coated with foreign matter such that its emissivity will increase. In that case the economic benefit of the coated material will be reduced.

2-138

For this problem, the net heat generated in the tube will be equal to the heat which will be delivered to the fluid by convection. The temperature gradient at the other surface of the tube will be zero. The problem does not state whether the fluid is on the outside or inside of the tube so both cases must be examined. In either case the maximum tube temperature will occur at the insulated surface. To effect the design one might first assume a surface temperature for the tube surface in contact with the fluid. This will then determine the surface area. Suitable combinations of tube length and diameter may then be examined to equal the total surface area. The heat generation equation for a hollow cylinder may then be solved for the other tube surface temperature if a tube wall thickness is assumed (i.e., establishing the other diameter). The resultant value of temperature must be reasonable, i.e., low enough. Obviously, there are many combinations which will be satisfactory.

2-145

$$d^2T/dx^2 - (\epsilon\sigma P/kA)(T^4 - T_s^4) = 0$$

Boundary conditions:

Base: $T = 0$ at $x = 0$

Tip: $-kA(dT/dx)_{x=L} = \sigma\epsilon A(T_{x=L}^4 - T_s^4)$

2-146

Insulated tip: $dT/dx = 0$ at $x = L$

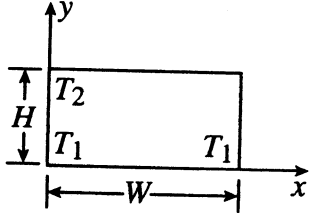
Very long fin: $T \rightarrow T_s$ as $x \rightarrow \infty$

2-147

Set $T_s = 0$ in differential equations

Chapter 3

3-1



$$T = T_1 \text{ at } y = 0 \quad T = T_1 \text{ at } x = 0 \quad T = T_1 \text{ at } x = W$$

$$T = T_2 \text{ at } y = H = XY \quad \text{For } \lambda^2 = 0 \quad X = c_1 + c_2x$$

$$Y = c_3 + c_4y \text{ at } y = 0$$

$$\therefore T - T_1 = (c_1 + c_2x)[c_3 + 0(c_4)] = \theta = 0 \text{ hence } c_3 = 0$$

$$\text{at } x = 0 \quad c_1 = 0 \text{ also } c_2 = 0 \quad T_2 - T_1 = [0 + (0)x](0 + c_4H) = 0 \text{ which isn't true}$$

$$\text{For } \lambda^2 < 0: \theta = T - T_1$$

$$T - T_1 = (c_5e^{-\lambda x} + c_6e^{\lambda x})[c_7 \cos(\lambda y) + c_8 \sin(\lambda y)]$$

$$\theta = 0 \text{ at } y = 0 \quad 0 = (c_5e^{-\lambda x} + c_6e^{\lambda x})(c_7) \quad \therefore c_7 = 0$$

$$\theta = 0 \text{ at } x = 0 \quad 0 = (c_5 + c_6)[c_8 \sin(\lambda y)] \quad \therefore \text{either } c_5 + c_6 = 0$$

or $c_8 = 0$ If $c_8 = 0$ then have trivial soln. then,

$$c_5 + c_6 = 0 \text{ and } c_5 = -c_6 \quad \theta = 0 \text{ at } x = W$$

$$0 = (c_5e^{-\lambda W} + c_6e^{\lambda W})[c_8 \sin(\lambda y)] \quad \therefore x = 0 \text{ but it was stated that } \lambda^2 < 0$$

3-2

$$\frac{T - T_1}{T_2 - T_1} = \frac{2}{\pi} \sum \frac{(-1)^{n+1}}{n} \sin \frac{n\pi x}{W} \frac{\sinh\left(\frac{n\pi y}{W}\right)}{\sinh\left(\frac{n\pi H}{W}\right)} \text{ at } y = H \quad x = \frac{W}{2}$$

$$\frac{T - T_1}{T_2 - T_1} = 1 \text{ (Ref Fig 3-2) Also, non-zero terms for } n = 1, 3, 5, \dots \text{ First four}$$

terms: $n = 1, 3, 5, 7$

$$\frac{T - T_1}{T_2 - T_1} = \frac{2}{\pi} \left[2 \sin \frac{\pi}{2} + \frac{2}{3} \sin \frac{3\pi}{2} + \frac{2}{5} \sin \frac{5\pi}{2} + \frac{2}{7} \sin \frac{7\pi}{2} \right]$$

$$\frac{T - T_1}{T_2 - T_1} = 0.92 \quad \text{Error is } (1.00 - 0.92) \times 100\% = 8\%$$

3-3

$$S = \frac{2\pi(1)}{\cosh^{-1}(1.2/0.125)} = 2.128$$

$$q = kS\Delta T = (2.128)(1.8)(67 - 15) = 199.2 \text{ W/m length}$$

3-4

$$\begin{aligned}q &= kS\Delta T & \Delta T &= 210 - 15 = 195^\circ\text{C} \\r &= 0.08 & D &= 0.225 & k &= 1.37 \\S &= \frac{2\pi L}{\ln(40/r)} = \frac{2\pi(1)}{\ln(0.9/0.03)} = 1.847 \\q &= (1.37)(1.847)(195) = 494 \text{ W/m}\end{aligned}$$

3-5

$$T_{\text{steam}} = 100^\circ\text{C}, \quad r = 0.0125; \quad D = 0.025 \quad T_\infty = 27^\circ\text{C}, \quad h = 5.1, \quad k = 0.1$$

$$\Sigma R = 1/kS + 1/hA$$

$A \rightarrow \infty$ for inf plate

$$S = 2\pi/\ln(0.1/0.0125) = 3.022$$

$$q = 0.1(3.022)(100 - 27) = 22.06 \text{ W/m length}$$

3-6

$$\begin{aligned}k_m &= 11 \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot ^\circ\text{F}} = 19.04 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \\k_{\text{glass}} &= 0.038 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \\q &= \frac{300 - 40}{\frac{\ln(2.5/1.5)}{2\pi(19.04)} + \frac{\ln(5/2.5)}{2\pi(0.038)}} = 89.38 \text{ W/m}\end{aligned}$$

3-8'

$$L = 0.5 \text{ ft} = 0.1524 \text{ m}$$

$$S_{\text{walls}} = \frac{2}{0.1524} [(0.3)(0.6) + (0.3)(0.9) + (0.6)(0.9)] = 12.992$$

$$S_{\text{edges}} = (4)(0.54)(0.3 + 0.6 + 0.9) = 3.888$$

$$S_{\text{corners}} = (8)(0.1524) = 1.219$$

$$S_{\text{total}} = 18.099$$

$$q = kS\Delta T = (0.5)(1.73)(18.099)(500 - 100) = 6262 \text{ W}$$

3-9

$$D = 35 - 10 = 25 \text{ cm} \quad L = 5 \text{ cm} \quad A = (0.25)^2 = 0.0625 \text{ m}^2$$

$$k = 1.04 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad S_{\text{wall}} = \frac{A}{L} = 1.25 \quad S_{\text{edge}} = 0.59D = 0.135$$

$$S_{\text{corner}} = 0.15L = 7.5 \times 10^{-3}$$

$$S = 6(1.25) + 12(0.135) + 8(7.5 \times 10^{-3}) = 9.18$$

$$q = kS\Delta T = (1.04)(9.18)(500 - 80) = 4009.8 \text{ W}$$

3-10

$$r_1 = 4 \text{ cm} \quad r_2 = 1.50 \text{ cm} \quad D = 10 \text{ cm} \quad k = 1.4 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$S = \frac{2\pi}{\cosh^{-1} \left[\frac{10^2 - 4^2 - 1.5^2}{(2)(4)(1.5)} \right]} = 2.411$$

$$q = ks\Delta T = (1.4)(2.411)(200 - 35) = 556.8 \text{ W/m}$$

Chapter 3

3-11

$$q = kS\Delta T \quad k = 1.2 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad r = 5 \text{ cm} \quad \Delta T = 30 - 0 = 30^\circ\text{C}$$

$$D = 24 \text{ cm}$$

$$S = \frac{4\pi r}{1 - r/20} = \frac{4\pi(0.05)}{1 - 5/48} = 0.7013$$

$$q = (1.2)(0.7013)(30) = 25.24 \text{ W}$$

3-12

$$S = 4\pi r = 1.257 \text{ m} \quad k = 0.038 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$q = (1.257)(0.038)(170 - 20) = 7.165 \text{ W}$$

3-12

$$r = 1 \text{ m} \quad k = 1.5 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad S = 4\pi r = 12.56 \text{ m}$$

$$q = (1.5)(12.56)(20 - 0) = 377 \text{ W}$$

3-15

$$k = 0.04; \quad T_{\text{steam}} = 100^\circ\text{C}; \quad L = 2 \text{ m}; \quad T_\infty = 27^\circ\text{C}; \quad h = 5.1$$

$$r = 0.0125, \quad W = 0.05$$

$$S = 2\pi(2.0)/\ln[(0.54)(0.05/0.0125)] = 16.318$$

$$1/hA = 1/(5.1)(2.0)(0.05)(4) = 0.4902$$

$$\Sigma R = 1/(0.04)(16.318) + 0.4902 = 2.022$$

$$q = (100 - 27)/2.022 = 36.1 \text{ W}$$

3-16

$$D > 3r \quad \frac{q}{L} = \frac{2\pi(1.2)(110 - 25)}{\ln\left[\frac{(2)(1.3)}{0.04}\right]} = 153.5 \text{ W/m} = I^2 R = I^2(1.1 \times 10^{-4})$$

$$I = 1181 \text{ amp}$$

3-17

$$S = 4\pi r$$

$$q = (1.3)(4\pi)(0.02)(70 - 12) = 18.95 \text{ W}$$

3-18

$$r_1 = 0.025 \text{ m} \quad r_2 = 0.01 \text{ m} \quad D = 0.055 \text{ m} \quad S = \frac{2\pi L}{\cosh^{-1}\left(\frac{r_1^2 + r_2^2 - D^2}{2r_1 r_2}\right)}$$

$$k = 2.5 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \Delta T = 100 - 20 \quad S = \frac{2\pi}{\cosh^{-1}\left(\frac{2.5^2 + 10^2 - 5.5^2}{2(2.5)(10)}\right)} = 6.41$$

$$q = kS\Delta T = (2.5)(6.41)(100 - 20) = 1282 \text{ W/m}$$

3-19

$$S = \frac{2\pi}{\cosh^{-1}\left(\frac{40^2 - 9^2 - 4.5^2}{2(9)(4.5)}\right)} = 1.74$$

$$\frac{q}{r} = (1.74)(1.1)(200 - 100) = 191.4 \text{ W/m}$$

3-20

$$S = \frac{4\pi(0.75)}{1 - \frac{0.75}{(2)(3.75)}} = 10.47$$

$$q = (10.47)(1.2)(300 - 30) = 3393 \text{ W}$$

3-21

$$r = 1.25 \text{ cm} \quad L = 1 \text{ m} \quad T_r = 55^\circ\text{C} \quad T_s = 10^\circ\text{C} \quad k = 1.7 \frac{\text{W}}{\text{m}\cdot^\circ\text{C}}$$

$$S = \frac{2\pi L}{\ln\left(\frac{2L}{r}\right)} = \frac{2\pi(1.0)}{\ln\left[\frac{(2)(1.0)}{0.0125}\right]} = 1.238$$

$$q = (1.238)(1.7)(55 - 10) = 94.71 \text{ W}$$

3-22

$$k = 0.8 \frac{\text{W}}{\text{m}\cdot^\circ\text{C}} \quad r_1 = 5 \text{ cm} \quad r_2 = 1.4 \text{ cm} \quad D = 12 \text{ cm}$$

$$S = \frac{2\pi}{\cosh^{-1}\left(\frac{12^2 - 1.4^2 - 5^2}{(2)(1.4)(5)}\right)} = 2.813$$

$$q = (2.813)(0.8)(300 - 15) = 641.4 \text{ W/m}$$

3-23

$$D = 5 \text{ m} \quad r = 1.0 \text{ m} \quad k = 1.5 \frac{\text{W}}{\text{m}\cdot^\circ\text{C}}$$

$$S = \frac{4\pi r}{1 - \frac{r}{20}} = \frac{4\pi(1.0)}{1 - \frac{1}{10}} = 13.96$$

$$q = (13.96)(1.5)(25 - 5) = 418.9 \text{ W}$$

3-24

$$S = \frac{2\pi}{\cosh^{-1}\left(\frac{100^2 - 10^2 - 20^2}{(2)(10)(20)}\right)} = 1.6278$$

$$r_1 = 10 \quad r_2 = 20 \quad D = 100$$

$$q = kS\Delta T = (3.5)(1.6278)(120 - 20) = 570 \text{ W/m}$$

3-25

$$r = 5 \text{ cm} \quad L = 100 \text{ m} \quad D = 23 \text{ cm}$$

$$S = \frac{2\pi L}{\cosh^{-1}\left(\frac{D}{r}\right)} = \frac{2\pi(100)}{\cosh^{-1}\left(\frac{23}{5}\right)} = 284.7$$

$$q = kS\Delta T = (1.2)(284.7)(150 - 15) = 46,120 \text{ W}$$

3-26

$$T_{\text{steam}} = 150^\circ\text{C}, \quad T_{\infty} = 20^\circ\text{C} \quad r = 0.025; \quad D = 0.075$$

$$k = 0.65$$

$$S = 2\pi/\ln(0.3/0.0125) = 1.977$$

$$q = (0.65)(1.977)(150 - 20) = 167.06 \text{ W/m}$$

3-27

$$T_{\text{steam}} = 100^\circ\text{C}; \quad T_{\text{surface}} = 25^\circ\text{C}; \quad k = 1.2; \quad D = 0.05; \quad r = 0.005;$$

$$l = 0.03$$

$$S = 2\pi/\ln[(0.03/\pi \times 0.005)\sinh(2\pi \times 0.05/0.03)] = 0.603$$

$$q = (1.2)(0.603)(100 - 25) = 54.24 \text{ W/m}$$

3-28

$$r_1 = 5 \text{ cm} \quad r_2 = 2.5 \text{ cm} \quad D = 20 \text{ cm} \quad k = 0.15 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$S = \frac{2\pi}{\cosh^{-1}\left[\frac{20^2 - 5^2 - 2.5^2}{(2)(2.5)(5)}\right]} = 1.857$$

$$q = (0.15)(1.857)(110 - 3) = 29.81 \text{ W/m}$$

3-29

$$r = 1.5 \text{ cm} \quad D = 5 \text{ cm} \quad k = 15.5 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$S = \frac{2\pi}{\cosh^{-1}\left(\frac{D}{r}\right)} = \frac{2\pi}{\cosh^{-1}\left(\frac{5}{1.5}\right)} = 3.353$$

$$q = (15.5)(3.353)(135 - 46) = 4626 \text{ W/m}$$

3-30

$$\Delta T = 30 - 0 = 30^\circ\text{C} \quad k = 0.2 \quad D = 8.5 \text{ m} \quad r = 1.25 \text{ m}$$

$$S = \frac{4\pi r}{1 - \frac{r}{2D}} = \frac{4\pi(1.25)}{1 - \frac{1.25}{17}} = 16.95$$

$$q = kS\Delta T = (0.2)(16.95)(30) = 101.7 \text{ W}$$

3-31

$$k = 0.74 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad D = 0 \quad W = 100 \text{ cm} \quad L = 50 \text{ cm}$$

$$S = \frac{\pi W}{\ln\left(\frac{4W}{L}\right)} = \frac{\pi(1.0)}{\ln\left(\frac{400}{50}\right)} = 1.511$$

$$q = kS\Delta T = (0.74)(1.511)(120 - 15) = 117.4 \text{ W}$$

3-32

$$T_{\text{disk}} = 40^\circ\text{C}; \quad k = 0.8; \quad T_{\text{surface}} = 15^\circ\text{C}$$

$$r = 0.009; \quad D = 0.02$$

$$S = 4\pi(0.009)/[\pi/2 - \tan^{-1}(0.009/0.04)] = 0.0795$$

$$q = (0.8)((0.0795)(40 - 15)) = 1.591 \text{ W}$$

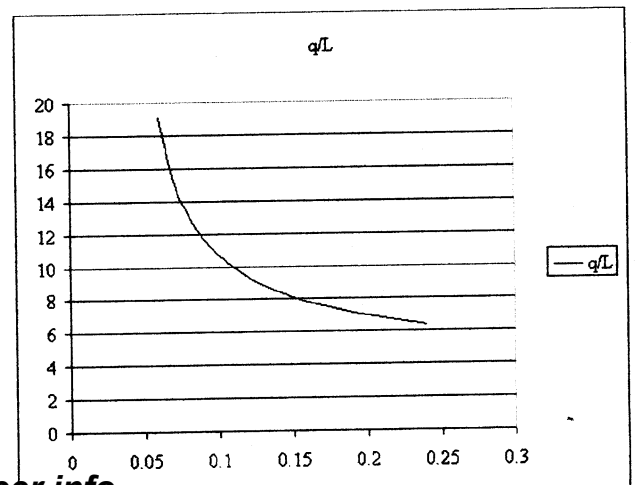
3-33

$$r_1 = r_2 = 0.025 \quad \Delta T = 115^\circ\text{C} \quad k = 0.04$$

$$0.05 < D < \text{large}$$

$$S = 2\pi/\cosh^{-1}[(0.5)(D/0.025)^2 - 0.5]$$

$$q/L = 0.04S(115) = 4.6S$$



3-34

$$L = 5 \text{ cm}$$

$$S_{\text{walls}} = \frac{(2)(0.6)(0.7) + 2(0.6)(0.8) + (0.7)(0.8)}{0.05} = 58.4$$

$$S_{\text{edges}} = (4)(0.54)(0.6 + 0.7 + 0.8) = 4.536$$

$$S_{\text{corners}} = (8)(0.15)(0.05) = 0.06$$

$$S_{\text{total}} = 62.996$$

3-35

$$r_1 = 7.5 \text{ cm} \quad T_1 = 150^\circ\text{C} \quad T_2 = 5^\circ\text{C} \quad k = 0.7 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad r_2 = 2.5 \text{ cm}$$

$$D = 15 \text{ cm}$$

$$S = \frac{2\pi}{\cosh^{-1} \left[\frac{15^2 - 7.5^2 - 2.5^2}{(2)(7.5)(2.5)} \right]} = 2.928$$

$$q = (0.7)(2.928)(150 - 5) = 297.2 \text{ W/m}$$

3-36

The temperature gradients are written:

$$\left. \frac{\partial T}{\partial x} \right|_{m+\frac{1}{2}, n, p} \approx \frac{T_{m+1, n, p} - T_{m, n, p}}{\Delta x}$$

$$\left. \frac{\partial T}{\partial x} \right|_{m-\frac{1}{2}, n, p} \approx \frac{T_{m, n, p} - T_{m-1, n, p}}{\Delta x}$$

$$\left. \frac{\partial T}{\partial y} \right|_{m, n+\frac{1}{2}, p} \approx \frac{T_{m, n+1, p} - T_{m, n, p}}{\Delta y}$$

$$\left. \frac{\partial T}{\partial y} \right|_{m, n-\frac{1}{2}, p} \approx \frac{T_{m, n, p} - T_{m, n-1, p}}{\Delta y}$$

$$\left. \frac{\partial T}{\partial z} \right|_{m, n, p+\frac{1}{2}} \approx \frac{T_{m, n, p+1} - T_{m, n, p}}{\Delta z}$$

$$\left. \frac{\partial T}{\partial z} \right|_{m, n, p-\frac{1}{2}} \approx \frac{T_{m, n, p} - T_{m, n, p-1}}{\Delta z}$$

For 3 dimensions 2g places eqn. is

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0 \quad \text{also if } \Delta x = \Delta y = \Delta z, \text{ the finite difference}$$

approximations become:

$$T_{m+1, n, p} + T_{m-1, n, p} + T_{m, n+1, p} + T_{m, n-1, p} + T_{m, n, p+1} + T_{m, n, p-1} - 6T_{m, n, p} = 0$$

3-37

the Temp. gradient is written:

$$\left. \frac{dT}{dx} \right|_{m+\frac{1}{2}, n} \approx \frac{T_{m+1, n} - T_{m, n}}{\Delta x}$$

$$\left. \frac{dT}{dx} \right|_{m-\frac{1}{2}, n} \approx \frac{T_{m, n} - T_{m-1, n}}{\Delta x}$$

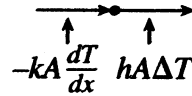
for 1 dimension: $\frac{d^2 T}{dx^2} = 0$ and the finite difference approximation is:

$$T_{m+1, n} + T_{m-1, n} - 2T_{m, n} = 0$$

Chapter 3

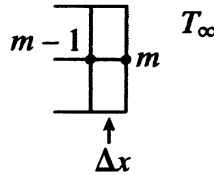
3-38

$$kA \frac{T_{m-1} - T_m}{\Delta x} - hA(T_m - T_\infty) = 0$$



then:

$$T_m \left[\frac{h}{k}(\Delta x) + 1 \right] - T_\infty \left[\frac{h}{k}(\Delta x) \right] - T_{m-1} = 0$$



3-39

$$\frac{d^2 T}{dx^2} - \frac{hP}{kA}(T - T_\infty) = 0 \quad \left. \frac{d^2 T}{dx^2} \right|_{m,n} \approx \frac{T_{m+1,n} - T_{m,n} - T_{m,n} + T_{m-1,n}}{(\Delta x)^2}$$

Substituting T_m for T above:

$$T_m \left[\frac{hP(\Delta x)^2}{kA} + 2 \right] - \left[\frac{hP(\Delta x)^2}{kA} \right] T_\infty - (T_{m-1} + T_{m+1}) = \bar{q}_m$$

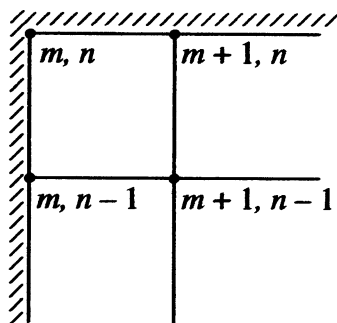
3-40

$$T_{m,n+1} + T_{m,n-1} + 2T_{m-1,n} - 4T_{m,n} = \bar{q}_{m,n}$$

$$\frac{hA(T_{m-1,n} - T_{m,n})}{\Delta x} + \frac{hA(T_{m,n+1} - T_{m,n})}{2\Delta y} + \frac{hA(T_{m,n-1} - T_{m,n})}{2\Delta y} = \bar{q}_{m,n}$$

for $\Delta x = \Delta y$: $T_{m,n+1} + T_{m,n-1} + 2T_{m-1,n} - 4T_{m,n} = \bar{q}_{m,n}$

3-42



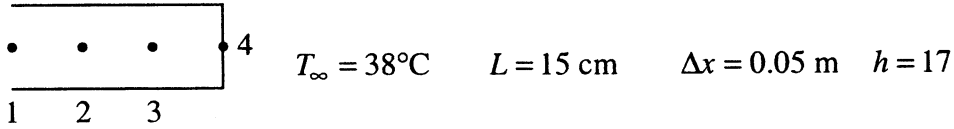
$$T_{m,n-1} + T_{m+1,n} - 2T_{m,n} = \bar{q}_{m,n}$$

3-37

$$k(T_{m-1,n} - T_{m,n}) + \frac{k}{2}(T_{m,n+1} - T_{m,n}) + \frac{k}{2}(T_{m,n-1} - T_{m,n}) + q''\Delta x = \bar{q}_{m,n}$$

3-46

$$k = 204 \quad A = \frac{\pi(0.025)^2}{4} = 4.91 \times 10^{-4} \quad T_1 = 300^\circ\text{C}$$



$$\frac{1}{R_{21}} = \frac{kA}{\Delta x} = \frac{(204)(4.91 \times 10^{-4})}{0.05} = 2.003 = \frac{1}{R_{23}}$$

$$\frac{1}{R_{1-\infty}} = hA_c = (17)\pi(0.025)(0.05) = 0.0668$$

$$\frac{1}{R_{4-\infty}} = \left(\frac{1}{2}\right)(0.0668) + \frac{(17)\pi(0.025)^2}{4} = 0.0417$$

$$\sum \frac{1}{R_{2j}} = (2)(2.003) + 0.0668 = 4.0728 = \sum \frac{1}{R_{3j}}$$

$$\sum \frac{1}{R_{4j}} = 2.003 + 0.0417 = 2.045$$

$$T_2 = \frac{(2.003)(300 + T_3) + (0.0668)(38)}{4.0728}$$

$$T_3 = \frac{(2.003)(T_2 + T_3) + (0.0668)(38)}{4.0728}$$

$$T_4 = \frac{(2.003)T_3 + (0.0417)(38)}{2.045}$$

	A	B
1	T ₂ =	=(2.003*(300+B ₂)+0.0668*38)/4.0728
2	T ₃ =	=(2.003*(B ₁ +B ₃)+0.0668*38)/4.0728
3	T ₄ =	=(2.003*B ₂ +0.0417*38)/2.045

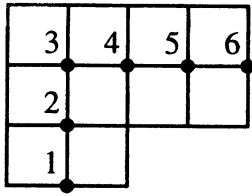
Solution:

	A	B
1	T ₂ =	279.5847538
2	T ₃ =	267.2265034
3	T ₄ =	262.5130984

$$q = -\frac{kA}{\Delta x}(T_2 - 300) = -(2.003)(279.5848 - 300) = 40.89 \text{ W}$$

Chapter 3

3-48



$\Delta x = \Delta y = 0.5 \text{ m}$ All internal nodes $k = 1.4$

	A	B
1	$T_1 =$	$=(2 \cdot B_2 + 800)/4$
2	$T_2 =$	$=(B_1 + B_3 + 800)/4$
3	$T_3 =$	$=(B_2 + B_4 + 300)/4$
4	$T_4 =$	$=(B_3 + B_5 + 800)/4$
5	$T_5 =$	$=(B_4 + B_6 + 800)/4$
6	$T_6 =$	$=(2 \cdot B_5 + 800)/4$

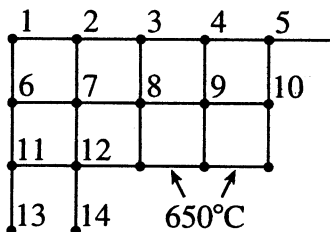
	A	B
1	$T_1 =$	379.2663
2	$T_2 =$	358.5327
3	$T_3 =$	254.8644
4	$T_4 =$	360.9250
5	$T_5 =$	388.8357
6	$T_6 =$	394.4179

q (inside) = 6781.2 W/m depth

q (outside) = 6187.2 W/m

q (avg) = 6484.2 W/m

3-49



$\Delta x = \Delta y = 0.5 \text{ m}$ $k = 1.4$ $h = 17$ $T_\infty = 38^\circ\text{C}$

Cond $\frac{1}{R} = \frac{kA}{\Delta x} = 0.7$ conv. $\frac{1}{R} = hA = 8.5$

Node	$\sum \frac{1}{R_{ij}}$
1	9.9
2, 3, 4, 5, 6, 11, 13	11.3

Using the Gauss Seidel format:

The Equations:

	A	B
1	T1=	$=(0.7*(B2+B6)+(8.5*38))/9.899999$
2	T2=	$=(0.7*(B1+B3)+(1.4*B7)+(8.5*38))/11.3$
3	T3=	$=(0.7*(B2+B4)+(1.4*B8)+(8.5*38))/11.3$
4	T4=	$=(0.7*(B3+B5)+(1.4*B9)+(8.5*38))/11.3$
5	T5=	$=(1.4*(B4+B10)+(8.5*38))/11.3$
6	T6=	$=(0.7*(B1+B11)+(1.4*B7)+(8.5*38))/11.3$
7	T7=	$=(B2+B6+B8+B12)/4$
8	T8=	$=(B3+B7+B9+650)/4$
9	T9=	$=(B4+B8+B10+650)/4$
10	T10=	$=(2*B9+B5+650)/4$
11	T11=	$=(0.7*(B6+B13)+(1.4*B12)+(8.5*38))/11.3$
12	T12=	$=(B7+B11+B14+650)/4$
13	T13=	$=(1.4*(B11+B14)+(8.5*38))/11.3$
14	T14=	$=(2*B12+B13+650)/4$

The Solution:

	A	B
1	T1=	40.96808
2	T2=	59.00557
3	T3=	76.51266
4	T4=	82.08207
5	T5=	83.26541
6	T6=	58.97151
7	T7=	186.80459
8	T8=	316.30837
9	T9=	351.91623
10	T10=	359.27447
11	T11=	75.96281
12	T12=	312.93290
13	T13=	79.99096
14	T14=	338.96419

Chapter 3

3-51

$$\frac{1}{R_{14}} = \frac{1}{R_{12}} = \frac{hA}{\Delta x} = 2.6$$

$$\frac{1}{R_{1-\infty}} = hA = 2.1$$

$$\frac{1}{R_{2-\infty}} = 4.2$$

$$\frac{1}{R_{2-5}} = 5.2$$

Node	$\sum \frac{1}{R_{ij}}$
1	7.3
2	14.6
4	10.4

The Equations:

	A	B
1	T1=	=(2.6*B2+2.6*B4)/7.3
2	T2=	=(2.6*B1+2.6*10+5.2*B5)/14.6
3		
4	T4=	=(2.6*B1+2.6*38+5.2*B5)/10.4
5	T5=	=(10+38+B2+B4)/4

The Solution:

	A	B
1	T1=	12.11864
2	T2=	11.24257
3		
4	T4=	22.78283
5	T5=	20.50635

3-53

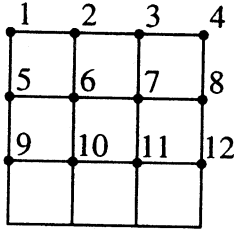
The Equations:

	A	B
1	T1=	=(1100+B3+B4)/4
2	T2=	=(600+B3+B4)/4
3	T3=	=(900+B1+B2)/4
4	T4=	=(800+B1+B2)/4

The Solution:

	A	B
1	T1=	487.5
2	T2=	362.5
3	T3=	437.5
4	T4=	412.5

3-55



$T = 50^\circ\text{C}$

$h = 40$ $T_\infty = 300^\circ\text{C}$ $k_A = 20$ $k_B = 1.2$ $k_C = 0.5$
 $\frac{1}{R_{12}} = 2.5$ $\frac{1}{R_{26}} = 80$ $\frac{1}{R_{1-\infty}} = 0.5$ $\frac{1}{R_{2-\infty}} = 0.8$ $\frac{1}{R_{15}} = 40$
 $\frac{1}{R_{9-\infty}} = 0.7$ $\frac{1}{R_{5-\infty}} = 0.4$ $\frac{1}{R_{56}} = 2.95$ $\frac{1}{R_{9-10}} = 0.70$ $\frac{1}{R_{6-10}} = 1.6$
 $R_{5-9} = 0.8$ $R_{10-50} = 0.5$ $R_{9-50} = 0.25$

The Equations:

	A	B
1	$T_1 =$	$=(0.5*300+2.5*B_2+40*B_5)/43$
2	$T_2 =$	$=(0.8*300+2.5*B_1+2.5*B_3+80*B_6)/85.8$
3	$T_3 =$	$=(0.8*300+2.5*B_2+2.5*B_4+80*B_7)/85.8$
4	$T_4 =$	$=(0.5*300+2.5*B_3+40*B_8)/43$
5	$T_5 =$	$=(40*B_1+2.95*B_6+0.8*B_9+0.4*300)/44.15$
6	$T_6 =$	$=(80*B_2+2.95*B_5+2.95*B_7+1.6*B_{10})/87.5$
7	$T_7 =$	$=(80*B_3+2.95*B_6+2.95*B_8+1.6*B_{11})/87.5$
8	$T_8 =$	$=(40*B_4+2.95*B_7+0.8*B_{12}+0.4*300)/44.15$
9	$T_9 =$	$=(0.25*50+0.8*B_5+0.7*B_{10}+0.7*300)/2.45$
10	$T_{10} =$	$=(0.5*50+1.6*B_6+0.7*B_9+0.7*B_{11})/3.5$
11	$T_{11} =$	$=(0.5*50+1.6*B_7+0.7*B_{10}+0.7*B_{12})/3.5$
12	$T_{12} =$	$=(0.25*50+0.8*B_8+0.7*B_{11}+0.7*300)/2.45$

The Solution:

	A	B
1	$T_1 =$	254.9386
2	$T_2 =$	250.6814
3	$T_3 =$	250.6819
4	$T_4 =$	254.9397
5	$T_5 =$	254.6422
6	$T_6 =$	250.0561
7	$T_7 =$	250.0565
8	$T_8 =$	254.6434
9	$T_9 =$	234.0597
10	$T_{10} =$	210.3326
11	$T_{11} =$	210.3329
12	$T_{12} =$	234.0603

Chapter 3

3-56

$$\frac{1}{R_{12}} = 0.25 \quad \frac{1}{R_{1-\infty}} = 0.8 \quad \frac{1}{R_{1-5}} = 2.0 \quad \sum \frac{1}{R_1} = 3.3 = \sum \frac{1}{R_2} = \sum \frac{1}{R_3}$$

$$\frac{1}{R_{4-\infty}} = 0.6 \quad \frac{1}{R_{8-\infty}} = 0.4 \quad \frac{1}{R_{5-6}} = 0.5 \quad \frac{1}{R_{4-8}} = 1.0$$

$$\sum \frac{1}{R_4} = 1.85 \quad \sum \frac{1}{R_5} = 5 = \sum \frac{1}{R_6} = \sum \frac{1}{R_7} \quad \sum \frac{1}{R_8} = 2.9$$

The Equations:

	A	B
1	T1=	=(75+0.25*B2+2*B5+16)/3.3
2	T2=	=(0.25*B1+0.25*B3+2*B6+16)/3.3
3	T3=	=(0.25*B2+0.25*B4+2*B7+16)/3.3
4	T4=	=(0.25*B3+B8+12)/1.85
5	T5=	=(150+0.5*B6+4*B1)/5
6	T6=	=(0.5*B5+0.5*B7+4*B2)/5
7	T7=	=(0.5*B6+0.5*B8+4*B3)/5
8	T8=	=(0.5*B7+2*B4+8)/2.9

The Solution:

	A	B
1	T1=	101.594256
2	T2=	45.79543347
3	T3=	28.45020861
4	T4=	23.35101566
5	T5=	116.4060956
6	T6=	51.30691016
7	T7=	30.29954059
8	T8=	24.08682814

3-57

The Equations:

	A	B
1	T1=	=(1.5+2*(B2/0.1)+B3/0.2)/25.15
2	T2=	=(2.25+B1/0.1+B4/0.4)/12.725
3	T3=	=(B1/0.2+2*(B4/0.05)+B5/0.2)/50
4	T4=	=(B2/0.4+B3/0.05+B6/0.4+3)/25.3
5	T5=	=(B3/0.2+2*(B6/0.05)+B7/0.2)/50
6	T6=	=(B4/0.4+B5/0.05+B8/0.4+3)/25.3
7	T7=	=(B5/0.2+2*(B8/0.05)+B9/0.2)/50
8	T8=	=(B6/0.4+B7/0.05+B10/0.4+3)/25.3
9	T9=	=(B7/0.2+2*(B10/0.05)+B13/0.2)/50
10	T10=	=(B8/0.4+B9/0.05+B14/0.1+B11/0.3+3.75)/36.21
11	T11=	=(B10/0.3+B15/0.08+B12/0.2+3.75)/21.21
12	T12=	=(B11/0.2+B16/0.2+1.5)/10.15
13	T13=	=(B9/0.2+2*(B14/0.05)+1000)/50
14	T14=	=(B10/0.1+B13/0.05+B15/0.15+2000)/46.67
15	T15=	=(B11/0.08+B14/0.15+B16/0.1+2500)/41.67
16	T16=	=(B12/0.2+B15/0.1+1000)/20

The Solution:

	A	B
1	T1=	109.7101
2	T2=	108.9655
3	T3=	115.6835
4	T4=	114.8946
5	T5=	127.9737
6	T6=	127.1008
7	T7=	147.2517
8	T8=	146.3765
9	T9=	173.5343
10	T10=	175.0162
11	T11=	184.3020
12	T12=	185.5951
13	T13=	187.9629
14	T14=	188.2619
15	T15=	191.5146
16	T16=	192.1561

3-58

$$\frac{1}{R_{12}} = \frac{(2.3)(0.125)}{0.25} = 1.15 = \frac{1}{R_{14}} \quad \frac{1}{R_{1-\infty}} = (25)(0.125) = 3.125$$

$$\sum \frac{1}{R_{1-j}} = 5.425$$

The Equations:

	A	B
1	T1=	=(5*3.125+1.15*B2+1.15*B4)/5.425
2	T2=	=(1.15*B1+1.15*B3+6.25*5+2.3*B5)/10.85
3	T3=	=(1.15*B2+115+6.25*5+2.3*B6)/10.85
4	T4=	=(1.15*B1+2.3*B5+1.15*B7)/4.6
5	T5=	=(B2+B4+B6+B8)/4
6	T6=	=(B3+B5+B9+100)/4
7	T7=	=(1.15*B4+115+2.3*B8)/4.6
8	T8=	=(B5+B7+B9+100)/4
9	T9=	=(B6+B8+200)/4

The Solution:

	A	B
1	T1=	17.86873
2	T2=	19.51926
3	T3=	29.93323
4	T4=	51.18759
5	T5=	54.59206
6	T6=	67.86016
7	T7=	77.69751
8	T8=	79.80123
9	T9=	86.91535

Chapter 3

3-59

$$\frac{1}{R_{1-\infty}} = (12)(0.25) = 3$$

$$\frac{1}{R_{12}} = \frac{(1.5)(0.125)}{0.25} = 0.75$$

The Equations:

	A	B
1	T1=	=(0.75*B2+37.5+45+1.5*B3)/6
2	T2=	=(0.75*B1+37.5+45+1.5*B4)/6
3	T3=	=(B1+B4+B5+50)/4
4	T4=	=(B2+B3+B6+50)/4
5	T5=	=(B3+B6+100)/4
6	T6=	=(B4+B5+100)/4

The Solution:

	A	B
1	T1=	27.6
2	T2=	27.6
3	T3=	41.6
4	T4=	41.6
5	T5=	47.2
6	T6=	47.2

3-60

$$\frac{1}{R_{12}} = \frac{(10)(0.005)}{0.01} = 5$$

$$\frac{1}{R_{1-\infty}} = (125)(0.01) = 1.25 \quad \frac{1}{R_{1-5}} = 10$$

$$\Sigma = 21.25 \quad \frac{1}{R_{59}} = 40$$

$$\frac{1}{R_{5-6}} = \frac{(40)(0.005)}{0.01} + \frac{10}{2} = 25$$

The Equations:

	A	B
1	T1=	=(10*B2+12.5+10*B5)/21.25
2	T2=	=(5*B1+5*B3+12.5+10*B6)/21.25
3	T3=	=(5*B2+5*B4+12.5+10*B7)/21.25
4	T4=	=(5*B3+12.5+5*B8)/11.25
5	T5=	=(10*B1+12000+50*B6)/100
6	T6=	=(25*B5+12000+10*B2+25*B7)/100
7	T7=	=(25*B6+10*B3+25*B11+10*B8)/70
8	T8=	=(10*B7+5*B4+5*B12+12.5)/21.25
9		
10		
11	T11=	=(12000+25*B7+10*B12+25*B14)/100
12	T12=	=(10*B11+12.5+5*B8+5*B15)/21.25
13		
14	T14=	=(50*B11+10*B15+12000)/100
15	T15=	=(10*B14+10*B12+12.5)/21.25

The Solution:

	A	B
1	T1=	253.5476
2	T2=	249.8672
3	T3=	236.6211
4	T4=	211.4409
5	T5=	287.6715
6	T6=	284.6335
7	T7=	270.9157
8	T8=	236.6211
9		
10		
11	T11=	284.6335
12	T12=	249.8672
13		
14	T14=	287.6715
15	T15=	253.5477

3-61

$$\frac{1}{R_{12}} = 0.5498 \quad \frac{1}{R_{1-\infty}} = 0.05027 \quad q_1 = (50 \times 10^6) \pi (0.01)^2 (0.02) = 3.142$$

$$\sum \frac{1}{R_1} = (2)(0.5498) + 0.05027 = 1.1499$$

$$\frac{1}{R_{5-\infty}} = (40)[\pi(0.01)^2 + \pi(0.01)(0.02)] = 0.0377$$

The Equations:

	A	B
1	T1=	=(200*0.5498+0.5498*B2+1.257+3.142)/1.1499
2	T2=	=(0.5498*(B1+B3)+1.257+3.142)/1.1499
3	T3=	=(0.5498*(B2+B4)+1.257+3.142)/1.1499
4	T4=	=(0.5498*(B3+B5)+1.257+3.142)/1.1499
5	T5=	=(0.5498*B4+0.0377*25+1.571)/0.5875

The Solution:

	A	B
1	T1=	172.9506
2	T2=	153.723
3	T3=	140.5582
4	T4=	132.2515
5	T5=	128.0432

Chapter 3

3-62

$$\frac{1}{R_{12}} = 0.2 \quad \frac{1}{R_{16}} = 0.05 \quad \frac{1}{R_{1-\infty_2}} = 0.25 \quad \frac{1}{R_{1-\infty_6}} = 0.5$$

$$\sum \frac{1}{R_{1-j}} = 1.0$$

The Equations:

	A	B
1	T1=	=(10+5+0.2*B2+0.05*B6)/1
2	T2=	=(0.2*B1+0.2*B3+0.1*B7+10)/1
3	T3=	=(0.2*B2+0.1*B4+0.15*B8+15)/1.2
4	T4=	=(0.1*B3+0.1*B5+0.2*B9+20)/1.4
5	T5=	=(0.2*B4+0.2*B10+20)/1.4
6	T6=	=(0.05*B1+0.05*B11+0.4*B7+20)/1.5
7	T7=	=(0.4*B6+0.4*B8+0.1*B2+0.1*B12)/1
8	T8=	=(0.4*B7+0.15*B3+75+0.2*B9)/0.9
9	T9=	=(0.2*B8+0.2*B4+100+0.2*B10)/0.8
10	T10=	=(0.4*B9+0.2*B5+100)/0.8
11	T11=	=(0.4*B12+0.05*B6+0.05*B13+20)/1.5
12	T12=	=(0.4*B11+0.1*B7+0.1*B14+200)/1
13	T13=	=(0.2*B11+0.4*B14+20)/1.5
14	T14=	=(0.4*B13+0.2*B12+200)/1

The Solution:

	A	B
1	T1=	25.497
2	T2=	38.959
3	T3=	50.304
4	T4=	59.435
5	T5=	61.412
6	T6=	54.101
7	T7=	137.990
8	T8=	210.866
9	T9=	260.187
10	T10=	270.446
11	T11=	93.603
12	T12=	281.077
13	T13=	105.378
14	T14=	298.367

3-63

$$\frac{1}{R_{12}} = \frac{(4.0)(0.00125)}{0.01} = 0.5 \quad \frac{1}{R_{1-\infty}} = (75)(0.01) = 0.75$$

$$\frac{1}{R_{13}} = \frac{(4.0)(0.01)}{0.0025} = 16 \quad \Sigma = 17.75$$

The Equations:

	A	B
1	T1=	=(0.5*B2+50+16*B3+0)/17.75
2	T2=	=(0.5*B1+50+16*B4)/17.75
3	T3=	=(1*B4+100+16*B5+16*B1)/34
4	T4=	=(1*B3+100+16*B6+16*B2)/34
5	T5=	=(0.5*B6+50+16*B3)/17
6	T6=	=(0.5*B5+50+16*B4)/17

The Solution:

	A	B
1	T1=	71.2456
2	T2=	71.2458
3	T3=	73.6871
4	T4=	73.6873
5	T5=	74.4844
6	T6=	74.4846

3-64

$$\frac{1}{R_{12}} = \frac{(20)(0.005)}{0.01} = 10 = \frac{1}{R_{14}}$$

$$q_1 = (90)(10^6)(0.005)(0.005) = 2250$$

$$\frac{1}{R_{1-\infty}} = (100)(0.005) = 0.5 \quad \sum \frac{1}{R_{1-j}} = 20.5$$

The Equations:

	A	B
1	T1=	=(10*B2+10*B4+10+2250)/20.5
2	T2=	=(10*B1+10*B3+20*B5+20+4500)/41
3	T3=	=(10*B2+1000+20*B6+20+4500)/41
4	T4=	=(10*B1+10*B7+20*B5+4500)/40
5	T5=	=(20*(B4+B2+B6+B8)+9000)/80
6	T6=	=(20*(B3+B5+100+B9)+9000)/80
7	T7=	=(10*B4+10*B10+20*B8+4500)/40
8	T8=	=(20*(B5+B7+B9+B11)+9000)/80
9	T9=	=(20*(B6+B8+100+B12)+9000)/80
10	T10=	=(10*B7+10*B11+2250)/20
11	T11=	=(10*B10+10*B12+20*B8+4500)/40
12	T12=	=(10*B11+1000+20*B9+4500)/40

The Solution:

	A	B
1	T1=	1923.864
2	T2=	1723.906
3	T3=	1120.150
4	T4=	1994.015
5	T5=	1786.001
6	T6=	1158.355
7	T7=	2030.197
8	T8=	1817.727
9	T9=	1177.269
10	T10=	2041.320
11	T11=	1827.442
12	T12=	1182.995

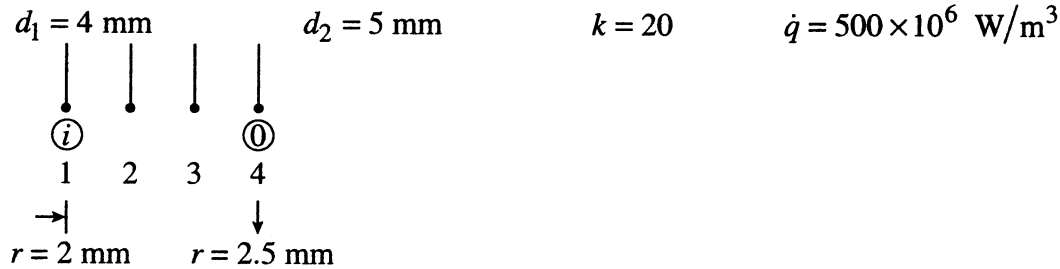
3-65

$$r = 15 \text{ cm} \quad D = 80 \text{ cm} \quad D > 5r$$

$$S = \frac{4\pi r}{\frac{\pi}{2} - \tan^{-1}\left(\frac{r}{D}\right)} = \frac{(4\pi)(0.15)}{\frac{\pi}{2} - \tan^{-1}\left(\frac{15}{80}\right)} = 1.3605$$

$$q = kS\Delta T = (3.4)(1.3605)(120 - 34) = 398 \text{ W}$$

3-67



node	r	$\frac{1}{R_+}$	$\frac{1}{R_-}$	$\sum \frac{1}{R}$	ΔV	q_i
1	2	1508	0	1508	1.05×10^{-6}	525
2	2.1667	1634	1508	3142	2.26×10^{-6}	1130
3	2.3333	1760	1634	3394	2.46×10^{-6}	1220
4	2.5	0	1760	1760	1.31×10^{-6}	654

Chapter 3

$$\frac{1}{R} = \frac{kA}{\Delta x} = \frac{(20)(2\pi r)(1)}{\Delta r} = 7.54 \times 10^5 r$$

$$\Delta r = 0.16667 \text{ mm} \quad \Delta V = 2\pi r \Delta r$$

$$T_4 = 100^\circ\text{C} \quad T_i = \frac{q_i + \sum \frac{T_j}{R_{ij}}}{\sum \frac{1}{R_{ij}}}$$

The Equations:

	A	B
1	T1=	=(525+1508*B2)/1508
2	T2=	=(1130+1508*B1+1634*B3)/3142
3	T3=	=(1220+1634*B2+176000)/3394

The Solution:

	A	B
1	T1=	102.994
2	T2=	102.646
3	T3=	101.633

3-68

Inside surface, node 1

$$\frac{1}{R_c} = hA = 2\pi rh = 2\pi(0.002)(40) = 0.503$$

$$\sum \frac{1}{R} = 0.503 + 1508 = 1508.503$$

Must specify convection temperature set at 100°C

Equation for node 1 becomes

$$T_1 = \frac{525 + 0.503(100) + 1508T_2}{1508.503}$$

Other nodal equations are the same as in Prob. 3-67

The Equations:

	A	B
1	T1=	=(525+(0.503*100)+1508*B2)/1508.503
2	T2=	=(1130+1508*B1+1634*B3)/3142
3	T3=	=(1220+1634*B2+176000)/3394

The Solution:

	A	B
1	T1=	102.992
2	T2=	102.645
3	T3=	101.633

3-69

The Equations:

	A	B
1	T1=	$=(20*B2+5*B3+1.5)/25$
2	T2=	$=(10*B1+2.5*B4+2.25)/12.5$
3	T3=	$=(40*B4+5*B1+5*B5)/50$
4	T4=	$=(20*B3+2.5*B2+2.5*B6+3)/25$
5	T5=	$=(40*B6+5*B3+5*B7)/50$
6	T6=	$=(20*B5+2.5*B4+2.5*B8+3)/25$
7	T7=	$=(40*B8+5*B5+5*B9)/50$
8	T8=	$=(20*B7+2.5*B6+2.5*B10+3)/25$
9	T9=	$=(40*B10+5*B7+5*B13)/50$
10	T10=	$=(20*B9+(10*B11/3)+10*B14+3.75)*(3/100)$
11	T11=	$=(10*B10/3)+5*B12+12.5*B15+3.75/20.8333$
12	T12=	$=(5*B11+2.5*B16+1.5)/7.5$
13	T13=	$=(5*B9+1000+40*B14)/50$
14	T14=	$=(20*B13+10*B10+2000+(10*B15/1.5))/46.6667$
15	T15=	$=(10*B14/1.5)+12.5*B11+2500+10*B16/41.6667$
16	T16=	$=(10*B15+2.5*B12+500)/15$

The Solution:

	A	B
1	T1=	207.2562
2	T2=	207.3315
3	T3=	206.6584
4	T4=	206.7337
5	T5=	205.4644
6	T6=	205.5389
7	T7=	203.6795
8	T8=	203.7402
9	T9=	201.4115
10	T10=	201.2273
11	T11=	200.8919
12	T12=	200.9536
13	T13=	200.6177
14	T14=	200.5958
15	T15=	200.4772
16	T16=	200.4771

3-70

$$\frac{1}{R_{9-10}} = \frac{(40)(0.005)}{0.01} = 20 = \frac{1}{R_{10-13}}$$

$$\frac{1}{R_{9-5}} = \frac{(40)(0.01)}{0.01} = 40$$

The Equations:

	A	B
1	T1=	$=(10*B2+12.5+10*B5)/21.25$
2	T2=	$=(5*B1+5*B3+12.5+10*B6)/21.25$
3	T3=	$=(5*B2+5*B4+12.5+10*B7)/21.25$
4	T4=	$=(5*B3+12.5+5*B8)/11.25$
5	T5=	$=(10*B1+12000+50*B6)/100$
6	T6=	$=(25*B5+12000+10*B2+25*B7)/100$
7	T7=	$=(25*B6+10*B3+25*B11+10*B8)/70$
8	T8=	$=(10*B7+5*B4+5*B12+12.5)/21.25$
9	T9=	$=(40*B5+40*B10+3)/80$
10	T10=	$=(40*B6+20*B9+20*B13+40*B11+3)/120$
11	T11=	$=(12000+25*B7+10*B12+25*B14)/100$
12	T12=	$=(10*B11+12.5+5*B8+5*B15)/21.25$
13	T13=	$=(40*B10+40*B14+3)/80$
14	T14=	$=(50*B11+10*B15+12000)/100$
15	T15=	$=(10*B14+10*B12+12.5)/21.25$

The Solution:

	A	B
1	T1=	253.5476
2	T2=	249.8672
3	T3=	236.6210
4	T4=	211.4409
5	T5=	287.6715
6	T6=	284.6335
7	T7=	270.9156
8	T8=	236.6210
9	T9=	286.5163
10	T10=	285.2861
11	T11=	284.6335
12	T12=	249.8672
13	T13=	286.5163
14	T14=	287.6715
15	T15=	253.5476

Chapter 3

3-71

Add nodes 13, 14, 15, 16 on right side

$$q_{13} = (500)(0.005)^2 + 2250 = 2252.5 = q_{16}$$

$$q_{14} = 5 + 4500 = 4505 = q_{15}$$

Equations for nodes 1, 2, 4, 5, 7, 8, 10, 11 remain the same as in Prob. 3-58.

The Equations:

	A	B
1	T1=	=(10*B2+10*B4+10+2250)/20.5
2	T2=	=(10*B1+10*B3+20*B5+20+4500)/41
3	T3=	=(10*B2+10*B13+20*B6+20+4500)/41
4	T4=	=(10*B1+10*B7+20*B5+4500)/40
5	T5=	=(20*(B4+B2+B6+B8)+9000)/80
6	T6=	=(20*(B3+B5+B9+B14)+9000)/80
7	T7=	=(10*B4+10*B10+20*B8+4500)/40
8	T8=	=(20*(B5+B7+B9+B11)+9000)/80
9	T9=	=(20*(B6+B8+B12+B15)+9000)/80
10	T10=	=(10*B7+10*B11+2250)/20
11	T11=	=(10*B10+10*B12+20*B8+4500)/40
12	T12=	=(10*B11+10*B16+20*B9+4500)/40
13	T13=	=(10*B3+10*B14+2262.5)/20.5
14	T14=	=(10*B13+20*B6+10*B15+4505)/40
15	T15=	=(10*B14+20*B9+10*B16+4505)/40
16	T16=	=(10*B12+10*B15+2252.5)/20

The Solution:

	A	B
1	T1=	27024.76
2	T2=	27024.80
3	T3=	27024.92
4	T4=	28149.96
5	T5=	28150.01
6	T6=	28150.13
7	T7=	28825.09
8	T8=	28825.13
9	T9=	28825.25
10	T10=	29050.13
11	T11=	29050.17
12	T12=	29050.29
13	T13=	27025.12
14	T14=	28150.33
15	T15=	28825.46
16	T16=	29050.50

3-72

Take resistance in terms of mean areas between nodes.

$$k = 210 \frac{W}{m \cdot ^\circ C} \quad h = 200 \frac{W}{m^2 \cdot ^\circ C} \quad r_0 = 0.5 \text{ cm} \quad r_4 = 0.25 \text{ cm}$$

$$T_\infty = 10^\circ C \quad r_2 = 0.375 \text{ cm} \quad r_1 = 0.4375 \text{ cm} \quad r_3 = 0.3125 \text{ cm}$$

$$A_0 = \pi(0.005)^2 = 7.85 \times 10^{-5}$$

$$A_1 = \pi(0.004375)^2 = 6.013 \times 10^{-5} \text{ m}^2$$

$$A_2 = \pi(0.00375)^2 = 4.418 \times 10^{-5}$$

$$A_3 = \pi(0.003125)^2 = 3.068 \times 10^{-5} \text{ m}^2$$

$$A_4 = \pi(0.0025)^2 = 1.963 \times 10^{-5}$$

Assume convection areas are $\pi d \Delta x$ at node.

$$\frac{1}{R_{10}} = \frac{kA}{\Delta x} = \frac{(210)(6.013 + 7.85)(10^{-5})}{(2)(0.015)} = 0.9704$$

$$\frac{1}{R_{12}} = \frac{(210)(6.013 + 4.418)(10^{-5})}{(2)(0.015)} = 0.7302$$

Also,

$$\frac{1}{R_{23}} = \frac{(210)(4.418 + 3.068)(10^{-5})}{(2)(0.015)} = 0.524$$

$$\frac{1}{R_{34}} = \frac{(210)(3.068 + 1.963)(10^{-5})}{(2)(0.015)} = 0.3522$$

$$\frac{1}{R_{4+}} = 0$$

$$\frac{1}{R_{1-\infty}} = \pi(2)(0.4375)(0.015)(200)(0.01) = 0.0825$$

$$\frac{1}{R_{2-\infty}} = \pi(2)(0.375)(0.015)(200)(0.01) = 0.0707$$

$$\frac{1}{R_{3-\infty}} = \pi(2)(0.3125)(0.015)(200)(0.01) = 0.0589$$

$$\frac{1}{R_{4-\infty}} = \pi(2)(0.25)(0.0075)(200)(0.01) = 0.0236$$

$$0.9704(200 - T_1) + 0.7302(T_2 - T_1) + 0.0825(10 - T_1) = 0$$

$$0.7302(T_1 - T_2) + 0.524(T_3 - T_2) + 0.0707(10 - T_2) = 0$$

$$0.524(T_2 - T_3) + 0.3522(T_4 - T_3) + 0.0589(10 - T_3) = 0$$

$$0.3522(T_3 - T_4) + 0.0236(10 - T_4) = 0$$

$$-1.7831T_1 + 0.7302T_2 = -194.905$$

$$0.7302T_1 - 1.3249T_2 + 0.524T_3 = -0.707$$

$$0.524T_2 - 0.9351T_3 + 0.3522T_4 = -0.589$$

$$0.3522T_3 - 0.3758T_4 = -0.236$$

Solution:

$$T_1 = 167.45^\circ\text{C}$$

$$T_2 = 141.99^\circ\text{C}$$

$$T_3 = 124.32^\circ\text{C}$$

$$T_4 = 117.14^\circ\text{C}$$

3-73

$$Bi = \frac{n\Delta x}{k}$$

Node

$$(1) \quad BiT_\infty + T_3 + T_2 - (Bi + 2)T_1 = 0$$

$$(2) \quad 2BiT_\infty + T_1 + T_4 - 2(Bi + 1)T_2 = 0$$

$$(3) \quad T_1 + 2T_4 + 100 - 4T_3 = 0$$

$$(4) \quad 2BiT_\infty + (2)(100) + 2T_3 + T_2 - 2(Bi + 2)T_4 = 0$$

$$(5) \quad BiT_\infty + \frac{1}{2}(200 + T_4 + T_6) - (Bi + 2)T_5 = 0$$

$$(6) \quad BiT_\infty + \frac{1}{2}(200 + T_5 + T_7) - (Bi + 2)T_6 = 0$$

$$(7) \quad T_6 + 100 - (Bi + 2)T_7 = 0$$

Chapter 3

3-74

Initial Equations:

$$140 + T_2 + T_3 - 4T_1 = 0$$

$$T_1 + T_4 + T_5 + 100 - 4T_3 = 0$$

$$40 + T_1 + T_4 - 4T_2 = 0$$

$$T_2 + T_3 + T_6 - 4T_4 = 0$$

$$200 + T_3 + T_6 - 4T_5 = 0$$

$$100 + T_4 + T_5 - 4T_6 = 0$$

Matrix Form:

T_1	T_2	T_3	T_4	T_5	T_6	C
-4	1	1	0	0	0	-140
1	-4	0	1	0	0	-40
1	0	-4	1	1	0	-100
0	1	1	-4	0	1	0
0	0	1	0	-4	1	-200
0	0	0	1	1	-4	-100

Solution:

$$T_1 = 61.615 \quad T_2 = 35.528 \quad T_3 = 70.932 \quad T_4 = 40.969 \quad T_5 = 81.615$$

$$T_5 = 55.528^\circ\text{C}$$

3-75

Node:

$$(1) \quad 100 + 2T_2 + T_4 - 4T_1 = 0$$

$$(2) \quad T_1 + 100 + T_3 + T_5 - 4T_2 = 0$$

$$(3) \quad T_2 + 150 + T_6 - 4T_3 = 0$$

$$(4) \quad T_1 + T_7 + 2T_5 - 4T_4 = 0$$

$$(5) \quad T_4 + T_2 + T_6 + T_8 - 4T_5 = 0$$

$$(6) \quad T_5 + T_3 + 50 + T_9 - 4T_6 = 0$$

$$(7) \quad \frac{k}{2}[T_4 + T_8 - 2T_7] + q'' \frac{\Delta x}{2} = 0$$

$$(8) \quad \frac{k}{2}(T_7 + 2T_5 + T_9 - 4T_8) + q'' \frac{\Delta x}{2} = 0$$

$$(9) \quad \frac{k}{2}[T_8 + 2T_6 + 50 - 4T_9] + q'' \frac{\Delta x}{2} = 0$$

3-76

Node:

$$(1) \quad k \frac{\Delta x/2}{\Delta y} (T_5 - T_1) + h \frac{\Delta x}{2} (T_\infty - T_1) + \frac{k \Delta y/2}{\Delta x} (T_2 - T_1) = 0$$

$$T_5 - T_1 + \frac{h \Delta y}{k} (T_\infty - T_1) + T_2 - T_1 = 0$$

$$T_1 = \frac{T_5 + T_2 + \frac{h \Delta y}{k} T_\infty}{2 + \frac{h \Delta y}{k}}$$

$$\text{Let } Bi = \frac{h \Delta y}{k}$$

$$k = 10 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad h = 30 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$T_\infty = 15^\circ\text{C} \quad \Delta x = \Delta y = 0.01 \text{ m}$$

$$Bi = \frac{h \Delta y}{k} = 0.03$$

$$(2) \quad T_2 = \frac{T_6 + \frac{T_1 + T_3}{2} + Bi T_\infty}{2 + Bi}$$

$$(3) \quad T_3 = \frac{T_7 + \frac{T_2 + T_4}{2} + Bi T_\infty}{2 + Bi}$$

$$(4) \quad T_4 = \frac{T_8 + \frac{T_3 + 50}{2} + Bi T_\infty}{2 + Bi}$$

$$(5) \quad T_5 = \frac{T_1 + T_9 + 2T_6}{4}$$

$$(6) \quad T_6 = \frac{T_5 + T_2 + T_7 + T_{10}}{4}$$

$$(7) \quad T_7 = \frac{T_6 + T_3 + T_8 + T_{11}}{4}$$

$$(8) \quad T_8 = \frac{T_7 + T_4 + 100 + T_{12}}{4}$$

$$(9) \quad T_9 = \frac{T_5 + T_{10}}{2}$$

$$(10) \quad T_{10} = \frac{T_9 + T_{11} + 2T_6}{4}$$

$$(11) \quad T_{11} = \frac{T_{10} + T_{12} + 2T_7}{4}$$

$$(12) \quad T_{12} = \frac{T_{11} + 150 + 2T_8}{4}$$

Chapter 3

3-77

$$x^2 + y^2 = 100 \quad \text{circle, } r = 10$$

$$\text{at } x = 6, y = 8 \text{ cm} \quad 6 + b\Delta y = 8 \quad b = \frac{2}{3}$$

$$\text{at } y = 6, x = 8 \text{ and} \quad a = \frac{2}{3}$$

$$\text{at } y = 9, x = \sqrt{19} = 4.359 \text{ cm} \quad 9 - 8 = 1 = c\Delta y \quad c = \frac{1}{3}$$

Using Table 3-2(f) for node 4

$$0 = \frac{2}{\left(\frac{2}{3}\right)\left(\frac{5}{3}\right)} T_3 + \frac{2}{\frac{4}{3}} T_6 + \frac{2}{\frac{5}{3}} T_5 + \frac{2}{\left(\frac{2}{3}\right)\left(\frac{5}{3}\right)} - 2\left(\frac{3}{2} + \frac{3}{2}\right) T_4$$

Using Table 3-2(g) for node 3

$$\frac{h\Delta x}{k} = \frac{(30)(0.03)}{10} = 0.09$$

$$\frac{\frac{\frac{2}{3}}{\left[\left(\frac{2}{3}\right)^2 + \left(\frac{2}{3}\right)^2\right]^{1/2}} T_2 + \frac{\frac{2}{3}}{\left(\frac{1}{3}\right)^2 + 1} T_7 + \frac{\frac{4}{3}}{\frac{3}{2}} T_4}{+ (0.09) \left\{ \left[\left(\frac{1}{3}\right)^2 + 1 \right]^{1/2} + \left[\left(\frac{2}{3}\right)^2 + \left(\frac{2}{3}\right)^2 \right]^{1/2} \right\}} (20) \\ - [\text{Insert values of } a, b, c, \text{ etc.}] T_3 = 0$$

3-78

$$b = \frac{1}{2} \quad a = \frac{1}{2} \quad c = \frac{3}{2}$$

Nomenclature fits Table 3-2(f, g) exactly. Insert above values for final equations.

3-79

Same as Prob. 3-78 except that insulated surface is equivalent to $h = 0$, inserted in the equations.

3-80

The same as Prob. 3-78 except that T_∞ would be inserted for T_1 and T_3 .

3-81

Assume $\Delta x = \Delta y$

Nodes 3 and 6 correspond to Node m, n of Table 3-2(f) but for different media.

The correspondence with the equations in Table 3-2(f) is as follows:

Node 3, Material A

$$a = 0.5 \quad b = 0.5 \quad T_{m, n} = T_3 \quad T_{m, n-1} = T_2 \quad T_{m+1, n} = T_1$$

$$T_2 = T_4 \quad T_1 = T_5$$

Node 6, Material A

$$a = 0.5 \quad b = 0.5 \quad T_{m, n} = T_6 \quad T_{m, n-1} = T_8 \quad T_{m+1, n} = T_7$$

$$T_2 = T_4 \quad T_1 = T_9$$

For nodes 4 and 5, the connecting resistances between the two materials must be

taken into account $a = \frac{1}{2}$, $b = \frac{1}{2}$, $c = \frac{1}{2}$ for Material A.

Node 4, Material A

$$R_{43_A} = \frac{2b}{k_A(a+1)} \quad R_{49_A} = \frac{2(c^2+1)^{1/2}}{bk_A} \quad R_{45_A} = \frac{2(a^2+b^2)^{1/2}}{bk_A}$$

Node 4, Material B

$$a = \frac{1}{2} \quad b = \frac{1}{2} \quad c = \frac{1}{2}$$

$$R_{46_B} = \frac{2a}{(1+b)k_B} \quad R_{45_B} = \frac{2(c^2+1)^{1/2}}{bk_B} \quad R_{49_B} = \frac{2(a^2+b^2)^{1/2}}{bk_B}$$

$$R_{49|_{\text{Tot}}} = \frac{1}{\frac{1}{R_{49_A}} + \frac{1}{R_{49_B}}} = R_{49} \quad R_{45|_{\text{Tot}}} = \frac{1}{\frac{1}{R_{45_A}} + \frac{1}{R_{45_B}}} = R_{45}$$

Nodal Equation for Node 4:

$$\frac{T_6 - T_4}{R_{46_B}} + \frac{T_3 - T_4}{R_{43_A}} + \frac{T_9 - T_4}{R_{49}} + \frac{T_5 - T_4}{R_{45}} = 0$$

Similar equation for Node 5 in terms of nodes 3, 4, 10, and 11.

3-82

$$W > L \quad W = 50 \text{ cm} \quad L = 25 \text{ cm}$$

$$S = \frac{2\pi W}{\ln(4W/L)} = \frac{2\pi(0.5)}{\ln(200/25)} = 1.511$$

$$q = kS\Delta T = (1.511)(2.8)(78 - 15) = 266.5 \text{ W}$$

Chapter 3

3-83

$$L = 0.2 \text{ m} \quad S = 8.24L = 1.648$$
$$q = kS\Delta T = (2.3)(1.648)(80 - 10) = 265.3 \text{ W}$$

Sphere

$$S = 4\pi r = 4\pi(0.1) = 1.2567$$
$$q = kS\Delta T = (2.3)(1.2567)(80 - 10) = 202.32 \text{ W}$$

$$V (\text{cube}) = (0.2)^3 = 8 \times 10^{-3} \text{ m}^3$$

$$V (\text{sphere}) = \frac{4}{3}\pi(0.1)^3 = 4.189 \times 10^{-3} \text{ m}^3$$

$$\frac{q}{V} (\text{cube}) = \frac{265.3}{8 \times 10^{-3}} = 33,162 \text{ W/m}^3$$

$$\frac{q}{V} (\text{sphere}) = \frac{202.32}{4.189 \times 10^{-3}} = 48,300 \text{ W/m}^3$$

3-84

$$r = 5 \text{ cm} \quad D = 15 \text{ cm}$$
$$\frac{S}{L} = \frac{2\pi}{\ln(4D/r)} = \frac{2\pi}{\ln(60/5)} = 2.529$$

$$\frac{q}{L} = kS\Delta T = (10)(2.529)(100 - 20) = 2023 \text{ W}$$

3-86

$$W = 90 \text{ cm} \quad L = 10 \text{ cm} \quad D = 2.0 \text{ m} \quad \Delta T = 50 - 10 = 40^\circ\text{C} \quad k = 1.5$$

$$D > 2W \quad W \gg L$$
$$S = \frac{2\pi W}{\ln\left(\frac{2\pi D}{L}\right)} = \frac{2\pi(0.9)}{\ln\left(\frac{2\pi(2)}{0.1}\right)} = 1.17$$

$$q = kS\Delta T = (1.5)(1.17)(40) = 70.19 \text{ W}$$

3-87

$$\Delta T = 75 - 15 = 60^\circ\text{C} \quad r = 5 \text{ cm} \quad S = 4r = 0.2 \text{ m}$$
$$q = kS\Delta T = (3)(0.2)(60) = 36 \text{ W}$$

3-88

$$\Delta T = 60^\circ\text{C} \quad W = L = 0.1$$

$$\text{Use } S = \frac{\pi W}{\ln\left(\frac{4W}{L}\right)} = \frac{\pi(0.1)}{\ln(4)} = 0.227$$

$$q = kS\Delta T = (3)(0.227)(60) = 40.86$$

$$\frac{q}{A_{\text{square}}} = \frac{40.86}{(0.1)^2} = 4086 \text{ W/m}^2$$

$$\frac{q}{A_{\text{disc}}} = \frac{(36)(4)}{\pi(0.1)^2} = 4584 \text{ W/m}^2$$

3-89

$$S = \frac{2\pi L}{\ln\left(\frac{0.54W}{r}\right)} \quad r = 5 \text{ cm} \quad L = 20 \text{ m} \quad W = 20 \text{ cm}$$

$$S = \frac{2\pi(20)}{\ln\left(\frac{(0.54)(20)}{5}\right)} = 163.2$$

$$q = kS\Delta T = (50 \times 10^{-3})(163.2)(200 - 35) = 1346 \text{ W}$$

3-90

$$q = kS\Delta T \quad \Delta T = 100 - 24 \quad k = 0.76 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad r = 5 \text{ cm}$$

$$D = 35 \text{ cm} \quad L = 1 \text{ m}$$

$$S = \frac{2\pi}{\ln\left(\frac{4D}{r}\right)} = \frac{2\pi(1)}{\ln\left[\frac{(4)(0.35)}{0.05}\right]} = 1.886$$

$$q = (0.76)(1.886)(100 - 24) = 108.9 \text{ W}$$

3-91

$$A = 2\pi r t \text{ (conduction)} \quad \Delta V = 2\pi r \Delta r t \quad A_{\text{conv}} = 2\pi r \Delta r (2)$$

$$T_0 = \text{base temperature} \quad T_\infty =$$

Base node (adjacent)

$$k(T_0 - T_m) \left(r_m - \frac{\Delta r}{2} \right) \frac{2\pi t}{\Delta r} + \dot{q}(2\pi) r_m \Delta r t + h(2)(2\pi) r_m \Delta r (T_\infty - T_m)$$

$$= k(T_m - T_{m+1}) \left(r_m + \frac{\Delta r}{2} \right) \left(\frac{2\pi t}{\Delta r} \right)$$

Middle node

$$k(T_{m-1} - T_m) \left(r_m - \frac{\Delta r}{2} \right) \frac{2\pi t}{\Delta r} + \dot{q}(2\pi) (r_m \Delta r t) + h(2)(2\pi r_m \Delta r) (T_\infty - T_m)$$

$$= k(T_m - T_{m+1}) \left(r_m + \frac{\Delta r}{2} \right) \left(\frac{2\pi t}{\Delta r} \right)$$

Chapter 3

Tip node

$$k(T_{m-1} - T_m) \left(r_m - \frac{\Delta r}{2} \right) \frac{2\pi t}{\Delta r} + \dot{q}(2\pi) r_m \left(\frac{\Delta r}{2} \right) t + h(2)(2\pi r_m) \frac{\Delta r}{2} (T_\infty - T_m) \\ = h(2\pi r_m) t (T_m - T_\infty)$$

3-92

$$A_{\text{cond}} = 2\pi r t \quad r = 0.25x + 0.01 \quad x = 0 \text{ at top of cone}$$

$$kt(2\pi r_{x-\frac{\Delta x}{2}}) \frac{T_{m-1} - T_m}{\Delta x} + kt(2\pi r_{x+\frac{\Delta x}{2}}) \frac{T_{m+1} - T_m}{\Delta x} = 0$$

$$\left[0.25 \left(x - \frac{\Delta x}{2} \right) + 0.01 \right] (T_{m-1} - T_m) + \left[0.25 \left(x + \frac{\Delta x}{2} \right) + 0.01 \right] (T_{m+1} - T_m) = 0$$

3-93

$$T_0 = 50 \text{ K} \quad T_6 = 0 \text{ K} \quad r_1 = \frac{1.5}{2} = 0.75 \text{ cm} \quad r_2 = \frac{1.7}{2} = 0.85 \text{ cm}$$

$$r_m = \frac{r_1 + r_2}{2} \quad \Delta\theta = \frac{\pi}{12} \quad rd\theta = r_m \Delta\theta \quad A = (r_2 - r_1)(1) \text{ per unit depth}$$

$$k = 100 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

Node 1

$$kA \frac{T_0 - T_1}{rd\theta} + kA \frac{T_2 - T_1}{rd\theta} = 0$$

$$T_1 = \frac{T_0 + T_2}{2} \quad T_2 = \frac{T_1 + T_3}{2} \quad T_3 = \frac{T_2 + T_4}{2} \quad T_5 = \frac{T_4 + T_6}{2}$$

Solution

$$T_0 = 50$$

$$T_1 = 41.667$$

$$T_2 = 33.333$$

$$T_3 = 25$$

$$T_4 = 16.667$$

$$T_5 = 8.333$$

$$T_6 = 0$$

Because outside surface is insulated a linear temperature distribution results.

3-94

$$S = 8.246 \quad L = 0.3$$

$$= 2.472$$

$$q = kS\Delta T = (1.8)(2.472)(30 - 10) = 88.99 \text{ W}$$

3-95)

$$D = 0.2 \quad r = 0.025$$

$$S = \frac{4\pi(0.075)}{\frac{\pi}{2} + \tan^{-1}\left(\frac{0.075}{0.4}\right)} = 0.5367$$

$$q = kS\Delta T = (2.7)(0.5367)(87 - 13) = 107.2 \text{ W}$$

3-96

$$s = \frac{4\pi L}{\ln\left(\frac{2L}{r}\right)} = \frac{2\pi(0.4)}{\ln\left(\frac{80}{1}\right)} = 0.5734$$

$$q = kS\Delta T = (3.4)(0.5734)(50 - 20) = 58.5 \text{ W}$$

3-97

$$T_0 = 323 \text{ K} \quad T_6 = 373 \text{ K} \quad T_\infty = 303 \text{ K} \quad r_1 = \frac{1.5}{2} \quad r_2 = \frac{1.7}{2}$$

$$r_m = \frac{r_1 + r_2}{2} \quad rd\theta = r_m \Delta\theta \quad \Delta\theta = \frac{\pi}{12} \quad A = (r_2 - r_1)(1) \text{ per m depth}$$

$$k = 100 \quad h = 75$$

Node 1

$$kA \frac{T_0 - T_1}{rd\theta} + kA \frac{T_2 - T_1}{rd\theta} + 2hrd\theta(1)(T_\infty - T_1) = 0$$

$$\text{Let } C = \frac{2hr_m(\Delta\theta)^2}{kA}$$

$$T_1 = \frac{T_0 + T_2 + CT_\infty}{2 + C}$$

$$T_2 = \frac{T_1 + T_3 + CT_\infty}{2 + C}$$

$$T_3 = \frac{T_2 + T_4 + CT_\infty}{2 + C}$$

$$T_4 = \frac{T_3 + T_5 + CT_\infty}{2 + C}$$

$$T_5 = \frac{T_4 + T_6 + CT_\infty}{2 + C}$$

Solution

$$T_1 = 330.7$$

$$T_2 = 338.6$$

$$T_3 = 346.7$$

$$T_4 = 355.1$$

$$T_5 = 363.9$$

Analytical solution is obtained from temperature equation of Example 2-10 with

$$\dot{q} = 0 \text{ and}$$

Chapter 3

$$m = \left(\frac{hP}{kA} \right)^{1/2} \quad P = 2[(r_2 - r_1) + 1] \quad \theta_1 = T_0 - T_\infty \quad \theta_2 = T_6 - T_\infty \quad x_1 = r_m \Delta \theta$$

$$x_2 = 2r_m \Delta \theta; \text{ etc.}$$

Numerical solution agrees with analytical solution.

3-99

$$q = \frac{\Delta T}{R_{\text{Overall}}}$$

$$R_{\text{Overall}} = R_{\text{inside convection}} + R_{\text{wall}} + R_{\text{outside}}$$

$$R_{\text{inside convection}} = \frac{1}{hA_{\text{inside}}}$$

$$R_{\text{wall}} = \frac{\Delta x}{kA_{\text{wall mean}}}$$

$$A_{\text{wall mean}} = \frac{A_{\text{inside}} + A_{\text{outside}}}{2}$$

$$R_{\text{outside}} = \frac{1}{k_{\text{soil}} S}$$

S = shape factor from outside wall to soil which must be estimated by considering several different geometries.

3-100

For this problem the overall thermal resistance will be the sum of the resistance of the pipe wall plus the resistance resulting from the shape factor for a buried pipe. From a practical standpoint one might want to use several small pipes operating in series to minimize pressure losses due to fluid friction, but that is not a consideration in this problem. Properties of plastic pipe may be taken as that of PVC from the appendix. The overall temperature difference may be taken as the mean water temperature minus the soil temperature at depth. To start the selection process take the outside wall temperature as that of the water and choose some convenient depth for the pipe. Then select a standard diameter (1 inch, 2 inch) and determine the shape factor per unit length. Then determine the required surface area and pipe length. Then refine calculation by including pipe wall thermal resistance. Repeat the calculation for several pipe sizes for both steel and plastic. If possible, obtain some cost information for the pipe as a function of diameter and examine the influence on the total cost. Something like copper tubing is probably not a viable alternative because of the high cost. PVC pipe will probably represent the lowest installed cost option.

3-101

For this problem only consider conventional electric burners which have spiral heating coils. Halogen and radiant burners have different characteristics. To simplify the study, one might consider just the aluminum layer for an initial calculation. The major spreading effect is caused by this layer. After the heat spreads, the stainless steel acts mainly as a series thermal resistance and the objective here is to evaluate the effectiveness of the aluminum in bringing about uniform heating. Although the pan is circular, an initial study could consider just the spreading effect of approximately 6 mm heater elements spaced 18 mm on centers in intimate contact with an infinite aluminum plate exposed to the given convection condition on the top surface. The objective is to determine the uniformity of the surface temperature in contact with the water. The analysis can then be refined to include a contact conductance between the heater element and the pan, but this should mainly be evidenced as a lowering of the effective burner temperature. Keep in mind that the given value of $h = 1500 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$ could vary by $\pm 40\%$ or more, so elaborate numerical models are not necessary.

3-103

The analysis of this problem requires that the heat gained by the building from all sources be equal to the cooling supplied by the refrigeration system. The heat gained from the ground passes through two thermal resistances: that of the concrete slab and that resulting from the shape factor of the slab in contact with the ground. In addition, of course, there is an internal convection resistance. The heat gained from the outside environment air passes through thermal resistances of the outside convection, concrete wall, inside convection, and whatever resistance results from installation of the outside insulating material. Note that the heat gained through the floor slab will not depend on the outside insulation, as long as the interior conditions are maintained constant.

Chapter 4

4-1

$$T_{\infty} = T_m + A_m \sin \omega \tau$$

$$\text{Energy balance: } q = hA(T - T_{\infty}) = \rho c V \left(\frac{dT}{d\tau} \right)$$

Let $K = \frac{hA}{\rho c V}$ along with initial condition $T = T_0$ at $\tau = 0$;

Solution is:

$$T - T_m = (T_0 - T_m)e^{-K\tau} + \left(\frac{KA_m}{\omega^2 + K^2} \right) [\omega(e^{-K\tau} - \cos \omega \tau) + K \sin \omega \tau]$$

4-2

$$\alpha = 1.8 \times 10^{-6} \text{ m}^2/\text{sec} \quad 2L = 2.5 \text{ cm} \quad T_i = 150^\circ\text{C} \quad T_1 = 30^\circ\text{C}$$

$$\tau = 1 \text{ min} = 60 \text{ sec} \quad \frac{\pi x}{2L} = \frac{\pi}{2}; \left(\frac{\pi}{2L} \right)^2 \alpha \tau = 1.705$$

1st four nonzero terms $n = 1, 3, 5, 7$

$$\frac{T - T_1}{T_i - T_1} = \frac{4}{\pi} [0.1818 - 7.22 \times 10^{-8} + 6.15 \times 10^{28}] = 0.231$$

$$T = 30 + (0.231)(150 - 30) = 57.8^\circ\text{C} \quad \frac{\alpha \tau}{L^2} = 0.69 \quad \frac{\theta_0}{\theta_i} = 0.25$$

4-3

$$\text{at } \tau = 0 \quad \frac{x}{2L} = \frac{1}{2} \quad \frac{\pi x}{2L} = \frac{\pi}{2}$$

$$\frac{T - T_1}{T_i - T_1} = \frac{4}{\pi} \left(\sin \frac{\pi}{2} + \frac{1}{3} \sin \frac{3\pi}{2} + \frac{1}{5} \sin \frac{5\pi}{2} + \frac{1}{7} \sin \frac{7\pi}{2} \right) = 0.9216$$

correct value is 1.0 Error = 7.84%

4-4

$$q = \sigma A(T^4 - T_{\infty}^4) + hA(T - T_{\infty}) = -c\rho V \frac{dT}{d\tau}$$

4-5

$$T_0 = 250^\circ\text{C} \quad T = 90^\circ\text{C} \quad T_\infty = 35^\circ\text{C}$$

$$R_{th} = \frac{1}{2} \left(\frac{\Delta x}{kA} \right) = \left(\frac{1}{2} \right) \left[\frac{0.05}{(0.2)^2 (370)} \right] = 1.69 \times 10^{-3}$$

$$C_{th} = \rho c V = (8900)(380)(0.05)(0.2)^2 = 6764$$

$$\frac{1}{R_{th} C_{th}} = 0.0875$$

$$\frac{T - T_\infty}{T_0 - T_\infty} = \exp(-0.0875\tau) = \frac{90 - 35}{250 - 35} = 0.2558$$

$$\tau = 15.58 \text{ sec}$$

4-6

$$m = \rho V \quad \rho = 2707 \text{ kg/m}^3 \quad c = 896 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}} \quad h = 58$$

$$\frac{4}{3} \pi r^3 (2700) = 6 \quad r = 0.0807 \text{ m}$$

$$A = 4\pi r^2 = 0.0822 \text{ m}^2$$

$$\frac{hA}{\rho c V} = \frac{(58)(0.0822)}{(6)(896)} = 8.87 \times 10^{-4}$$

$$\frac{90 - 20}{300 - 20} = \exp(-8.87 \times 10^{-4} \tau) = 0.25$$

$$\tau = 1563 \text{ sec}$$

4-9

$$\frac{q}{A} = \sigma \epsilon (T^4 - T_s^4) = -\rho c (2L) \frac{dT}{d\tau}$$

$$\frac{dT}{T_s^4 - T^4} = \frac{\sigma \epsilon}{2\rho c L} d\tau$$

$$\int_{T_i}^T \frac{dT}{T_s^4 - T^4} = \left[\frac{1}{4T_s^3} \log \left| \frac{T_s + T}{T_s - T} \right| + \frac{1}{2T_s^3} \tan^{-1} \left(\frac{T}{T_s} \right) \right]_{T_i}^T \quad (\text{a})$$

$$\int_0^\tau \frac{\sigma \epsilon d\tau}{2\rho c L} = \frac{\sigma \epsilon \tau}{2\rho c L} \quad (\text{b})$$

Setting (a) = (b) produces an equation for T as a function of τ . For specific problems the answer is more easily obtained with numerical methods.

Chapter 4

4-10

$$T_0 = 25^\circ\text{C} \quad T_\infty = 150^\circ\text{C} \quad h = 120 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad T = 120^\circ\text{C}$$

$$\rho = 7817 \quad c = 460 \quad d = 6.4 \text{ mm}$$

$$\frac{A}{V} = \frac{4}{d}$$

$$\frac{hA}{\rho c V} = \frac{(120)(4)}{(0.0064)(7817)(460)} = 0.02086$$

$$\frac{T - T_\infty}{T_0 - T_\infty} = \exp\left(-\frac{hA}{\rho c V} \tau\right)$$

$$\frac{120 - 25}{150 - 25} = 0.76 = e^{-0.02086\tau}$$

$$\tau = 13.16 \text{ sec}$$

4-11

$$T_\infty = 20^\circ\text{C} \quad T_0 = 200^\circ\text{C} \quad h = 28 \quad d = 5 \text{ cm} \quad T = 90^\circ\text{C}$$

$$\rho = 8954 \quad c = 383$$

$$\frac{A}{V} = \frac{3}{r}$$

$$\frac{hA}{\rho c V} = \frac{(28)(3)}{(0.025)(8954)(383)} = 9.8 \times 10^{-4}$$

$$\frac{90 - 20}{200 - 20} = 0.3889 = e^{-9.8 \times 10^{-4} \tau}$$

$$\tau = 964 \text{ sec}$$

4-13

$$\text{Lumped Capacity} \quad \rho = 8954 \quad c = 383$$

$$\frac{hA}{\rho c V} = \frac{(15)(4\pi)(0.015)^2}{(8954)(383)\left[\frac{4}{3}\pi(0.015)^3\right]} = 8.75 \times 10^{-4}$$

$$\frac{25 - 10}{50 - 10} = e^{-8.75 \times 10^{-4} \tau} \quad \tau = 1121 \text{ sec}$$

4-14

$$\rho = 2707 \quad c = 896 \quad \sigma A T^4 = -\rho c V \frac{dT}{d\tau} \quad T \text{ in } ^\circ\text{K}$$

$$\frac{dT}{T^4} = \frac{-\sigma A}{\rho c V} d\tau \quad \frac{1}{T^3} - \frac{1}{T_0^3} = \frac{\sigma A \tau}{\rho c V}$$

$$T = -240 + 273 = 33 \text{ K} \quad T_0 = 40 + 273 = 313 \text{ K} \quad \tau = 9.9 \times 10^6 \text{ sec}$$

4-15

$$\rho = 999.8 \quad c = 4225 \quad L = 2d \quad A = 2.5\pi d^2 \quad V = \frac{1}{2}\pi d^3$$

$$d = 6.06 \text{ cm} \quad A = 288.5 \text{ cm}^2$$

$$\frac{hA}{\rho c V} = \frac{(15)(288.5)(10^{-4})}{(999.8)(4225)(350)(10^{-6})} = 2.927 \times 10^{-4}$$

$$\frac{15 - 20}{1 - 20} = e^{-2.927 \times 10^{-4} \tau} \quad \tau = 456 \text{ sec}$$

4-16

$$\frac{h(V/A)}{k} = \frac{(10)(0.006)}{(3)(204)} = 9.8 \times 10^{-5}$$

$$\text{lumped capacity} \quad \rho = 2707 \quad c = 896$$

$$\frac{200 - 20}{400 - 20} = e^{-\left[\frac{(10)(3)\tau}{(0.006)(896)(2707)}\right]} = 0.4737 \quad \tau = 362 \text{ sec}$$

4-17

$$\frac{h(V/A)}{k} = \frac{hV}{3k} = \frac{(20)(0.02)}{(3)(380)} = 3.5 \times 10^{-4}$$

$$\text{lumped capacity} \quad c = 383 \quad \rho = 8954$$

$$\frac{80 - 30}{220 - 30} = e^{-\left[\frac{(20)(3)\tau}{(0.02)(383)(8954)}\right]} = 0.263 \quad \tau = 1494 \text{ sec}$$

4-18

$$A = \frac{90 - 35}{2} = 27.5^\circ\text{C} \quad x = 5 \text{ cm} = 0.05 \text{ m} \quad k = 1.37 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$a = 7 \times 10^{-7} \text{ m}^2/\text{sec} \quad n = \frac{1 \text{ cyc}}{15 \text{ min}} = 1.1111 \times 10^{-3} \text{ cyc/sec}$$

$$x = \sqrt{\frac{\pi n}{\alpha}} = 0.05 \left[\frac{\pi(1.1111 \times 10^{-3})}{7 \times 10^{-7}} \right]^{1/2} = 3.531$$

$$2n\pi\tau = 2\pi(1.1111 \times 10^{-3})(2)(3600) = 50.26$$

$$2n\pi\tau - x\sqrt{\frac{\pi n}{\alpha}} = 46.734 \text{ radians} = 2677.66^\circ$$

$$\cos(2677.66) = -0.925 \quad \sin(2677.66) = 0.3801$$

$$\frac{q}{A} = kAe^{-x\sqrt{\frac{\pi n}{\alpha}}} \left(\sqrt{\frac{\pi n}{\alpha}} \right) [\cos(2677.66) + \sin(2677.66)]$$

$$\frac{q}{A} = (1.37)(27.5)(e^{-3.531})(-0.925 + 0.3801) = -0.601 \text{ W/m}^2$$

Chapter 4

4-19

Maximum points when sine function is max, i.e.:

$$2\pi n\tau - x\sqrt{\frac{\pi n}{\alpha}} = \frac{\pi}{2} \quad \text{at } x=0 \quad \tau = \frac{\pi}{4\pi n} = \frac{1}{4n}$$

$$\text{at } x = x_1 \quad \tau = \frac{\pi}{4\pi n} + \frac{x\sqrt{\frac{\pi n}{\alpha}}}{2\pi n} = \frac{1}{4n} + \frac{x}{2}\sqrt{\frac{1}{\pi\alpha n}}$$

$$\Delta\tau = \frac{x}{2}\sqrt{\frac{1}{\pi\alpha n}}$$

4-20

$$T_i = 54^\circ\text{C} \quad T_\infty = 10^\circ\text{C} \quad h = 10 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad x = 7 \text{ cm} \quad \tau = 30 \text{ min}$$

$$\alpha = 7 \times 10^{-7} \text{ m}^2/\text{sec} \quad k = 1.37 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\frac{x}{2\sqrt{\alpha\tau}} = \frac{0.07}{2[(7 \times 10^{-7})(30)(60)]^{1/2}} = 0.986$$

$$\frac{T - T_i}{T_\infty - T_i} = 0.021$$

$$\frac{h\sqrt{\alpha\tau}}{k} = \frac{(10)[(7.7 \times 10^{-7})(30)(60)]^{1/2}}{1.37} = 0.258$$

$$T = 53.08^\circ\text{C}$$

4-21

$$T_i = 300^\circ\text{C} \quad T_0 = 35^\circ\text{C} \quad x = 7.5 \text{ cm} \quad \tau = 4 \text{ min} = 240 \text{ sec}$$

$$\alpha = 11.23 \times 10^{-5} \text{ m}^2/\text{s}$$

$$X = \frac{x}{2\sqrt{\alpha\tau}} = \frac{0.075}{2[(11.23 \times 10^{-5})(240)]^{1/2}} = 0.2284$$

$$\text{erf } X = 0.2533 = \frac{T - T_0}{T_i - T_0} \quad T = 102.1^\circ\text{C}$$

4-22

$$\alpha = 7 \times 10^{-7} \text{ m}^2/\text{s} \quad T_i = 55^\circ\text{C} \quad T_0 = 15^\circ\text{C} \quad T = 25^\circ\text{C}$$

$$x = 5 \text{ cm}$$

$$\frac{T - T_0}{T_i - T_0} = \frac{25 - 15}{55 - 15} = 0.25 = \text{erf } X$$

$$X = 0.2253 = \frac{x}{2\sqrt{\alpha\tau}}$$

$$\tau = 17,589 \text{ sec} = 4.89 \text{ hr}$$

4-23

$$\frac{q_0}{A} = 0.5 \times 10^6 \text{ W/m}^2 \quad \tau = 300 \text{ s} \quad T_i = 20^\circ\text{C} \quad k = 386$$

$$\alpha = 11.23 \times 10^{-5} \text{ m}^2/\text{s}$$

$$x = 0$$

$$T = 20 + \frac{(2)(0.5 \times 10^6) \left[\frac{(11.23 \times 10^{-5})(300)}{\pi} \right]^{1/2}}{386} e^0 = 288.3^\circ\text{C}$$

$$x = 15 \text{ cm}$$

$$X = \frac{x}{2\sqrt{\alpha\tau}} = \frac{0.15}{2[(11.23 \times 10^{-5})(300)]^{1/2}} = 0.4086$$

$$\frac{x^2}{4\alpha\tau} = 0.167 \quad \text{erf } X = 0.4173$$

$$T - T_i = \frac{2(0.5 \times 10^6) \left[\frac{(11.23 \times 10^{-5})(300)}{\pi} \right]^{1/2}}{386} e^{-0.167} - \frac{(0.5 \times 10^6)(0.15)}{386} (1 - 0.4173)$$

$$= 113.8$$

$$T = 133.8^\circ\text{C}$$

4-24 All cases remain at 20°C because $x/2(\alpha\tau)^{1/2}$ is so large.

4-26

$$T_i = 90^\circ\text{C} \quad T_0 = 30^\circ\text{C} \quad x = 7.5 \text{ cm} \quad \tau = 10 \text{ sec} \quad k = 386 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\alpha = 11.23 \times 10^{-5} \text{ m}^2/\text{s}$$

$$\frac{q}{A} = \frac{-k(T_i - T_0)}{\sqrt{\pi\alpha\tau}} e^{-\frac{x^2}{4\alpha\tau}}$$

$$\frac{q}{A} = \frac{(-386)(90 - 30)}{[\pi(11.23 \times 10^{-5})(10)]^{1/2}} \exp\left[\frac{-(0.075)^2}{4(11.23 \times 10^{-5})(10)}\right] = -111.3 \text{ kW/m}^2$$

Chapter 4

4-27

$$T_i = 30^\circ\text{C} \quad \frac{q_0}{A} = 15,000 \text{ W/m}^2 \quad x = 2.5 \text{ cm} \quad \tau = 120 \text{ sec}$$

$$k = 204 \quad \alpha = 8.42 \times 10^{-5}$$

$$T - T_i = \frac{15,000}{204} \left\{ 2 \left[\frac{(8.42 \times 10^{-5})(120)}{\pi} \right]^{1/2} \exp \left[\frac{-(0.025)^2}{4(8.42 \times 10^{-5})(120)} \right] - (0.025) \left[1 - \operatorname{erf} \left(\frac{0.025}{2\sqrt{8.42 \times 10^{-5}(120)}} \right) \right] \right\}$$

$$= 6.59$$

$$T = 36.59^\circ\text{C}$$

4-30

$$\frac{h(V/A)}{k} = \frac{h(r/3)}{k} = \frac{(78)\left(\frac{0.028}{3}\right)}{204} = 0.00357$$

Therefore: Lumped capacity $\rho = 2707$, $c = 896$

$$\frac{hA}{\rho c V} = \frac{3h}{r\rho c} = \frac{(3)(78)}{(0.028)(2707)(896)} = 0.00345$$

$$\frac{73 - 23}{355 - 23} = e^{-0.00345\tau}$$

$$\tau = 549 \text{ sec}$$

4-31

$$\frac{T - T_0}{T_i - T_0} = \frac{-1 - (-1)}{-20 - (-1)} = 0.5263 = \operatorname{erf} \frac{x}{2\sqrt{\alpha\tau}}$$

$$\frac{x}{2\sqrt{\alpha\tau}} = 0.5267$$

$$\tau = \frac{1}{0.048} \left[\frac{(0.015)(3.2808)}{2(0.5267)} \right]^2 = 0.04547 \text{ hr} = 163.7 \text{ sec}$$

4-32

$$\frac{q}{A} = 900 \text{ W/m}^2 \quad T_i = 20^\circ\text{C} \quad x = 10 \text{ cm} \quad \tau = 9 \text{ hr} = 32,400 \text{ sec}$$

$$k = 1.37 \frac{\text{W}}{\text{m}\cdot^\circ\text{C}} \quad \alpha = 7.5 \times 10^{-7} \text{ m}^2/\text{s}$$

$$T = 20 + \frac{(2)(900) \left[(7.5 \times 10^{-7}) \frac{32,400}{\pi} \right]^{1/2}}{1.37} \exp \left[\frac{-(0.1)^2}{4(7.57 \times 10^{-7})(32,400)} \right] \\ - \frac{(900)(0.1)}{1.37} \left[1 - \operatorname{erf} \left(\frac{0.1}{(2)(7.5 \times 10^{-7})(32,400)^{1/2}} \right) \right] \\ = 81.5^\circ\text{C}$$

4-33

$$T_i = 300^\circ\text{C} \quad T_0 = 100^\circ\text{C} \quad x = 0.03 \text{ m} \quad T = 200^\circ\text{C}$$

$$\frac{200 - 100}{300 - 100} = 0.5 = \operatorname{erf} \left(\frac{x}{2\sqrt{\alpha\tau}} \right) \quad \alpha = 0.444 \times 10^{-5}$$

$$\frac{x}{2\sqrt{\alpha\tau}} = 0.48 \quad \tau = \frac{\left[\frac{0.03}{(2)(0.48)} \right]^2}{0.444 \times 10^{-5}} = 2200 \text{ sec}$$

4-34

$$T_i = 40^\circ\text{C} \quad h = 25 \frac{\text{W}}{\text{m}^2\cdot^\circ\text{C}} \quad T_\infty = 2^\circ\text{C} \quad x = 0.08 \text{ m} \quad T(x) = 20^\circ\text{C}$$

$$\alpha = 5.2 \times 10^{-7} \quad k = 0.69 \frac{\text{W}}{\text{m}\cdot^\circ\text{C}}$$

$$\frac{T - T_i}{T_\infty - T_i} = \frac{20 - 40}{2 - 40} = 0.5263 \quad \frac{x}{2\sqrt{\alpha\tau}} \approx 0.4$$

$$\tau = \frac{\left[\frac{0.08}{(2)(0.4)} \right]^2}{5.2 \times 10^{-7}} = 19,231 \text{ sec}$$

Chapter 4

4-35

$$T_i = 30^\circ\text{C} \quad \frac{q}{A} = 3 \times 10^4 \quad \tau = 10 \text{ min} = 600 \text{ sec} \quad x = 3 \text{ cm}$$

$$k = 2.32 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 9.2 \times 10^{-7} \text{ m}^2/\text{s}$$

$$T = 30 + \frac{(2)(3 \times 10^4) \left[(9.2 \times 10^{-7}) \frac{600}{\pi} \right]^{1/2}}{2.32} \exp \left[\frac{-(0.03)^2}{(4)(9.2 \times 10^{-7})(600)} \right] \\ - \frac{(3 \times 10^4)(0.03)}{2.32} \left\{ 1 - \operatorname{erf} \left[\frac{0.03}{(2)(9.2 \times 10^{-7})(600)} \right] \right\} \\ = 30 + 228 = 258^\circ\text{C}$$

4-36

From symmetry same as inf. plate 6 cm thick

$$\tau = 360 \text{ sec} \quad L = 30 \text{ cm} \quad \alpha = 11.23 \times 10^{-5} \quad k = 370 \quad \frac{\alpha\tau}{L^2} = 44.92$$

$$\frac{\theta_{x=L}}{\theta_i} = \frac{150 - 100}{250 - 100} = 0.33$$

Iterative Solution:

$\frac{k}{hL}$	$\frac{\theta_0}{\theta_i}$	$\frac{\theta}{\theta_0}$	$\frac{\theta}{\theta_i}$	$\frac{\theta}{\theta_i} - 0.33$
100	0.65	1.0	0.65	0.32
50	0.42	0.98	0.41	0.08
45	0.38	0.98	0.37	0.04
40	0.34	0.98	0.33	0

$$h = \frac{370}{(40)(0.03)} = 308.3 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

4-37

$$L = 5 \text{ cm} \quad h = 1400 \quad k = 230 \quad T_i = 400 \quad \alpha = 8.42 \times 10^{-5}$$

$$T_\infty = 90 \quad T_0 = 180 \quad \frac{k}{hL} = 3.29 \quad \frac{\theta_0}{\theta_i} = 0.29 \quad \frac{\alpha\tau}{L^2} = 5.0$$

$$\tau = \frac{(0.05)^2(5)}{8.42 \times 10^{-5}} = 148 \text{ sec}$$

4-38

$$T_i = 350^\circ\text{C} \quad T_\infty = 80^\circ\text{C} \quad T_0 = 150^\circ\text{C} \quad \tau = 6 \text{ min} = 360 \text{ sec}$$

$$k = 374 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 11.23 \times 10^{-5} \quad L = 0.1 \text{ m} \quad \frac{\alpha\tau}{L^2} = 4.04$$

$$\frac{\theta_0}{\theta_i} = \frac{150 - 80}{250 - 80} = \frac{70}{170} = 0.412 \quad \frac{x}{L} = 1.0 \quad \frac{k}{hL} \approx 4.0$$

$$h = \frac{374}{(4.0)(0.1)} = 935 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

4-39

$$L = 5 \text{ cm} \quad T_i = 400^\circ\text{C} \quad T_\infty = 90^\circ\text{C} \quad h = 1400 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 8.4 \times 10^{-5} \text{ m}^2/\text{s} \quad \frac{\theta_0}{\theta_i} = \frac{180 - 90}{400 - 90} = 0.29$$

$$\frac{k}{hL} = \frac{204}{(1400)(0.05)} = 2.91 \quad \frac{\alpha\tau}{L^2} = 4.2 \quad \tau = \frac{(4.2)(0.05)^2}{8.4 \times 10^{-5}} = 125 \text{ sec}$$

4-40

$$L = 0.015 \text{ m} \quad T_i = 500^\circ\text{C} \quad T_\infty = 40^\circ\text{C} \quad h = 150 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$k = 16.3 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 0.44 \times 10^{-5} \text{ m}^2/\text{s} \quad \frac{k}{hL} = \frac{6.3}{(150)(0.015)} = 7.24$$

$$\text{at } \frac{x}{L} = 1.0 \quad \frac{\theta}{\theta_0} = 0.93$$

$$\text{For } \frac{\theta_0}{\theta_i} = \frac{120 - 40}{500 - 40} = 0.174 \quad \frac{\alpha\tau}{L^2} = 13.9$$

$$\tau = \frac{(13.9)(0.015)^2}{0.44 \times 10^{-5}} = 711 \text{ sec}$$

$$\text{For } \frac{\theta}{\theta_i} = 0.174 \quad \frac{\theta_0}{\theta_i} = \frac{0.174}{0.93} = 0.187 \quad \frac{\alpha\tau}{L^2} = 13$$

$$\tau = \frac{(13)(0.015)^2}{0.44 \times 10^{-5}} = 665 \text{ sec}$$

4-41

$$r_0 = 5 \text{ cm} \quad L = 5 \text{ cm} \quad T_i = 250^\circ\text{C} \quad T_\infty = 30^\circ\text{C} \quad h = 280 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$k = 43 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 1.172 \times 10^{-5} \text{ m}^2/\text{sec} \quad \tau = 2 \text{ min} = 120 \text{ sec}$$

$$\frac{\alpha\tau}{L^2} = \frac{\alpha\tau}{r_0^2} = 0.563 \quad \frac{k}{hL} = \frac{k}{hr_0} = 3.071$$

$$\text{cylinder: } \frac{\theta_0}{\theta_i} = 0.86 \quad \text{plate: } \frac{\theta_0}{\theta_i} = 0.93 \quad \frac{\theta_2}{\theta_0} = 0.86$$

$$\text{center: } \frac{\theta}{\theta_i} = (0.86)(0.93) = 0.8 \quad T = 175^\circ\text{C}$$

$$\text{End center: } \frac{\theta}{\theta_i} = (0.86)(0.93)(0.86) = 0.688 \quad T = 151^\circ\text{C}$$

4-42

$$T - T_i = \left[\frac{Q_0}{A\rho c(\pi\alpha\tau)^{1/2}} \right] \exp\left(\frac{-x^2}{4\alpha\tau}\right)$$

$$\frac{q}{A} = -k \frac{\partial T}{\partial x}$$

$$= -k \left[\frac{Q_0}{A\rho c(\pi\alpha\tau)^{1/2}} \right] \exp\left(\frac{-x^2}{4\alpha\tau}\right) \left(\frac{-2x}{4\alpha\tau}\right)$$

$$= \frac{1}{2} \frac{x}{\tau} \left[\frac{Q_0}{A(\pi\alpha\tau)^{1/2}} \right] \exp\left(\frac{-x^2}{4\alpha\tau}\right)$$

4-43

Assume behaves like center of 20 cm thick wall with $T_i = 15^\circ\text{C}$,

$$c = 900, \rho = 2200, k = 2.32, \alpha = 1.17 \times 10^{-6}$$

$$h = 65, \quad \theta_0/\theta_i = (5 - (-10))/(15 - (-10)) = 0.6$$

$$k/hL = 0.356$$

Fig. 4-7(b) $\alpha\tau/L^2 = 0.48$

$$\tau = (0.48)(0.1)^2 / 1.17 \times 10^{-6} = 4100 \text{ sec}$$

4-44

$$Q/A = 1.0 \text{ MJ/m}^2; \quad T_i = 20^\circ\text{C}; \quad x = 0.023; \quad \tau = 1.8 \text{ s}$$

$$\alpha = 8.4 \times 10^{-5}; \quad \rho = 2700; \quad c = 896$$

Eq. (4-13b)

$$T = 20 + \{10^6 / (2700)(896)[\pi(8.4 \times 10^{-5})(1.8)]^{1/2}\} \exp[-0.023^2 / (4)(8.4 \times 10^{-5})(1.8)] \\ = 27.91^\circ\text{C}$$

4-45

$$\rho = 7817 \quad c = 460 \quad \alpha = 0.44 \times 10^{-5} \quad x = 0.01 \quad \tau = 3$$

$$\frac{Q_0}{A} = 10^7 \text{ J/m}^2 \quad T_i = 0^\circ\text{C}$$

$$T - 0 = \frac{10^7}{(7817)(460)[\pi(0.44 \times 10^{-5})(3)]^{1/2}} \exp\left[\frac{-(0.01)^2}{(4)(0.44 \times 10^{-5})(3)}\right]$$

$$T = 431.9e^{-1.894} = 64.99^\circ\text{C}$$

4-46

$$64.99 = \frac{431.9}{1 \times 10^7} \left(\frac{Q_0}{A}\right) \exp\left[-\left(\frac{1.2}{1}\right)^2 (1.894)\right]$$

$$\frac{Q_0}{A} = 2.3 \times 10^7 \text{ J/m}^2$$

4-47

From Prob. 4-40

$$\begin{aligned}\frac{q}{A} &= \frac{1}{2} \frac{x}{\tau} \left[\frac{Q_0}{A(\pi\alpha\tau)^{1/2}} \right] \exp\left(\frac{-x^2}{4\alpha\tau}\right) \\ &= \frac{0.01}{(2)(3)} \frac{(10^7)}{[\pi(0.44 \times 10^{-5})(3)]^{1/2}} e^{-1.894} \\ &= (2.588 \times 10^6)(0.1505) = 3.89 \times 10^5 \text{ W/m}^2\end{aligned}$$

4-48

$$\begin{aligned}\rho &= 2700 & c &= 896 & \alpha &= 8.42 \times 10^{-5} & x &= 0.002 & \tau &= 0.2 \\ T_i &= 30^\circ\text{C} & T &= 600^\circ\text{C}\end{aligned}$$

$$\begin{aligned}600 - 30 &= \frac{Q_0/A}{(2700)(896)[\pi(8.42 \times 10^{-5})(0.2)]^{1/2}} \times \exp\left[\frac{-(0.002)^2}{(4)(8.42 \times 10^{-5})(0.2)}\right] \\ 570 &= \frac{\left(\frac{Q_0}{A}\right)e^{-0.0594}}{17,596}\end{aligned}$$

$$\frac{Q_0}{A} = 10.64 \text{ MJ/m}^2$$

4-49

$$\begin{aligned}\rho &= 4000 & c &= 760 & \alpha &= 120 \times 10^{-7} & x &= 0.0002 & \tau &= 0.2 \\ T_i &= 40^\circ\text{C} & T &= 900^\circ\text{C}\end{aligned}$$

$$\begin{aligned}900 - 40 &= \frac{Q_0/A}{(2700)(760)[\pi(120 \times 10^{-7})(0.2)]^{1/2}} \exp\left[\frac{-(0.0002)^2}{(4)(120 \times 10^{-7})(0.2)}\right] \\ 860 &= \frac{\left(\frac{Q_0}{A}\right)e^{-0.0042}}{8347}\end{aligned}$$

$$\frac{Q_0}{A} = 7.2 \text{ MJ/m}^2$$

4-50

$$\rho = 2700 \quad c = 840 \quad \alpha = 3.4 \times 10^{-7} \quad x = 0.0002 \quad \tau = 0.2$$

$$\begin{aligned}900 - 40 &= \frac{Q_0/A}{(2700)(840)[\pi(3.4 \times 10^{-7})(0.2)]^{1/2}} \exp\left[\frac{-(0.0002)^2}{(4)(3.4 \times 10^{-7})(0.2)}\right] \\ 860 &= \frac{\left(\frac{Q_0}{A}\right)e^{-0.1471}}{1048}\end{aligned}$$

$$\frac{Q_0}{A} = 1.04 \text{ MJ/m}^2$$

Chapter 4

4-51

$$r_0 = 5.5 \text{ cm} \quad T_i = 300^\circ\text{C} \quad T_\infty = 50^\circ\text{C} \quad h = 1200 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad T_0 = 80^\circ\text{C}$$

$$\rho = 2707 \quad c = 896 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}} \quad k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 8.4 \times 10^{-5} \text{ m}^2/\text{s}$$

$$\frac{k}{hr_0} = \frac{204}{(1200)(0.055)} = 3.09 \quad \frac{\theta_0}{\theta_i} = \frac{80 - 50}{300 - 50} = 0.12 \quad \frac{\alpha\tau}{r_0^2} = 3.7$$

$$\tau = \frac{(3.7)(0.055)^2}{8.4 \times 10^{-5}} = 133 \text{ sec} \quad \frac{h^2\alpha\tau}{k^2} = \frac{(1200)^2(8.4 \times 10^{-5})(133)}{(204)^2} = 0.386$$

$$\frac{hr_0}{k} = 0.324 \quad \frac{Q}{Q_0} = 0.85$$

$$Q_0 = \rho c V \theta_i = (2707)(896)(300 - 50)\pi(0.055)^2 = 5.76 \text{ MJ}$$

$$Q = (0.85)(5.76) = 4.9 \text{ MJ}$$

4-52

$$\alpha = 9.5 \times 10^{-7} \text{ m}^2/\text{s} \quad r_0 = 1.25 \text{ cm} \quad k = 1.52 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$T_i = 25^\circ\text{C} \quad T_\infty = 200^\circ\text{C} \quad h = 110 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \tau = 3 \text{ min} = 180 \text{ sec}$$

$$\frac{k}{hr_0} = \frac{1.52}{(110)(0.0125)} = 1.105 \quad \frac{r}{r_0} = \frac{0.64}{1.25} = 0.51$$

$$\frac{\alpha\tau}{r_0^2} = \frac{(9.5 \times 10^{-7})(180)}{(0.0125)^2} = 1.094 \quad \frac{\theta_0}{\theta_i} = 0.12 \quad \frac{\theta_r}{\theta_0} = 0.89$$

$$\text{center } T = (25 - 200)(0.12) + 200 = 179^\circ\text{C} \quad r = 6.4 \text{ mm}$$

$$T = (25 - 200)(0.12)(0.89) + 200 = 181.3^\circ\text{C}$$

4-53

$$T_i = 300^\circ\text{C} \quad T_0 = 120^\circ\text{C} \quad d = 1.5 \text{ mm} \quad r_0 = 0.75 \text{ mm} \quad T_\infty = 100^\circ\text{C}$$

$$h = 5000 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad k = 35 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 2.34 \times 10^{-5} \text{ m}^2/\text{s}$$

$$\frac{k}{hr_0} = \frac{35}{(5000)(0.00075)} = 9.33 \quad \frac{\theta_0}{\theta_i} = \frac{120 - 100}{300 - 100} = 0.1$$

$$\frac{\alpha\tau}{r_0^2} = 7.3 \quad \tau = \frac{(7.3)(0.00075)^2}{2.34 \times 10^{-5}} = 0.175 \text{ sec}$$

4-54

$$r_0 = 5 \text{ cm} \quad T_\infty = 10^\circ\text{C} \quad T_i = 250^\circ\text{C} \quad h = 280 \quad \alpha = 1.172 \times 10^{-5}$$

$$T_0 = 150^\circ\text{C} \quad k = 43 \quad \frac{\theta_0}{\theta_i} = \frac{150 - 10}{250 - 10} = 0.583$$

$$\frac{k}{hr_0} = \frac{43}{(280)(0.05)} = 3.07 \quad \frac{\alpha\tau}{r_0^2} = 0.75$$

$$\tau = \frac{(0.75)(0.05)^2}{1.172 \times 10^{-5}} = 160 \text{ sec} = 2.67 \text{ min}$$

4-55

$$T_i = 200^\circ\text{C} \quad T_\infty = 20^\circ\text{C} \quad h = 14 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad r_0 = 0.0075 \text{ m}$$

$$T_0 = 50^\circ\text{C} \quad k = 0.78 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 3.4 \times 10^{-7}$$

$$\frac{k}{hr_0} = \frac{0.78}{(14)(0.0075)} = 7.43 \quad \frac{\theta_0}{\theta_i} = \frac{50 - 20}{200 - 20} = 0.167$$

$$\frac{\alpha\tau}{r_0^2} = 4.5 \quad \tau = \frac{(4.5)(0.0075)^2}{3.4 \times 10^{-7}} = 744 \text{ sec}$$

4-56

$$r_0 = 0.0075 \text{ m} \quad T_i = 200^\circ\text{C} \quad h = 5000 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad T_\infty = 100^\circ\text{C}$$

$$T_0 = 120^\circ\text{C} \quad k = 35 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 2.34 \times 10^{-5}$$

$$\frac{k}{hr_0} = \frac{35}{(5000)(0.00075)} = 9.33 \quad \frac{\theta_0}{\theta_i} = \frac{120 - 100}{200 - 100} = 0.2$$

$$\frac{\alpha\tau}{r_0^2} = 5.2 \quad \tau = \frac{(5.2)(0.00075)^2}{2.34 \times 10^{-5}} = 0.125 \text{ sec}$$

4-57

$$T_i = 250^\circ\text{C} \quad T_\infty = 30^\circ\text{C} \quad h = 570 \quad \tau = 120 \text{ sec} \quad L_1 = L_2 = 1.25 \text{ cm}$$

$$L_3 = 3.75 \text{ cm} \quad k = 43 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 1.172 \times 10^{-5} \text{ m}^2/\text{sec}$$

$$\left. \frac{k}{hL} \right|_{1,2} = 6.035 \quad \left. \frac{k}{hL} \right|_3 = 2.01 \quad \left. \frac{\alpha\tau}{L^2} \right|_{1,2} = 9.00 \quad \left. \frac{\alpha\tau}{L^2} \right|_3 = 1.00$$

$$\left. \frac{\theta_0}{\theta_i} \right|_{1,2} = 0.25 \quad \left. \frac{\theta_0}{\theta_i} \right|_3 = 0.7 \quad \text{Center } \frac{\theta_0}{\theta_i} = (0.25)^2(0.07) = 0.0438$$

$$T = 39.6^\circ\text{C}$$

Chapter 4

4-58

$$T_{\infty} = 30^{\circ}\text{C} \quad \tau = 120 \text{ sec} \quad T_i = 220^{\circ}\text{C} \quad h = 570 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$$
$$\alpha = 1.17 \times 10^{-5} \text{ m}^2/\text{s} \quad k = 43 \frac{\text{W}}{\text{m} \cdot ^{\circ}\text{C}} \quad L_1 = L_2 = 0.025$$

$$L_3 = 0.075$$

$$\frac{\alpha\tau}{L_1^2} = \frac{(1.17 \times 10^{-5})(120)}{(0.025)^2} = 2.246$$

$$\frac{\alpha\tau}{L_3^2} = 0.25$$

$$\frac{k}{hL_1} = \frac{43}{(570)(0.025)} = 3.02$$

$$\frac{k}{hL_3} = 1.01$$

$$\left(\frac{\theta_0}{\theta_i}\right)_{L_1} = 0.54 \quad \left(\frac{\theta_0}{\theta_i}\right)_{L_3} = 0.92 \quad \left(\frac{\theta_0}{\theta_i}\right)_{\text{bar}} = (0.54)^2(0.92) = 0.268$$

$$T_0 = 30 + (0.268)(220 - 30) = 81^{\circ}\text{C}$$

4-59

$$L = 5 \text{ cm} \quad T_i = 300^{\circ}\text{C} \quad T_{\infty} = 100^{\circ}\text{C} \quad h = 900 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}} \quad \tau = 60 \text{ sec}$$

$$k = 204 \frac{\text{W}}{\text{m} \cdot ^{\circ}\text{C}} \quad \alpha = 8.42 \times 10^{-5} \text{ m}^2/\text{s} \quad \frac{k}{hL} = 4.53 \quad \frac{\alpha\tau}{L^2} = 2.02$$

$$\frac{\theta_0}{\theta_i} = 0.7 \quad \frac{\theta_L}{\theta_0} = 0.9 \quad \text{Center of face: } \frac{\theta}{\theta_i} = (0.7)(0.9) = 0.63$$

$$T = (0.63)(300 - 100) + 100 = 226^{\circ}\text{C}$$

4-60

$$r_0 = 7.5 \text{ cm} \quad L = 15 \text{ cm} \quad T_i = 25^\circ\text{C} \quad T_\infty = 0^\circ\text{C} \quad T_0 = 6^\circ\text{C}$$

$$h = 17 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \alpha = 7 \times 10^{-7} \text{ m}^2/\text{s} \quad k = 1.37 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \frac{k}{hL} = 0.54$$

$$\frac{k}{hr_0} = 1.075 \quad \frac{\theta_0}{\theta_i} = \frac{6-0}{25-0} = 0.24 = \left(\frac{\theta_0}{\theta_i} \right)_{\text{cyl}} \left(\frac{\theta_0}{\theta_i} \right)_{\text{plate}}$$

Iterative Solution:

τ	$\frac{\alpha\tau}{r_0^2}$	c	$\frac{\alpha\tau}{L^2}$	ρ	CP
3600	0.448	0.65	0.112	1.0	0.65
7200	0.896	0.28	0.224	0.9	0.252

$$\tau = 7200 \text{ sec} = 2 \text{ hr}$$

4-61

$$\frac{1}{R_{m+1}} = \frac{1}{R_{m-1}} = \frac{kA}{\Delta x} = \frac{(0.8)\pi(0.02)^2}{(4)(0.01)} = 0.02513$$

$$\frac{1}{R_\infty} = hA = (50)\pi(0.02)(0.01) = 0.031416$$

$$\sum \frac{1}{R} = 0.08168$$

$$C_m = (2700)(840)\pi(0.01)^2(0.01) = 7.125$$

$$\Delta\tau_{\max} = \frac{7.125}{0.08168} = 87.2 \text{ sec}$$

$$T_m^{p+1} = \frac{\Delta\tau}{7.125} [0.025(T_{m-1}^p - T_m^p) + (0.025)(T_{m+1}^p - T_m^p) + 0.03142(35 - T_m^p)] + T_m^p$$

4-62

$$k = 290 \quad \frac{h(V/A)}{k} = \frac{(120)(0.04)^3}{(6)(0.04)^2(240)} = 3.3 \times 10^{-3} < 0.1$$

Lumped capacity: $\rho = 2707$ $c = 896$

$$\frac{hA}{\rho c V} = \frac{(120)(6)(0.04)^2}{(2707)(896)(0.04)^3} = 7.42 \times 10^{-3}$$

$$\frac{250 - 100}{450 - 100} = e^{-7.42 \times 10^{-3} \tau} \quad \tau = 114 \text{ sec}$$

Chapter 4

4-63

$$L = 5.5 \text{ cm} \quad T_i = 400^\circ\text{C} \quad T_\infty = 85^\circ\text{C} \quad h = 1100 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \tau = 60 \text{ sec}$$

$$k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 8.4 \times 10^{-5} \text{ m}^2/\text{s} \quad \frac{k}{hL} = \frac{204}{(1100)(0.055)} = 3.37$$

$$\frac{\alpha\tau}{L^2} = \frac{(8.4 \times 10^{-5})(60)}{(0.055)^2} = 1.67 \quad \frac{\theta_0}{\theta_i} = 0.7$$

at $\frac{x}{L} = 1.0$ $\frac{\theta}{\theta_0} = 0.86$ $\frac{\theta}{\theta_i}$ at center of face = $(0.7)^3(0.86) = 0.295$

$$T = (0.295)(400 - 85) + 85 = 178^\circ\text{C}$$

4-64

$$L = 0.025 \quad T_i = 100^\circ\text{C} \quad T_\infty = 25^\circ\text{C} \quad h = 20 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad T_0 = 50^\circ\text{C}$$

$$k = 204 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \alpha = 8.4 \times 10^{-5} \text{ m}^2/\text{s}$$

$$\frac{h(V/A)}{k} = \frac{(20)(0.05)^3}{(6)(0.05)^2(204)} = 8.16 \times 10^{-4}$$

Lumped Capacity: $\frac{50 - 25}{100 - 25} = \exp\left[\frac{-(20)(6)(0.05)^2\tau}{(2707)(896)(0.05)^3}\right]$

$$\tau = 1111 \text{ sec}$$

4-65

$$T_i = 200^\circ\text{C} \quad T_\infty = 30^\circ\text{C} \quad \tau = 600 \text{ sec} \quad h = 200 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad d = 10 \text{ cm}$$

$$L = 15 \text{ cm} \quad T_0 = 100^\circ\text{C} \quad k = 16.3 \quad \alpha = 0.44 \times 10^{-5} \quad \rho = 7817$$

$$c = 460$$

$$\frac{k}{hr_0} = \frac{16.3}{(200)(0.05)} = 1.63 \quad \frac{k}{hL} = \frac{16.3}{(200)(0.075)} = 1.09$$

$$\frac{\alpha\tau}{r_0^2} = 1.056 \quad \frac{\alpha\tau}{L^2} = 0.47$$

$$\left.\frac{\theta_0}{\theta_i}\right|_c = 0.45 \quad \left.\frac{\theta_0}{\theta_i}\right|_p = 0.9 \quad \frac{\theta_0}{\theta_i} = (0.45)(0.9) = 0.405$$

$$T = (0.405)(200 - 30) + 30 = 98.8^\circ\text{C}$$

Plate

$$\frac{hL}{k} = 0.92 \quad \frac{h^2\alpha\tau}{k^2} = 0.397$$

$$\frac{hr_0}{k} = 0.61$$

$$\left. \frac{Q}{Q_0} \right|_{\text{cyl}} = 0.55 \quad \left. \frac{Q}{Q_0} \right|_{\text{plate}} = 0.2$$

$$\left. \frac{Q}{Q_0} \right|_{\text{total}} = 0.55 + 0.2(1 - 0.55) = 0.64$$

$$Q_0 = \rho c V \theta_i = (7817)(460)\pi(0.05)^2(0.15)(200 - 30) = 0.72 \text{ MJ}$$

$$Q = (0.64)(0.72) = 0.46 \text{ MJ}$$

4-66

$$L = 0.15 \quad r_0 = 0.075 \quad T_i = 300^\circ\text{C} \quad T_\infty = 20^\circ\text{C} \quad h = 35 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$T = 120^\circ\text{C} \quad k = 2.3 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \rho = 300 \text{ kg/m}^3 \quad c = 840 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}$$

$$\frac{k}{hL} = \frac{2.3}{(35)(0.15)} = 0.44 \quad \frac{k}{hr_0} = 0.88$$

$$\frac{\theta}{\theta_i} = \frac{120 - 20}{300 - 20} = 0.36 \quad \alpha = \frac{k}{\rho c} = 9.12 \times 10^{-6}$$

Geometric Center

$$\text{At } \tau = 300 \text{ sec} \quad \frac{\alpha\tau}{L^2} = \frac{(9.12 \times 10^{-6})(300)}{(0.15)^2} = 0.12 \quad \frac{\alpha\tau}{r_0^2} = 0.36$$

$$\left. \begin{array}{l} (\theta_0/\theta_i)_{\text{cyl}} = 0.7 \\ (\theta_0/\theta_i)_{\text{plate}} = 0.96 \end{array} \right\} \frac{\theta}{\theta_i} = 0.67 \text{ therefore } \tau \text{ is too small}$$

$$\text{At } \tau \approx 500 \text{ sec} \quad \frac{\alpha\tau}{r_0^2} = 0.6 \quad \frac{\theta}{\theta_i} \approx 0.4$$

Therefore $\tau \approx 500 \text{ sec}$ Center of Face

$$\frac{x}{L} = 1.0 \quad \frac{\theta}{\theta_0} = 0.43$$

$$\left(\frac{\theta_0}{\theta_i} \right)_{\text{cyl}} \times \left(\frac{\theta_0}{\theta_i} \right)_{\text{plate}} \times 0.43 = 0.36 \quad \left(\frac{\theta_0}{\theta_i} \right)_{\text{cyl}} \times \left(\frac{\theta_0}{\theta_i} \right)_{\text{plate}} = 0.84$$

 $\tau \approx 250 \text{ sec}$

Chapter 4

4-73

$$\frac{1}{R_{12}} = \frac{kA}{\Delta x} = \frac{(20)(1)}{0.0025} = 8000 = \frac{1}{R_{23}}$$

$$\frac{1}{R_{1-\infty}} = hA = 70(1) = 70$$

$$\frac{1}{R_{34}} = \frac{(1.2)(1)}{0.0075} = 160 = \frac{1}{R_{45}}$$

$$\frac{1}{R_{56}} = \frac{(0.5)(1)}{0.01} = 50 = \frac{1}{R_{67}}$$

$$C_1 = (7800)(1) \left(\frac{0.005}{4} \right) (460) = 4485$$

$$C_2 = (2)(4485) = 8970$$

$$C_3 = 4485 + (1600)(1) \left(\frac{0.015}{4} \right) (850) = 9585$$

$$C_4 = (2)(5100) = 10,200$$

$$C_5 = 5100 + (2500)(1)(0.005)(800) = 15,100$$

$$C_6 = (2)(10,000) = 20,000$$

$$C_7 = 10,000$$

$$\sum \frac{1}{R_1} = 8070 \quad \sum \frac{1}{R_2} = 16,600 \quad \sum \frac{1}{R_3} = 8000 + 160 = 8160$$

$$\sum \frac{1}{R_4} = (2)(160) = 320 \quad \sum \frac{1}{R_5} = 160 + 50 = 210$$

$$\sum \frac{1}{R_6} = (2)(50) = 100 \quad \sum \frac{1}{R_7} = 50$$

Nodes	$\frac{C_i}{\sum \frac{1}{R_i}}$
1	$4485/8070 = 0.5558 \text{ sec}$
2	$8970/16,000 = 0.5606$
3	$9585/8160 = 1.175$
4	$10,200/320 = 31.88$
5	$15,100/210 = 71.9$
6	$20,000/100 = 200$
7	$10,000/50 = 200$

Use $\Delta\tau = 0.5558 \text{ sec}$

Compute for 2, 20, 120 time increments.

The Equations

	A	B	C	D
1	T1=			$= (70 * (10 - C1) + 8000 * (C2 - C1)) * \$9 / 4485 + C1$
2	T2=			$= (8000 * (C1 - C2) + 8000 * (C3 - C2)) * \$9 / 8970 + C2$
3	T3=			$= (8000 * (C2 - C3) + 160 * (C4 - C3)) * \$9 / 9585 + C3$
4	T4=			$= (160 * (C3 - C4) + 160 * (C5 - C4)) * \$9 / 10200 + C4$
5	T5=			$= (160 * (C4 - C5) + 50 * (C6 - C5)) * \$9 / 15100 + C5$
6	T6=			$= (50 * (C5 - C6) + 50 * (C7 - C6)) * \$9 / 2000 + C6$
7	T7=			$= (50 * (C6 - C7)) * \$9 / 2000 + C7$
8				
9	Dt=		0.5558	

The Solution

4-74

$$\rho = 2000 \text{ kg/m}^3 \quad c = 960 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}} \quad k = 1.04 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\frac{1}{R_{12}} = \frac{kA}{\Delta x} = \frac{(1.04)(0.005)}{0.02} = 0.26$$

$$\frac{1}{R_{13}} = \frac{(1.04)(0.02)}{0.01} = 2.08$$

$$C_i = \rho_i c_i V_i$$

Node	V_i	C_i	$\sum \frac{1}{R_{ij}}$	$\Delta\tau_{\max}$
1	0.0001	192	3.6	53.3
2	0.00005	96	2.05	46.8
3	0.0002	384	5.2	73.8
4	0.0001	192	3.1	61.9

$$\frac{1}{R_{1-\infty}} = (50)(0.02) = 1.0$$

$$\frac{1}{R_{2-\infty}} = (50)(0.015) = 0.75$$

$$\frac{1}{R_{4-\infty}} = (50)(0.01) = 0.5$$

$$\frac{1}{R_{34}} = \frac{(1.04)(0.01)}{0.02} = 0.52$$

$$\frac{1}{R_{24}} = \frac{(1.04)(0.01)}{0.01} = 1.04$$

Chapter 4

4-75

$$k = 204 \quad c = 896 \quad \rho = 2707 \quad T_{\infty} = 20^{\circ}\text{C} \quad d = 2.5 \text{ cm}$$

$$\Delta x = 4 \text{ cm} \quad h = 50$$

$$\frac{1}{R_{m-1}} = \frac{kA}{\Delta x} = \frac{(204)\pi(0.0125)^2}{0.04} = 2.503$$

$$\frac{1}{R_{\infty}} = hA = 50 \left[\pi \left(\frac{0.04}{2} \right) (0.025) + \pi(0.0125)^2 \right] = 0.1031$$

$$\sum \frac{1}{R} = 2.6065$$

$$C = \rho c \Delta V = (2707)(896)\pi(0.0125)^2(0.02) = 23.812$$

$$\Delta \tau_{\max} = \frac{23.812}{2.6065} = 9.1356 \text{ sec}$$

$$T_m^{p+1} = \frac{\Delta \tau}{23.812} [2.503T_{m-1}^p + 0.1031(20)] + \left(1 - \frac{\Delta \tau}{9.1356} \right) T_m^p$$

4-76

$$\frac{1}{R_{31}} = \frac{kA}{\Delta x} = \frac{(2.32)(0.01)}{0.01} = 2.32$$

$$\frac{1}{R_{35}} = \frac{(0.48)(0.01)}{0.01} = 0.48$$

$$\frac{1}{R_{3-\infty}} = hA = (50)(0.01) = 0.5$$

$$\sum \frac{1}{R_3} = 2.32 + 0.48 + 0.5 = 3.3$$

$$C_3 = (3000)(0.005)(0.01)(840) + (1440)(0.005)(0.01)(1000) = 198$$

$$\Delta \tau_{\max} = \frac{198}{3.3} = 60 \text{ sec}$$

$$T_3^{p+1} = [2.32(T_1^p - T_3^p) + 0.48(T_5^p - T_3^p) + 0.05(40 - T_3^p)] \frac{\Delta \tau}{198} + T_3^p$$

4-77

$$\frac{1}{R_{m+}} = \frac{kA}{\Delta x} = \frac{1}{2}k = \frac{1}{R_{m-}}$$

$$\frac{1}{R_{n-}} = k \quad \frac{1}{R_{n+}} = hA = h\Delta x$$

$$T_{m, n}^{p+1} = \frac{\Delta\tau}{C_{m, n}} \left[\frac{k}{2} (T_{m-1, n}^p + T_{m+1, n}^p + 2T_{m, n-1}^p) + h\Delta x T_{\infty} \right]$$

$$+ \left[1 - \frac{\Delta\tau}{\Delta\tau_{\max}} \right] T_{m, n}^p$$

4-78

$$\frac{1}{R_{12}|_A} = \frac{kA}{\Delta x} = \frac{(20)(0.02)}{0.02} = 20 \quad T_{\infty} = 30^{\circ}\text{C} \quad \frac{1}{R_{13}} = \frac{(20)(0.01)}{0.04} = 5$$

$$\frac{1}{R_{12}|_B} = \frac{(1.2)(0.02)}{0.02} = 1.2 \quad \frac{1}{R_{14}} = \frac{(1.2)(0.01)}{0.04} = 0.3$$

$$\frac{1}{R_{1-\infty}} = hA = (40)(0.02) = 0.8$$

$$\sum \frac{1}{R_{1-j}} = 27.3$$

$$C_1 = \sum \rho c \Delta V = (7800)(460)(0.01)(0.02) + (1600)(850)(0.01)(0.02) = 989.6$$

$$\Delta\tau_{\max} = \frac{989.6}{27.3} = 36.25 \text{ sec}$$

$$T_1^{p+1} = \frac{\Delta\tau}{C_1} [5T_3^p + 21.2T_2^p + 0.3T_4^p + (0.8)(30)] + \left[1 - \frac{\Delta\tau}{36.25} \right] T_1^p$$

Chapter 4

4-79

$$\frac{1}{R_{13}} = \frac{(1.2)(0.0225)}{0.02} = 1.35$$

$$\frac{1}{R_{1-7}|_B} = \frac{(1.2)(0.01)}{0.03} = 0.4$$

$$\frac{1}{R_{1-7}|_C} = \frac{(0.5)(0.005)}{0.03} = 0.0833$$

$$\frac{1}{R_{12}|_B} = \frac{(1.2)(0.01)}{0.015} = 0.8$$

$$\frac{1}{R_{1-2}|_A} = \frac{(20)(0.05)}{0.015} = 6.6667$$

$$\frac{1}{R_{1-4}|_A} = \frac{(20)(0.0075)}{0.01} = 15.0$$

$$\frac{1}{R_{1-4}|_C} = \frac{(0.5)(0.015)}{0.01} = 0.75$$

$$\sum \frac{1}{R_1} = 25.05$$

$$\begin{aligned} C &= C_A + C_B + C_C = (7800)(460)(0.005)(0.0075) + (1600)(850)(0.0225)(0.01) \\ &\quad + (2500)(800)(0.005)(0.015) \\ &= 590.55 \end{aligned}$$

$$\Delta\tau_{\max} = \frac{590.55}{25.05} = 23.57 \text{ sec}$$

$$\begin{aligned} T_1^{p+1} &= \frac{\Delta\tau}{590.55} [(T_3^p - T_1^p)(1.35) + (T_7^p - T_1^p)(0.4833) + (7.4667)(T_2^p - T_1^p) \\ &\quad + (15.75)(T_4^p - T_1^p)] + T_1^p \end{aligned}$$

4-80

	ρ	C	k
A	1440	840	0.48
B	2787	883	164

$$\frac{1}{R_{54}} = \frac{(0.48)(0.005)}{0.02} + \frac{(164)(0.005)}{0.02} = 41.12$$

$$\frac{1}{R_{52}} = \frac{(0.48)(0.02)}{0.01} = 0.96 \quad \frac{1}{R_{56}} = 0.12 \quad \frac{1}{R_{58}} = \frac{(164)(0.005)}{0.02} = 41$$

$$\frac{1}{R_{5-\infty}} = (35)(0.005 + 0.01) = 0.525 \quad \sum \frac{1}{R} = 83.725$$

$$C_5 = (1440)(840)(0.02)(0.005) + (2787)(883)(0.01)(0.005) = 244.006$$

$$\Delta\tau_{\max} = \frac{244.006}{83.725} = 2.914 \text{ sec}$$

$$T_5^{p+1} = [41.12T_4^p + 0.96T_2^p + 0.12T_6^p + 41T_8^p + (55)(0.525)] \frac{\Delta\tau}{C_5} + \left(1 - \frac{\Delta\tau}{2.914}\right) T_5^p$$

4-81

Node 1

$$\frac{1}{R_{12}} = \frac{(1.04)(0.02)}{0.01} = 2.08$$

$$\frac{1}{R_{13}} = \frac{(1.04)(0.01)}{0.02} = 0.52$$

$$\sum \frac{1}{R} = (2)(2.08) + (2)(0.52) = 5.2$$

$$C_1 = (2000)(960)(0.01)(0.02) = 384$$

Node 2

$$C_2 = \frac{384}{2} = 192$$

$$\frac{1}{R_{2-\infty}} = (60)(0.02) = 1.2$$

$$\frac{1}{R_{24}} = \frac{(1.04)(0.005)}{0.02} = 0.26$$

$$\sum \frac{1}{R} = 2.08 + (2)(0.26) + 1.2 = 3.8$$

Chapter 4

Node 3

$$C_3 = (2000)(960)(0.01)(0.015) = 288$$

$$\frac{1}{R_{34}} = \frac{(1.04)(0.015)}{0.01} = 1.56$$

$$\frac{1}{R_{35}} = \frac{(1.04)(0.01)}{0.01} = 1.04$$

$$\sum \frac{1}{R} = (2)(1.56) + 1.04 + 0.52 = 4.68$$

Node 4

$$C_4 = (2000)(960)[(0.005)(0.015) + (0.005)(0.01)] = 240$$

$$\frac{1}{R_{4+}} = \frac{(1.04)(0.005)}{0.02} = 0.26$$

$$\frac{1}{R_{4-\infty}} = (60)(0.02) = 1.2$$

$$\frac{1}{R_{46}} = \frac{(1.04)(0.015)}{0.01} = 1.56$$

$$\sum \frac{1}{R} = 0.26 + 0.26 + 1.56 + 1.56 + 1.2 = 4.84$$

Node 5

$$\text{Take all } \frac{1}{R} = \frac{(1.04)(0.01)}{0.01} = 1.04$$

$$\sum \frac{1}{R} = 4.16$$

$$C_5 = (2000)(960)(0.01)(0.01) = 192$$

Node	C	$\sum \frac{1}{R}$	$\Delta\tau_{\max, \text{ sec.}}$
1	384	5.2	73.85
2	192	3.8	50.53
3	288	4.68	61.54
4	240	4.84	49.59
5	192	4.16	46.15

4-82

$$\frac{1}{R_{35}} = \frac{(15)(0.0025)}{0.02} = \frac{1}{R_{31}} = 1.875$$

$$\frac{1}{R_{34}} = \frac{(15)(0.02)}{0.005} = 60 \quad \frac{1}{R_{4-\infty}} = (25)(0.02) = 0.5$$

$$\sum \frac{1}{R} = 64.25$$

$$T_3 = \frac{(1.875)(T_1 + T_5) + 60T_4 + 0.5T_\infty}{64.25}$$

4-83

$$\text{Fraction liquified} = (1/u_{if}\rho\Delta V)\sum [(T_j - T_i)/R_{ij}]$$

4-84

$$\frac{1}{R_{76}} = \frac{(16)(0.0125)}{0.01} = 20 \quad \frac{1}{R_{74}|_A} = \frac{(16)(0.005)}{0.01} = 8$$

$$\frac{1}{R_{78}} = \frac{(100)(0.0125)}{0.02} = 62.5 \quad \frac{1}{R_{74}|_B} = \frac{(100)(0.01)}{0.01} = 100$$

$$\frac{1}{R_{7-10}|_A} = \frac{(16)(0.005)}{0.015} = 5.333 \quad \frac{1}{R_{7-10}|_B} = \frac{(100)(0.01)}{0.015} = 66.667$$

$$\sum \frac{1}{R_{7-j}} = 262.5$$

$$C_7 = (7800)(800)(0.005)(0.0125) + (2600)(500)(0.01)(0.0125) = 390 + 162.5$$

$$= 552.5$$

$$\Delta\tau_{\max} = \frac{552.5}{262.5} = 2.1048 \text{ sec}$$

4-85

$$\frac{1}{R_{21}} = \frac{(10)(0.005)}{0.02} = 2.5 \quad \frac{1}{R_{23}} = \frac{2}{4} = 0.5 \quad \frac{1}{R_{25}} = 10 + 2 = 12$$

$$\frac{1}{R_{2-\infty}} = (40)(0.02) = 0.8 \quad \sum \frac{1}{R} = 15.8$$

$$C_2 = (6500)(300)(0.01)(0.005) + (2000)(700)(0.01)(0.005) = 167.5$$

$$\Delta\tau_{\max} = 10.601 \text{ sec}$$

$$T_2^{P+1} = [2.5T_1^P + 0.5T_3^P + 12T_5^P + (0.8)(20)] \frac{\Delta\tau}{167.5} + \left(1 - \frac{\Delta\tau}{10.601}\right) T_2^P$$

Chapter 4

4-86

	ρ	C	k
A	1440	840	0.48
B	2787	883	164
C	7817	460	16.3

$$\frac{1}{R_{52}} = \frac{(0.48)(0.01)}{0.01} = 0.48$$

$$\frac{1}{R_{54}} = \frac{(0.48)(0.005)}{0.01} + \frac{(164)(0.005)}{0.01} = 82.24$$

$$\frac{1}{R_{56}} = \frac{(0.48)(0.005)}{0.01} + \frac{(16.3)(0.005)}{0.01} = 8.39$$

$$\frac{1}{R_{58}} = \frac{(164 + 16.3)(0.005)}{0.01} = 90.15$$

$$\sum \frac{1}{R} = 181.26$$

$$C_5 = (1440)(840)(0.01)(0.005) + [(2787)(883) + (7817)(460)](0.005)(0.005) = 211.90$$

$$\Delta\tau_{\max} = \frac{211.90}{181.26} = 1.169 \text{ sec}$$

4-87

$$\frac{1}{R_{42}} = \frac{(20)(0.005)}{0.01} = 10$$

$$\frac{1}{R_{43}} = \frac{(20)(0.01)}{0.01} = 20$$

$$\frac{1}{R_{45}} = \frac{(2)(0.005)}{0.02} = 0.5$$

$$\frac{1}{R_{47}} = 10 + \frac{(2)(0.01)}{0.01} = 12$$

$$\frac{1}{R_{4-\infty}} = (50)(0.01 + 0.005) = 0.75$$

$$\sum \frac{1}{R} = 43.25$$

$$C_4 = (7800)(500)(0.01)(0.005) + (1600)(800)(0.005)(0.01) = 259$$

$$\Delta\tau_{\max} = \frac{259}{43.25} = 5.988 \text{ sec}$$

$$T_4^{P+1} = [10T_2^P + 20T_3^P + 0.5T_5^P + 12T_7^P + (0.75)(50)] \frac{\Delta\tau}{C_4} + \left(1 - \frac{\Delta\tau}{5.988}\right) T_4^P$$

4-88

$$\frac{1}{R_{14}} = \frac{(200)(0.005)}{0.01} = 100$$

$$\frac{1}{R_{15}} = \frac{(30)(0.005)}{0.015} = 10$$

$$\frac{1}{R_{12}} = \frac{(200)(0.005)}{0.01} + \frac{(30)(0.0075)}{0.01} = 122.5$$

$$\frac{1}{R_{1-\infty}} = hA = (50)(0.0125) = 0.625$$

$$\sum \frac{1}{R_i} = 233.125$$

$$C_1 = (2700)(900)(0.005)(0.005) + (7800)(800)(0.005)(0.0075) = 294.75$$

$$\Delta\tau_{\max} = \frac{294.75}{233.125} = 1.264 \text{ sec}$$

$$T_1^{p+1} = \frac{\Delta\tau}{294.75} [100(T_4^p - T_1^p) + 10(T_5^p - T_1^p) + 122.5(T_2^p - T_1^p) + 0.625(10 - T_1^p)] + T_1^p$$

4-89

$$\frac{1}{R_{21}|_A} = \frac{(2)(0.005)}{0.02} = 0.5$$

$$\frac{1}{R_{25}|_A} = \frac{(2)(0.01)}{0.01} = 2$$

$$\frac{1}{R_{2-\infty}} = hA = (120)(0.005) = 0.6$$

$$\frac{1}{R_{23}|_B} = \frac{(20)(0.005)}{0.01} = 10$$

$$\frac{1}{R_{25}|_B} = \frac{(20)(0.005)}{0.01} = 10$$

$$\sum \frac{1}{R_{2-j}} = 23.1 \text{ W/}^\circ\text{C}$$

$$C_2 = (1600)(800)(0.005)(0.01) + (7800)(500)(0.005)(0.005) = 161.5 \text{ J/}^\circ\text{C}$$

$$\Delta\tau_{\max} = \frac{161.5}{23.1} = 6.991 \text{ sec}$$

$$T_2^{p+1} = \frac{\Delta\tau}{161.5} [0.5(T_1^p - T_2^p) + 10(T_3^p - T_2^p) + 12(T_5^p - T_2^p) + 0.6(10 - T_2^p)] + T_2^p$$

4-90

$$k = 16.3 \quad \rho = 7817 \quad C = 460$$

see Table 4-2(d)

$$Bi = \frac{h\Delta x}{k} = \frac{(60)(0.01)}{16.3} = 0.0368$$

$$F_0 = \frac{\alpha\Delta\tau}{(\Delta x)^2} \quad F_0(3 + Bi) \leq \frac{3}{4}$$

Chapter 4

$$\alpha = \frac{16.3}{(7817)(460)} = 4.53 \times 10^{-6}$$

$$F_0 < \frac{\frac{3}{4}}{3.0368} = 0.24697$$

$$\Delta\tau \leq \frac{(0.24697)(0.01)^2}{4.53 \times 10^{-6}} = 5.452 \text{ sec}$$

4-91

For $\Delta\tau = 1942 \text{ sec}$

$$T_1 = 11.912$$

$$T_2 = 11.097$$

$$T_4 = 22.532$$

$$T_5 = 20.329$$

The Equations

	A	B	C	D
1	T1=			$=(((2.6 * C2 + 2.6 * C4) * \$C\$7) / 14175 + (1 - \$C\$7 / 1942) * C1)$
2	T2=			$=(((2.6 * C1 + 26 + 5.2 * C5) * \$C\$7) / 28350 + (1 - \$C\$7 / 1942) * C2)$
3				
4	T4=			$=(((2.6 * C1 + 2.6 * 38 + 5.2 * C5) * \$C\$7) / 28350 + (1 - \$C\$7 / 2726) * C4)$
5	T5=			$= (5.2 * ((C2 + C4 + 38 + 10) * \$C\$7) / 56700 + (1 - \$C\$7 / 2726) * C5)$
6				
7	Dr=		1942	

The Solution

	G	H	I	J	K	L
1	Time	T1=	T2=		T4=	T5=
2	incr					
3	0	10	10		10	10
4	1	7.124092	7.124092		14.98696	14.98696
5	2	7.87606	8.388266		17.68539	16.7972
6	3	9.287557	9.167008		19.24021	18.02358
7	4	10.11878	9.85524		20.3756	18.7919
8	5	10.76837	10.27696		21.12387	19.33766
9	6	11.18512	10.58706		21.64916	19.703
10	7	11.48269	10.79142		22.0046	19.95685
11	8	11.68209	10.93484		22.25025	20.12956
12	9	11.82068	11.03187		22.41793	20.24853
13	10	11.91497	11.09893		22.53321	20.32989
14	11	11.97992	11.14471		22.61214	20.38577
15	12	12.02434	11.17618		22.66631	20.42405
16	13	12.05485	11.19773		22.70344	20.45031
17	14	12.07575	11.21251		22.72891	20.46831
18	15	12.09009	11.22265		22.74637	20.48066
19	16	12.09992	11.2296		22.75834	20.48913
20	17	12.10666	11.23437		22.76655	20.49493
21	18	12.11128	11.23764		22.77218	20.49891
22	19	12.11445	11.23988		22.77604	20.50164
23	20	12.11663	11.24141		22.77869	20.50351
24	21	12.11812	11.24247		22.7805	20.5048
25	22	12.11914	11.24319		22.78175	20.50568
26	23	12.11984	11.24368		22.7826	20.50628
27	24	12.12032	11.24402		22.78318	20.50669
28	25	12.12065	11.24426		22.78359	20.50698
29	26	12.12087	11.24442		22.78386	20.50717
30	27	12.12103	11.24453		22.78405	20.50731
31	28	12.12113	11.2446		22.78418	20.5074
32	29	12.12121	11.24465		22.78427	20.50746
33	30	12.12126	11.24469		22.78433	20.5075

4-92

The Equations

	A	B	C	D
1	T1=			$=(1100+C3+C4)/4$
2	T2=			$=(600+C3+C4)/4$
3	T3=			$=(900+C1+C2)/4$
4	T4=			$=(800+C1+C2)/4$

The Solution

	G	H	I	J	K
1	Time	T1=	T2=	T3=	T4=
2	incr				
3	0	1000	1000	1000	1000
4	1	775	650	725	700
5	2	631.25	506.25	581.25	556.25
6	3	559.375	434.375	509.375	484.375
7	4	523.4375	398.4375	473.4375	448.4375
8	5	505.4688	380.4688	455.4688	430.4688
9	6	496.4844	371.4844	446.4844	421.4844
10	7	491.9922	366.9922	441.9922	416.9922
11	8	489.7461	364.7461	439.7461	414.7461
12	9	488.623	363.623	438.623	413.623
13	10	488.0615	363.0615	438.0615	413.0615
14	11	487.7808	362.7808	437.7808	412.7808
15	12	487.6404	362.6404	437.6404	412.6404
16	13	487.5702	362.5702	437.5702	412.5702
17	14	487.5351	362.5351	437.5351	412.5351
18	15	487.5175	362.5175	437.5175	412.5175
19	16	487.5088	362.5088	437.5088	412.5088
20	17	487.5044	362.5044	437.5044	412.5044
21	18	487.5022	362.5022	437.5022	412.5022
22	19	487.5011	362.5011	437.5011	412.5011
23	20	487.5005	362.5005	437.5005	412.5005
24	21	487.5003	362.5003	437.5003	412.5003
25	22	487.5001	362.5001	437.5001	412.5001
26	23	487.5001	362.5001	437.5001	412.5001
27	24	487.500	362.500	437.500	412.500
28	25	487.500	362.500	437.500	412.500
29	26	487.500	362.500	437.500	412.500
30	27	487.500	362.500	437.500	412.500
31	28	487.500	362.500	437.500	412.500
32	29	487.500	362.500	437.500	412.500
33	30	487.500	362.500	437.500	412.500

Chapter 4

4-94

	$\Delta\tau_{\max}$
$C_1 = 89.7$	3.5666
$C_2 = 44.85$	3.8114
$C_3 = 179.4$	3.5880
$C_4 = 89.7$	3.5455
$C_5 = 179.4$	3.5880
$C_6 = 89.7$	3.5455
$C_7 = 179.4$	3.5880
$C_8 = 89.7$	3.5455
$C_9 = 179.4$	3.5880
$C_{10} = 224.25$	6.6527
$C_{11} = 224.25$	10.5737
$C_{12} = 89.7$	8.8374
$C_{13} = 179.4$	3.5880
$C_{14} = 358.8$	7.6885
$C_{15} = 448.5$	10.7639
$C_{16} = 179.4$	8.9700

The Equations

	A	B	C	D
1	T1=			$-C1+(\$CS18/89.7)*(((C3-C1)/0.2)+2*((C2-C1)/0.1))+((10-C1)/6.67)$
2	T2=			$-C2+(\$CS18/44.85)*(((C1-C2)/0.1))+((C4-C2)/0.4)+((10-C2)/4.44)$
3	T3=			$-C3+(\$CS18/179.4)*(((C1-C3)/0.2)+2*((C4-C3)/0.05))+((C5-C3)/0.2)$
4	T4=			$-C4+(\$CS18/89.7)*(((C2-C4)/0.4)+(C3-C4)/0.05)+(C6-C4)/0.4)+((10-C4)/3.33)$
5	T5=			$-C5+(\$CS18/179.4)*(((C3-C5)/0.2)+2*((C6-C5)/0.05))+((C7-C5)/0.2)$
6	T6=			$-C6+(\$CS18/89.7)*(((C4-C6)/0.4)+(C5-C6)/0.05)+(C8-C6)/0.4)+((10-C6)/3.33)$
7	T7=			$-C7+(\$CS18/179.4)*(((C5-C7)/0.2)+2*((C8-C7)/0.05))+((C9-C7)/0.2)$
8	T8=			$-C8+(\$CS18/89.7)*(((C6-C8)/0.4)+(C7-C8)/0.05)+(C10-C8)/0.4)+((10-C8)/3.33)$
9	T9=			$-C9+(\$CS18/179.4)*(((C7-C9)/0.2)+2*((C10-C9)/0.05))+((C13-C9)/0.2)$
10	T10=			$-C10+(\$CS18/224.25)*(((C8-C10)/0.4)+(C9-C10)/0.05))+((C14-C10)/0.1))+((C11-C10)/0.3))+((10-C10)/2.67)$
11	T11=			$-C11+(\$CS18/224.25)*(((C10-C11)/0.3))+((C15-C11)/0.08))+((C12-C11)/0.2))+((10-C11)/2.67)$
12	T12=			$-C12+(\$CS18/89.7)*(((C11-C12)/0.2)+(C16-C12)/0.2))+((10-C12)/6.67)$
13	T13=			$-C13+(\$CS18/179.4)*(((C9-C13)/0.2)+2*((C14-C13)/0.05))+((200-C13)/0.2)$
14	T14=			$-C14+(\$CS18/358.8)*(((C10-C14)/0.1)+(C13-C14)/0.05))+((C15-C14)/0.15))+((200-C14)/0.1)$
15	T15=			$-C15+(\$CS18/448.5)*(((C11-C15)/0.08))+((C14-C15)/0.15))+((C16-C15)/0.1))+((200-C15)/0.08)$
16	T16=			$-C16+(\$CS18/179.4)*(((C12-C16)/0.2)+(C15-C16)/0.1))+((200-C16)/0.2)$
17				
18	Dt=		3.5455	

The Solution

Chapter 4

4-95

	$\Delta\tau_{\max}$
$C_1 = 37,500$	6912
$C_2 = 75,000$	6912
$C_3 = 75,000$	6912
$C_4 = 75,000$	16,304
$C_5 = 150,000$	16,304
$C_6 = 150,000$	16,304
$C_7 = 75,000$	16,304
$C_8 = 150,000$	16,304
$C_9 = 150,000$	16,304

The Equations

	A	B	C	D
1	T1=			$=((5*(5-C1)+1.15*(C2-C1)+1.15*(C4-C1))*\$C\$11)/37500+C1$
2	T2=			$=((1.15*(C1-C2)+1.15*(C3-C2)+6.25*(5-C2)+2.3*(C5-C2))*\$C\$11/75000+C2)$
3	T3=			$=((1.15*(C2-C3)+1.15*(100-C3)+6.25*(5-C3)+2.3*(C6-C3))*\$C\$11/75000+C3)$
4	T4=			$=((1.15*(C1-C4)+1.15*(C7-C4)+2.3*(C5-C4))*\$C\$11/75000+C4)$
5	T5=			$=((2.3*(C2+C4+C6+C8-4*C5))*\$C\$11/150000+C5)$
6	T6=			$=((2.3*(C3+C5+100+C9-4*C6))*\$C\$11/150000+C6)$
7	T7=			$=((1.15*(C4-C7)+1.15*(100-C7)+2.3*(C8-C7))*\$C\$11/75000+C7)$
8	T8=			$=((2.3*(C5+C7+100+C9-4*C8))*\$C\$11/150000+C8)$
9	T9=			$=((2.3*(C6+C8+200-4*C9))*\$C\$11/150000+C9)$
10				
11	Dt=		6912	

The Solution

	G	H	I	J	K	L	M	N	O	P
1		T1=	T2=	T3=	T4=	T5=	T6=	T7=	T8=	T9=
2	Time									
3	incr	100	100	100	100	100	100	100	100	100
4	0	12.448	45.28	45.28	100	100	100	100	100	100
5	1	31.10148	30.19794	39.47705	90.72089	94.20056	94.20056	100	100	100
6	2	19.49224	30.32963	36.64893	86.1232	87.66316	89.63004	99.01656	99.38535	99.38535
7	3	22.557	27.41379	35.6939	80.7543	82.87434	85.93939	97.83247	98.16904	98.48173
8	4	19.74192	26.62213	34.60251	76.84571	78.71756	83.10881	96.32353	96.73957	97.44113
9	5	19.71833	25.32695	33.91854	73.25473	75.37334	80.81171	94.73702	95.20534	96.39018
10	6	18.69077	24.54301	33.29432	70.30658	72.52294	78.95012	93.1173	93.68756	95.3787
11	7	18.25474	23.7637	32.8166	67.7235	70.12722	77.40228	91.55006	92.23226	94.43787
12	8	17.69269	23.15899	32.40588	65.51535	68.0725	76.10637	90.06499	90.87419	93.5776
13	9	17.29066	22.62032	32.06707	63.59082	66.30944	75.00737	88.6876	89.62552	92.80076
14	10	16.90746	22.16806	31.77701	61.91986	64.78394	74.06918	87.42549	88.49104	92.10443
15	11	16.58981	21.77331	31.53019	60.45955	63.46045	73.2625	86.28086	87.46826	91.48363
16	12	16.30636	21.43293	31.31735	59.1828	62.30754	72.56557	85.24991	86.5517	90.93211
17	13	16.06152	21.13593	31.13353	58.06362	61.30099	71.9609	84.32643	85.7338	90.4434
18	14	15.84594	20.87712	30.97387	57.08173	60.42029	71.43462	83.50245	85.00628	90.0111
19	15	15.65744	20.65066	30.83488	56.21924	59.64858	70.97537	82.76952	84.3607	89.62919
20	16	15.49175	20.45235	30.71352	55.46115	58.97152	70.57381	82.11905	83.78886	89.29209
21	17	15.34628	20.2784	30.60738	54.79443	58.37696	70.22214	81.54278	83.28302	88.99473
22	18	15.21835	20.1257	30.51439	54.20784	57.85448	69.91378	81.03293	82.83602	88.73255
23	19	15.10584	19.99152	30.43284	53.69158	57.39508	69.64313	80.5823	82.44132	88.50146
24	20	15.00685	19.87357	30.36124	53.23712	56.99099	69.40539	80.18433	82.09301	88.29783

4-96

	Node	$\Delta\tau_{\max}$
$C_1 = 70,312$	1	11,719
$C_2 = 70,312$	2	11,719
$C_3 = 140,625$	3	23,438
$C_4 = 140,625$	4	23,438
$C_5 = 140,625$	5	23,438
$C_6 = 140,625$	6	23,438

The Equations

	A	B	C	D
1	T1=			$=((0.75*(C2-C1))+3*(15-C1)+0.75*(50-C1)+1.5*(C3-C1))*\$C\$8/70312+C1$
2	T2=			$=((0.75*(C1-C2))+3*(15-C2)+0.75*(50-C2)+1.5*(C4-C2))*\$C\$8/70312+C2$
3	T3=			$=((1.5*(C1+C4+C5+50-4*C3))*\$C\$8)/140625+C3$
4	T4=			$=((1.5*(C2+C3+C6+50-4*C4))*\$C\$8)/140625+C4$
5	T5=			$=((1.5*(C3+C6+100-4*C5))*\$C\$8)/140625+C5$
6	T6=			$=((1.5*(C4+C5+100-4*C6))*\$C\$8)/140625+C6$
7				
8	Dt=		11719	

Chapter 4

The Solution

	G	H	I	J	K	L	M
1		T1=	T2=	T3=	T4=	T5=	T6=
2	Time						
3	incr	50	50	50	50	50	50
4	1	32.4995	32.4995	50	50	50	50
5	2	30.31238	30.31238	47.81239	47.81239	50	50
6	3	29.49212	29.49212	46.17176	46.17176	49.72654	49.72654
7	4	28.97944	28.97944	45.00966	45.00966	49.35055	49.35055
8	5	28.62483	28.62483	44.17227	44.17227	48.97029	48.97029
9	6	28.37116	28.37116	43.55704	43.55704	48.62796	48.62796
10	7	28.18565	28.18565	43.09803	43.09803	48.3371	48.3371
11	8	28.04771	28.04771	42.75161	42.75161	48.09794	48.09794
12	9	27.94386	27.94386	42.48795	42.48795	47.90516	47.90516
13	10	27.86497	27.86497	42.28609	42.28609	47.75171	47.75171

4-98

$$\rho = 7600 \quad C = 450 \quad k = 35$$

$$C_1 = (7600)(450)\pi(0.01)^2(0.02) = 21.488 = C_2 = C_3 = C_4$$

$$C_5 = 10.744$$

$$\Delta\tau_{\max, 1} = \frac{21.488}{1.1499} = 18.687 \text{ sec}$$

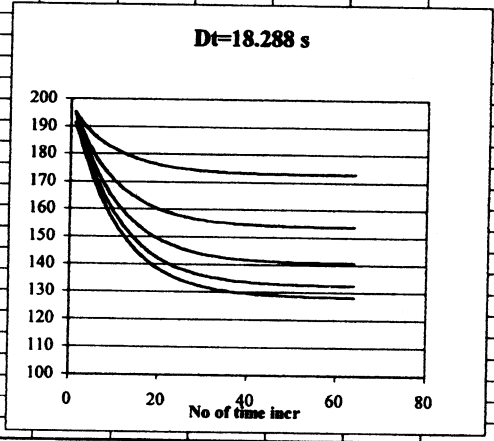
$$\Delta\tau_{\max, 5} = \frac{10.744}{0.5875} = 18.288 \text{ sec}$$

The Equations

	A	B	C	D
1	T1			$=(0.5498*(200-C1)+0.5498*(C2-C1)+0.05027*(25-C1)+3.142)*\$C\$7/21.488+C1$
2	T2			$=(0.5498*(C1-C2)+0.5498*(C3-C2)+0.05027*(25-C2)+3.142)*\$C\$7/21.488+C2$
3	T3			$=(0.5498*(C2-C3)+0.5498*(C4-C3)+0.05027*(25-C3)+3.142)*\$C\$7/21.488+C3$
4	T4			$=(0.5498*(C3-C4)+0.5498*(C5-C4)+0.05027*(25-C4)+3.142)*\$C\$7/21.488+C4$
5	T5			$=(0.5498*(C4-C5)+0.0377*(25-C5)+1.571)*\$C\$7/10.744+C5$
6				
7	Dt			

The Solution

	G	H	I	J	K	L	M	N	O	P	Q	R	S
1		T1	T2	T3	T4	T5							
2	Time												
3	Incr	200	200	200	200	200							
4	1	195.1869	195.1869	195.1869	195.1869	191.4441							
5	2	192.8319	190.5798	190.5798	188.8284	186.94							
6	3	190.6258	187.2236	185.3502	184.4292	180.9895							
7	4	189.0082	183.6725	181.6095	179.1037	176.8725							
8	5	187.312	181.0894	177.3761	175.3132	171.8888							
9	6	186.0671	178.2596	174.3032	170.9193	168.3415							
10	7	184.7163	176.1787	170.8574	167.7276	164.2296							
11	8	183.7138	173.8898	168.3166	164.123	161.2427							
12	9	182.6213	172.1829	165.5046	161.4594	157.8694							
13	10	181.7993	170.3194	163.3995	158.5082	155.3768							
14	11	180.9097	168.9099	161.1016	156.2938	152.615							
15	12	180.2312	167.3883	159.3567	153.8789	150.5426							
16	13	179.5047	166.2218	157.4775	152.0412	148.2827							
17	14	178.9434	164.9776	156.0316	150.0651	146.5629							
18	15	178.3492	164.0118	154.4938	148.5415	144.7136							
19	16	177.8845	162.9936	153.2961	146.9241	143.2879							
20	17	177.3982	162.194	152.0373	145.662	141.7742							
21	18	177.0136	161.3602	151.0456	144.3377	140.5931							
22	19	176.6153	160.6985	150.0146	143.2927	139.3538							
23	20	176.2971	160.0155	149.194	142.208	138.3758							
24	21	175.9707	159.468	148.3493	141.3432	137.3608							
25	22	175.7076	158.9084	147.6705	140.4546	136.5515							



4-94

	Node	$\Delta\tau_{\max}$
$C_1 = 600$	1	600
$C_2 = 1200$	2	1200
$C_3 = 1800$	3	1500
$C_4 = 2400$	4	1714
$C_5 = 2400$	5	1714
$C_6 = 1200$	6	800
$C_7 = 2400$	7	2400
$C_8 = 3600$	8	4000
$C_9 = 4800$	9	6000
$C_{10} = 4800$	10	6000
$C_{11} = 1200$	11	800
$C_{12} = 2400$	12	2400
$C_{13} = 1200$	13	800
$C_{14} = 2400$	14	2400

Chapter 4

The Equations

	A	B	C	D
1	T1=			$=((0.2*(C2-C1)+0.05*(C6-C1)+0.75*(20-C1))*\$C\$16)/600+C1$
2	T2=			$=((0.2*(C1-C2)+0.2*(C4-C2)+0.1*(C7-C2)+0.5*(20-C2))*\$C\$16)/1200+C2$
3	T3=			$=((0.2*(C2-C3)+0.1*(C4-C3)+0.15*(C8-C3)+0.75*(20-C3))*\$C\$16)/1800+C3$
4	T4=			$=((0.1*(C3-C4)+0.1*(C5-C4)+0.2*(C9-C4)+(20-C4))*\$C\$16)/2400+C4$
5	T5=			$=((0.2*(C4-C5)+0.2*(C10-C5)+(20-C5))*\$C\$16)/2400+C5$
6	T6=			$=((0.05*(C1-C6)+0.05*(C11-C6)+0.4*(C7-C6)+(20-C6))*\$C\$16)/1200+C6$
7	T7=			$=((0.4*(C6-C7)+0.4*(C8-C7)+0.1*(C2-C7)+0.1*(C12-C7))*\$C\$16)/2400+C7$
8	T8=			$=((0.4*(C7-C8)+0.15*(C3-C8)+0.2*(C9-C8)+0.15*(500-C8))*\$C\$16)/3600+C8$
9	T9=			$=((0.2*(C8-C9)+0.2*(C4-C9)+0.2*(C10-C9)+0.2*(500-C9))*\$C\$16)/4800+C9$
10	T10=			$=((0.4*(C9-C10)+0.2*(C5-C10)+0.2*(500-C10))*\$C\$16)/4800+C10$
11	T11=			$=((0.4*(C12-C11)+0.05*(C6-C11)+0.05*(C13-C11)+(20-C11))*\$C\$16)/1200+C11$
12	T12=			$=((0.4*(C11-C12)+0.1*(C7-C12)+0.1*(C14-C12)+0.4*(500-C12))*\$C\$16)/2400+C12$
13	T13=			$=((0.8*(C11-C13)+0.4*(C14-C13)+(20-C13))*\$C\$16)/1200+C13$
14	T14=			$=((0.4*(C13-C14)+0.2*(C12-C14)+0.4*(500-C14))*\$C\$16)/2400+C14$
15				
16	Dt=		600	

The Solution

	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1															
2	Time	T1=	T2=	T3=	T4=	T5=	T6=	T7=	T8=	T9=	T10=	T11=	T12=	T13=	T14=
3	incr		500	500	500	500	500	500	500	500	500	500	500	500	500
4	1	140	380	380	380	380	260	500	500	500	500	260	500	260	500
5	2	104	272	296	296	296	183	473	497	497	497	188	476	188	476
6	3	78.65	204.65	235.45	237.05	237.05	158.15	441.65	490.45	492.05	492.05	161.525	449.525	161.6	449.6
7	4	63.8375	160.9775	192.3375	195.4975	195.5375	143.8719	412.4519	481.1138	485.8338	485.8738	148.28	425.5775	148.37	425.8363
8	5	54.38909	132.0448	161.7066	166.0619	166.1679	133.7613	386.5013	469.9464	478.8125	478.9665	139.4915	404.9683	139.6423	405.4931
9	6	48.09703	112.3926	139.8597	145.0777	145.2606	125.5876	363.6721	457.7243	471.3056	471.6647	127.1334	372.6767	127.454	373.9162
10	7	43.7579	98.69738	124.1308	129.9938	130.2565	118.6513	343.582	445.0171	463.5367	464.195	127.1334	372.6767	127.454	373.9162
11	8	40.67204	88.90296	112.6423	119.0325	119.3762	112.6515	325.8377	432.2245	455.6632	456.7088	122.4713	360.1583	122.8912	361.8164
12	9	38.41317	81.71382	104.0912	110.9547	111.3816	107.409	310.0924	419.6182	447.796	449.30*4	118.5381	349.5572	119.0627	351.6593
13	10	36.71321	76.29832	97.58171	104.8972	105.411	102.7945	296.0538	407.3771	440.0134	442.04*2	115.2078	340.5655	115.8408	343.1286
14	11	35.39939	72.11289	92.50101	100.2587	100.8645	98.70741	283.4791	395.6141	432.3701	434.9803	112.3809	332.9245	113.1247	335.9588
15	12	34.35795	68.79621	88.43079	96.62078	97.32387	95.06718	272.1674	384.3954	424.9044	428.1224	109.9759	326.4174	110.8317	329.9278
16	13	33.5126	66.10435	85.08535	93.6926	94.49767	91.80862	261.9522	373.7549	417.6425	421.4884	107.9249	320.863	108.8928	324.8499
17	14	32.8113	63.8703	82.269	91.27189	92.18254	88.87852	252.6946	363.7037	410.60*6	415.0842	106.1714	316.1098	107.2507	320.5699
18	15	32.21799	61.9782	79.847	89.2181	90.23645	86.23313	244.2787	354.2379	403.7929	408.9104	104.668	312.0311	105.8575	316.9579
19	16	31.7073	60.34664	77.72591	87.4335	88.56012	83.83617	236.6064	345.3434	397.2*28	402.9649	103.3755	308.5211	104.6731	313.9058
20	17	31.26114	58.91772	75.84027	85.85006	87.084	81.65739	229.5944	336.9995	390.6*41	397.2436	102.2608	305.4911	103.664	311.3227
21	18	30.86641	57.6497	74.14366	84.42035	85.75928	79.67128	223.1717	329.1817	384.807	391.741	101.2965	302.8674	102.8025	309.133
22	19	30.5135	56.51211	72.60261	83.11115	84.5516	77.85624	217.277	321.8631	378.9599	386.4512	100.4594	300.5878	102.0649	307.2733
23	20	30.19523	55.48237	71.19256	81.8991	83.43666	76.19379	211.8572	315.0158	373.3495	381.3679	99.73045	298.6005	101.4319	305.6909

4-101

	Node	$\Delta\tau_{max}$
$C_1 = 412.5$	1	23.23
$C_2 = 412.5$	2	23.23
$C_3 = 825$	3	24.26
$C_4 = 825$	4	24.26
$C_5 = 412.5$	5	24.26
$C_6 = 412.5$	6	24.26

The Equations

	A	B	C	D
1	T1=			$=((0.5*(C2-C1)+16*(C3-C1)+0.5*(100-C1)+0.75*(0-C1))*\$C\$8)/412.5+C1$
2	T2=			$=((0.5*(C1-C2)+16*(C4-C2)+0.5*(100-C2)+0.75*(0-C2))*\$C\$8)/412.5+C2$
3	T3=			$=((C4-C3+100-C3+16*(C5-C3)+16*(C1-C3))*\$C\$8)/825+C3$
4	T4=			$=((C3-C4+100-C4+16*(C6-C4)+16*(C2-C4))*\$C\$8)/825+C4$
5	T5=			$=((0.5*(C6-C5)+0.5*(100-C5)+16*(C3-C5))*\$C\$8)/412.5+C5$
6	T6=			$=((0.5*(C5-C6)+0.5*(100-C6)+16*(C4-C6))*\$C\$8)/412.5+C6$
7				
8	Dt=		23.23	

The Solution

	G	H	I	J	K	L	M
1		T1=	T2=	T3=	T4=	T5=	T6=
2	Time						
3	incr	100	100	100	100	100	100
4	1	95.77636	95.77636	100	100	100	100
5	2	95.65572	95.65572	98.09716	98.09716	100	100
6	3	93.93774	93.93774	97.90809	97.90809	98.28546	98.28546
7	4	93.7183	93.7183	96.34828	96.34828	97.99371	97.99371
8	5	92.30658	92.30658	96.00754	96.00754	96.5676	96.5676
9	6	91.95924	91.95924	94.70492	94.70492	96.15961	96.15961
10	7	90.7756	90.7756	94.2724	94.2724	94.95701	94.95701
11	8	90.35207	90.35207	93.16672	93.16672	94.48215	94.48215
12	9	89.34371	89.34371	92.6837	92.6837	93.45226	93.45226
13	10	88.87968	88.87968	91.73122	91.73122	92.94412	92.94412

Chapter 4

4-102

	Node	$\Delta\tau_{\max}$
$C_1 = 87.4$	1	4.263
$C_2 = 174.8$	2	4.263
$C_3 = 174.8$	3	4.263
$C_4 = 174.8$	4	4.37
$C_5 = 349.6$	5	4.37
$C_6 = 349.6$	6	4.37
$C_7 = 174.8$	7	4.37
$C_8 = 349.6$	8	4.37
$C_9 = 349.6$	9	4.37
$C_{10} = 87.4$	10	4.37
$C_{11} = 174.8$	11	4.37
$C_{12} = 174.8$	12	4.37

The Equations

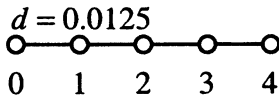
	A	B	C	D
1	$T_1 =$			$=((10*(C_2-C_1)+10*(C_4-C_1)+0.5*(20-C_1)+2250)*\$C\$14)/87.4+C_1$
2	$T_2 =$			$=((10*(C_1-C_2)+10*(C_3-C_2)+20*(C_5-C_2)+(20-C_2)+4500)*\$C\$14)/174.8+C_2$
3	$T_3 =$			$=((10*(C_2-C_3)+10*(100-C_3)+20*(C_6-C_3)+(20-C_3)+4500)*\$C\$14)/174.8+C_3$
4	$T_4 =$			$=((20*(C_5-C_4)+10*(C_1-C_4)+10*(C_7-C_4)+4500)*\$C\$14)/174.8+C_4$
5	$T_5 =$			$=((20*(C_2+C_4+C_6+C_8-4*C_5+4500)*\$C\$14)/349.6+C_5$
6	$T_6 =$			$=((20*(C_3+C_5+100+C_9-4*C_6+4500)*\$C\$14)/349.6+C_6$
7	$T_7 =$			$=((20*(C_8-C_7)+10*(C_4-C_7)+10*(C_{10}-C_7)+4500)*\$C\$14)/174.8+C_7$
8	$T_8 =$			$=((20*(C_5+C_7+C_9+C_{11}-4*C_8+4500)*\$C\$14)/349.6+C_8$
9	$T_9 =$			$=((20*(C_6+C_8+100+C_{12}-4*C_9+4500)*\$C\$14)/349.6+C_9$
10	$T_{10} =$			$=((10*(C_{11}-C_{10})+10*(C_7-C_{10})+2250)*\$C\$14)/87.4+C_{10}$
11	$T_{11} =$			$=((10*(C_{10}-C_{11})+10*(C_{12}-C_{11})+4500)*\$C\$14)/174.8+C_{11}$
12	$T_{12} =$			$=((10*(C_{11}-C_{12})+10*(100-C_{12})+4500)*\$C\$14)/174.8+C_{12}$
13				
14	$D_t =$		4.263	

The Solution

	G	H	I	J	K	L	M	N	O	P	Q	R	S
1		T1=	T2=	T3=	T4=	T5=	T6=	T7=	T8=	T9=	T10=	T11=	T12=
2	Time												
3	incr	100	100	100	100	100	100	100	100	100	100	100	100
4	1	207.7944	207.7944	207.7944	209.7454	209.7454	209.7454	209.7454	209.7454	209.7454	209.7454	209.7454	209.7454
5	2	313.9115	313.9115	287.6228	319.015	319.015	292.2505	319.4908	319.4908	292.7263	319.4908	319.4908	292.7263
6	3	418.9784	412.5671	353.7527	427.6319	421.1046	360.6248	429.1202	422.5929	361.8811	429.2363	422.709	361.9972
7	4	520.0872	504.1228	411.1692	532.4461	515.973	420.1895	535.3472	518.7892	422.2876	535.7413	519.2399	422.6534
8	5	615.878	589.0655	462.5564	631.8501	604.1731	473.5189	636.405	608.4612	476.5462	637.2459	609.4543	477.2659
9	6	705.8037	667.9876	509.2889	725.3115	686.1659	522.0996	731.6148	692.0467	526.0685	733.0256	693.7396	527.2421
10	7	789.8938	741.3159	552.2365	812.7431	762.4467	566.7599	820.8674	769.9421	571.7017	822.9209	772.4608	573.3975
11	8	868.3139	809.5113	591.9073	894.365	833.4091	608.0596	904.2931	842.5468	613.9641	907.0524	845.9651	616.2386
12	9	941.396	872.9303	628.6868	970.4467	899.4628	646.3588	982.173	910.2095	653.2258	985.6561	914.583	656.1098
13	10	1009.446	931.9475	662.8376	1041.344	960.9432	681.9505	1054.807	973.2781	689.7527	1059.036	978.6255	693.268
14	11	1072.819	986.8653	694.5941	1107.377	1018.193	715.0525	1122.534	1032.057	723.7703	1127.498	1038.389	727.9206
15	12	1131.82	1037.995	724.1362	1168.891	1071.5	745.866	1185.663	1086.846	755.4621	1191.359	1094.149	760.2461
16	13	1186.768	1085.594	751.638	1226.183	1121.153	774.5545	1244.509	1137.912	784.9983	1250.911	1146.17	790.4035
17	14	1237.935	1129.926	777.2423	1279.556	1167.4	801.2767	1299.353	1185.513	812.5265	1306.446	1194.696	818.5381
18	15	1285.596	1171.21	801.0901	1329.274	1210.486	826.1675	1350.474	1229.88	838.1878	1358.225	1239.958	844.7843
19	16	1329.988	1209.669	823.3015	1375.598	1250.625	849.359	1398.119	1271.238	862.1076	1406.504	1282.172	869.2671
20	17	1371.346	1245.494	843.9949	1418.756	1288.027	870.9663	1442.53	1309.788	884.4064	1451.515	1321.54	892.1032
21	18	1409.874	1278.874	863.273	1458.973	1322.877	891.1018	1483.923	1345.724	905.1927	1493.482	1358.253	913.4021
22	19	1445.775	1309.973	881.2366	1496.447	1355.353	909.8646	1522.507	1379.221	924.5706	1532.606	1392.488	933.2658
23	20	1479.226	1338.953	897.9745	1531.371	1385.617	927.3511	1558.471	1410.446	942.6344	1569.082	1424.411	951.7901

4-103

$$k = 43 \quad \rho = 7800 \quad C = 470 \quad \Delta x = 5 \text{ cm} \quad h = 35 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$



$$\frac{1}{R_{12}} = \frac{kA}{\Delta x} = \frac{(43)\pi(0.0125)^2}{(4)(0.05)} = 0.1055$$

$$\frac{1}{R_{1-\infty}} = hA = (35)\pi(0.0125)(0.05) = 0.0687$$

$$\frac{1}{R_{4-\infty}} = (35)[\pi(0.00625)^2 + \pi(0.025)(0.0125)] = 0.0387$$

$$C_1 = \frac{(7800)(470)\pi(0.0125)^2(0.05)}{4} = 22.494$$

$$C_4 = \frac{C_1}{2} = 11.247$$

Node	$\sum \frac{1}{R}$	$\frac{C}{\sum \frac{1}{R}}$
1	0.2797	80.42
2	0.2797	80.42
3	0.2797	80.42
4	0.1442	78.00

Chapter 4

Excel solution for $\Delta\tau = 25$ sec and 75 sec shown below

$T_2 = 190^\circ\text{C}$ occurs at six, 25 sec time increments.

Time = (25)(6) = 150 sec

Steady state reached at about (30)(75) = 2250 sec

The Equations

	A	B	C
1	T1=	250	$=(0.1055*(250-B1))+0.1055*(B2-B1)+0.0687*(30-B1))*\$E\$1/22.494+B1$
2	T2=	250	$=(0.1055*(B1-B2))+0.1055*(B3-B2)+0.0687*(30-B2))*\$E\$1/22.494+B2$
3	T3=	250	$=(0.1055*(B2-B3))+0.1055*(B4-B3)+0.0687*(30-B3))*\$E\$1/22.494+B3$
4	T4=	250	$=(0.1055*(B3-B4))+0.0387*(30-B4))*\$E\$1/11.247+B4$

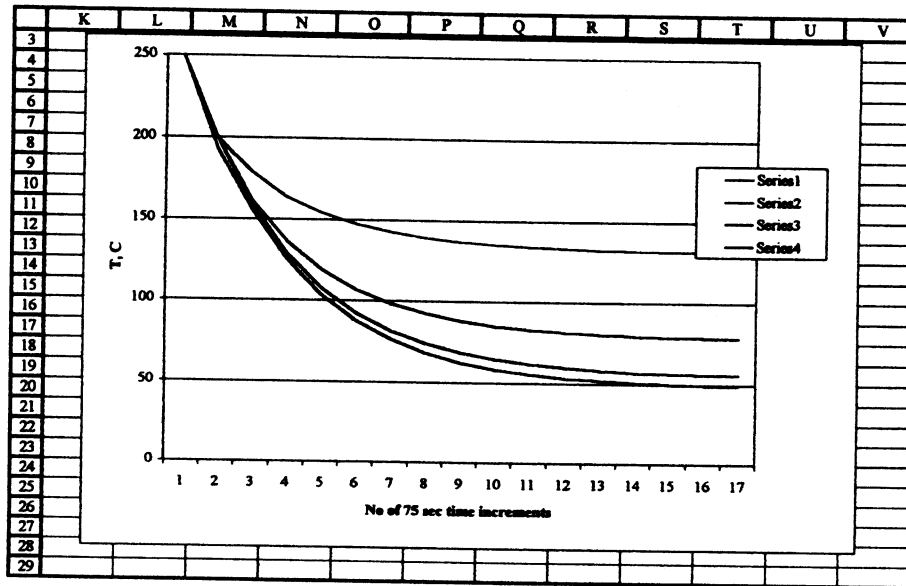
The Solution $\Delta\tau = 25$ sec

	E	F	G	H	I	J
1	25	T1=	T2=	T3=	T4=	NO. time
2		250	250	250	250	0
3		233.2021872	233.202	233.202	231.075	1
4		219.6565517	217.687	217.438	214.277	2
5		208.5025058	203.558	202.785	199.166	3
6		199.1591519	190.795	189.258	185.462	4
7		191.2238042	179.318	176.833	172.979	5
8		184.4095428	169.022	165.462	161.584	6
9		178.5062724	159.794	155.081	151.174	7
10		173.3560731	151.525	145.625	141.666	8
11		168.8373313	144.114	137.025	132.989	9
12		164.8543305	137.469	129.211	125.076	10
13		161.3302817	131.506	122.119	117.867	11
14		158.2025554	126.152	115.688	111.306	12
15		155.4193442	121.341	109.858	105.339	13
16		152.9372761	117.017	104.577	99.9179	14
17		150.7196685	113.126	99.7953	94.996	15
18		148.7352253	109.624	95.4665	90.5303	16
19		146.9570465	106.47	91.5491	86.4809	17
20		145.3618616	103.629	88.0049	82.8108	18
21		143.9294278	101.069	84.7989	79.4859	19
22		142.6420506	98.7601	81.8995	76.4749	20
23		141.48841976	96.6784	79.2777	73.7491	21
24		140.4421843	94.8006	76.9072	71.2822	22
25		139.5039146	93.1064	74.7642	69.0501	23
26		138.6586669	91.5776	72.827	67.0309	24
27		137.8969134	90.1977	71.0759	65.2046	25

The Solution $\Delta\tau = 75$ sec

	F	G	H	I	J
1	T1=	T2=	T3=	T4=	NO. time
2	250	250	250	250	0
3	199.6065617	199.607	199.607	193.225	1
4	178.4827185	160.756	158.511	155.591	2
5	163.3926051	136.251	128.837	125.235	3
6	153.7552402	118.852	107.538	103.192	4
7	146.9853904	106.797	92.2282	87.3609	5
8	142.2884591	98.2178	81.3868	75.9821	6
9	138.9538804	92.1736	73.6354	67.9179	7
10	136.60297	87.8665	68.15	62.1549	8
11	134.9294051	84.8196	64.2379	58.0744	9
12	133.7448107	82.6494	61.4671	55.1655	10
13	132.9015472	81.1117	59.4936	53.1044	11
14	132.3038016	80.0172	58.0947	51.6368	12
15	131.8785075	79.2411	57.0992	50.5963	13
16	131.5768177	78.689	56.393	49.8559	14
17	131.3622656	78.2972	55.8908	49.3307	15
18	131.2100006	78.0187	55.5343	48.9572	16
19	131.1017517	77.821	55.2809	48.6921	17
20	131.0249059	77.6804	55.1011	48.5036	18
21	130.9702875	77.5806	54.9732	48.3698	19
22	130.931506	77.5097	54.8824	48.2748	20
23	130.9039466	77.4594	54.8179	48.2072	21
24	130.8843754	77.4236	54.7721	48.1593	22
25	130.8704692	77.3982	54.7395	48.1252	23
26	130.8605927	77.3801	54.7164	48.101	24
27	130.8535756	77.3673	54.7	48.0838	25
28	130.8485916	77.3582	54.6883	48.0716	26
29	130.8450507	77.3517	54.68	48.0629	27
30	130.8425356	77.3471	54.6742	48.0567	28
31	130.8407489	77.3439	54.67	48.0523	29
32	130.8394797	77.3415	54.667	48.0492	30
33	130.8385781	77.3399	54.6649	48.047	31
34	130.8379376	77.3387	54.6634	48.0455	32
35	130.8374826	77.3379	54.6623	48.0443	33
36	130.8371594	77.3373	54.6616	48.0435	34
37	130.8369298	77.3369	54.661	48.043	35
38	130.8367668	77.3366	54.6606	48.0426	36
39	130.8366509	77.3364	54.6604	48.0423	37

Chapter 4



4-105

$$\frac{\alpha \Delta \tau}{(\Delta x)^2} = \frac{1}{4}$$

$$\Delta \tau_{\max} = \frac{(0.15)^2}{4 \times 1.29 \times 10^{-5}} = 436 \text{ sec}$$

$$C_1 = C_2 = C_3 = C_4 = 78,488$$

The Equations

	A	B	C	D
1	T1=			$= (45 * (C_2 + C_3 + 100 + 30 - 4 * C_1) * \$C\$6) / 78488 + C_1$
2	T2=			$= (45 * (C_1 + C_4 + 30 + 100 - 4 * C_2) * \$C\$6) / 78488 + C_2$
3	T3=			$= (45 * (C_1 + C_4 + 200 - 4 * C_3) * \$C\$6) / 78488 + C_3$
4	T4=			$= (45 * (C_2 + C_3 + 200 - 4 * C_4) * \$C\$6) / 78488 + C_4$
5				
6	Dt=		436	

The Solution

	G	H	I	J	K
1		T1=	T2=	T3=	T4=
2	Time				
3	intr	500	500	500	500
4	1	282.5222	282.5222	300.0204	300.0204
5	2	178.1463	178.1463	195.6463	195.6463
6	3	125.9535	125.9535	143.4535	143.4535
7	4	99.85439	99.85439	117.3544	117.3544
8	5	86.80353	86.80353	104.3035	104.3035
9	6	80.27743	80.27743	97.77743	97.77743
10	7	77.01405	77.01405	94.51405	94.51405
11	8	75.38219	75.38219	92.88219	92.88219
12	9	74.56618	74.56618	92.06618	92.06618
13	10	74.15813	74.15813	91.65813	91.65813

4-106

	Node	$\Delta\tau_{\max}$
$C_1 = 350$	1	16.83
$C_2 = 700$	2	17.16
$C_3 = 700$	3	17.16
$C_4 = 350$	4	16.83
$C_5 = 700$	5	17.16
$C_6 = 1400$	6	17.16
$C_7 = 1400$	7	17.5
$C_8 = 700$	8	17.5

The Equations

	A	B	C	D
1	T1=			$=((10*(C2-C1)+10*(C5-C1)+0.8*(300-C1))*\$C\$8)/350+C1$
2	T2=			$=((10*(C1-C2)+20*(C5-C2)+0.8*(300-C2))*\$C\$8)/700+C2$
3				
4				
5	T5=			$=((10*(C1-C5)+20*(C6-C5)+10*(50-C5))*\$C\$8)/700+C5$
6	T6=			$=((20*(C2-C5)+50-3*C6))*\$C\$8)/1400+C6$
7				
8	Dt=			

Chapter 4

The Solution 10 sec

	G	H	I	J	K	L	M
1	Dt= 0.25	T1=	T2=			T5=	T6=
2	Time						
3	incr	50	50			50	50
4	1	50.14286	50.07143			50	49.98214
5	2	50.2841	50.14258			50.00038	49.96455
6	3	50.42376	50.21346			50.00114	49.94722
7	4	50.56185	50.28406			50.00226	49.93015
8	5	50.69841	50.35439			50.00373	49.91334
9	6	50.83345	50.42444			50.00556	49.89678
10	7	50.96699	50.49422			50.00772	49.88047
11	8	51.09907	50.56372			50.01021	49.86442
12	9	51.2297	50.63294			50.01302	49.84861
13	10	51.3589	50.70189			50.01614	49.83305
14	11	51.48669	50.77057			50.01957	49.81773
15	12	51.61311	50.83897			50.0233	49.80265
16	13	51.73816	50.9071			50.02732	49.78781
17	14	51.86186	50.97495			50.03162	49.77321
18	15	51.98425	51.04253			50.0362	49.75884
19	16	52.10533	51.10984			50.04104	49.74471
20	17	52.22513	51.17687			50.04615	49.73081
21	18	52.34366	51.24363			50.05152	49.71713
22	19	52.46095	51.31012			50.05713	49.70368
23	20	52.57701	51.37633			50.06299	49.69046
24	21	52.69186	51.44227			50.06908	49.67746
25	22	52.80552	51.50794			50.0754	49.66468
26	23	52.91801	51.57334			50.08195	49.65212
27	24	53.02933	51.63847			50.08872	49.63977
28	25	53.13952	51.70333			50.0957	49.62765
29	26	53.24858	51.76792			50.10288	49.61573
30	27	53.35654	51.83224			50.11027	49.60402
31	28	53.4634	51.89629			50.11785	49.59253
32	29	53.56919	51.96007			50.12563	49.58124
33	30	53.67392	52.02358			50.13359	49.57016
34	31	53.7776	52.08682			50.14173	49.55928
35	32	53.88025	52.1498			50.15005	49.54861
36	33	53.98189	52.21251			50.15854	49.53814
37	34	54.08252	52.27496			50.1672	49.52786
38	35	54.18217	52.33713			50.17602	49.51779
39	36	54.28084	52.39905			50.185	49.5079
40	37	54.37855	52.4607			50.19413	49.49822
41	38	54.47532	52.52208			50.20341	49.48873
42	39	54.57116	52.5832			50.21283	49.47942
43	40	54.66607	52.64406			50.2224	49.47031

The Solution 1 min

	G	H	I	J	K	L	M
1	Dt= 5	T1=	T2=			T5=	T6=
2	Time						
3	incr	50	50			50	50
4	1	52.85714	51.42857			50	49.64286
5	2	55.06939	52.74694			50.15306	49.39158
6	3	56.83448	53.95515			50.38451	49.22623
7	4	58.28076	55.0567			50.65229	49.13243
8	5	59.4929	56.05746			50.93347	49.09918
9	6	60.528	56.96481			51.21614	49.11769
10	7	61.42553	57.78686			51.49463	49.18062
11	8	62.21358	58.53195			51.76664	49.2817
12	9	62.91278	59.20827			52.03167	49.41549
13	10	63.53868	59.8236			52.29003	49.57722
14	11	64.10342	60.38518			52.54239	49.76272
15	12	64.61663	60.89959			52.78948	49.96832

The Solution 1 sec

	G	H	I	J	K	L	M
1	Dt= 0.25	T1=	T2=			T5=	T6=
2	Time						
3	incr	50	50			50	50
4	1	50.14286	50.07143			50	49.98214
5	2	50.2841	50.14258			50.00038	49.96455
6	3	50.42376	50.21346			50.00114	49.94722
7	4	50.56185	50.28406			50.00226	49.93015

The Solution Steady state

Chapter 4

	G	H	I	J	K	L	M
1	D=15	T1=	T2=			T5=	T6=
2	Time						
3	hour	50	50			50	50
4	1	58.57143	54.28571			50	48.92857
5	2	61.33878	57.57959			51.37755	48.80995
6	3	63.64127	59.88289			52.11651	49.10578
7	4	65.19508	61.4761			52.84225	49.72732
8	5	66.35762	62.66179			53.34536	50.51477
9	6	67.29328	63.61532			54.23228	51.38033
10	7	68.09796	64.43446			54.90189	52.27519
11	8	68.82336	65.17237			55.53348	53.17332
12	9	69.49762	65.85796			56.18693	54.06109
13	10	70.13612	66.50702			56.80237	54.93149
14	11	70.74728	67.12829			57.40015	55.78111
15	12	71.33619	67.72669			57.98065	56.60847
16	13	71.90536	68.30511			58.54433	57.41306
17	14	72.45663	68.86551			59.09165	58.19495
18	15	72.99113	69.40848			59.62306	58.95447
19	16	73.50997	69.93344			60.13902	59.69209
20	17	74.01396	70.44685			60.63998	60.40836
21	18	74.50148	70.94327			61.12636	61.10385
22	19	74.97572	71.42518			61.59859	61.77914
23	20	75.43612	71.89304			62.05708	62.43479
24	21	75.88312	72.34727			62.50223	63.07138
25	22	76.31711	72.78827			62.93444	63.68943
26	23	76.73844	73.21643			63.35406	64.28954
27	24	77.14753	73.63214			63.76148	64.87217
28	25	77.54471	74.03574			64.15704	65.43785
29	26	77.93033	74.42761			64.54109	65.98707
30	27	78.30474	74.80807			64.91397	66.52031
31	28	78.66825	75.17746			65.276	67.03803
32	29	79.02118	75.5361			65.6275	67.54069
33	30	79.36384	75.88491			65.96876	68.02873
34	31	79.69653	76.22329			66.3001	68.50257
35	32	80.01958	76.55063			66.6218	68.96262
36	33	80.33316	76.86992			66.93414	69.40928
37	34	80.63765	77.17873			67.23739	69.84295
38	35	80.93328	77.47915			67.53182	70.264
39	36	81.22031	77.77082			67.81768	70.6728
40	37	81.49899	78.05401			68.09522	71.06971
41	38	81.76956	78.32896			68.36469	71.45506
42	39	82.03226	78.5959			68.62632	71.82921
43	40	82.28731	78.85508			68.88033	72.19246
44	41	82.53494	79.10672			69.12696	72.54515
45	42	82.77537	79.35104			69.3664	72.88758
46	43	83.0088	79.58825			69.59889	73.22005
47	44	83.23544	79.81856			69.8246	73.54284
48	45	83.45549	80.04216			70.04375	73.85623
49	46	83.66913	80.25926			70.25653	74.16051
50	47	83.87656	80.47005			70.46311	74.45594
51	48	84.07795	80.67477			70.66368	74.74277
52	49	84.27348	80.87339			70.85842	75.02126
53	50	84.46333	81.06631			71.04749	75.29164
54	51	84.64764	81.25361			71.23106	75.55416
55	52	84.8266	81.43546			71.40928	75.80903
56	53	85.00035	81.61202			71.58233	76.05665
57	54	85.16904	81.78345			71.75033	76.29676
58	55	85.33283	81.94988			71.91345	76.53003
59	56	85.49185	82.11147			72.07183	76.75651
60	57	85.64624	82.26837			72.22559	76.97641
61	58	85.79615	82.42069			72.37488	77.18999
62	59	85.94169	82.56859			72.51983	77.39719
63	60	86.08299	82.71218			72.66056	77.59844
64	61	86.22018	82.85159			72.79719	77.79384
65	62	86.35339	82.98695			72.92985	77.98355
66	63	86.48271	83.11837			73.05865	78.16774
67	64	86.60828	83.24596			73.18371	78.34657
68	65	86.73019	83.36985			73.30512	78.5202
69	66	86.84855	83.49012			73.423	78.68878
70	67	86.96347	83.6069			73.53745	78.85245
71	68	87.07504	83.72028			73.64857	79.01136
72	69	87.18337	83.83037			73.75646	79.16565
73	70	87.28855	83.93724			73.86121	79.31545
74	71	87.39067	84.04101			73.96291	79.46089
75	72	87.48981	84.14176			74.06165	79.6021
76	73	87.58607	84.23958			74.15732	79.7392
77	74	87.67953	84.33455			74.2506	79.87231
78	75	87.77027	84.42676			74.34097	80.00154
79	76	87.85837	84.51629			74.42872	80.12702
80	77	87.94391	84.60321			74.51391	80.24885
81	78	88.02696	84.6876			74.59662	80.36713
82	79	88.10759	84.76954			74.67692	80.48197
83	80	88.18588	84.84909			74.75489	80.59346
84	81	88.26189	84.92633			74.83059	80.70172
85	82	88.33568	85.00132			74.90408	80.80682
86	83	88.40733	85.07413			74.97544	80.90887
87	84	88.4769	85.14482			75.04472	81.00795
88	85	88.54444	85.21346			75.11199	81.10414
89	86	88.61001	85.28009			75.1773	81.19754
90	87	88.67368	85.34479			75.2407	81.28822
91	88	88.7355	85.40761			75.30227	81.37626
92	89	88.79551	85.46859			75.36204	81.46173
93	90	88.85378	85.52781			75.42007	81.54473
94	91	88.91036	85.5853			75.47642	81.6253
95	92	88.96539	85.64111			75.53112	81.70353
96	93	89.01862	85.69531			75.58434	81.77949
97	94	89.0704	85.74792			75.63581	81.85324
98	95	89.12087	85.79901			75.68587	81.92484
99	96	89.16948	85.84861			75.73448	81.99435
100	97	89.21687	85.89677			75.78168	82.06185
101	98	89.26288	85.94352			75.8275	82.12738
102	99	89.30755	85.98892			75.87199	82.191
103	100	89.35092	86.03299			75.91519	82.25277

4-112

$$\text{Wall thickness} = 0.25 \text{ m} \quad T_{\infty} = 600^{\circ}\text{C} \quad h = 100 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$$

$$k = 0.16 \frac{\text{W}}{\text{m} \cdot ^{\circ}\text{C}} \quad \alpha = 3.5 \times 10^{-7} \text{ m}^2/\text{s}$$

Approximate as inf. plate with $2L = 0.5$

Center plane is insulated

$$\frac{k}{hL} = \frac{0.16}{(100)(0.25)} = 6.4 \times 10^{-3} \quad A = (6)(1.0) = 6.0 \text{ m}^2$$

$$V = 1.0 - (0.5)^3 = 0.875 \text{ m}^3$$

$$\frac{h(V/A)}{k} = 546.9 \quad \text{Not lumped capacity}$$

$$\frac{\theta_0}{\theta_i} = \frac{150 - 600}{30 - 600} = 0.789 \quad \frac{\alpha\tau}{L^2} = 0.2$$

$$\tau = \frac{(0.25)^2(0.2)}{3.5 \times 10^{-7}} = 3.57 \times 10^4 \text{ sec} = 9.92 \text{ hr}$$

4-114

$$k = 1.07 \quad \alpha = 5.4 \times 10^{-7} \quad T_i = 20^{\circ}\text{C} \quad x = 2.0 \text{ cm}$$

$$\frac{q}{A} = 4500 \text{ W/m}^2 \quad T_0 = T_i + \frac{\left(2 \frac{q_0}{A}\right) \sqrt{\frac{\alpha\tau}{\pi}}}{k}$$

τ	T_0
0	20
100	54.87
300	80.4
900	124.61
1500	155.05
1400	150.47
1390	150
2000	175.94

Chapter 4

at $x = 2 \text{ cm}$ $\tau = 1390$

$$\begin{aligned} \frac{q}{A} &= -k \frac{\partial T}{\partial x} \\ &= \frac{2q_0}{A} \sqrt{\frac{\alpha\tau}{\pi}} \left(\frac{-x^2}{4\alpha\tau} \right) \exp\left(\frac{-x^2}{4\alpha\tau} \right) \left(\frac{-2x}{4\alpha\tau} \right) - \frac{q_0}{A} x \left[-\exp\left(\frac{-x^2}{4\alpha\tau} \right) \left(\frac{1}{2\sqrt{\alpha\tau}} \right) \right] \\ &\quad - \frac{q_0}{A} \left[1 - \operatorname{erf}\left(\frac{x}{2\sqrt{\alpha\tau}} \right) \right] \\ &= 1180 \text{ W/m}^2 \end{aligned}$$

4-117

$$\begin{aligned} \frac{k}{hr_0} &= \frac{3.2}{(350)(0.075)} = 0.122 & \frac{\alpha\tau}{r_0^2} &= \frac{(13 \times 10^{-7})(21)(60)}{(0.075)^2} = 0.291 \\ \frac{r}{r_0} &= \frac{4.5}{7.5} = 0.6 & \frac{\theta_0}{\theta_i} &= 0.65 & \frac{\theta}{\theta_0} &= 0.59 \\ T &= (0.65)(0.59)(120 - 30) + 30 = 64.5^\circ\text{C} \\ \frac{hr_0}{k} &= 8.2 & \frac{h^2\alpha\tau}{k^2} &= \frac{(350)^2(13 \times 10^{-7})(21)(60)}{(3.2)^2} = 19.6 \\ \frac{Q}{Q_0} &= 0.92 & \rho c &= \frac{k}{\alpha} \\ Q &= \frac{(0.92)(3.2)}{13 \times 10^{-7}} (120 - 30) \frac{4}{3} \pi (0.075)^3 = 3.6 \times 10^5 \text{ J} \end{aligned}$$

4-127

$$\frac{1}{R} = \frac{kA}{\Delta x} = \frac{(20)(0.01)}{0.01} = 20$$

$$\alpha = \frac{k}{\rho c} = 5 \times 10^{-6}$$

$$\sum \frac{1}{R} = (4)(20) = 80$$

$$C = \rho c \Delta V = \frac{k}{\alpha} (\Delta x)^2 = \frac{(20)(0.01)^2}{5 \times 10^{-6}} = 400$$

$$\Delta \tau_{\max} = \frac{C}{\sum \frac{1}{R}} = \frac{400}{80} = 5 \text{ sec}$$

$$T_i = 100^\circ\text{C} \quad \frac{\Delta \tau}{C} = \frac{5}{400} = \frac{1}{80}$$

Excel solution shown for $\Delta \tau = 5 \text{ sec}$

1 minute = 12 time increments

The Equations

	A	B	C	D	E	F
1	T1=	T2=	T3=	T4=	T5=	T6=
2	100	100	100	100	100	100
3	=(140+B2+C2)/4	=(40+A2+D2)/4	=(100+A2+E2+D2)/4	=(B2+C2+F2)/4	=(200+C2+F2)/4	=(100+D2+E2)/4
4	=(140+B3+C3)/4	=(40+A3+D3)/4	=(100+A3+E3+D3)/4	=(B3+C3+F3)/4	=(200+C3+F3)/4	=(100+D3+E3)/4
5	=(140+B4+C4)/4	=(40+A4+D4)/4	=(100+A4+E4+D4)/4	=(B4+C4+F4)/4	=(200+C4+F4)/4	=(100+D4+E4)/4
6	=(140+B5+C5)/4	=(40+A5+D5)/4	=(100+A5+E5+D5)/4	=(B5+C5+F5)/4	=(200+C5+F5)/4	=(100+D5+E5)/4
7	=(140+B6+C6)/4	=(40+A6+D6)/4	=(100+A6+E6+D6)/4	=(B6+C6+F6)/4	=(200+C6+F6)/4	=(100+D6+E6)/4
8	=(140+B7+C7)/4	=(40+A7+D7)/4	=(100+A7+E7+D7)/4	=(B7+C7+F7)/4	=(200+C7+F7)/4	=(100+D7+E7)/4
9	=(140+B8+C8)/4	=(40+A8+D8)/4	=(100+A8+E8+D8)/4	=(B8+C8+F8)/4	=(200+C8+F8)/4	=(100+D8+E8)/4
10	=(140+B9+C9)/4	=(40+A9+D9)/4	=(100+A9+E9+D9)/4	=(B9+C9+F9)/4	=(200+C9+F9)/4	=(100+D9+E9)/4
11	=(140+B10+C10)/4	=(40+A10+D10)/4	=(100+A10+E10+D10)/4	=(B10+C10+F10)/4	=(200+C10+F10)/4	=(100+D10+E10)/4
12	=(140+B11+C11)/4	=(40+A11+D11)/4	=(100+A11+E11+D11)/4	=(B11+C11+F11)/4	=(200+C11+F11)/4	=(100+D11+E11)/4
13	=(140+B12+C12)/4	=(40+A12+D12)/4	=(100+A12+E12+D12)/4	=(B12+C12+F12)/4	=(200+C12+F12)/4	=(100+D12+E12)/4
14	=(140+B13+C13)/4	=(40+A13+D13)/4	=(100+A13+E13+D13)/4	=(B13+C13+F13)/4	=(200+C13+F13)/4	=(100+D13+E13)/4
15	=(140+B14+C14)/4	=(40+A14+D14)/4	=(100+A14+E14+D14)/4	=(B14+C14+F14)/4	=(200+C14+F14)/4	=(100+D14+E14)/4
16	=(140+B15+C15)/4	=(40+A15+D15)/4	=(100+A15+E15+D15)/4	=(B15+C15+F15)/4	=(200+C15+F15)/4	=(100+D15+E15)/4
17	=(140+B16+C16)/4	=(40+A16+D16)/4	=(100+A16+E16+D16)/4	=(B16+C16+F16)/4	=(200+C16+F16)/4	=(100+D16+E16)/4
18	=(140+B17+C17)/4	=(40+A17+D17)/4	=(100+A17+E17+D17)/4	=(B17+C17+F17)/4	=(200+C17+F17)/4	=(100+D17+E17)/4
19	=(140+B18+C18)/4	=(40+A18+D18)/4	=(100+A18+E18+D18)/4	=(B18+C18+F18)/4	=(200+C18+F18)/4	=(100+D18+E18)/4
20	=(140+B19+C19)/4	=(40+A19+D19)/4	=(100+A19+E19+D19)/4	=(B19+C19+F19)/4	=(200+C19+F19)/4	=(100+D19+E19)/4
21	=(140+B20+C20)/4	=(40+A20+D20)/4	=(100+A20+E20+D20)/4	=(B20+C20+F20)/4	=(200+C20+F20)/4	=(100+D20+E20)/4
22	=(140+B21+C21)/4	=(40+A21+D21)/4	=(100+A21+E21+D21)/4	=(B21+C21+F21)/4	=(200+C21+F21)/4	=(100+D21+E21)/4
23	=(140+B22+C22)/4	=(40+A22+D22)/4	=(100+A22+E22+D22)/4	=(B22+C22+F22)/4	=(200+C22+F22)/4	=(100+D22+E22)/4
24	=(140+B23+C23)/4	=(40+A23+D23)/4	=(100+A23+E23+D23)/4	=(B23+C23+F23)/4	=(200+C23+F23)/4	=(100+D23+E23)/4
25	=(140+B24+C24)/4	=(40+A24+D24)/4	=(100+A24+E24+D24)/4	=(B24+C24+F24)/4	=(200+C24+F24)/4	=(100+D24+E24)/4
26	=(140+B25+C25)/4	=(40+A25+D25)/4	=(100+A25+E25+D25)/4	=(B25+C25+F25)/4	=(200+C25+F25)/4	=(100+D25+E25)/4
27	=(140+B26+C26)/4	=(40+A26+D26)/4	=(100+A26+E26+D26)/4	=(B26+C26+F26)/4	=(200+C26+F26)/4	=(100+D26+E26)/4
28	=(140+B27+C27)/4	=(40+A27+D27)/4	=(100+A27+E27+D27)/4	=(B27+C27+F27)/4	=(200+C27+F27)/4	=(100+D27+E27)/4
29	=(140+B28+C28)/4	=(40+A28+D28)/4	=(100+A28+E28+D28)/4	=(B28+C28+F28)/4	=(200+C28+F28)/4	=(100+D28+E28)/4

Chapter 4

The Solution

	A	B	C	D	E	F
1	T1=	T2=	T3=	T4=	T5=	T6=
2	100	100	100	100	100	100
3	85	60	100	75	100	75
4	75	50	90	58.75	93.75	68.75
5	70	43.4375	81.875	52.1875	89.6875	63.125
6	66.3281	40.5469	77.96875	47.1094	86.25	60.4688
7	64.6289	38.3594	74.92188	44.7461	84.6094	58.3398
8	63.3203	37.3438	73.49609	42.9053	83.3154	57.3389
9	62.71	36.5564	72.38525	42.0447	82.7087	56.5552
10	62.2354	36.1887	71.86584	41.3742	82.2351	56.1884
11	62.0136	35.9024	71.46118	41.0607	82.0135	55.9023
12	61.8409	35.7686	71.27197	40.8165	81.8409	55.7686
13	61.7601	35.6643	71.12456	40.7023	81.7601	55.6643
14	61.6972	35.6156	71.05564	40.6133	81.6972	55.6156
15	61.6678	35.5776	71.00194	40.5717	81.6678	55.5776
16	61.6449	35.5599	70.97683	40.5393	81.6449	55.5599
17	61.6342	35.546	70.95727	40.5241	81.6342	55.546
18	61.6258	35.5396	70.94813	40.5123	81.6258	55.5396
19	61.6219	35.5345	70.941	40.5068	81.6219	55.5345
20	61.6189	35.5322	70.93767	40.5025	81.6189	55.5322
21	61.6175	35.5304	70.93507	40.5005	81.6175	55.5304
22	61.6164	35.5295	70.93386	40.4989	81.6164	55.5295
23	61.6158	35.5288	70.93291	40.4982	81.6158	55.5288
24	61.6154	35.5285	70.93247	40.4976	81.6154	55.5285
25	61.6152	35.5283	70.93213	40.4974	81.6152	55.5283
26	61.6151	35.5282	70.93197	40.4972	81.6151	55.5282
27	61.615	35.5281	70.93184	40.4971	81.615	55.5281
28	61.615	35.528	70.93178	40.497	81.615	55.528
29	61.615	35.528	70.93174	40.497	81.615	55.528

4-134

Plate

$$\frac{hV}{kA} = \frac{h(2LA)}{kA} = \frac{2hL}{k} < 0.1 \quad \frac{hL}{k} < 0.05$$

From figure $\frac{\theta}{\theta_0} = 0.98$ for $\frac{k}{hL} = 20$ and $\frac{x}{L} = 1.0$ worst case

Cylinder

$$\frac{hV}{kA} = \frac{1}{2} \frac{hr_0}{k} < 0.1 \quad \frac{hr_0}{k} < 0.2$$

From figure $\frac{\theta}{\theta_0} = 0.91$ for $\frac{k}{hr_0} = 5$ and $\frac{r}{r_0} = 1.0$ worst case

Sphere

$$\frac{hV}{kA} = \frac{1}{3} \frac{hr_0}{k} < 0.1 \quad \frac{hr_0}{k} < 0.3$$

From figure $\frac{\theta}{\theta_0} = 0.85$ for $\frac{k}{hr_0} = 3.333$ and $\frac{r}{r_0} = 1.0$ worst case

4-135

Aluminum $k = 204$ $\alpha = 8.4 \times 10^{-5} \text{ m}^2/\text{s}$ $T_i = 200^\circ\text{C}$
 $T_\infty = 25^\circ\text{C}$ $h = 5000 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$ $T_0 = 90^\circ\text{C}$ $L = 5 \text{ cm} = 0.05 \text{ m}$
 $\frac{\theta_0}{\theta_i} = \frac{90 - 25}{200 - 25} = 0.37$ $\frac{k}{hL} = \frac{204}{(5000)(0.05)} = 0.82$
 From chart $\frac{\alpha\tau}{L^2} = 1.3$ $\tau = \frac{(1.3)(0.05)^2}{8.4 \times 10^{-5}} = 38.7 \text{ sec}$

4-136

$\frac{k}{hL} = 0$ for $h \rightarrow \infty$
 $\frac{\theta_0}{\theta_i} = 0.37$ From chart $\frac{\alpha\tau}{L^2} = 0.5$ $\tau = \frac{(0.5)(0.05)^2}{8.4 \times 10^{-5}} = 14.9 \text{ sec}$

4-137

Lumped capacity $\rho = 2707 \text{ kg/m}^3$ $c = 896 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}$
 $\frac{hA}{\rho c V} = \frac{(5000)A}{(2707)(896)A(0.05)} = 0.041$
 $\frac{90 - 25}{200 - 25} = e^{-0.041\tau} = 0.37$
 $\tau = 24.2 \text{ sec}$

4-138

Suddenly exposed plate

$\frac{90 - 25}{200 - 25} = 0.37 = \text{erf}\left(\frac{x}{2\sqrt{\alpha\tau}}\right)$ $\frac{x}{2\sqrt{\alpha\tau}} = 0.34$
 $\tau = \frac{\left[\frac{0.05}{(2)(0.34)}\right]^2}{8.4 \times 10^{-5}} = 64.4 \text{ sec}$

Convectively exposed plate

$\frac{hx}{k} = \frac{(5000)(0.05)}{204} = 1.22$ $\frac{\alpha\tau}{L^2} \approx 7$
 $\tau = \frac{(7)(0.05)^2}{8.4 \times 10^{-5}} = 208 \text{ sec}$

Chapter 4

4-139

$$h = 23 \quad k = 1.37 \quad \alpha = 7.5 \times 10^{-7} \quad L = 18 \text{ cm}$$

$$T_i = 30^\circ\text{C} \quad T_\infty = 0^\circ\text{C} \quad T_{x=0} = 5^\circ\text{C}$$

a. Back side insulated

$$\frac{\theta_L}{\theta_i} = \frac{5-0}{30-0} = 0.167 \quad \frac{k}{hL} = \frac{1.37}{(23)(0.18)} = 0.331$$

At $\frac{x}{L} = 1.0$, using infinite plate Heisler chart $\frac{\theta}{\theta_0} = 0.355$

By iteration, $F_0 = \frac{\alpha\tau}{L^2} = 0.7 \quad \tau = 8.4 \text{ h}$

b. Semi-infinite solid

Iterative solution of Eq. (4-15) yields $\tau = 13.7 \text{ h}$

4-140

$$T_1 = 70^\circ\text{F} \quad T_\infty = 350^\circ\text{F} \quad h = 2.5 \quad k_w = 0.395 \quad \rho = 59.6$$

$$c_p = 1.0 \quad \alpha = 0.00663 \quad V = 0.084 \text{ ft}^3 \text{ (assume spherical roast)}$$

$$r = 0.271 \text{ ft} = r_0 \quad \frac{k}{hr_0} = 0.583 \quad \frac{\theta_0}{\theta_i} = 0.536 \quad \frac{\alpha\tau}{r_0^2} = 0.3$$

4-145

$$r_0 = 1.5 \text{ in} = 3.81 \text{ cm} \quad k = 0.585 \quad \alpha = 1.4 \times 10^{-7} \quad \rho = 999$$

$$c = 4195$$

Take $T = 3^\circ\text{C}$ at outside of orange to prevent frostbite

$$\frac{k}{hr_0} = \frac{0.585}{(45)(0.0381)} = 0.34 \quad \frac{\theta}{\theta_0} = 0.33$$

$$\frac{\theta}{\theta_i} = \frac{3-0}{25-0} = 0.12 = \frac{\theta_0}{\theta_i} (0.33)$$

$$\frac{\theta_0}{\theta_i} = 0.364 \rightarrow \frac{\alpha\tau}{r_0^2} = 0.35$$

$$\tau = \frac{(0.35)(0.0381)^2}{1.3 \times 10^{-7}} = 3888 \text{ sec}$$

$$\frac{hr_0}{k} = 2.93 \quad \frac{h^2\alpha\tau}{k^2} = \frac{(45)^2(1.3 \times 10^{-7})(3888)}{(0.585)^2} = 2.99$$

$$\frac{Q}{Q_0} = 0.84$$

For 100 oranges:

$$Q = (100)(999)(4195) \frac{4}{3} \pi (0.0381)^3 (0.84)(25-0) = 1.19 \times 10^6 \text{ J} = 1125 \text{ Btu}$$

4-147

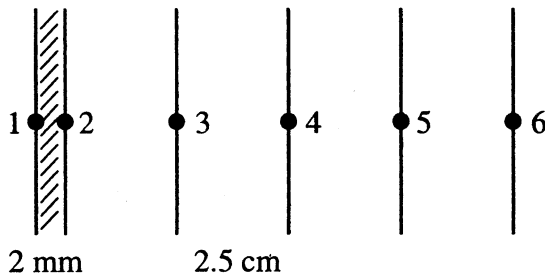
The thermal resistance between the slab in contact with the ground may be determined from the shape factors of table 3-1. This information may be used in conjunction with properties of the insulation to determine the steady state temperature distribution. For the transient analysis a numerical model must be formulated.

4-149

Polyethylene $k = 0.33$ $\rho = 960$ $c = 2100$ $\alpha = 1.64 \times 10^{-7}$

Particle board $k = 0.17$ $\rho = 1000$ $c = 1300$ $\alpha = 1.31 \times 10^{-7}$

Assume all heat flux absorbed



Because polyethylene is so thin it can be neglected in comparison to other material

Node 2

$$1300 + \frac{0.17}{0.025}(T_3^p - T_2^p) = (1000)(1300)(0.0125) \frac{T_2^{p+1} - T_2^p}{\Delta\tau}$$

$$= 16,250 \frac{T_2^{p+1} - T_2^p}{\Delta\tau}$$

$\Delta\tau_{\max} = 2390$ sec, and the same value results for other nodes. Choosing

$\Delta\tau = 2390$ sec for the time increment, the nodal equations are

$$T_2^{p+1} = 191.2 + T_3^p$$

$$T_3^{p+1} = \frac{(T_2^p + T_4^p)}{2}$$

$$T_4^{p+1} = \frac{(T_3^p + T_5^p)}{2}$$

$$T_5^{p+1} = \frac{(T_4^p + T_6^p)}{2}$$

$$T_6^{p+1} = T_5^p$$

Time to reach $50^\circ\text{C} = 5.8$ time increments $= (5.8)(2390) = 13,860$ sec $= 3.85$ h

Chapter 4

4-150

A_r = surface area for radiation

A_c = surface area for convection

m = mass

c = specific heat

$$h = A(T - T_\infty)^n$$

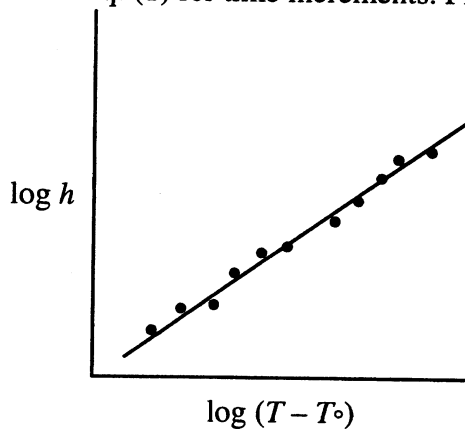
$$q_{\text{rad}} = \sigma \varepsilon A_r (T^4 - T_\infty^4)$$

$$q_{\text{conv}} = h A_c (T - T_\infty)$$

$$q_r + q_c = -mc \frac{dT}{d\tau}$$

$$\sigma \varepsilon A_r [(T^P)^4 - T_\infty^4] + h A_c (T^P - T_\infty) = \frac{T^{P+1} - T^P}{\Delta \tau} \quad (1)$$

T^P measured as function of time during cooling process. Calculate values of h from Eq. (1) for time increments. Plot



Determine values of A and n from graph or from least squares analysis of $\log h = \log A + n \log(T - T_\infty)$

Chapter 5

5-2

$$\frac{u}{u_\infty} = \frac{y}{\delta} \quad \rho \frac{d}{dx} \int_0^\delta (u_\infty - u)u \, dy = \mu \left. \frac{du}{dy} \right|_{y=0}$$

$$\rho \frac{d}{dx} \int_0^\delta \left(u_\infty - u_\infty \frac{y}{\delta} \right) u_\infty \frac{y}{\delta} \, dy = \mu \left. \frac{u_\infty}{\delta} \right|_{y=0} \quad \frac{d}{dx} \frac{1}{6} \rho u_\infty^2 \delta = \frac{\mu u_\infty}{\delta}$$

$$\delta d\delta = \frac{6\nu}{u_\infty} dx \quad \delta^2 = \frac{12\nu x}{u_\infty} \quad \delta = \frac{3.47x}{\sqrt{\text{Re}_x}}$$

5-3

$$\delta = \frac{4.64x}{\sqrt{\text{Re}_x}} = 4.64x^{1/2} \left(\frac{\mu}{u_\infty \rho} \right)^{1/2} \quad u = \frac{3u_\infty}{2} - \frac{u_\infty}{2} \left(\frac{y}{\delta} \right)^3$$

$$u = \frac{3u_\infty y x^{1/2}}{2 \left[4.64 \left(\frac{\mu}{u_\infty \rho} \right)^{1/2} \right]} - \frac{u_\infty y^3 x^{1/2}}{2 \left[4.64 \left(\frac{\mu}{u_\infty \rho} \right)^{1/2} \right]^3} \quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad \frac{\partial u}{\partial x} = -\frac{\partial v}{\partial y}$$

$$\frac{\partial u}{\partial x} = -\frac{3u_\infty x^{-1} y}{4\delta} + \frac{3u_\infty x^{-1} y^3}{4\delta^3} \quad v = \int \left[\frac{-3u_\infty 4.64}{4\sqrt{\text{Re}_x}} \left(\frac{y}{\delta^2} \right) + \frac{3u_\infty 4.64}{4\delta\sqrt{\text{Re}_x}} \left(\frac{y^3}{\delta} \right) \right] dy$$

$$v = \frac{2.32u_\infty}{\sqrt{\text{Re}_x}} \left[\frac{3}{4} \left(\frac{y}{\delta} \right)^2 - \frac{3}{8} \left(\frac{y}{\delta} \right)^4 \right] \quad \text{at } y = \delta \quad v = \frac{2.32u_\infty \left(\frac{3}{8} \right)}{\sqrt{\text{Re}_x}}$$

at $x = 6 \text{ in} = 15.24 \text{ cm}$
 $\text{Re} = \frac{(0.99)(30)(0.1524)}{2.13 \times 10^{-5}} = 213,000$

at $x = 12 \text{ in.}$ $\text{Re} = 426,000$

$$v = \frac{(2.32)(30)\left(\frac{3}{8}\right)}{(213,000)^{1/2}} = 0.0566 \text{ m/sec} \quad v = \frac{(2.32)(30)\left(\frac{3}{8}\right)}{(426,000)^{1/2}} = 0.0400 \text{ m/sec}$$

Chapter 5

5-4

$$\frac{u}{u_\infty} = \frac{y}{\delta} \quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad \delta = \frac{3.47x}{\sqrt{\text{Re}_x}}$$

$$u = u_\infty \frac{y}{3.47} \sqrt{\frac{\rho u_\infty}{\mu}} x^{-1/2} \quad \frac{\partial u}{\partial x} = -u_\infty \frac{y}{2(3.47)} \sqrt{\text{Re}_x} x^{-2}$$

$$\frac{\partial v}{\partial y} = u_\infty \frac{y}{2(3.47)} \frac{1}{x^2} \sqrt{\text{Re}_x} \quad v = u_\infty \frac{y^2}{4(3.47)} \frac{1}{x^2} \sqrt{\text{Re}_x}$$

$$\text{at } x = 6 \text{ in.} \quad v = \frac{(3.47)(30)}{(4)(213,000)^{1/2}} = 0.0563 \text{ m/sec}$$

$$\text{at } x = 12 \text{ in.} \quad v = \frac{(3.47)(30)}{(4)(426,000)^{1/2}} = 0.040 \text{ m/sec}$$

5-5

$$\frac{u}{u_\infty} = \frac{y}{\delta} \quad \frac{\theta}{\theta_\infty} = \frac{T - T_w}{T_\infty - T_w} = \frac{3}{2} \frac{y}{\delta_t} - \frac{1}{2} \left(\frac{y}{\delta_t} \right)^3$$

$$\frac{d}{dx} \int_0^H (T_\infty - T) u dy = \alpha \left(\frac{dT}{dy} \right)_w \quad \frac{d}{dx} \int_0^H (\theta_\infty - \theta) u dy = \alpha \left(\frac{dT}{dy} \right)_w$$

$$\frac{d}{dx} \int_0^H \left[\theta_\infty - \theta_\infty \frac{3}{2} \frac{y}{\delta_t} + \frac{\theta_\infty}{2} \left(\frac{y}{\delta_t} \right)^3 \right] u dy = \alpha \left(\frac{dT}{dy} \right)_w$$

$$\frac{\theta_\infty u_\infty}{10} \frac{d}{dx} \left(\frac{\delta_t^2}{\delta} \right) = \alpha \left(\frac{dT}{dy} \right)_w \quad \zeta = \frac{\delta_t}{\delta}$$

$$\frac{\theta_\infty u_\infty}{10} \frac{d}{dx} (\delta \zeta^2) = \alpha \left(\frac{dT}{dy} \right)_w$$

$$\alpha \left(\frac{dT}{dy} \right)_w = \alpha \theta_0 \left[\frac{3}{2\delta_t} - \frac{3y^2}{2\delta_t^3} \right]_0 = \frac{3\alpha\theta_\infty}{2\delta_t}$$

$$\frac{\theta_\infty u_\infty}{10} \frac{d}{dx} (\delta \zeta^2) = \frac{3\alpha\theta_\infty}{2\delta_t}$$

$$\frac{1}{15} u_\infty \frac{d}{dx} (\delta \zeta^2) = \frac{\alpha}{\zeta \delta} \quad \frac{1}{15} u_\infty \left(2\delta^2 \zeta^2 \frac{d\zeta}{dx} + \zeta^3 \delta \frac{d\delta}{dx} \right) = \alpha$$

$$\rho \frac{d}{dx} \int_0^\delta (u_\infty - u) u dy = \mu \left. \frac{du}{dy} \right|_{y=0}$$

$$\rho \frac{d}{dx} \left(u_\infty^2 \frac{\delta}{6} \right) = \mu \left. \frac{du}{dy} \right|_{y=0}$$

$$\delta d\delta = \frac{6\mu}{\rho u_\infty} dx \quad \delta^2 = \frac{12\mu}{\rho u_\infty} x$$

$$\frac{1}{15} u_\infty \left(\frac{24\mu}{\rho u_\infty} x \zeta^2 \frac{d\zeta}{dx} + \frac{6u}{\rho u_\infty} \zeta^3 \right) = x$$

$$4x \zeta^2 \frac{d\zeta}{dx} + \zeta^3 = \frac{15x}{6\nu} \quad \zeta^2 \frac{d\zeta}{dx} = \frac{1}{3} \frac{d}{dx} (\zeta^3)$$

$$\frac{d}{dx} (\zeta^3) + \frac{3}{4x} (\zeta^3) = \frac{15x}{6\nu} \frac{3}{4x}$$

$$x^{3/4} \zeta^3 = \frac{45}{24} \frac{\alpha}{\nu} \int x^{-1/4} dx + c \quad \zeta^3 = \frac{15}{6} \frac{\alpha}{\nu} + cx^{-3/4}$$

$$\zeta = 0 \text{ at } x = x_0 \quad c = -\frac{15}{6} \frac{\alpha}{\nu} x_0^{3/4}$$

$$\zeta = \frac{\delta_t}{\delta} = \left\{ \frac{15}{6} \frac{\alpha}{\nu} \left[1 - \left(\frac{x_0}{x} \right)^{3/4} \right] \right\}^{1/3}$$

$$\delta = \left(\frac{12\mu x}{\rho u_\infty} \right)^{1/2} = \frac{3.47x}{\sqrt{\text{Re}_x}}$$

$$h = \frac{3}{2} \frac{k}{\delta \zeta} = \frac{3}{2} \frac{k \sqrt{\text{Re}_x}}{3.47x} \frac{\text{Pr}^{1/3}}{\left\{ \frac{15}{6} \left[1 - \left(\frac{x_0}{x} \right)^{3/4} \right] \right\}^{1/3}}$$

$$h_x = 0.319 \frac{k}{x} \sqrt{\text{Re}_x} \text{Pr}^{1/3} \left[1 - \left(\frac{x_0}{x} \right)^{3/4} \right]^{-1/3}$$

5-6

$$p = 2 \times 10^4 \text{ N/m}^2 \quad T = 5^\circ\text{C} = 278^\circ\text{K} \quad \text{Air}$$

$$\delta = 1.25 \text{ cm} = 0.0125 \text{ m} \quad u = 1.5 \text{ m/sec}$$

$$\rho = \frac{2 \times 10^4}{(287)(278)} = 0.251 \text{ kg/m}^3 \quad \mu = 1.864 \times 10^{-5} \frac{\text{kg}}{\text{m} \cdot \text{sec}}$$

$$x = \frac{\rho u_\infty}{\mu} \left(\frac{\delta}{4.64} \right)^2 = \frac{(0.25)(1.5)}{1.864 \times 10^{-5}} \left(\frac{0.0125}{4.64} \right)^2 = 0.147 \text{ m}$$

Chapter 5

5-7

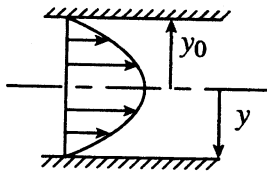
$$\text{O}_2 \text{ at 2 atm} \quad T_f = 250 \text{ K} \quad v = \frac{20.8 \times 10^{-6}}{2} \quad k = 0.0307$$

$$\text{Pr} = 0.702 \quad \text{Re} = \frac{(30)(0.5)(2)}{20.8 \times 10^{-6}} = 1.442 \times 10^6$$

$$\bar{h} = \frac{0.0307}{0.5} [(0.037)(1.442 \times 10^6)^{0.8} - 871](0.702)^{1/3} = 123 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (123)(0.5)^2(127 - 27) = 3080 \text{ W}$$

5-8



$$2yp - 2yp - 2yp = -2\tau dx = -2\left(\mu \frac{du}{dy}\right) dx$$

$$y dp = \mu dx \frac{du}{dy}$$

$$u = \frac{1}{2\mu} \frac{dp}{dx} y^2 + c \quad \text{at } y = y_0 \quad u = 0 \quad c = -\frac{1}{2\mu} \frac{dp}{dx} y_0^2$$

$$u = \frac{1}{2\mu} \frac{dp}{dx} (y^2 - y_0^2)$$

$$\text{at } y = 0 \quad u = u_0 \quad u_0 = \frac{1}{2\mu} \frac{dp}{dx} (-y_0^2)$$

$$\frac{u}{u_0} = \left(1 - \frac{y^2}{y_0^2}\right)$$

5-9

$$\frac{\theta}{\theta_{\infty}} = \frac{T - T_w}{T_{\infty} - T_w} = \frac{y}{\delta_t}$$

$$u = u_{\infty} = \text{const}$$

$$\left. \frac{\partial T}{\partial y} \right|_w = \frac{\theta_{\infty}}{\delta_t}$$

$$\frac{q}{A} = -k \left. \frac{\partial T}{\partial y} \right|_w = h(T_w - T_{\infty})$$

$$h = \frac{k}{\delta_t}$$

$$\frac{d}{dx} \left[\int_0^H (T_{\infty} - T) u dy \right] = \frac{d}{dx} \left[\int_0^{\delta_t} \theta_{\infty} u_{\infty} \left(1 - \frac{y}{\delta_t} \right) dy \right] = \theta_{\infty} u_{\infty} \frac{d}{dx} \left(\frac{\delta_t}{2} \right) = \frac{\theta_{\infty} \alpha}{\delta_t}$$

$$\delta_t \frac{d\delta_t}{dx} = \frac{2\alpha}{u_{\infty}}$$

$$\delta_t = 0 \text{ at } x = 0$$

$$\delta_t^2 = \frac{4\alpha x}{u_{\infty}}$$

$$\delta_t = \left(\frac{4\alpha x}{u_{\infty}} \right)^{1/2} = 2 \left(\frac{\alpha x}{u_{\infty}} \right)^{1/2}$$

$$h = \frac{k}{\delta_t} = \frac{k}{2} \left(\frac{u_{\infty}}{\alpha x} \right)^{1/2}$$

$$\text{Nu}_x = \frac{hx}{k} = \frac{x}{2} \left(\frac{u_{\infty}}{\alpha x} \right)^{1/2} = \frac{1}{2} \left(\frac{u_{\infty} x}{\alpha} \right)^{1/2} \quad \alpha = \frac{\nu}{\text{Pr}}$$

$$\text{Nu}_x = \frac{1}{2} \left(\frac{u_{\infty} x}{\nu} \text{Pr} \right)^{1/2} = \frac{1}{2} (\text{Re Pr})^{1/2}$$

5-11

$$\frac{\partial^2 u}{\partial y^2} = \frac{1}{\nu} \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right)$$

$$\frac{\partial^3 u}{\partial y^3} = \frac{1}{\nu} \left(u \frac{\partial^2 u}{\partial y \partial x} + \frac{\partial u}{\partial y} \cdot \frac{\partial y}{\partial x} + v \frac{\partial^2 u}{\partial y^2} + \frac{\partial v}{\partial y} \cdot \frac{\partial u}{\partial y} \right) - \frac{1}{\nu} \left[u \frac{\partial^2 u}{\partial y \partial x} + \frac{\partial u}{\partial y} \left(\frac{\partial y}{\partial x} + \frac{\partial v}{\partial y} \right) + v \frac{\partial^2 u}{\partial y^2} \right]$$

$$u = v = 0 \text{ at } y = 0 \quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad \therefore \frac{\partial^3 u}{\partial y^3} = 0 \text{ at } y = 0$$

Chapter 5

5-13

$$\frac{\delta_t}{\delta} = \frac{1}{1.026 \text{Pr}^{1/3}}$$

	Pr	$\frac{\delta_t}{\delta}$
Air	0.709	1.093
H ₂ O	7	0.5095
He	0.705	1.095
NH ₃	2.02	0.771
Glycerine	12.5	0.42

5-14

$$T_\infty = 15^\circ\text{C} \quad u_\infty = 3 \text{ m/s} \quad x = 5 \text{ cm} \quad \mu = 1.13 \times 10^{-3} \frac{\text{kg}}{\text{m} \cdot \text{s}}$$

$$\rho = 999.8 \text{ kg/m}^3 \quad \text{Re} = \frac{(999.8)(3)(0.05)}{1.13 \times 10^{-3}} = 1.33 \times 10^5$$

$$\delta = \frac{(4.64)(0.05)}{(1.33 \times 10^5)^{1/2}} = 6.37 \times 10^{-4} \text{ m}$$

$$\text{mass flow} = \int_0^\delta \rho u \, dy = \frac{5}{8} \rho u_\infty \delta = 1.19 \text{ kg/sec for 1 m depth.}$$

5-15

$$\rho = \frac{p}{RT} = \frac{1.032 \times 10^5}{(287)(363)} = 0.99 \text{ kg/m}^3 \quad T_\infty = 363^\circ\text{K}$$

$$\mu = 2.13 \times 10^{-5} \frac{\text{kg}}{\text{m} \cdot \text{sec}}$$

$$\text{Re} = \frac{(0.99)(30)(0.025)}{2.13 \times 10^{-5}} = 34,860$$

$$\delta = \frac{(4.64)(0.025)}{(34,860)^{1/2}} = 6.21 \times 10^{-4} \text{ m}$$

5-16

$$T_f = \frac{75 + 20}{2} = 47.5^\circ\text{C} = 320.5 \text{ K} \quad \mu = 1.94 \times 10^{-5}$$

$$\rho = \frac{2 \times 10^4}{(287)(320.5)} = 0.217 \quad k = 0.028 \quad \text{Pr} = 0.7$$

$$\text{Re}_x = \frac{(0.217)(20)x}{1.94 \times 10^{-5}} = 2.24 \times 10^5 x$$

$$h_x = (0.332)(0.028)(0.7)^{1/3} (2.24 \times 10^5)^{1/2} x^{-1/2} \left[1 - \left(\frac{x_0}{x} \right)^{3/4} \right]^{1/3}$$

$$h_x = \frac{3.904}{x^{1/2} \left[1 - \left(\frac{x_0}{x} \right)^{3/4} \right]^{1/3}} \quad q = \int_{x_0}^x h_x dx (T_w - T_\infty)$$

x	$h_x \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$
0.08	38.18
0.19	11.27
0.3	8.24

$$\int h_x dx = 3.79 \quad q = (3.79)(75 - 20) = 208.6 \text{ W}$$

5-17

$$\delta = 7.5 \text{ mm} = 0.0075 \text{ m} \quad \rho = 1000 \quad \mu = 1.5 \times 10^{-3} \frac{\text{kg}}{\text{m} \cdot \text{sec}}$$

$$x = \frac{\rho u_\infty}{\mu} \left(\frac{\delta}{4.64} \right)^2 = \frac{(1000)(1.5) \left(\frac{0.0075}{4.64} \right)^2}{1.5 \times 10^{-3}} = 2.61 \text{ m}$$

5-18

$$T_f = \frac{90 + 30}{2} = 60^\circ\text{C} = 333 \text{ K} \quad \nu = 19.09 \times 10^{-6} \quad k = 0.0288$$

$$\text{Pr} = 0.7 \quad \text{Re} = \frac{(20)(0.6)}{19.09 \times 10^{-6}} = 6.29 \times 10^5$$

$$\bar{h} = \frac{0.0288}{0.6} (0.7)^{1/3} [(0.037)(6.29 \times 10^5)^{0.8} - 871] = 31.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

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

Chapter 5

5-19

$$\begin{aligned}
 p &= 7 \text{ kN/m}^2 & T_\infty &= 35^\circ\text{C} & L &= 0.3 \text{ m} & u_\infty &= 7.5 \text{ m/sec} \\
 T_w &= 65^\circ\text{C} & T_f &= \frac{65+35}{2} = 50^\circ\text{C} = 323 \text{ K} \\
 \rho &= \frac{7000}{(287)(323)} = 0.0755 \text{ kg/m}^3 & \mu &= 2.025 \times 10^{-5} \frac{\text{kg}}{\text{m} \cdot \text{sec}} \\
 k &= 0.02798 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} & \text{Pr} &= 0.71 & \text{Re} &= \frac{(0.0755)(7.5)(0.3)}{2.025 \times 10^{-5}} = 8390 \\
 \bar{h} &= \frac{0.02798}{0.3} (0.71)^{1/3} (8390)^{1/2} (0.664) = 5.04 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \\
 q &= (5.04)(0.3)^2 (65 - 35) = 13.6 \text{ W}
 \end{aligned}$$

5-20

$$\begin{aligned}
 T_\infty &= 90^\circ\text{C} & u_\infty &= 60 \text{ m/sec} & L &= 60 \text{ cm} & T_w &= 10^\circ\text{C} \\
 T_f &= 50^\circ\text{C} = 323 \text{ K} & \rho &= \frac{1.0132 \times 10^5}{(287)(323)} = 1.093 & \mu &= 1.716 \times 10^{-5} \\
 k &= 0.0241 & \text{Pr} &= 0.71 \\
 \text{Re} &= \frac{(1.093)(60)(0.6)}{1.716 \times 10^{-5}} = 2.292 \times 10^6 \\
 \bar{h} &= \frac{0.0241}{0.6} (0.71)^{1/3} [(0.037)(2.29 \times 10^6)^{0.8} - 871] \\
 \bar{h} &= 131.1 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} & q &= (131.1)(0.6)^2 (10 - 90) = 3776
 \end{aligned}$$

5-21

$$\begin{aligned}
 \text{N}_2 \text{ at } 2 \text{ atm} & & T_f &= 400 \text{ K} & \nu &= \frac{25.74 \times 10^{-6}}{2} & k &= 0.03335 \\
 \text{Pr} &= 0.691 & \text{Re} &= \frac{(0.4)(2)(25)}{25.74 \times 10^{-6}} = 7.78 \times 10^5 \text{ turbulent} \\
 \bar{h} &= \frac{0.0335}{0.4} [0.037(7.78 \times 10^5)^{0.8} - 871] (0.691)^{1/3} = 76.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \\
 q &= \bar{h}A(T_w - T_\infty) = (76.4)(0.4)^2 (500 - 300) = 2446 \text{ W}
 \end{aligned}$$

5-23

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

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

$$\mu = 2.349 \times 10^{-5} \quad k = 0.03474 \quad \text{Pr} = 0.685$$

$$\text{Re} = \frac{(0.117)(6)(0.2)}{2.349 \times 10^{-5}} = 5977$$

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

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

5-24

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

$$u_{\infty} = 30 \text{ m/sec} \quad u = 22.5 \text{ m/sec} \quad T_f = \frac{55 + 20}{2} = 37.5^{\circ}\text{C} = 310 \text{ K}$$

$$\rho = \frac{20,000}{(287)(310)} = 0.225 \text{ kg/m}^3 \quad \mu = 2.001 \times 10^{-5}$$

$$\text{Re} = \frac{(0.225)(30)(0.3)}{2.001 \times 10^{-5}} = 1.01 \times 10^5 \quad \delta = \frac{(0.3)(4.64)}{(1.01 \times 10^5)^{1/2}} = 4.38 \times 10^{-3} \text{ m}$$

$$\frac{u}{u_{\infty}} = \frac{22.5}{30} = \frac{3}{2} \left(\frac{y}{\delta} \right) - \frac{1}{2} \left(\frac{y}{\delta} \right)^3 \quad \frac{y}{\delta} = 0.56 \quad y = 2.45 \times 10^{-3} \text{ m}$$

5-25

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

5-26

$$T_f = ^\circ\text{C} = 315 \text{ K}$$

$$v = 17.2 \times 10^{-6} / 2 = 8.6 \times 10^{-6}$$

$$k = 0.0274; \text{ Pr} = 0.7$$

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

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

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

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

5-27

$$\text{Eq. (5-95); } \delta = (0.287) [0.381(10^6)^{-0.2} - 10256/10^6]$$

$$0.00396 \text{ m} = 3.96 \text{ mm}$$

Chapter 5

5-28

$$T_f = 308 \text{ K} \quad \rho = \frac{70,000}{(287)(308)} = 0.792 \quad \mu = 2 \times 10^{-5}$$

$$k = 0.0268 \quad \text{Pr} = 0.7 \quad \text{Re}_{x_0} = \frac{(0.792)(6)(0.15)}{2 \times 10^{-5}} = 35,640$$

Use Eq. (5-43) and numerically integrate: $\text{Re}_{16.5} = \frac{16.5}{15}(35,640) = 38,610$

$$h_{16.25} = \frac{0.0268}{0.1625} (0.332)(38,610)^{1/2} (0.7)^{1/3} \left[1 - \left(\frac{15}{16.25} \right)^{3/4} \right]^{-1/3} = 24.64$$

$$h_{17.5} = 19.98 \left(\frac{16.25}{17.5} \right)^{1/2} = 19.25$$

$$h_x = (0.332)k \text{Pr}^{1/3} \left(\frac{400}{2} \right)^{1/2} \frac{1}{x^{1/2}} \frac{1}{\left[1 - \left(\frac{x_0}{x} \right)^{3/4} \right]^{1/3}}$$

$$h_{15.5} = 33.76 \quad h_{15.25} = 42.68$$

$$\bar{h} = \frac{\int h_x dx}{\Delta x} = 27.85 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (27.85)(0.025)(65 - 5) = 41.8 \text{ W}$$

5-29

$$T_f = \frac{55 + 27}{2} = 41^\circ\text{C} = 314 \text{ K} \quad \nu = 17.94 \times 10^{-6} \quad k = 0.0273$$

$$\text{Pr} = 0.7 \quad \text{Re}_L = \frac{(4.5)(15)}{17.94 \times 10^{-6}} = 3.76 \times 10^6$$

$$\bar{h} = \frac{0.0273}{15} (0.7)^{1/3} [(0.037)(3.76 \times 10^6)^{0.8} - 871] = 9.48$$

$$q = (9.48)(15)(55 - 27) = 3980 \text{ W/m}$$

5-30

$$T_f = \frac{300 + 400}{2} = 350 \text{ K} \quad \rho = \frac{75,000}{(287)(350)} = 0.747 \text{ kg/m}^3$$

$$\mu = 2.075 \times 10^{-5} \quad k = 0.03003 \quad \text{Pr} = 0.697$$

$$\text{Re} = \frac{(0.747)(45)(1.0)}{2.075 \times 10^{-5}} = 1.62 \times 10^6$$

$$\bar{h} = \frac{0.03003}{1.0} (0.697)^{1/3} [(0.037)(1.62 \times 10^6)^{0.8} - 871] = 68.25 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (68.25)(1)^2(400 - 300) = 6825 \text{ W}$$

5-31

$$T_f = \frac{50 + 10}{2} = 30^\circ\text{C} = 303 \text{ K} \quad \rho = \frac{50,000}{(287)(303)} = 0.575 \text{ kg/m}^3$$

$$\mu = 1.85 \times 10^{-5} \quad k = 0.0263 \quad \text{Pr} = 0.7$$

$$\text{Re} = \frac{(0.575)(0.5)(20)}{1.85 \times 10^{-5}} = 3.11 \times 10^5$$

$$\bar{h} = \frac{0.0263}{0.5} (0.664)(3.11 \times 10^5)^{1/2} (0.7)^{1/3} = 17.3 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (17.3)(0.5)^2(50 - 10) = 172.9 \text{ W}$$

5-32

$$T_f = \frac{100 + 10}{2} = 55^\circ\text{C} = 328 \text{ K} \quad \rho = \frac{1.01 \times 10^5}{(2)(287)(328)} = 0.538$$

$$\mu = 1.974 \times 10^{-5} \quad k = 0.0284 \quad \text{Pr} = 0.7$$

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

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

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

$$\frac{h_x}{k} = 0.453 \text{Re}_x^{1/2} \text{Pr}^{1/3}$$

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

5-33

	v	u (m/s)
H ₂ O	9.8×10^{-7}	9.8
Air	1.53×10^{-5}	153
F-12	0.198×10^{-6}	1.98
NH ₃	0.359×10^{-6}	3.59
He	122.2×10^{-6}	1222

$$u = \frac{10^7 v}{L} = 10^7 v$$

Chapter 5

5-34

$$L = 1.0 \text{ m}$$

$$\text{Re}_L = 10^7$$

	ν	k	Pr	\bar{h}
H ₂ O	9.8×10^{-7}	0.6	6.8	15,750
Air	1.53×10^{-5}	0.026	0.7	320
F-12	0.198×10^{-6}	0.073	3.5	1536
NH ₃	0.359×10^{-6}	0.521	2.02	9127
He	122.2×10^{-6}	0.147	0.72	1825

$$\bar{h} = k[0.037(10^7)^{0.8} - 871]\text{Pr}^{1/3} = 13,859k\text{Pr}^{1/3}$$

5-35

$$L = 1.0 \text{ m} \quad \frac{\delta}{L} = 0.381\text{Re}_L^{-1/5} - \frac{10,256}{\text{Re}_L}$$

$$\delta = (1.0) \left[(0.381)(10^7)^{-0.2} - \frac{10,256}{10^7} \right] = 0.0141 \text{ m for all fluids}$$

5-36

Evaluate properties at 350 K $\nu = 20.76 \times 10^{-6}$ $k = 0.03003$

$$\text{Pr} = 0.697 \quad \text{Re}_L = \frac{(3)(0.25)}{20.76 \times 10^{-6}} = 36,127$$

$$\overline{T_w - T_\infty} = \frac{q_w L/k}{0.6795\text{Re}_L^{1/2}\text{Pr}^{1/3}} = \frac{(800)(0.25)/0.03003}{(36,127)^{1/2}(0.697)^{1/3}(0.6795)} = 58.16^\circ\text{C}$$

$$\overline{T_w} = 25 + 58.16 = 83.16^\circ\text{C}$$

at $x = 25 \text{ cm}$

$$h = \frac{k}{x} 0.453\text{Re}_x^{1/2}\text{Pr}^{1/3} = \frac{0.03003}{0.25} (0.453)(36,127)^{1/2}(0.697)^{1/3} = 9.17 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{or } \text{Nu}_x = 76.34$$

$$T_w - T_\infty = \frac{q_w x}{k \text{Nu}_x} = \frac{(800)(0.25)}{(0.03003)(76.34)} = 87.24^\circ\text{C}$$

$$T_w = 87.24 + 25 = 112.24^\circ\text{C}$$

5-37

$$u_\infty = 20 \text{ m/s} \quad \text{Air at } \frac{1}{2} \text{ atm} \quad T_\infty = 27^\circ\text{C} \quad T_w = 127^\circ\text{C}$$

$$L = 34 \text{ cm square}$$

$$T_f = 350 \text{ K} \quad \nu = \frac{20.76 \times 10^{-6}}{0.5} \quad k = 0.03003 \quad \text{Pr} = 0.697$$

$$\text{Re} = \frac{(20)(0.34)(0.5)}{20.76 \times 10^{-6}} = 1.638 \times 10^5$$

$$\bar{h} = \frac{0.03003}{0.34} (0.664)(0.697)^{1/3} (1.638 \times 10^5)^{1/2} = 21.04 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (21.04)(0.34)^2(127 - 27) = 243.3 \text{ W}$$

5-38

$$T_f = \frac{113 + 73}{2} = 93^\circ\text{C} = 366 \text{ K} \quad \nu = \frac{173.6 \times 10^{-6}}{3} \quad k = 0.1691 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\text{Pr} = 0.71$$

$$\text{Re}_L = \frac{(50)(0.35)(3)}{173.6 \times 10^{-6}} = 3.02 \times 10^5$$

$$\bar{h} = \frac{0.1691}{0.35} (0.664)(3.02 \times 10^5)^{1/2} (0.71)^{1/3} = 157.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (157.4)(0.35)^2(113 - 73) = 771 \text{ W}$$

5-39

$$T_f = 350 \text{ K} \quad \nu = 20.76 \times 10^{-6} \quad k = 0.03003 \quad \text{Pr} = 0.697$$

$$u_\infty = \frac{1.1 \times 10^5 \nu}{L} = 4.57 \text{ m/sec} \quad x_0 = 25 \text{ cm}$$

$$h_x = \frac{k}{x} 0.332 \text{Pr}^{1/3} \text{Re}^{1/2} \left[1 - \left(\frac{x_0}{x} \right)^{3/4} \right]^{-1/3}$$

$$x \text{ (cm)} \quad h_x \left(\frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \right)$$

$$26 \quad 36.7$$

$$35 \quad 13.81$$

$$44 \quad 9.50$$

$$50 \quad 7.92$$

$$\int_{x_0}^L h_x dx = 3.844 \quad \bar{h} = \frac{3.844}{0.25} = 15.38 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}(L - x_0)L(T_w - T_\infty) = (15.38)(0.5 - 0.25)(0.5)(400 - 300) = 192.2 \text{ W}$$

Chapter 5

5-40

$$u_\infty = 150 \text{ m/sec} \quad T_w = 150^\circ\text{C} \quad L = 1 \text{ m} \quad T_\infty = 20^\circ\text{C}$$

$$\mu = 2.11 \times 10^{-5}$$

$$T_f = \frac{150 + 20}{2} = 85^\circ\text{C} = 358 \text{ K} \quad \rho = \frac{p}{RT} = \frac{14,000}{(287)(358)} = 0.136 \text{ kg/m}^3$$

$$k = 0.03060 \quad \text{Pr} = 0.695 \quad \text{Re} = \frac{(0.136)(150)(1)}{2.11 \times 10^{-5}} = 9.67 \times 10^5$$

$$\bar{h} = \frac{0.03060}{1} (0.695)^{1/3} [(0.037)(9.67 \times 10^5)^{0.8} - 871] = 38.00 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{A} = (38.00)(150 - 20) = 4939 \text{ W/m}^2$$

5-41

$$\overline{\text{St}} \text{Pr}^{2/3} = \frac{\overline{C_f}}{2} = 0.074 \text{Re}_L^{-1/5} - \frac{A}{2} \text{Re}_L^{-1}$$

Re_{crit}	Eq. (5-85) becomes
3×10^5	$\text{Pr}^{1/3}(0.037 \text{Re}_L^{0.8} - 528)$
5×10^5	$\text{Pr}^{1/3}(0.037 \text{Re}_L^{0.8} - 871)$
10^6	$\text{Pr}^{1/3}(0.037 \text{Re}_L^{0.8} - 1670)$
5×10^6	$\text{Pr}^{1/3}(0.037 \text{Re}_L^{0.8} - 4420)$

5-42

$$h_x = cx^{-1/5}$$

$$\bar{h} = \frac{1}{L} \int_0^L cx^{-1/5} dx = 1.25cL^{-1/5}$$

$$\overline{\text{St}} \text{Pr}^{2/3} = (1.25)(0.0296) \text{Re}_L^{-1/5} = 0.037 \text{Re}_L^{-1/5}$$

5-43

$$T_f = \frac{80 + 10}{2} = 45^\circ\text{C} \quad \rho = 990 \quad \mu = 6 \times 10^{-4} \quad k = 0.64$$

$$\text{Pr} = 4.81 \quad \text{Max Temp. at } x = L \quad \text{Re}_L = \frac{(990)(2)(0.1)}{6 \times 10^{-4}} = 3.3 \times 10^5$$

$$\text{Nu}_x = 0.453 \text{Re}_x^{1/2} \text{Pr}^{1/3} = (0.453)(3.3 \times 10^5)^{1/2} (4.81)^{1/3} = 439$$

$$q_w = \frac{\text{Nu}_x k}{x} (T_w - T_\infty) = \frac{(439)(0.64)}{0.1} (80 - 10) = 1.97 \times 10^5 \text{ W/m}^2$$

$$q = q_w A = (1.97 \times 10^5)(0.1)^2 = 1968 \text{ W}$$

5-44

Take properties at 350 K. $\nu = 20.76 \times 10^{-6}$ $k = 0.03003$

$$\text{Pr} = 0.697 \quad \text{Re}_L = \frac{(3)(0.1)}{20.76 \times 10^{-6}} = 14,451$$

$$\text{Nu}_x = (0.453)(14,451)^{1/2} (0.697)^{1/3} = 48.28$$

$$q_w = \frac{\text{Nu}_x}{x} (T_w - T_\infty) k = \frac{(48.28)(0.03003)}{0.1} (80 - 10) = 1015 \text{ W/m}^2$$

$$q = q_w A = (1015)(0.1)^2 = 10.15 \text{ W}$$

5-45

$$T_f = \frac{300 + 500}{2} = 400 \text{ K} \quad \nu = 202.9 \times 10^{-6} \quad k = 0.178 \quad \text{Pr} = 0.72$$

$$\text{Re} = \frac{(50)(1)}{202.9 \times 10^{-6}} = 2.46 \times 10^5$$

$$\bar{h} = \frac{k}{L} 0.664 \text{Re}^{1/2} \text{Pr}^{1/3} = \frac{0.178}{1} (0.664)(2.46 \times 10^5)^{1/2} (0.72)^{1/3} = 52.59 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h} A (T_w - T_\infty) = (52.59)(1)^2 (500 - 300) = 10.52 \text{ kW}$$

$$\frac{\delta}{L} = \frac{4.64}{\text{Re}_L^{1/2}} \quad \delta = \frac{(1)(4.64)}{(2.46 \times 10^5)^{1/2}} = 0.0094 \text{ m}$$

5-46

$$u_\infty = 10 \text{ mi/h} = 4.47 \text{ m/s} \quad T_\infty = 27^\circ\text{C} \quad \left. \frac{q}{A} \right|_{\text{sun}} = 347 \text{ W/m}^2$$

$$L = 6.1 \text{ m} \quad k = 0.0262 \quad \text{Pr} = 0.71 \quad \mu = 1.98 \times 10^{-5} \quad \rho = 1.177$$

$$\text{Re}_L = \frac{(1.177)(4.47)(6.1)}{1.98 \times 10^{-5}} = 1.62 \times 10^6$$

$$\bar{h} = \frac{0.0262}{6.1} (0.71)^{1/3} [(0.037)(1.62 \times 10^6)^{0.8} - 871] = 9.81 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$T_w - T_\infty = \frac{347}{9.81} = 35.4^\circ\text{C}$$

$$T_w = 62.4^\circ\text{C}$$

Chapter 5

5-47

$$T_{\infty} = 400^{\circ}\text{C} \quad T_w = 420^{\circ}\text{F} \quad u_{\infty} = 1 \text{ ft/sec} = 0.3048 \text{ m/sec}$$

$$L = 10 \text{ ft} = 3.048 \text{ m} \quad \text{Re} = \frac{(0.3048)(3.048)}{2 \times 10^{-6}} = 4.645 \times 10^5$$

$$\bar{h} = \frac{0.12}{3.048} (0.664)(4.645 \times 10^5)^{1/2} (40)^{1/3} = 60.93 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$$

$$q = (60.93)(3.048)(3)(0.3048)(420 - 400) \left(\frac{5}{9}\right) = 1887 \text{ W}$$

$$\delta = \frac{(3.048)(4.64)}{(4.645 \times 10^5)^{1/2}} = 0.0208 \text{ m}$$

5-48

$$T_f = \frac{27 + 77}{2} = 57^{\circ}\text{C} = 325 \text{ K} \quad \nu = 18.23 \times 10^{-6} \quad k = 0.0281$$

$$\text{Pr} = 0.7 \quad \text{Re}_L = \frac{(40)(4)}{18.23 \times 10^{-6}} = 8.78 \times 10^6$$

$$\text{Nu}_L = \text{Pr}^{1/3} (0.037 \text{Re}_L^{0.8} - 850)$$

$$\bar{h} = \frac{0.0281}{4} (0.7)^{1/3} [(0.037)(8.78 \times 10^6)^{0.8} - 871] = 77.4 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$$

$$q = \bar{h}A(T_w - T_{\infty}) = (77.4)(4)^2(77 - 27) = 6.19 \times 10^4 \text{ W}$$

5-49

$$T_f = \frac{300 + 273}{2} = 287 \text{ K} \quad \nu = 14.51 \times 10^{-6} \quad k = 0.0252 \quad \text{Pr} = 0.71$$

$$u_{\infty} = 5 \text{ mi/hr} = 7.33 \text{ ft/sec} = 2.235 \text{ m/sec}$$

$$\text{Re}_L = \frac{(2.235)(30)}{14.51 \times 10^{-6}} = 4.62 \times 10^6$$

$$\text{Nu}_L = \text{Pr}^{1/3} (0.037 \text{Re}_L^{0.8} - 871)$$

$$\bar{h} = \frac{0.0252}{30} (0.71)^{1/3} [(0.037)(4.62 \times 10^6)^{0.8} - 871] = 5.30 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$$

$$q = \bar{h}A(T_w - T_{\infty}) = (5.30)(30)(60)(300 - 273) = 2.58 \times 10^5 \text{ W}$$

5-50

$$\text{at } 300 \text{ K} \quad \nu = 15.69 \times 10^{-6}$$

$$\text{Re}_L = \frac{(10)(0.15)}{15.69 \times 10^{-6}} = 9.56 \times 10^4$$

$$\frac{\delta}{L} = \frac{4.64}{\text{Re}^{1/2}}$$

$$\delta = (0.15)(9.56 \times 10^4)^{1/2}(4.64) = 0.00225 \text{ m}$$

5-51

$$T_f = 350 \text{ K} \quad \nu = 20.69 \times 10^{-6} \quad k = 0.0318 \quad \text{Pr} = 0.7$$

$$\text{Re}_L = \frac{(33)(0.6)}{20.69 \times 10^{-6}} = 9.57 \times 10^5 > 5 \times 10^5 \rightarrow \text{Turbulent}$$

$$\bar{h} = \frac{0.0318}{0.6} (0.7)^{1/3} [0.037(9.57 \times 10^5)^{0.8} - 871] = 65.08 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (65.08)(0.6)(0.3)(400 - 300) = 1171 \text{ W}$$

5-52

$$T = 303 \text{ K}; \quad \nu = 128 \times 10^{-6}; \quad u_\infty = 15$$

$$L = (250000)(128 \times 10^{-6})/15 = 2.13 \text{ m}$$

$$\delta = (2.13)(5)/(250000)^{1/2} = 0.0213 \text{ m} = 21.3 \text{ mm}$$

5-53

$$T_f = 45^\circ\text{C} = 318 \text{ K}; \quad k = 0.155; \quad \text{Pr} = 0.7$$

$$h = (0.155/2.13)(0.664)(250000)^{1/2} (0.7)^{1/3} = 21.45$$

$$q = (21.45)(2.13)(60 - 30) = 1371 \text{ W/m depth}$$

5-54

$$T_f = \frac{25 + 150}{2} = 87.5^\circ\text{C} = 360.5 \text{ K} \quad \mu = 2.119 \times 10^{-5} \quad k = 0.0308$$

$$\text{Pr} = 0.693 \quad \rho = \frac{0.2 \times 10^6}{(287)(360.5)} = 1.933 \text{ kg/m}^3$$

$$\text{Re}_L = \frac{(1.933)(60)(0.5)}{2.119 \times 10^{-5}} = 2.74 \times 10^6$$

$$\text{Nu} = \text{Pr}^{1/3} (0.037 \text{Re}^{0.8} - 871)$$

$$\bar{h} = \frac{(0.693)^{1/3}}{0.5} (0.0308) [(0.037)(2.74 \times 10^6)^{0.8} - 871] = 238.6 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (238.6)(0.5)^2(150 - 25) = 7424 \text{ W}$$

5-55

$$T_w = 100^\circ\text{C} \quad T_\infty = 20^\circ\text{C} \quad T_f = \frac{20 + 100}{2} = 60^\circ\text{C} = 333 \text{ K}$$

$$p = 150 \text{ kPa} \quad u_\infty = 50 \text{ m/sec} \quad \mu = 216 \times 10^{-7} \quad k = 0.15$$

$$\text{Pr} = 0.7$$

$$\rho = \frac{150 \times 10^3}{(2078)(333)} = 0.217 \text{ kg/m}^3$$

$$\text{Re}_L = \frac{(50)(1)(0.217)}{216 \times 10^{-7}} = 4.98 \times 10^5$$

$$\bar{h} = 0.664 \frac{k}{L} \text{Re}_L^{1/2} \text{Pr}^{1/3} = (0.664) \frac{0.15}{1.0} (4.98 \times 10^5)^{1/2} (0.7)^{1/3} = 62.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (62.4)(1)^2(100 - 20) = 4993 \text{ W}$$

Chapter 5

5-56

$$T_f = 300 \text{ K} \quad \mu = 1.8462 \times 10^{-5} \quad k = 0.02624 \quad \text{Pr} = 0.71$$

$$\rho = \frac{40,000}{(287)(300)} = 0.465 \text{ kg/m}^3 \quad \text{Re}_L = \frac{(0.465)(20)(2)}{1.8462 \times 10^{-5}} = 1.01 \times 10^6$$

$$\bar{h} = \frac{k}{L} \text{Pr}^{1/3} (0.037 \text{Re}_L^{0.8} - 871) = \frac{0.02624}{2} (0.71)^{1/3} [(0.037)(1.01 \times 10^6)^{0.8} - 871]$$

$$= 17.3 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (17.3)(2)^2(350 - 250) = 693 \text{ W}$$

5-57

$$T_f = 350 \text{ K} \quad \mu = 19.91 \times 10^{-6} \quad k = 0.0298 \quad \text{Pr} = 0.7$$

$$\rho = \frac{50,000}{(287)(350)} = 0.481 \text{ kg/m}^3 \quad \text{Re}_L = \frac{(0.481)(1.2)(100)}{19.91 \times 10^{-6}} = 2.9 \times 10^6$$

$$\bar{h} = \frac{0.0298}{1.2} (0.7)^{1/3} [(0.037)(2.9 \times 10^6)^{0.8} - 871] = 101.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (101.4)(1.2)(400 - 300) = 1.22 \times 10^4 \text{ W/m}$$

5-58

$$T_f = \frac{15 + 139}{2} = 77^\circ\text{C} = 350 \text{ K} \quad \mu = 9.954 \times 10^{-6} \quad k = 0.206$$

$$\text{Pr} = 0.697 \quad \rho = \frac{(2)(1.01 \times 10^5)}{(4157)(350)} = 9.139 \text{ kg/m}^3$$

$$\text{Re}_L = \frac{(0.139)(6)(1)}{9.954 \times 10^{-6}} = 83,952$$

$$\bar{h} = \frac{k}{L} 0.664 \text{Re}_L^{1/2} \text{Pr}^{1/3} = \frac{0.206}{1} (0.664)(83,952)^{1/2} (0.697)^{1/3} = 35.14 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (35.14)(1)^2(139 - 15) = 4357 \text{ W}$$

5-59

$$T_f = \frac{10 + 50}{2} = 30^\circ\text{C} \quad \nu = 0.349 \times 10^{-6} \quad k = 0.507 \quad \text{Pr} = 2.01$$

$$\text{Re}_L = \frac{(5)(0.4)}{0.349 \times 10^{-6}} = 5.73 \times 10^6$$

$$\bar{h} = \frac{k}{L} \text{Pr}^{1/3} (0.037 \text{Re}_L^{0.8} - 871) = \frac{0.507}{0.4} (2.01)^{1/3} [(0.037)(5.73 \times 10^6)^{0.8} - 871]$$

$$= 13,698 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (13,698)(0.4)^2(50 - 10) = 87,670 \text{ W}$$

5-60

$$T_f = \frac{50 + 136}{2} = 93^\circ\text{C} = 366 \text{ K} \quad \rho = \frac{45 \times 10^3}{(2078)(366)} = 0.0592 \text{ kg/m}^3$$

$$\mu = 230.5 \times 10^{-7} \quad k = 0.1691 \quad \text{Pr} = 0.71$$

$$\text{Re}_L = \frac{(0.0592)(1)(50)}{230.5 \times 10^{-7}} = 1.28 \times 10^5$$

$$\bar{h} = \frac{k}{L} 0.664 \text{Re}_L^{1/2} \text{Pr}^{1/3} = \frac{0.1691}{1} (0.664)(1.28 \times 10^5)^{1/2} (0.71)^{1/3}$$

$$= 35.88 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (35.88)(1)^2(136 - 50) = 3086 \text{ W}$$

5-61

$$T_f = \frac{100 + 10}{2} = 55^\circ\text{C} = 328 \text{ K} \quad \nu = (18.53 \times 10^{-6})(10) = 18.53 \times 10^{-5}$$

$$k = 0.0284 \quad \text{Pr} = 0.7$$

$$\text{Re}_L = \frac{(300)(0.8)}{18.53 \times 10^{-5}} = 1.295 \times 10^6$$

$$\bar{h} = \frac{k}{L} \text{Pr}^{1/3} (0.037 \text{Re}_L^{0.8} - 871) = \frac{0.0284}{0.8} (0.7)^{1/3} [(0.037)(1.295 \times 10^6)^{0.8} - 871]$$

$$= 63.04 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (63.04)(0.8)^2(100 - 10) = 3631 \text{ W}$$

5-62

$$T_f = \frac{21 + 54}{2} = 37.5^\circ\text{C} \quad \rho = 993 \quad \mu = 6.82 \times 10^{-4} \quad k = 0.63$$

$$\text{Pr} = 4.53 \quad L = 0.3 \quad u_\infty = 6 \text{ m/s}$$

$$\text{Re}_L = \frac{(993)(6)(0.3)}{6.82 \times 10^{-4}} = 2.62 \times 10^6$$

$$\bar{h} = \frac{0.63}{0.3} (4.53)^{1/3} [(0.037)(2.62 \times 10^6)^{0.8} - 871] = 14,500 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (14,500)(0.3)^2(54 - 21) = 43,080 \text{ W}$$

Chapter 5

5-64

$$\frac{u}{u_\infty} = \left(\frac{y}{\delta}\right)^{1/7} \quad \dot{m} = \int_0^\delta \rho u \, dy = \int_0^\delta \rho u_\infty \left(\frac{y}{\delta}\right)^{1/7} dy = \rho \frac{u_\infty}{\delta^{1/7}} \frac{y^{8/7}}{8/7} \Big|_0^\delta = \frac{7}{8} \rho u_\infty \delta$$

$$v = 20.76 \times 10^{-6} \text{ m}^2/\text{s at 350 K} \quad \rho = 0.998 \text{ kg/m}^3$$

$$\text{At } Re_x = 10^6 \quad x = \frac{(10^6)(20.76 \times 10^{-6})}{30} = 0.692 \text{ m}$$

$$\delta = x[(0.381)Re_x^{-1/5} - 10,256Re_x^{-1}] = 9.54 \times 10^{-3} \text{ m}$$

$$\dot{m} = \frac{7}{8}(0.998)(6)(9.54 \times 10^{-3}) = 4.998 \times 10^{-2} \text{ kg/s}$$

$$\text{At } Re_x = 10^7 \quad x = 6.92 \text{ m} \quad \delta = 0.0979 \text{ m}$$

$$\dot{m} = \frac{7}{8}(0.998)(6)(0.0979) = 0.513 \text{ kg/s}$$

5-65

$$T_f = \frac{600 + 300}{2} = 450 \text{ K} \quad \mu = 2.484 \times 10^{-5} \quad k = 0.03707$$

$$Pr = 0.683 \quad \rho = \frac{50,000}{(287)(450)} = 0.387 \text{ kg/m}^3$$

$$Re_x = \frac{(0.387)(6)(0.2)}{2.484 \times 10^{-5}} = 18,703$$

$$Nu_x = 0.453 Re_x^{1/2} Pr^{1/3} = (0.453)(18,703)^{1/2} (0.683)^{1/3} = 54.56$$

$$q_w = \frac{k Nu_x (T_w - T_\infty)}{x} = \frac{(0.03707)(54.56)(600 - 300)}{0.2} = 3034 \text{ W/m}^2$$

$$q = q_w A = (3034)(0.2)^2 = 121.3 \text{ W}$$

5-66

$$\frac{1}{ur} \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) = \frac{1}{\alpha} \frac{\partial T}{\partial x} \quad \frac{\partial T}{\partial r} = \frac{u_0}{\alpha} \frac{\partial T}{\partial x} \frac{r}{2} + \frac{c_1}{r}$$

$$T = \frac{u_0}{\alpha} \frac{\partial T}{\partial x} \frac{r^2}{4} + c_1 \ln r + c_2 \quad \frac{c_1}{r} = f(x) = c \quad c_1 = 0$$

$$\text{at } r=0 \quad T = T_c \quad T_c = c_2 \quad \text{then } T = \frac{u_0}{\alpha} \frac{\partial T}{\partial x} \frac{r^2}{4} + T_c$$

$$T_b = \frac{\int_0^{r_0} \rho(2\pi r dr) u c_p T}{\int_0^{r_0} \rho(2\pi r dr) u c_p} = \frac{u_0}{8\alpha} r_0^2 \frac{\partial T}{\partial x} + T_c \quad T = T_w \text{ at } r = r_0$$

$$T_w = \frac{u_0}{4\alpha} \frac{\partial T}{\partial x} r_0^2 + T_c \quad h = \frac{-k \left(\frac{\partial T}{\partial r} \right)_{r=r_0}}{T_w - T_b}$$

$$\left. \frac{\partial T}{\partial r} \right|_{r=r_0} = \left. \frac{u_0}{\alpha} \frac{\partial T}{\partial x} \cdot \frac{2r}{4} \right|_{r=r_0} = \frac{u_0 r_0}{2\alpha} \frac{\partial T}{\partial x}$$

$$h = \frac{-k \frac{u_0 r_0}{2\alpha} \frac{\partial T}{\partial x}}{\frac{u_0}{4\alpha} \frac{\partial T}{\partial x} r_0^2 + T_c - \left[\frac{u_0}{8\alpha} \frac{\partial T}{\partial x} r_0^2 + T_c \right]} = \frac{-k \frac{u_0 r_0}{2\alpha} \frac{\partial T}{\partial x}}{\frac{u_0}{8\alpha} r_0^2 \frac{\partial T}{\partial x}} = -\frac{4k}{r_0}$$

$$h = \frac{8k}{d_0} \text{ or } Nu_d = 8.0$$

5-68

$$\text{Air } T_f = \frac{27 + 127}{2} = 102^\circ\text{C} = 375 \text{ K}$$

$$v = \frac{23.33 \times 10^{-6}}{1.2} \quad k = 0.03184 \quad \text{Pr} = 0.698$$

$$Re_L = \frac{(40)(0.6)(1.2)}{23.33 \times 10^{-6}} = 1.234 \times 10^6 \text{ Turbulent}$$

$$\bar{h} = \frac{0.03184}{0.6} (0.693)^{1/3} [0.037(1.234 \times 10^6)^{0.8} - 871] = 88.85 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h} A (T_w - T_\infty) = (88.85)(0.6)^2 (179 - 27) = 4798 \text{ W}$$

Chapter 5

5-69

$$p = \frac{1}{2} \text{ atm} \quad T_f = \frac{77 - 23}{2} = 27^\circ\text{C} = 300 \text{ K}$$

$$v = (15.69 \times 10^{-6})(2) = 31.38 \times 10^{-6} \quad k = 0.02624 \quad \text{Pr} = 0.71$$

$$\text{Re}_L = \frac{(30)(0.5)}{31.38 \times 10^{-6}} = 4.78 \times 10^5 < 5 \times 10^5 \quad \text{Laminar}$$

$$\bar{h} = \frac{0.02624}{0.5} (0.664)(4.78 \times 10^5)^{1/2} (0.71)^{1/3} = 21.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (21.5)(0.5)^2(77 + 23) = 537 \text{ W}$$

5-70

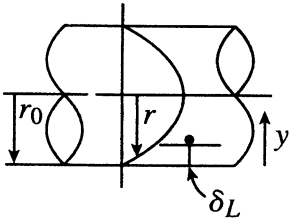
$$v = \left(\frac{101}{200}\right)(134.6 \times 10^{-6}) = 6.8 \times 10^{-5} \quad k = 0.152 \quad \text{Pr} = 0.7$$

$$\text{Re}_L = \frac{(20)(0.3)}{6.8 \times 10^{-5}} = 88,235 \quad \text{Laminar}$$

$$\bar{h} = \frac{0.152}{0.3} (0.664)(88,235)^{1/2} (0.7)^{1/3} = 88.7 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (88.7)(0.3)^2(93 + 18) = 886 \text{ W}$$

5-71



$$\frac{u}{u_c} = \left(1 - \frac{r}{r_0}\right)^{1/7} \quad f = \frac{0.316}{\text{Re}_r^{1/4}} \quad u_m = \frac{49}{60} u_c = 0.816 u_c$$

$$\frac{dp}{dx} = f \frac{1}{d} \rho \frac{u_m^2}{2} \quad \pi r_0^2 dp = \tau_w (2\pi r_0 dx) \quad \frac{dp}{dx} = 2 \frac{\tau_w}{r_0}$$

$$\tau_w = \mu \left. \frac{du}{dy} \right|_{r=r_0} \quad \tau = \mu b = \frac{\mu u_c}{\delta_L^{6/7} r_0^{1/7}}$$

Assume Linear profile in sublayer $u = a + br$ at $r = r_0$ $u = 0$

$$a = -br \quad u_c = \left(1 - \frac{r_0 - \delta_L}{y_0}\right)^{1/7} = -b\delta_L \quad b = \frac{-u}{\delta_L^{6/7} r_0^{1/7}}$$

$$\frac{dp}{dx} = \frac{0.316}{[\rho(0.816)u_c(2r_0)]^{1/4}} \left(\frac{1}{2r_0}\right) \rho \frac{(0.816)^2 u_c}{2}$$

$$\delta_t^{6/7} = \frac{2\mu u_c}{r_0^{8/7} (0.316)} \left[\frac{(0.816)\rho u_c (2r_0)}{\mu} \right]^{1/4} \frac{(2r_0)(2)}{(0.816)^2 \rho u_c^2}$$

$$\delta_L = \left[43 \left(\frac{\mu}{u_c \rho} \right)^{3/4} r_0^{3/28} \right]^{7/6}$$

$$\delta_L = 81 \left(\frac{\mu}{u_c \rho} \right)^{7/8} r_0^{1/8} \quad \text{or} \quad \frac{\delta_L}{r_0} = 124 \text{Re}_d^{-7/8}$$

5-72

$$\Delta p \pi r^2 = \tau (2\pi r) \Delta x \quad \tau = \frac{\Delta p}{\Delta x} \frac{r}{2} = \rho(v + \varepsilon_m) \frac{du}{dy} \quad \frac{u}{u_0} = \left(1 - \frac{r}{r_0} \right)^{1/7}$$

$$\frac{du}{dy} = -\frac{du}{dr} = -u_c \left(\frac{1}{7} \right) \left(1 - \frac{r}{r_0} \right)^{-6/7} \left(-\frac{1}{r_0} \right) \quad \frac{du}{dy} = \frac{u_c}{7r_0} \left(1 - \frac{r}{r_0} \right)^{-6/7}$$

$$\varepsilon_m = \frac{\tau}{\rho \frac{du}{dy}} - v = \frac{\frac{dp}{dx} \frac{r}{2}}{\rho \frac{u_c}{7r_0} \left(1 - \frac{r}{r_0} \right)^{-6/7}} - v \quad u_m = \frac{1}{\pi r_0^2} \int_0^{r_0} 2\pi r u \, dr$$

$$u_m = \frac{1}{\pi r_0^2} \int_0^{r_0} 2\pi r u_c \left(1 - \frac{r}{r_0} \right)^{1/7} \, dr = \frac{1}{\pi r_0^2} (2\pi u_c) \left(\frac{7}{8} \right) \left(\frac{7}{15} \right) r_0^2 = 0.816 u_c$$

$$\frac{dp}{dx} = f \frac{1}{2r_0} \rho \frac{u_m^2}{2g_c} \quad f = 0.316 \left(\frac{2u_m r_0}{v} \right)^{-1/4} = 0.316 \left(\frac{2(0.816)u_c r_0}{v} \right)^{-1/4}$$

$$\frac{dp}{dx} = 0.316 \left(\frac{v}{2(0.816)u_c r_0} \right)^{1/4} \frac{1}{2r_0} \rho \frac{(0.816u_c)^2}{2g_c}$$

$$\varepsilon_m = 0.316 \left(\frac{v}{2(0.816)u_c r_0} \right)^{1/4} \frac{\rho (0.816u_c)^2}{2r_0} \frac{r \left(1 - \frac{r}{r_0} \right)^{6/7} 7r_0}{2 \rho u_c} - v$$

$$\varepsilon_m = 0.162 \left(\frac{r}{g_c} \right) u_c^{3/4} \left(\frac{v}{r_0} \right)^{1/4} \left(1 - \frac{r}{r_0} \right)^{6/7} - v$$

Chapter 5

5-74

$$\begin{aligned} \text{Re} = 1500 &= \frac{\rho u_m d}{\mu} & T = 35^\circ\text{C} & d = 0.025 \text{ m} \\ \rho = 993 \text{ kg/m}^3 & & \mu = 7.24 \times 10^{-4} & k = 0.627 \\ u_m &= \frac{(1500)(7.24 \times 10^{-4})}{(993)(0.025)} = 0.0437 \text{ m/sec} \\ u_0 &= 2u_m = 0.0875 \text{ m/sec} \\ h &= \frac{(4.364)(0.627)}{0.025} = 109.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \end{aligned}$$

5-75

$$\begin{aligned} u = \text{const} \quad \frac{\partial T}{\partial x} &= \text{const} \\ \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) &= \frac{ur}{\alpha} \frac{\partial T}{\partial x} \\ r \frac{\partial T}{\partial r} &= \frac{ur^2}{2\alpha} \frac{\partial T}{\partial x} + c_1 \\ \frac{\partial T}{\partial r} &= \frac{ur}{2\alpha} \frac{\partial T}{\partial x} + \frac{c_1}{r} \\ T &= \frac{ur^2}{4\alpha} \frac{\partial T}{\partial x} + c_1 \ln r + c_2 \\ T = T_w(x) &\quad \text{at } r = r_1 \text{ and } r = r_2 \\ T_w(x) &= \frac{ur_2^2}{4\alpha} \frac{\partial T}{\partial x} + c_1 \ln r_1 + c_2 \\ T_w(x) &= \frac{ur_1^2}{4\alpha} \frac{\partial T}{\partial x} + c_1 \ln r_2 + c_2 \\ \frac{u(r_2^2 - r_1^2)}{4\alpha} \frac{\partial T}{\partial x} + c_1 \ln \left(\frac{r_2}{r_1} \right) &= 0 \\ c_1 &= \frac{-u(r_2^2 - r_1^2)}{4\alpha} \frac{\partial T}{\partial x} \left[\frac{1}{\ln(r_2/r_1)} \right] \\ T - T_w(x) &= \frac{u}{4\alpha} \frac{\partial T}{\partial x} \left[(r^2 - r_1^2) - \frac{\ln(r/r_1)}{\ln(r_2/r_1)} (r_2^2 - r_1^2) \right] \end{aligned}$$

5-76

Air at $m_\infty = 4$ $p = 3$ psia $T_\infty = 0^\circ\text{F}$ Plate: 18 in long

$$T_w = 200^\circ\text{F} \quad \gamma = 1.402 \quad d = \sqrt{\gamma g_c R T} = 1052 \text{ ft/sec}$$

$$u_\infty = m_\infty = 1.51 \times 10^7 \text{ ft/hr} \quad \rho_\infty = 0.0176 \quad u_\infty = 0.0394$$

$$\text{Re}_{L_\infty} = \frac{u_\infty x}{\nu_\infty} = 9.98 \times 10^6$$

$$T_0 = T_\infty \left(1 + \frac{\gamma - 1}{2} M_\infty^2 \right) \text{ (laminar portion)} = 1940^\circ\text{R}$$

$$\text{Pr} = 0.681 \text{ (Assume)} \quad r = \text{Pr}^{1/2} = 0.825 \quad r = \frac{T_{aw} - T_\infty}{T_0 - T_\infty}$$

$$T_{aw} = 1680^\circ\text{R} \quad T^* = T_\infty + 0.5(T_w - T_\infty) + 0.22(T_{aw} - T_\infty) = 829^\circ\text{R}$$

$$\rho^* = 0.00977 \quad \mu^* = 0.061 \quad k^* = 0.0218 \quad c_p = 0.2444$$

$$\text{Turbulent portion: Pr} = 0.682 \quad r = \text{Pr}^{1/3} = 0.882 \quad T_{aw} = 1800^\circ\text{R}$$

$$T^* = 855^\circ\text{R} \quad \therefore \text{Pr} = 0.681 \text{ (close enough)}$$

$$\rho^* = 0.00947 \quad \mu^* = 0.0626 \quad c_p^* = 0.245$$

$$u_\infty = 1.51 \times 10^7 \quad x = 1.5 \text{ ft}$$

$$\text{Laminar Heat Transfer: } x_c = \frac{\text{Re}_{\text{crit}}^* \mu^*}{\rho^* u_\infty} = 0.206 \text{ ft} \quad \overline{\text{Nu}}^* = \frac{\bar{h} x_c}{k^*}$$

$$\overline{\text{Nu}}^* = 0.664(\text{Re}_{\text{crit}}^*)^{1/2}(\text{Pr}^*)^{1/3} = 416$$

$$q = \bar{h} A (T_w - T_\infty) = -9250 \text{ Btu/hr}$$

Turbulent Heat Transfer:

$$h_x = (\text{Pr}^*)^{-2/3} (\rho^* c_p^* u_\infty) (0.0288) \left(\frac{\rho^* u_\infty x}{\mu^*} \right)^{-1/5} = 69x^{-1/5}$$

$$\bar{h} = \frac{\int_{0.206}^{1.5} h_x dx}{\int_{0.206}^{1.5} dx} = 73.3 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$$

$$q = \bar{h} A (T_w - T_\infty) = -108,000 \text{ Btu/hr}$$

$$\text{Total Cooling} = -117,250 \text{ Btu/hr}$$

Chapter 5

5-77

$$T_w = 65^\circ\text{C} \quad u_\infty = 600 \text{ m/s} \quad T_\infty = 15^\circ\text{C} = 288 \text{ K}$$

$$p = 7000 \text{ N/m}^2 \quad L = 1 \text{ m} \quad a = [(1.4)(287)(288)]^{1/2} = 340.2 \text{ m/s}$$

$$M = \frac{600}{340.2} = 1.764 \quad T_0 = 288[1 + (0.2)(1.764)^2] = 467 \text{ K}$$

$$\text{Assume Pr} = 0.7 \quad \text{Laminar: } r = (0.7)^{1/2} = \frac{T_{aw} - 288}{467 - 288} \quad T_{aw} = 438 \text{ K}$$

$$T^* = 288 + 0.5(467 - 288) + 0.22(438 - 288) = 346 \text{ K}$$

$$\rho = \frac{7000}{(287)(346)} = 0.0705 \text{ kg/m}^3$$

$$\mu = 2.07 \times 10^{-5} \quad k = 0.02973 \quad \text{Pr} = 0.7$$

$$x_c = \frac{(5 \times 10^5)(2.07 \times 10^{-5})}{(0.0705)(600)} = 0.245 \text{ m}$$

$$\text{Turbulent: } r = \text{Pr}^{1/3} = (0.7)^{1/3} = \frac{T_{aw} - 288}{467 - 288} \quad T_{aw} = 347 \text{ K}$$

$$\rho = \frac{7000}{(287)(347)} = 0.0701 \quad \mu = 2.07 \times 10^{-5} \quad c_p = 1009 \quad k = 0.0298$$

$$\text{Pr} = 0.7$$

$$h_x = (0.0701)(600)(1009)(0.7)^{2/3} (0.0296) \left[\frac{2.07 \times 10^{-5}}{(0.0901)(600)} \right]^{1/5} x^{-1/5} = 87.24x^{-1/5}$$

$$\int_{x_c}^L h_x dx = (87.24) \left(\frac{5}{4} \right) [(1)^{4/5} - (0.245)^{4/5}] = 73.66$$

$$\text{Laminar heat transfer coeff. } \bar{h} = \frac{(0.664)(0.02973)}{0.245} (5 \times 10^5)^{1/2} (0.7)^{1/3} = 50.59$$

$$\text{For entire plate: } \bar{h} = \int \frac{h_x dx}{L} = \frac{(50.59)(0.245) + 73.66}{1} = 86.05 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

5-78

$$\text{Pr} = 0.69 \quad T_0 = 233[1 + (0.2)(4)^2] = 979 \text{ K}$$

$$r = (0.69)^{1/2} = \frac{T_{aw} - 233}{979 - 233} \quad T_{aw} = 853 \text{ K}$$

5-79

$$T_{\infty} = -40^{\circ}\text{C} = 233 \text{ K} \quad a = [(1.4)(1)(287)(233)]^{1/2} = 306 \text{ m/s}$$

$$u_{\infty} = (2.8)(306) = 856.7 \quad T_0 = (233)[1 + (0.2)(2.8)^2] = 598 \text{ K}$$

$$T^* \approx 450 \text{ K} \quad \text{Pr} = 0.69$$

$$\text{Laminar:} \quad r = \text{Pr}^{1/2} = 0.83 \quad T_{aw} = (0.83)(598 - 233) + 233 = 536 \text{ K}$$

$$\text{Turbulent:} \quad r = \text{Pr}^{1/3} = 0.88 \quad T_{aw} = (0.88)(598 - 233) + 233 = 555 \text{ K}$$

5-81

$$T_{\infty} = 30^{\circ}\text{C} = 303 \text{ K} \quad \rho = 1258 \quad L = 0.3 \text{ m} \quad c_p = 2445$$

$$u_{\infty} = 1.5 \text{ m/sec} \quad \text{Pr} = 5380 \quad D = 8.9 \text{ N} = \tau_w A \text{ (both sides)}$$

$$\tau_w = \frac{8.9}{2(0.3)^2} = 49.44 \text{ N/m}^2 \quad C_f = \frac{(2)(49.44)}{(1258)(1.5)^2} = 0.0349$$

$$\text{St Pr}^{2/3} = \frac{C_f}{2} \quad \text{St} = \frac{0.0349}{2} (5380)^{-2/3} = 5.689 \times 10^{-5}$$

$$\bar{h} = (5.689 \times 10^{-5})(1258)(1.5)(2445) = 262 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$$

5-83

$$T_f = 60^{\circ}\text{C} = 333 \text{ K} \quad \rho = 1.046 \quad c_p = 1042 \quad \mu = 19.22 \times 10^{-6}$$

$$k = 0.02858 \quad \text{Re} = \frac{(1.046)(3.0)(1.3)}{19.22 \times 10^{-6}} = 2.122 \times 10^5$$

$$h = \frac{0.02858}{1.3} (0.664)(2.122 \times 10^5)^{1/2} (0.7)^{1/3} = 5.97$$

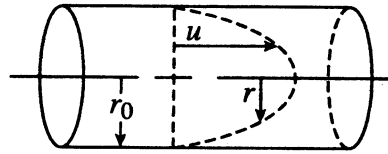
$$q = (5.97)(1.3)^2 (100 - 20) = 807.2 \text{ W}$$

$$\bar{C}_f = (2)(0.664)(2.122 \times 10^5)^{-1/2} = 2.883 \times 10^{-3}$$

Chapter 5

5-84

$$\frac{u}{u_0} = 1 - \frac{r^2}{r_0^2} \quad \Delta p = f \frac{L}{D} \rho u_m^2$$



$$f = \frac{\Delta p d 2g_c}{L \rho u_m^2} = \left(\frac{\Delta p}{L} \right) \frac{d}{\rho u_m^2 / 2g_c}$$

$$\frac{dp}{dx} = \frac{2\mu}{r} \frac{du}{dr} = \frac{\Delta p}{L}$$

$$f = \frac{2\mu}{r} \left(\frac{du}{dr} \right) \frac{d}{\rho u_m^2 / 2g_c} \quad du = -2r dr \left(\frac{u_0}{r_0^2} \right)$$

$$\frac{du}{dr} = -2r \quad f = \left(\frac{2\mu}{r} \right) \left(\frac{-2ru_0}{r_0^2} \right) \frac{d}{\rho u_m^2 / 2g_c}$$

$$u_m = \frac{\int_0^{r_0} 2\pi r u dr}{\pi r_0^2} = \frac{2u_0 \int_0^{r_0} \left(1 - \frac{r^2}{r_0^2}\right) r dr}{r_0^2}$$

$$u_m = \frac{u_0}{2} \quad \therefore f = \frac{64g_c}{\frac{\rho u_m d}{\mu}} = \frac{64}{Re_d}$$

5-85

oil at 10°C 15 cm square plate

$$q_w = 10 \text{ kW/m}^2$$

Oil at 20°C $\nu = 9 \times 10^{-4} \text{ m}^2/\text{s}$ $k = 0.145 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$ $Pr = 10,400$

$$Nu_x = \frac{h_x x}{k} = \frac{q_w x}{k(T_w - T_\infty)} = \frac{0.4637 Re_x^{1/2} Pr^{1/3}}{\left[1 + \left(\frac{0.0207}{Pr}\right)^{2/3}\right]^{1/4}} = c Re_x^{1/2}$$

$$q_w = h_x (T_w - T_\infty)$$

$$T_w - T_\infty = \frac{q_w x}{k Nu_x} = \frac{q_w x}{kc Re_x^{1/2}}$$

$$\overline{T_w - T_\infty} = \frac{1}{L} \int_0^L \frac{q_w x}{kc \left(\frac{\rho u_\infty x}{\mu}\right)^{1/2}} dx = \frac{q_w L/k}{(1/2)c Re_L^{1/2}}$$

$$q_w = \frac{3}{2} h_{x=L} (\overline{T_w - T_\infty})$$

At $T_f = 20^\circ\text{C}$ $Re_L = \frac{(0.5)(0.15)}{0.0009} = 83.33$

$$h_{x=L} = \frac{(0.145)(0.4637)(83.33)^{1/2}(10,400)^{1/3}}{0.15 \left[1 + \left(\frac{0.0207}{10,400} \right)^{2/3} \right]^{1/4}} = 92.76$$

$$\overline{T_w - T_\infty} = \frac{10,000}{(3/2)(92.36)} = 72.18^\circ\text{C}$$

Recalculate $T_f = 10 + \frac{72}{2} = 46^\circ\text{C}$

Evaluate properties at 40°C

$$\nu = 0.00024 \quad k = 0.144 \quad \text{Pr} = 2870$$

$$\text{Re}_L = \frac{(0.5)(0.15)}{0.00024} = 312.5$$

$$h_{x=L} = \frac{0.144 (0.4637)(312.5)^{1/2}(2870)^{1/3}}{0.15 \left[1 + \left(\frac{0.0207}{2870} \right)^{2/3} \right]^{1/4}} = 112$$

$$\overline{T_w - T_\infty} = \frac{10,000}{\left(\frac{3}{2}\right)(112)} = 59.6^\circ\text{C}$$

Check $T_f = 10 + \frac{59.6}{2} = 39.8^\circ\text{C} \approx 40^\circ\text{C}$

Close enough

$$\bar{h} = \left(\frac{3}{2}\right)(112) = 168 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad (T_w - T_\infty)_{x=L} = \frac{10,000}{112} = 89.3^\circ\text{C}$$

5-86

$$T_\infty = 10^\circ\text{C} \quad T_w = 10 + 89.3 = 99.3^\circ\text{C} \quad T_f = 55^\circ\text{C} \quad \nu = 0.000123 \text{ m}^2/\text{s}$$

$$k = 0.141 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \text{Pr} = 1505 \quad \text{Re}_L = \frac{(0.5)(0.15)}{0.000123} = 610$$

$$h_{x=L} = \frac{(0.141/0.15)(0.3387)(610)^{1/2}(1505)^{1/3}}{\left[1 + \left(\frac{0.0468}{1505} \right)^{2/3} \right]^{1/4}} = 90.1 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\bar{h} = (2)(90.1) = 180.2 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (180.2)(0.15)^2(89.3) = 362 \text{ W}$$

Chapter 5

5-87

$$\nu = 15.51 \times 10^{-6} \text{ m}^2/\text{s}$$

$$\text{Re}_1 = 5 \times 10^5 = \frac{45x}{15.51 \times 10^{-6}} \quad x = 0.172 \text{ m}$$

$$\text{Re}_2 = 10^8 = \frac{45x}{15.51 \times 10^{-6}} \quad x = 34.467 \text{ m}$$

$$\delta_1 = \frac{(5.0)(0.172)}{(5 \times 10^5)^{1/2}} = 1.22 \times 10^{-3} \text{ m}$$

$$\delta_2 = (34.467) \left[0.381(10^8)^{-1/5} - \frac{10,256}{10^8} \right] = 0.326 \text{ m}$$

5-88

$$x = \frac{5 \times 10^5 \nu}{u_\infty} \quad u_\infty = 20 \text{ m/s}$$

$$\delta = 5x(5 \times 10^5)^{-1/2} = \frac{5\nu}{u_\infty} (5 \times 10^5)^{1/2} = 3536 \frac{\nu}{u_\infty} = 1768\nu$$

(a) $\nu = 14.2 \times 10^{-6} \text{ m}^2/\text{s} \quad \delta = 0.025 \text{ m}$

(b) $\nu = 1.31 \times 10^{-6} \quad \delta = 0.0023 \text{ m}$

(c) $\nu = 99.69 \times 10^{-6} \quad \delta = 0.176 \text{ m}$

(d) $\nu = 0.368 \times 10^{-6} \quad \delta = 6.5 \times 10^{-4} \text{ m}$

(e) $\nu = 0.203 \times 10^{-6} \quad \delta = 3.59 \times 10^{-4} \text{ m}$

5-89

$$\bar{h}_L = \frac{1}{L} \int_0^L h_x dx = \frac{1}{L} \int_0^L kC \left(\frac{\rho u_\infty}{\mu} \right)^n x^{n-1} f(\text{Pr}) dx = \frac{1}{L} Ck f(\text{Pr}) \left(\frac{\rho u_\infty}{\mu} \right)^n \frac{L^n}{n} = \frac{h_{x=L}}{n}$$

$$\frac{\bar{h}_L}{h_{x=L}} = \frac{1}{n}$$

5-90

$$\nu = 0.0009 \text{ m}^2/\text{s}$$

$$\text{Pr} = 10,400$$

$$\text{Eq. (5-44)} \quad \text{Nu}_x = (0.332)(10,000)^{1/2}(10,400)^{1/3} = 724.7$$

$$\text{Eq. (5-51)} \quad \text{Nu}_x = \frac{(0.3387)(10,000)^{1/2}(10,400)^{1/3}}{\left[1 + \left(\frac{0.0468}{10,400}\right)^{2/3}\right]^{1/4}} = 739.3$$

5-91

$$T_f = 325 \text{ K}$$

$$\nu = 18.23 \times 10^{-6}$$

$$k = 0.02814$$

$$\text{Pr} = 0.7$$

$$\rho = 1.086$$

$$\text{Re} = \frac{(45)(0.75)}{18.23 \times 10^{-6}} = 1.85 \times 10^6$$

$$h = \frac{0.02814}{0.75} (0.7)^{1/3} [(0.037)(1.85 \times 10^6)^{0.8} - 871] = 98.3 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (98.3)(0.75)^2 (350 - 300) = 2764 \text{ W}$$

$$\bar{C}_f = \frac{0.074}{(1.85 \times 10^6)^{0.2}} - \frac{1055}{1.85 \times 10^6} = 0.00356$$

$$D = \frac{(0.00356)(0.75)^2 (1.086)(45)^2}{2} = 2.2 \text{ N}$$

$$\text{Laminar Portion:} \quad L = \frac{(5 \times 10^5)(18.23 \times 10^{-6})}{45} = 0.203 \text{ m}$$

$$h = \frac{0.02814}{0.203} (0.7)^{1/3} (5 \times 10^5)^{1/2} (0.332) = 28.96 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (28.96)(0.203)(0.75)(350 - 300) = 220 \text{ W}$$

5-92

$$x_c = 0.203 \text{ m}$$

$$\delta_c = \frac{(5)(0.203)}{(5 \times 10^5)^{1/2}} = 0.0014 \text{ m}$$

$$\delta_L = (0.75) \left[(0.381)(1.85 \times 10^6)^{-1/5} - \frac{10,256}{1.85 \times 10^6} \right] = 0.0118 \text{ m}$$

$$\text{All turbulent} \quad \delta = \frac{(0.75)(0.381)}{(1.85 \times 10^6)^{0.2}} = 0.0159 \text{ m}$$

Chapter 5

5-93

$$T_w = 500 \text{ K} \quad T_f = 400 \text{ K}$$

(a) Properties at $T_\infty = 300 \text{ K}$: $\nu = 15.69 \times 10^{-6}$, $k = 0.02624$, $\text{Pr} = 0.708$

(b) Properties at $T_f = 400 \text{ K}$: $\nu = 25.9 \times 10^{-6}$, $k = 0.03365$, $\text{Pr} = 0.689$

(c) Properties at $T_w = 500 \text{ K}$: $\nu = 37.9 \times 10^{-6}$, $k = 0.04038$, $\text{Pr} = 0.68$

$$(a) \text{ Re} = \frac{(45)(0.75)}{15.69 \times 10^{-6}} = 2.15 \times 10^6$$

$$h = \frac{0.02624}{0.78} (0.708)^{1/3} [(0.037)(2.15 \times 10^6)^{0.8} - 871] = 107.2$$

$$q = (107.2)(0.75)^2 (500 - 300) = 12,053 \text{ W}$$

$$(b) \text{ Re} = \frac{(45)(0.75)}{25.9 \times 10^{-6}} = 1.303 \times 10^6$$

$$h = \frac{0.03365}{0.75} (0.689)^{1/3} [(0.037)(1.303 \times 10^6)^{0.8} - 871] = 79.82$$

$$q = (79.82)(0.75)^2 (500 - 300) = 8979 \text{ W}$$

$$(c) \text{ Re} = \frac{(45)(0.75)}{37.9 \times 10^{-6}} = 8.9 \times 10^5$$

$$h = \frac{0.04038}{0.75} [(0.037)(8.9 \times 10^5)^{0.8} - 871] (0.68)^{1/3} = 59.5$$

$$q = (59.5)(0.75)^2 (500 - 300) = 6694 \text{ W}$$

Properties rather strongly dependent on temperature.

5-94

$$q_w = 700 \text{ W/m}^2 \quad L = 0.3 \text{ m}$$

Properties at 300 K

$$\nu = 15.69 \times 10^{-6} \quad k = 0.02624 \quad \text{Pr} = 0.708$$

$$\text{at } x = 15 \text{ cm} \quad \text{Re} = \frac{(10)(0.15)}{15.69 \times 10^{-6}} = 95,600$$

$$\text{Nu}_x = 0.453(95,600)^{1/2}(0.708)^{1/3} = 124.8$$

$$T_w - T_\infty = \frac{(700)(0.15)}{(124.8)(0.02624)} = 32^\circ\text{C}$$

300 K is close to average film temperature.

$$\text{at } x = 1 \text{ cm} \quad \text{Re} = 6373 \quad \text{Nu}_x = 32.2$$

$$T_w - T_\infty = 8.3^\circ\text{C} \quad T_w = 258.3 \text{ K}$$

$$\text{at } x = 5 \text{ cm} \quad \text{Re} = 31,865 \quad \text{Nu}_x = 72.1$$

$$T_w - T_\infty = 18.5^\circ\text{C} \quad T_w = 268.5 \text{ K}$$

$$\text{at } x = 10 \text{ cm} \quad \text{Re} = 63,730 \quad \text{Nu}_x = 101.5$$

$$T_w - T_\infty = 26.3^\circ\text{C} \quad T_w = 276 \text{ K}$$

$$\text{at } x = 20 \text{ cm} \quad \text{Re} = 128,670 \quad \text{Nu}_x = 144.8$$

$$T_w - T_\infty = 36.8^\circ\text{C} \quad T_w = 286.8 \text{ K}$$

$$\text{at } x = 30 \text{ cm} \quad \text{Re} = 191,200 \quad \text{Nu}_x = 176.5$$

$$T_w - T_\infty = 45.3^\circ\text{C} \quad T_w = 295.3 \text{ K}$$

5-95

$$\text{at } 30^\circ\text{C} = T_f \quad \nu = 0.00057 \quad k = 0.144 \quad \text{Pr} = 6635$$

$$\text{Re} = \frac{(10)(0.2)}{0.00057} = 3509$$

$$h = \frac{0.144}{0.2}(0.664)(3509)^{1/2}(6635)^{1/3} = 532 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (532)(0.2)^2(40 - 20) = 426 \text{ W}$$

$$\text{at } 20^\circ\text{C} \quad \nu = 0.0009 \quad \rho = 888.2$$

$$\text{Re} = \frac{(10)(0.2)}{0.0009} = 2228$$

$$\frac{\bar{C}_f}{2} = 0.664(2228)^{-1/2} = 0.0141$$

$$D = (0.0141)(0.2)^2(888.2)(10)^2 = 50.1 \text{ N}$$

5-96 ,pter 5

5-96

$$T_f = \frac{27 + 77}{2} = 52^\circ\text{C} = 325 \text{ K} \quad \nu = 18.23 \times 10^{-6} \quad k = 0.02814$$

$$\text{Pr} = 0.7 \quad u_\infty = 44 \text{ ft/s} = 13.4 \text{ m/s}$$

$$\text{Re}_L = \frac{(13.4)(4)}{18.23 \times 10^{-6}} = 2.94 \times 10^6$$

$$\bar{h} = \frac{0.02814}{4} (0.7)^{1/3} [(0.037)(2.94 \times 10^6)^{0.8} - 871] = 29.1 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (29.1)(4)(1)(77 - 27) = 5820 \text{ W}$$

$$h_{x=L} = \frac{(0.0296)(2.94 \times 10^6)^{0.8} (0.7)^{1/3} (0.02814)}{4} = 27.64 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{A} = (27.64)(50) = 1383 \text{ W/m}^2$$

$$\text{at } x = 50 \text{ cm} \quad \text{Re}_L = 3.68 \times 10^5$$

$$h_x = \frac{0.02814}{0.5} (0.332)(3.68 \times 10^5)^{1/2} (0.7)^{1/3} = 10.06$$

$$\frac{q}{A} = (10.06)(50) = 500 \text{ W/m}^2$$

5-97

$$\text{at } T_f = 350 \text{ K} \quad \nu = 20.76 \times 10^{-6} \quad k = 0.03003 \quad \text{Pr} = 0.697$$

$$\text{Re}_L = \frac{(30)(0.1)}{20.76 \times 10^{-6}} = 1.445 \times 10^5 \quad x_0 = 0.05 \text{ m}$$

x	Re_x	$\left[1 - \left(\frac{x_0}{x}\right)^{3/4}\right]^{-1/3}$	Nu_x	h_x
0.06	0.867×10^5	1.985	171.8	85.98
0.075	1.084×10^5	1.562	151.2	60.54
0.1	1.445×10^5	1.351	151	45.34

$$\bar{h} = \left[\frac{85.98 + 60.54}{2} (0.015) + \frac{60.54 + 45.34}{2} (0.025) \right] \frac{1}{0.04} = 60.56 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (60.56)(0.1 - 0.05)(0.1)(400 - 300) = 30.3 \text{ W}$$

5-98

at $x = 5 \text{ cm}$

$$\text{Re}_x = 72,250$$

$$h_x = \frac{0.03003}{0.05} (0.332)(72,250)^{1/2} (0.697)^{1/3} = 47.52 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (47.52)(0.1)(0.005)(400 - 300) = 2.38 \text{ W}$$

5-99

$$v = 15.69 \times 10^{-6} \quad \text{Re}_L = \frac{(15)(0.2)}{15.69 \times 10^{-6}} = 1.91 \times 10^5$$

$$\delta = \frac{(5)(0.2)}{(1.91 \times 10^5)^{0.8}} = 0.00229 \text{ m} = 0.23 \text{ cm}$$

No interference

5-100

$$T_f = 26.7^\circ\text{C}$$

$$u_\infty = 2 \text{ m/s}$$

$$x_0 = 0.1 \text{ m}$$

$$x_1 = 0.105 \text{ m}$$

$$\mu = 8.6 \times 10^{-4}$$

$$k = 0.614$$

$$\rho = 996$$

$$\text{Pr} = 5.85$$

$$\bar{h} = \frac{\int_{x_0}^{x_1} 0.332k \text{Pr}^{1/3} \left(\frac{\rho u_\infty}{\mu x}\right)^{1/2} \left[1 - \left(\frac{x_0}{x}\right)^{3/4}\right]^{-1/3} dx}{x_1 - x_0} = 40,450 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (40,450)(0.2)(0.005)(37.8 - 15.6) = 898 \text{ W}$$

5-101

$$T_f = \frac{300 + 400}{2} = 350 \text{ K}$$

$$L = 0.1 \text{ m}$$

$$T_w = 400 \text{ K}$$

$$u_\infty = 35 \text{ m/s}$$

$$v = \frac{20.76 \times 10^{-6}}{4} = 5.19 \times 10^{-6} \text{ m}^2/\text{s} \quad k = 0.03003 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\text{Pr} = 0.697$$

$$\text{Re}_L = \frac{u_\infty L}{v} = \frac{(35)(0.1)}{5.19 \times 10^{-6}} = 6.74 \times 10^5$$

$$\begin{aligned} \bar{h} &= \frac{k}{L} \text{Pr}^{1/3} (0.037 \text{Re}_L^{0.8} - 871) \\ &= \frac{(0.697)^{1/3} (0.03003)}{0.1} [(0.037)(6.74 \times 10^5)^{0.8} - 871] \\ &= 222 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \end{aligned}$$

$$q = \bar{h}A(T_w - T_\infty) = (222)(0.1)^2(400 - 300) = 222 \text{ W}$$

Chapter 5

5-102

For same flow properties

$$Re_L = 6.74 \times 10^5$$

$$h(\text{const heat flux}) = 1.04 \quad (h \text{ isothermal})$$

At $x = L$ ($T = c$)

$$Nu = Pr^{1/3}(0.0296)Re_L^{0.8} = (0.697)^{1/3}(0.0296)(6.74 \times 10^5)^{0.8} = 1208$$

$$h = \frac{(1208)(0.03003)}{0.1} = 363 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Minimum h and max ΔT will occur at $Re_{\text{crit}} = 5 \times 10^5$ and $L = 0.074$ m

$$h = \frac{0.03003}{0.074}(0.453)(5 \times 10^5)^{1/2}(0.697)^{1/3} = 115.3 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\Delta T_{\text{max}} = \frac{q/A}{h} = \frac{1000}{115.3} = 8.68^\circ\text{C}$$

$$T_{\text{max}} = 300 + 8.68 = 308.68^\circ\text{C}$$

5-103

$$Re_{\text{crit}} = 10^6 \quad Re_L = 5 \times 10^6 \quad u_\infty = 10 \text{ m/s} \quad T_f = 350 \text{ K}$$

$$\nu = 20.76 \times 10^{-6} \text{ m}^2/\text{s} \quad k = 0.03003 \quad Pr = 0.697$$

$$5 \times 10^6 = \frac{(10)L}{20.76 \times 10^{-6}} \quad L = 10.38 \text{ m}$$

$$\bar{C}_f = \frac{0.074}{Re_L^{1/5}} - \frac{A}{Re_L} \quad A = 3340$$

$$St Pr^{2/3} = \frac{\bar{C}_f}{2} = 0.037 Re_L^{-1/5} - 1670 Re_L^{-1}$$

$$\frac{\bar{h}L}{k} = Pr^{1/3}(0.037 Re_L^{0.8} - 1670)$$

At $Re_L = 5 \times 10^6$

$$\bar{h} = \frac{0.03003}{10.38}(0.697)^{1/3}[(0.037)(5 \times 10^6)^{0.8} - 1670] = 17.41 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (17.41)(10.38)(400 - 300) = 18,080 \frac{\text{W}}{\text{m} \cdot \text{depth}}$$

5-104

$$\bar{h} = \frac{0.03003}{10.38}(0.697)^{1/3}[(0.037)(5 \times 10^6)^{0.8} - 871] = 19.47 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (19.47)(10.38)(400 - 300) = 20,207 \frac{\text{W}}{\text{m} \cdot \text{depth}}$$

5-105

$$T_f = \frac{10 + 30}{2} = 20^\circ\text{C} \quad L = 30 \text{ cm} \quad u_\infty = 2 \text{ m/s} \quad \nu = 0.00118 \text{ m}^2/\text{s}$$

$$k = 0.286 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \text{Pr} = 12.5 \times 10^3 \quad \text{Re}_L = \frac{(2)(0.3)}{0.00118} = 508.4$$

$$\overline{\text{Nu}}_L = \frac{(2)(0.3387)\text{Re}_L^{1/2}\text{Pr}^{1/3}}{\left[1 + \left(\frac{0.0468}{\text{Pr}}\right)^{2/3}\right]^{1/4}} = \frac{(2)(0.3387)(508.4)^{1/2}(12,500)^{1/3}}{\left[1 + \left(\frac{0.0468}{12,500}\right)^{2/3}\right]^{1/4}} = 354.5$$

$$\bar{h} = \frac{(354.5)(0.286)}{0.3} = 338 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (338)(0.3)^2(30 - 10) = 608 \text{ W}$$

5-106

$$T_\infty = 20^\circ\text{C} \quad T_w = 0^\circ\text{C} \quad T_f = 10^\circ\text{C} \quad L = 0.2 \text{ m}$$

$$\text{Re}_L = 1 \times 10^5 \quad k = 0.246 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \text{Pr} = 410$$

$$\overline{\text{Nu}}_L = \frac{(2)(0.3387)\text{Re}_L^{1/2}\text{Pr}^{1/3}}{\left[1 + \left(\frac{0.0468}{\text{Pr}}\right)^{2/3}\right]^{1/4}} = \frac{(2)(0.3387)(1 \times 10^5)^{1/2}(410)^{1/3}}{\left[1 + \left(\frac{0.0468}{410}\right)^{2/3}\right]^{1/4}} = 1591$$

$$\bar{h} = \frac{(1591)(0.246)}{0.2} = 1957 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (1957)(0.2)^2(0 - 20) = -1566 \text{ W}$$

5-107

$$\nu = 15.7 \times 10^{-6} \quad \text{Re} = 10^7 = \frac{u_\infty x}{\nu} \quad x = \frac{(10^7)(15.7 \times 10^{-6})}{30} = 5.23 \text{ m}$$

$$\text{at } \begin{array}{ll} u = 7 \text{ m/s} & x = 22.4 \text{ m} \\ u = 12 \text{ m/s} & x = 13.08 \text{ m} \end{array}$$

Chapter 5

5-109

$$T_f = \frac{50 + 10}{2} = 30^\circ\text{C} = 86^\circ\text{F} \quad \mu = 8.03 \times 10^{-4} \quad k = 0.619$$

$$\text{Pr} = 5.41 \quad \rho = 995$$

$$\text{at Re} = 10^4 \quad u_\infty = \frac{(10^4)(8.03 \times 10^{-4})}{(995)(0.3)} = 0.027 \text{ m/sec}$$

$$\text{at Re} = 10^7 \quad u_\infty = 27 \text{ m/sec}$$

$$\text{at Re} = 10^4 \quad \bar{h} = \frac{0.619}{0.3} (0.664)(10^4)^{1/2} (5.41)^{1/3} = 240.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (240.5)(0.3)(50 - 10) = 866 \text{ W}$$

$$\text{at Re} = 10^7 \quad \bar{h} = \frac{0.619}{0.3} (5.41)^{1/3} [(0.037)(10^7)^{0.8} - 871] = 49,956 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (49,956)(0.3)^2(50 - 10) = 1.80 \times 10^5 \text{ W}$$

5-110

For laminar flow

$$\bar{h} = \left(\frac{k}{L}\right) (0.664) \left(\frac{\rho u_\infty L}{\mu}\right)^{1/2} \left(\frac{c_p \mu}{k}\right)^{1/3}$$

$\text{Pr} \sim \text{constant}$ which implies $\mu \sim k$

For ideal gas $\rho \sim \frac{1}{T}$ ($T = \text{abs. temp.}$)

$$\mu \sim T^a \quad (a = \text{const})$$

Therefore, for constant u_∞ and L

$$\bar{h} = \text{const} \times T^a \left(\frac{1}{T}\right)^{1/2} \left(\frac{1}{T^a}\right)^{1/2} = \text{const} \times T^{\frac{a-1}{2}}$$

For air at 350 K $a = 0.74$ and $\bar{h} = \text{const} \times T^{-0.13}$
or, not a strong function of absolute temperature

Chapter 6

6-1

For $L = 20$ cm $\frac{L}{d} = 40$ at 120°C $\text{Pr} = 175$ $k = 0.135$

$c_p = 2.307$ $\mu = (0.124 \times 10^{-4})(829)$

1st iteration

$$h = \frac{0.135}{0.005} (1.86)(175,000)^{1/3} \left(\frac{1}{40}\right)^{1/3} = 821.3$$

$$\text{Re} = 1000 = \frac{\dot{m}(0.005)(4)}{\pi(0.005)^2(0.124 \times 10^{-4})(829)}$$

$\dot{m} = 0.0404$ kg/sec

$$(0.0404)(2307)(120 - T_2) = (821.3)\pi(0.005)(2) \left(60 + \frac{T_2}{2} - 50\right) \quad (\text{a})$$

$T_2 = 118.1^\circ\text{C}$ Small change in temp.
at $T_w = 50^\circ\text{C}$ $\nu = 0.00057$

$$\bar{h} = (821.3) \left(\frac{0.124 \times 10^{-4}}{0.00057}\right)^{0.14} = 480.6$$

Recalculating T_2 from eq. (a) gives $T_2 = 118.9^\circ\text{C}$

$q = (0.0404)(2307)(120 - 118.9) = 104.8$ W

6-2

$\rho = 996$ $c_p = 4180$ $k = 0.614$ $\text{Pr} = 5.85$ $\mu = 8.6 \times 10^{-4}$

$d = 3$ mm $u_m = 0.04$ m/s $L = 2$ m

$$\dot{m} = \frac{(996)\pi(0.003)^2(0.04)}{4} = 2.82 \times 10^{-4} \text{ kg/s}$$

$$\text{Re}_d = \frac{(996)(0.04)(0.003)}{8.6 \times 10^{-4}} = 139 \quad \text{Laminar}$$

$$\text{Gz}^{-1} = \frac{2}{(0.003)(139)(5.85)} = 0.82$$

For $T_w = \text{const}$ $\bar{\text{Nu}} \rightarrow 3.66$

$$\bar{h} = \frac{(3.66)(0.614)}{0.003} = 749 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_b) = (749)\pi(0.003)(2)(180 - 80) \left(\frac{5}{9}\right) = 784 \text{ W}$$

6-3

$$d = 0.025, T = 300 \text{ K}$$

$$\mu_{\text{air}} = 1.846 \times 10^{-5}$$

$$\mu_{\text{water}} = 8.6 \times 10^{-4}$$

$$\text{Re} = 15000 = 4\dot{m}/\pi d\mu$$

$$\dot{m}_{\text{air}} = 0.0054 \text{ kg/s} \quad \dot{m}_{\text{water}} = 0.253 \text{ kg/s}$$

6-4

$$\text{Nu}_T = 2.47 \quad k = 0.521$$

$$D_H = \frac{4A}{p} = \frac{(4)(1)\left(\frac{1}{2}\right)(0.866)}{3} = 0.5744 \text{ cm}$$

$$h = \frac{(2.47)(0.521)}{0.005744} = 222.9 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (222.9)(0.03)(50 - 20) = 200.6 \text{ W/m}$$

6-5

$$D_H = \frac{(4)(5)(10)}{30} = 6.667 \text{ mm} \quad k = 0.6 \quad \text{Nu}_T = 3.657$$

$$h = \frac{(3.657)(0.6)}{6.667 \times 10^{-3}} = 329.1$$

$$\frac{q}{L} = (329.1)(30 \times 10^{-3})(60 - 20) = 394.9 \text{ W/m}$$

6-6

$$q = (3)(4175)(15 - 5) = 125,850 \text{ W} \quad \text{at } 10^\circ\text{C} \quad \mu = 1.31 \times 10^{-3}$$

$$k = 0.585 \quad \text{Pr} = 9.40 \quad \text{Re} = \frac{(0.05)(3)(4)}{\pi(0.05)^2(1.31 \times 10^{-3})} = 58,316$$

$$\bar{h} = \frac{0.585}{0.05} (0.023)(58,316)^{0.8} (9.4)^{0.4} = 4283 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = 125,850 = (4283)\pi(0.05)L(90 - 10) \quad L = 2.338 \text{ m}$$

6-7

$$q = (0.8)(4221)(40 - 35) = 16,884 \text{ W} \quad \mu = 6.82 \times 10^{-4} \quad \rho = 993$$

$$k = 0.63 \quad \text{Pr} = 4.53 \quad \text{Re} = \frac{(0.025)(0.8)(4)}{\pi(0.025)^2(6.82 \times 10^{-4})} = 59,741$$

$$h = \frac{(0.023)(0.63)}{0.025} (59,741)^{0.8} (4.53)^{0.4} = 7024 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = 16,884 = (7024)\pi(0.025)L(90 - 37.5) \quad L = 0.583 \text{ m}$$

6-8

$$4D = \frac{1.5}{0.025} = 60 \quad T_f \approx \frac{50 + 20}{2} = 35^\circ\text{C} \quad \text{at } 20^\circ\text{C} \quad \rho = 998$$

$$c = 4180 \quad \text{at } 35^\circ\text{C} \quad \text{Pr} = 5.45 \quad 1.0 = (998) \frac{\pi(0.025)^2 u_m}{4}$$

$$u_m = 2.04 \text{ m/sec} \quad 7000 = f(60) \frac{(998)(2.04)^2}{2} \quad f = 0.0562$$

$$\text{St} = \frac{(0.0562)(5.45)^{-2/3}}{8} = 2.268 \times 10^{-3}$$

$$\bar{h} = (2.268 \times 10^{-3})(998)(4180)(2.04) = 19,297 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (19,297)\pi(0.025)(1.5) \left(50 - \frac{T_{b_{\text{out}}} + 20}{2} \right) = 1.0(4180)(T_{b_{\text{out}}} - 20)$$

$$T_{b_{\text{out}}} = 32.83^\circ\text{C}$$

6-9

$$\bar{T}_b = 80^\circ\text{F} = 26.67^\circ\text{C} \quad k = 0.614 \quad c_p = 4179 \quad \mu = 8.6 \times 10^{-4}$$

$$\text{Pr} = 5.85 \quad \text{Re}_d = \frac{(\dot{m}/A_c)d}{\mu} = \frac{(1.3)(0.025)(4)}{\pi(0.025)^2(8.6 \times 10^{-4})} = 76,990 > 2300$$

$$\bar{h} = \frac{k}{d} 0.023 \text{Re}_d^{0.8} \text{Pr}^{0.4} = \frac{0.614}{0.025} (0.023)(76,990)^{0.8} (5.85)^{0.4} = 9289 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \dot{m}c_p(T_{b_2} - T_{b_1}) = \bar{h}\pi dL(T_w - \bar{T}_b)$$

$$= (1.3)(4179)(100 - 60) \left(\frac{5}{9} \right) = (9289)\pi(0.025)L(40 - 26.67)$$

$$L = 12.42 \text{ m}$$

6-10

$$T_{b_{\text{avg}}} = \frac{15 + 50}{2} = 32.5^\circ\text{C} \quad q = 1.0(4170)(50 - 15) = 145,950 \text{ W}$$

$$\text{Pr} = 5.1 \quad \mu = 7.7 \times 10^{-4} \quad k = 0.623$$

$$\text{Re} = \frac{(0.025)(1.0)(4)}{\pi(0.025)^2(7.7 \times 10^{-4})} = 66,142$$

$$\bar{h} = \frac{(0.023)(0.623)}{0.025} (66,142)^{0.8} (5.1)^{0.4} = 7901 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = 145,950 = (7901)\pi(0.025)L(14) \quad L = 16.8 \text{ m}$$

Chapter 6

6-11

Assume $T_{b_{avg}}$ about 50°C $\rho = 870$ $c_p = 2000$ $u_m = 30 \text{ cm/s}$

$k = 0.139$ $\nu = 1.24 \times 10^{-4} \text{ m}^2/\text{sec}$ $\text{Pr} = 1960$

$$\text{Re} = \frac{(0.30)(0.0125)}{1.24 \times 10^{-4}} = 30.24$$

$$\text{Nu} = 1.86 \left[(30.24)(1960) \left(\frac{0.0125}{3} \right) \right]^{1/3} \left(\frac{1.24}{0.723} \right)^{0.14} = 12.59$$

$$h = \frac{(12.59)(0.139)}{0.0125} = 139.9 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (139.9)\pi(0.0125)(3) \left(65 - \frac{T_c}{2} - \frac{38}{2} \right) = (870) \frac{\pi(0.0125)^2}{4} (0.3)(2000)(T_c - 38)$$

$$49.839 = 1.287T_c \quad T_c = 44.16^\circ\text{C} \quad q = 394.6 \text{ W}$$

6-12

$7.5 \times 15 \text{ cm}$ $L = 1.8 \text{ m}$ air at 1 atm

$T_w = 120^\circ\text{C}$ $T_b \text{ (inlet)} = 15^\circ\text{C}$ $T_b \text{ (exit)} = 25^\circ\text{C}$

$$D_H = \frac{(4)(0.075)(0.15)}{(2)(0.075 + 0.15)} = 0.1 \text{ m} \quad A_c = (0.075)(0.15) = 0.01125 \text{ m}^2$$

$$\bar{T}_b = \frac{15 + 25}{2} = 20^\circ\text{C} = 293 \text{ K}$$

$$A = 2(0.15 + 0.075)(1.8) = 0.81 \text{ m}^2$$

$c_p = 1005$ $\text{Pr} = 0.7$ $\mu = 1.83 \times 10^{-5}$ $k = 0.026$

$$q = \dot{m}c_p(T_{b_2} - T_{b_1}) = \bar{h}A(T_w - \bar{T}_b)$$

$$\bar{h} = \frac{k}{D_H} (0.023) \left(\frac{\dot{m}D_H}{A_c\mu} \right)^{0.8} \text{Pr}^{0.4} \quad \text{Assuming turbulent}$$

$$q = \dot{m}(1005)(25 - 15) = \frac{(0.026)(0.023)}{0.1} \left[\frac{\dot{m}(0.1)}{(0.01125)(1.83 \times 10^{-5})} \right]^{0.8} (0.7)^{0.4}$$

$$\dot{m} = 0.141 \text{ kg/s}$$

$$q = (0.141)(1005)(25 - 15) = 1417 \text{ W}$$

$\text{Re}_{DH} = 68,500$ so turbulent assumption was correct.

6-13

$$\mu = 1.31 \times 10^{-3} \quad k = 0.585 \quad \text{Pr} = 9.4$$

$$\text{Re} = \frac{(0.5)(0.025)(4)}{\pi(0.025)^2(1.31 \times 10^{-3})} = 19,439$$

$$h = \frac{(0.023)(0.585)}{0.025} (19,439)^{0.8} (9.4)^{0.4} = 3557 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (3557)\pi(0.025)(15)(15) = (0.5)(4190)\Delta T_b \quad \Delta T_b = 30.01^\circ\text{C}$$

$$T_{\text{out}} = 40.01^\circ\text{C}$$

6-14

$$\Delta p = f \frac{L}{D} \rho \frac{u_m^2}{2g_c} \quad \text{at } T_f = \frac{27 + 55}{2} = 41^\circ\text{C} \quad \text{Pr}_f = 4.23 \quad \rho = 996$$

$$\mu = 8.6 \times 10^{-4} \quad k = 0.614 \quad \text{Pr} = 5.85 \quad c_p = 4179$$

$$u_m = \frac{0.7}{(996)\pi(0.0125)^2} = 1.43 \text{ m/s} \quad f = \frac{(2000)(0.025)(2)}{(6)(996)(1.43)^2} = 8.16 \times 10^{-3}$$

$$\text{St}_b \text{Pr}_f^{2/3} = \frac{f}{8}$$

$$h = \frac{(8.16 \times 10^{-3})(996)(1.43)(4179)}{8} (4.23)^{-2/3} = 2321 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(\overline{T_w - T_b}) = \dot{m}c_p\Delta T_b$$

$$\Delta T_b = \frac{(2321)\pi(0.025)(6)(55 - 27)}{(0.7)(4179)} = 10.47^\circ\text{C}$$

$$T_{\text{exit}} = 27 + \frac{10.47}{2} = 32.24^\circ\text{C}$$

6-15

$$\text{Re} = \frac{(0.3)(0.0025)}{1.6 \times 10^{-4}} = 4.69 \quad \text{Re Pr} \frac{d}{L} = (4.69)(1960) \frac{0.25}{60} = 38.28$$

$$h = \frac{0.14}{0.0025} (1.86)(38.28)^{1/3} = 351 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad c_p = \frac{\text{Pr} k}{\mu} = \frac{(1960)(0.14)}{(1.6 \times 10^{-4})(860)}$$

$$c_p = 1994 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}} \quad \dot{m} = \frac{(860)\pi(0.0025)^2(0.3)}{4} = 1.266 \times 10^{-3} \text{ kg/sec}$$

$$q = (1.266 \times 10^{-3})(1994)(T_e - 20) = (351)\pi(0.0025)(0.6) \left(120 - \frac{T_e - 20}{2} \right)$$

$$T_e = 69.36^\circ\text{C} \quad q = 120.67 \text{ W}$$

Chapter 6

6-16

$$m = 0.4 \text{ kg/sec} \quad T_{b,avg} = \frac{10 + 38}{2} = 24^\circ\text{C} \quad \rho = 605.6$$

$$v = 0.355 \times 10^{-6} \quad k = 0.515 \quad c_p = 4840 \quad \text{Pr} = 2.02$$

$$\text{Re} = \frac{(0.025)(0.4)(4)}{\pi(0.025)^2(0.355 \times 10^{-6})(605.6)} = 1.0 \times 10^5$$

$$h = \frac{0.515}{0.025} (0.023)(1.0 \times 10^5)^{0.8} (2.02)^{0.4} = 6277 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (0.4)(4840)(38 - 10) = 54,200 \text{ W} = (6277)\pi(0.025)(2.5)(T_w - 24)$$

$$T_w = 68^\circ\text{C}$$

6-17

$$\text{Freon 12} \quad \rho = 1364 \quad k = 0.073 \quad v = 0.203 \times 10^{-6} \quad \text{Pr} = 3.6$$

$$\text{Re} = \frac{(3)(0.0125)}{0.203 \times 10^{-6}} = 184,700$$

$$h = \frac{0.073}{0.0125} (0.023)(184,700)^{0.8} (3.6)^{0.4} = 3663 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{water} \quad \rho = 999 \quad \mu = 1.31 \times 10^{-3} \quad k = 0.585 \quad \text{Pr} = 9.4$$

$$\text{Re} = \frac{(999)(3)(0.0125)}{1.31 \times 10^{-3}} = 57,195$$

$$h = \frac{0.585}{0.0125} (0.023)(57,195)^{0.8} (9.4)^{0.4} = 16,870 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

6-18

$$T_f = \frac{50 + 10}{2} = 30^\circ\text{C} \quad L = 6 \text{ m} \quad d = 2.5 \text{ cm} \quad m = 0.4 \text{ kg/s}$$

$$\Delta p = 3000 \text{ N/m}^2 \quad \text{at } 10^\circ\text{C} \quad \rho = 999 \quad c_p = 4195$$

$$\text{at } 30^\circ\text{C} \quad \text{Pr} = 5.22 \quad 0.4 = \frac{(999)\pi(0.025)^2 u_m}{4}$$

$$u_m = 0.816 \text{ m/s} \quad \Delta p = f \frac{L}{D} \rho \frac{u_m^2}{2} \quad f = \frac{(3000)(2)(0.025)}{(6)(0.816)^2 (999)} = 0.0376$$

$$\text{St}_b \text{Pr}_f^{2/3} = \frac{f}{8} \quad \text{St}_b = \frac{(0.0376)(5.22)^{-2/3}}{8} = 1.56 \times 10^{-3}$$

$$h = (1.56 \times 10^{-3})(999)(4195)(0.816) = 5338 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (5338)\pi(0.025)(6)(50 - 10) = (0.4)(4195)\Delta T_b$$

$$q = 100,600 \text{ W} \quad \Delta T_b = 60^\circ\text{C} \quad T_{\text{out}} \approx \frac{60}{2} + 10 = 40^\circ\text{C}$$

6-19

$$q = (0.4)(4175)(71 - 32) = 65,130 \text{ W} \quad T_{b,avg} = 51.5^\circ\text{C} = 125^\circ\text{F}$$

$$\mu = 5.38 \times 10^{-4} \quad k = 0.647 \quad \text{Pr} = 3.47 \quad \rho = 987$$

$$(a) \quad 12.5 \text{ mm} = d \quad \text{Re} = \frac{(0.4)(0.0125)(4)}{\pi(0.0125)^2(5.38 \times 10^{-4})} = 75,731$$

$$h = \frac{0.647}{0.0125} (0.023)(75,731)^{0.8} (3.47)^{0.3} = 13,843 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = 65,130 = (13,843)\pi(0.0125)L(51.5 - 4) \quad L = 2.52 \text{ m}$$

$$u_m = \frac{(0.4)(4)}{\pi(0.0125)^2(987)} = 3.3 \text{ m/s} \quad f = 0.019$$

$$\Delta p = (0.019) \left(\frac{2.52}{0.0125} \right) \left(\frac{987}{2} \right) (3.3)^2 = 20.6 \text{ kPa}$$

$$(b) \quad d = 25 \text{ mm} \quad T_w = 20^\circ\text{C} \quad \text{Re} = 37,866$$

$$h = \frac{(0.64)(0.023)(37,866)^{0.8} (3.47)^{0.3}}{0.025} = 3932$$

$$65,130 = (3932)\pi(0.025)L(51.5 - 20) \quad L = 6.7 \text{ m}$$

$$f = 0.024 \quad u = \frac{3.3}{4} = 0.825$$

$$\Delta p = \frac{(0.024)(6.7) \left(\frac{987}{2} \right) (0.825)^2}{0.025} = 2.16 \text{ kPa}$$

6-20

$$\bar{T}_b = 550 \text{ K} \quad \mu = 2.848 \times 10^{-5} \quad k = 0.0436 \quad \text{Pr} = 0.68$$

$$c_p = 1.039 \quad \rho = \frac{1.4 \times 10^6}{(287)(550)} = 8.87 \text{ kg/m}^3$$

$$\text{Re} = \frac{(0.075)(4)(0.5)}{\pi(0.075)^2(2.848 \times 10^{-5})} = 298,000$$

$$\text{Nu} = 0.036 \text{Re}^{0.8} \text{Pr}^{1/3} \left(\frac{d}{L} \right)^{0.0555}$$

$$h = \frac{0.0436}{0.075} (0.036)(298,000)^{0.8} (0.68)^{1/3} \left(\frac{0.075}{6} \right)^{0.0555} = 346.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (346.5)\pi(0.075)(6)(550 - 500) = (0.5)(1039)\Delta T_b = 24,493 \text{ W}$$

$$\Delta T_b = 47.15^\circ\text{C}$$

6-21

Neglect conduction resistance

At 100°C (373 K) $k = 0.032$; $Pr = 0.693$

$$h_{\text{inside}} = (0.032/0.012)(0.023)(15000)^{0.8}(0.693)^{0.3} = 120$$

At tube outside $T_f \approx 65^\circ\text{C} = 338\text{ K}$; $k = 0.029$; $\nu = 20 \times 10^{-6}$; $Pr = 0.7$

$$Re = (20)(0.014)/20 \times 10^{-6} = 14000$$

$$h_{\text{outside}} = (0.029/0.014)(0.193)(14000)^{0.618}(0.7)^{1/3} = 130$$

$$U_i = 1/[1/120 + (1/130)(0.012/0.014)] = 67$$

$$q/\text{cm} = (67)(\pi)(0.012)(0.01)(100 - 30) = 1.768\text{ W}$$

$$= mc_p(\Delta T/\text{cm})$$

At 100°C $\mu = 2.2 \times 10^{-5}$; $m = (15000)\pi(0.012)(2.2 \times 10^{-5})/4 = 0.00311\text{ kg/s}$

$$c_p = 1010; \quad \Delta T/\text{cm} = 1.768/(0.00311)(1010) = 0.56^\circ\text{C}/\text{cm}$$

Chapter 6

6-22

$$T_b = 90^\circ\text{F} \quad \mu = 7.65 \times 10^{-4} \quad k = 0.623 \quad \text{Pr} = 5.12$$

$$\rho = 995 \quad c_p = 4174$$

$$\text{Re}_d = 100,000 = \frac{(\dot{m}/A_c)d}{\mu} \quad A_c = \frac{\pi d^2}{4}$$

$$\frac{\dot{m}}{d} = \frac{\pi}{4}(100,000)(7.65 \times 10^{-4}) = 60.08 \quad \dot{m} = 60.08(d) = 0.3$$

$$q = \dot{m}c_p\Delta T_b = \bar{h}\pi dL(T_w - \bar{T}_b)$$

$$(0.3)(4174)(120 - 60)\left(\frac{5}{9}\right) = \bar{h}\pi(0.005)L(30)\left(\frac{5}{9}\right)$$

$$\bar{h} = \frac{k}{d}0.023\text{Re}^{0.8}\text{Pr}^{0.4} = \frac{0.623}{0.005}(0.023)(100,000)^{0.8}(5.12)^{0.4} = 55,075 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$L = 2.894 \text{ m}$$

6-23

$$\bar{T}_b = 30^\circ\text{C} \quad v_b = 13.94 \times 10^{-6} \quad k = 0.252 \quad \text{Pr} = 148 \quad c_p = 2.428$$

$$v_w = 2.98 \times 10^{-6} \quad \rho = 1109 \quad D_H = 5 - 4 = 1 \text{ cm} = 0.01 \text{ m}$$

$$\dot{m} = \rho A u_m = (1109)\frac{\pi}{4}(0.05^2 - 0.04^2)(6.9) = 5.409 \text{ kg/s}$$

$$\dot{q} = \dot{m}c_p\Delta T_b = (5.409)(2428)(40 - 20) = 2.627 \times 10^5 \text{ W}$$

$$\text{Re}_{D_H} = \frac{(6.9)(0.01)}{13.94 \times 10^{-6}} = 4950$$

$$\bar{h} = \frac{0.252}{0.01}(0.027)(4950)^{0.8}(148)^{1/3}\left(\frac{13.94}{2.98}\right)^{0.14} = 4033 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}\pi d_i L(T_w - \bar{T}_b)$$

$$2.627 \times 10^5 = (4033)\pi(0.04)L(80 - 30) \quad L = 10.37 \text{ m}$$

6-24

$$\text{At } 300 \text{ K and } 1 \text{ atm. } \nu = 15.69 \times 10^{-6} \quad \rho = 1.1774 \quad k = 0.02624$$

$$\text{Pr} = 0.708 \quad D_H = \frac{(4)(45)(90)}{(2)(45 + 90)} = 60 \text{ cm} = 0.6 \text{ m}$$

$$\text{Re} = \frac{(0.6)(7.5)}{15.69 \times 10^{-6}} = 2.87 \times 10^5 \quad \bar{h} = \frac{0.02624}{0.6}(0.023)(2.87 \times 10^5)^{0.8}(0.708)^{0.4}$$

$$\bar{h} = 20.35 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \Delta p = f \frac{L}{d} \rho \frac{u_m^2}{2} \quad f = 0.0145$$

$$\Delta p = (0.0145)\left(\frac{1}{0.6}\right)\frac{(1.1774)(7.5)^2}{2} = 0.8 \text{ Pa}$$

6-25

Assume \bar{T}_b about $38^\circ\text{C} = 100^\circ\text{F}$ $\rho = 993$ $c_p = 4.174$
 $\mu = 6.82 \times 10^{-4}$ $k = 0.63$ $\text{Pr}_f = 2.9$
 $\text{Re} = \frac{\rho u_m d}{\mu} = 10^5 = \frac{(993)u(0.03)}{6.82 \times 10^{-4}}$ $u = 2.29 \text{ m/sec}$ $\rho u = 2274$
 $f = 0.0255$ $\text{St}_b \text{Pr}_f^{2/3} = \frac{f}{8}$
 $h = \frac{0.0255}{8} (2274)(4174)(2.9)^{-2/3} = 14,878 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$

6-26

$\bar{T}_b = 10^\circ\text{C}$ $T_w = 40^\circ\text{C}$ $c_p = 0.9345$ at 0°C $\nu = 0.214 \times 10^{-6}$
 $\rho = 1397$ $700 = \frac{u(0.0035)}{0.214 \times 10^{-6}}$ $u = 0.0428 \text{ m/sec}$
 $q = (1397)(934.5)(0.0428) \frac{\pi}{4} (0.0035)^2 (20 - 0) = 10.75 \text{ W}$
At 10°C $k = 0.073$ $\text{Pr} = 3.6$
 $q = hA(T_w - \bar{T}_b) = h\pi(0.0035)L(40 - 10) = 10.75$
 $\bar{h}L = 32.59$ $\text{Gz} = \text{Re Pr} \frac{d}{L} = (700)(3.6) \frac{d}{L} = 2520 \frac{d}{L}$
 $\bar{\text{Nu}}_d = \frac{\bar{h}L}{k} \times \frac{d}{L} = \left(\frac{32.59}{0.073} \right) \frac{d}{L} = 446.4 \frac{d}{L}$
From Figure:

$\frac{1}{\text{Gz}}$	$\frac{d}{L}$	$\bar{\text{Nu}}_d$	$446.4 \frac{d}{L}$
0.1	0.00397	4.3	1.771
0.01	0.0397	7.5	17.72
0.03	0.0132	5.4	5.89
0.035	0.0134	5.2	5.06

$$\frac{d}{L} \approx 0.035$$

$$L = \frac{0.0035}{0.035} = 0.1 \text{ m}$$

Chapter 6

6-27

$$\bar{T}_b = \frac{27 + 77}{2} = 52^\circ\text{C} = 325 \text{ K} \quad \mu = 1.96 \times 10^{-5} \quad k = 0.0282$$

$$\text{Pr} = 0.7 \quad c_p = 1.007 \quad L = 30 \text{ cm} \quad \rho = 1.088$$

$$D_H = \frac{(4)(0.003)^2/2}{(3)(0.003)} = 0.002 \quad \text{Re} = \frac{(0.002)(5 \times 10^{-5})(2)}{(0.003)^2(1.96 \times 10^{-5})} = 1134$$

$$q = \dot{m}c_p\Delta T_b = (5 \times 10^{-5})(1007)(77 - 27) = 2.518 \text{ W}$$

$$\text{Re Pr} \frac{d}{L} = (1134)(0.7) \left(\frac{0.002}{0.3} \right) = 5.292$$

$$\text{From Figure for } \frac{1}{\text{Gz}} = \frac{1}{5.292} = 0.189$$

$\bar{\text{Nu}}_d \cong 4.0$ and flow is nearly developed.

Assuming ratio for Nu_T from table

$$\bar{\text{Nu}}_{D_H} = (2.47) \frac{4.0}{3.66} = 2.7$$

$$h = \frac{(2.7)(0.0282)}{0.002} = 38.1 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - \bar{T}_b) \quad T_w - \bar{T}_b = \frac{2.518}{(38.1)(3)(0.3)(0.003)} = 24.5^\circ\text{C}$$

$$T_w = 24.5 + 52 = 76.5^\circ\text{C}$$

6-28

$$\text{At } 27^\circ\text{C} = 300 \text{ K} \quad \mu = 1.8462 \times 10^{-5} \quad k = 0.02624 \quad \text{Pr} = 0.708$$

$$\rho = \frac{9000}{(287)(300)} = 1.045 \text{ kg/m}^3 \quad \text{Re} = \frac{(0.004)(7 \times 10^{-5})(4)}{\pi(0.004)^2(1.8462 \times 10^{-5})} = 1207$$

$$\text{Gz} = (1207)(0.708) \left(\frac{0.004}{0.12} \right) = 28.48 > 10$$

$$\text{At } T_w = 27 + 70 = 97^\circ\text{C} = 390 \text{ K} \approx 400 \text{ K} \quad \mu_w = 2.286 \times 10^{-5}$$

$$h = \frac{k}{d}(1.86)\text{Gz}^{1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14} = \frac{0.02624}{0.004}(1.86)(28.48)^{1/3} \left(\frac{1.8462}{2.286} \right)^{0.14}$$

$$= 36.16 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - T_b) = \dot{m}c_p\Delta T_b$$

$$\Delta T_b = \frac{(36.16)\pi(0.004)(0.12)(70)}{(7 \times 10^{-5})(1007)} = 54.15^\circ\text{C}$$

$$T_{b_e} = 54.15 + 27 = 81.15^\circ\text{C}$$

6-29

$$\begin{aligned} \text{At } 40^\circ\text{C} = 313 \text{ K} \quad \mu &= 1.906 \times 10^{-5} \quad k = 0.0272 \quad \text{Pr} = 0.7 \\ \rho &= \frac{110 \times 10^3}{(287)(313)} = 1.225 \text{ kg/m}^3 \quad \text{Re} = \frac{(0.006)(8 \times 10^{-5})(4)}{\pi(0.006)^2(1.906 \times 10^{-5})} = 891 \\ \text{Gz} &= (891)(0.7) \left(\frac{0.006}{0.14} \right) = 26.73 \quad \frac{1}{\text{Gz}} = 0.0374 \quad \overline{\text{Nu}}_d = 5.2 \\ h &= \frac{(5.2)(0.0272)}{0.006} = 23.57 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \\ q &= \bar{h}A(T_w - \bar{T}_b) = \dot{m}c_p(T_{b_e} - T_{b_i}) \\ (23.57)\pi(0.006)(0.14) \left(140 - 20 - \frac{T_{b_e}}{2} \right) &= (8 \times 10^{-5})(1005)(T_{b_e} - 40) \\ T_{b_e} &= 95.8^\circ\text{C} \end{aligned}$$

6-30

$$\begin{aligned} \text{At } 40^\circ\text{C} \quad \rho &= 876 \text{ kg/m}^3 \quad c_p = 1.964 \frac{\text{kJ}}{\text{kg} \cdot ^\circ\text{C}} \quad \nu = 0.00024 \\ k &= 0.144 \quad \text{Pr} = 2870 \quad \text{Re} = 50 = \frac{u(0.01)}{0.00024} \quad u = 1.2 \text{ m/s} \\ \dot{m} &= \frac{(876)(1.2)\pi(0.01)^2}{4} = 0.0826 \text{ kg/sec} \\ \text{Gz} &= (50)(2870) \left(\frac{0.01}{0.08} \right) = 1.794 \times 10^4 \\ \text{at } T_w &= 80^\circ\text{C} \quad \nu_w = 0.375 \times 10^{-4} \\ \text{Nu}_d &= (1.86)(1.794 \times 10^4)^{1/3} \left(\frac{2.4}{0.375} \right)^{0.15} = 64.3 \\ h &= \frac{(64.3)(0.144)}{0.01} = 926 \\ q &= (926)\pi(0.01)(0.08) \left(80 - 20 - \frac{T_e}{2} \right) = (0.0826)(1964)(T_e - 40) \\ T_e &= 40.57^\circ\text{C} \end{aligned}$$

Chapter 6

6-31

$$\begin{aligned}\bar{T}_b &= 25^\circ\text{C} = 77^\circ\text{F} & \rho &= 996 & \mu &= 8.96 \times 10^{-4} & k &= 0.611 \\ \text{Pr} &= 6.13 & c_p &= 4180 & \text{Re} &= \frac{(996)(8)(0.02)}{8.96 \times 10^{-4}} = 1.78 \times 10^5 \\ h &= (0.023) \frac{0.611}{0.02} (1.78 \times 10^5)^{0.8} (6.13)^{0.4} = 23,003 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \\ q &= hA(\bar{T}_w - \bar{T}_b) = \dot{m}c_p\Delta T_b \\ (23,003)\pi(0.02)(10)(\bar{T}_w - 25) &= (996)(8)\pi \frac{(0.02)^2}{4} (4180)(10) \\ \bar{T}_w &= 32.2^\circ\text{C}\end{aligned}$$

6-32

$$\begin{aligned}\text{At } 20^\circ\text{C} & \quad \rho = 888 & c_p &= 1880 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}} & \nu &= 0.0009 & k &= 0.145 \\ \text{Pr} &= 10,400 & \text{Re} &= \frac{(1.2)(0.002)}{0.0009} = 2.67 \\ \text{Gz} &= (2.666)(10,400) \left(\frac{0.002}{1} \right) = 55.47 > 10 & \frac{1}{\text{Gz}} &= 0.018 \\ \bar{\text{Nu}}_d &= 6.1 & h &= \frac{(6.1)(0.145)}{0.002} = 442 \\ q &= (442)\pi(0.002)(1.0) \left(60 - 10 - \frac{T_e}{2} \right) = (888)(1.2) \frac{\pi}{4} (0.002)^2 (1880)(T_e - 20) \\ T_e &= 34.46^\circ\text{C}\end{aligned}$$

6-33

$$\begin{aligned}\bar{T}_b &= 40^\circ\text{C} = 104^\circ\text{F} & \rho &= 993 & \mu &= 6.55 \times 10^{-4} & k &= 0.633 \\ \text{Pr} &= 4.33 & c_p &= 4175 & \text{Re} &= \frac{(993)(1)(0.025)(3)}{6.55 \times 10^{-4}} = 1.14 \times 10^5 \\ h &= \frac{0.633}{0.025} (0.023)(1.14 \times 10^5)^{0.8} (4.33)^{0.4} = 11,600 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \\ q &= \dot{m}c_p\Delta T_b = hA(T_w - T_b) \\ (993)\pi \frac{(0.025)^2}{4} (3.0)(4175)(50 - 30) &= (11,600)\pi(0.025)L(20) \\ L &= 6.7 \text{ m}\end{aligned}$$

6-34

Liquid NH₃ $T_\infty = 10^\circ\text{C}$ $T_w = 30^\circ\text{C}$ $u_\infty = 5 \text{ m/s}$ $d = 0.025$
 $L = 1.25$ $T_f = 20^\circ\text{C}$ $\nu = 0.359 \times 10^{-6}$ $k = 0.521$ $\text{Pr} = 2.02$

$$\text{Re}_d = \frac{(5)(0.025)}{0.359 \times 10^{-6}} = 3.88 \times 10^5 \quad C = 0.0266 \quad n = 0.805$$

$$\bar{h} = \frac{0.521}{0.025} (0.0266)(3.48 \times 10^5)^{0.805} (2.02)^{1/3} = 20,653 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (20,653)\pi(0.025)(1.25)(30 - 10) = 39,788 \text{ W}$$

6-35

$$\bar{T}_b = \frac{21 + 32}{2} = 26.5^\circ\text{C} \quad \rho = 996 \quad \mu = 8.6 \times 10^{-4}$$

$$\text{Re} = 600 = \frac{\rho u d}{\mu} \quad u = \frac{(600)(8.6 \times 10^{-4})}{(996)(0.003)} = 0.173 \text{ m/s}$$

$$\dot{m} = \rho A u = (996)\pi \frac{(0.003)^2}{4} (0.173) = 0.00122 \text{ kg/s}$$

6-36

$$\bar{T}_b = 26.5^\circ\text{C} \quad \rho = 996 \quad \mu = 8.6 \times 10^{-4} \quad k = 0.614$$

$$\text{Pr} = 5.85 \quad c_p = 4180 \quad \text{Re} = \frac{(0.03)(1.0)(4)}{\pi(0.03)^2(8.6 \times 10^{-4})} = 49,350$$

$$h = \frac{(0.023)(0.614)}{0.03} (49,350)^{0.8} (5.85)^{0.4} = 5423 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \dot{m} c_p \Delta T_b = hA(T_w - \bar{T}_b)$$

$$(1.0)(4180)(38 - 15) = (5423)\pi(0.03)L(60 - 26.5)$$

$$L = 5.61 \text{ m}$$

Chapter 6

6-37

$$\text{At } \bar{T}_b = 20^\circ\text{C} \quad \rho = 1264 \quad c_p = 2386 \quad k = 0.286$$

$$\text{Pr} = 12.5 \times 10^3 \quad \nu = 0.003 \quad \text{Re} = 10 = \frac{ud}{\nu}$$

$$u = \frac{(10)(0.003)}{0.005} = 6 \text{ m/sec}$$

$$\dot{m} = \rho Au = (1264)\pi \frac{(0.005)^2}{4} (6) = 0.149 \text{ kg/sec}$$

$$q = \dot{m} c_p \Delta T_b = (0.149)(2386)(30 - 10) = 7106 \text{ W}$$

$$= hA(T_w - \bar{T}_b) = h\pi(0.005)L(40 - 20)$$

$$hL = 22,619 \quad h = \frac{22,619}{L}$$

$$\frac{hd}{k} = 1.86 \left(\text{Re Pr} \frac{d}{L} \right)^{1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

$$\text{At } T_w = 40^\circ\text{C} \quad \nu_w = 0.00022$$

$$\frac{(22,619)(0.005)}{0.286L} = 1.86 \left[\frac{(10)(12,500)(0.005)}{L} \right]^{1/3} \left(\frac{0.003}{0.00022} \right)^{0.14}$$

$$L^{2/3} = 17.25 \quad L = 71.66 \text{ m}$$

$$\text{Gz} = (10)(12,500) \left(\frac{0.005}{71.66} \right) = 8.72 < 10$$

$$\text{Below range of equations: } \frac{1}{\text{Gz}} \approx \frac{1}{8.72} = 0.115$$

$$\text{From Figure: } \bar{\text{Nu}}_d \approx 4.2$$

$$h = \frac{(4.2)(0.286)}{0.005} = 240.2 \quad L = \frac{22,619}{240.2} = 94.2 \text{ m}$$

$$\text{New } \frac{1}{\text{Gz}} = (0.115) \left(\frac{94.2}{71.66} \right) = 0.15$$

$$\text{New iteration: } \bar{\text{Nu}}_d \approx 4.0 \quad h = 228.8 \quad L = 98.8 \text{ m}$$

Close enough to fully developed tube, could take $\bar{\text{Nu}}_d = 3.66$.

6-38

$$T_f = \frac{100 + 10}{2} = 55^\circ\text{C} = 328 \text{ K} \quad \mu = 19 \times 10^{-6} \quad k = 0.0282$$

$$\text{Pr} = 0.7 \quad \rho = \frac{(2)(1.01 \times 10^5)}{(297)(328)} = 2.08 \text{ kg/m}^3$$

$$\text{Re} = \frac{(2.08)(5)(0.05)}{19.0 \times 10^{-6}} = 27,377 \quad C = 0.193 \quad n = 0.618$$

$$h = \frac{k}{d} C \text{Re}^n \text{Pr}^{1/3} = \frac{0.0282}{0.05} (0.193)(27,377)^{0.618} (0.7)^{1/3} = 53.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d(T_w - T_\infty) = (53.4)\pi(0.05)(100 - 10) = 755 \text{ W/m}$$

6-39

$$T_f = \frac{54 + 0}{2} = 27^\circ\text{C} = 300 \text{ K} \quad \nu = 15.69 \times 10^{-6} \quad k = 0.02624$$

$$\text{Pr} = 0.708 \quad \text{Re} = \frac{\rho u d}{\mu} = \frac{(25)(0.04)}{15.69 \times 10^{-6}} = 63,735 \quad C = 0.0266$$

$$n = 0.805$$

$$h = \frac{k}{d} C \text{Re}^n \text{Pr}^{1/3} = \frac{0.02624}{0.04} (0.0266)(63,735)^{0.805} (0.708)^{1/3} = 114.6 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d(T_w - T_\infty) = (114.6)\pi(0.04)(54 - 0) = 778 \text{ W/m}$$

6-40

$$T_f = \frac{80 + 10}{2} = 45^\circ\text{C} = 318 \text{ K} \quad \mu = 1.929 \times 10^{-5} \quad k = 0.0276$$

$$\text{Pr} = 0.7 \quad \rho = \frac{200 \times 10^3}{(287)(318)} = 2.191 \text{ kg/m}^3$$

$$\text{Re} = \frac{\rho u d}{\mu} = \frac{(2.191)(20)(0.2)}{1.929 \times 10^{-5}} = 5.68 \times 10^5$$

Churchill Equation:

$$\text{Nu}_d = 0.3 + \frac{(0.62)(5.68 \times 10^5)^{1/2} (0.7)^{1/3}}{\left[1 + \left(\frac{0.4}{0.7}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{5.68 \times 10^5}{282,000}\right)^{5/8}\right]^{4/5} = 769.7$$

$$h = \frac{k}{d} \text{Nu} = \frac{(0.0276)(769.7)}{0.2} = 106.2 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d(T_w - T_\infty) = (106.2)\pi(0.2)(80 - 10) = 4672 \text{ W/m}$$

Chapter 6

From Figure $C_D = 0.3$

$$F_D = C_D A \frac{\rho u_\infty^2}{2g_c} = \frac{(0.3)(0.2)(2.191)(25)^2}{2} = 41.1 \text{ N/m Length}$$

6-41

$$T_f = \frac{71 + 43}{2} = 57^\circ\text{C} = 135^\circ\text{F} \quad \text{Pr}_f = 3.15 \quad \rho_b = 991 \quad c = 4174$$

$$\mu = 6.16 \times 10^{-4} \quad \text{Re} = \frac{(0.05)(6)(4)}{\pi(0.05)^2(6.16 \times 10^{-4})} = 2.48 \times 10^5 \quad f = 0.014$$

$$\dot{m} = \rho A u_m \quad u_m = \frac{(6)(4)}{(991)\pi(0.05)^2} = 3.08 \text{ m/sec} \quad \text{St}_b \text{Pr}_f^{2/3} = \frac{f}{8}$$

$$h = \frac{(0.014)(991)(3.08)(4174)}{(8)(3.15)^{2/3}} = 10,388 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - \bar{T}_b) = \dot{m}c_p\Delta T_b$$

$$(10,388)\pi(0.05)(9) \left(71 - 21.5 - \frac{T_e}{2} \right) = (6)(4174)(T_e - 43)$$

$$T_e = 55.7^\circ\text{C}$$

6-42

$$\text{At } 38^\circ\text{C} \quad \rho = 993 \quad \mu = 6.82 \times 10^{-4} \quad k = 0.63 \quad \text{Pr} = 4.53$$

$$c_p = 4180 \quad \text{Re} = \frac{(993)(1.5)(0.0064)}{6.82 \times 10^{-4}} = 13,978$$

$$h = \frac{0.63}{0.0064} (0.036)(13,978)^{0.8} (453)^{1/3} \left(\frac{0.0064}{0.15} \right)^{0.055} = 10,213 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (10,213)\pi(0.0064)(0.15)(28) = (993) \frac{\pi}{4} (0.0064)^2 (1.5)(4180)(T_e - 38)$$

$$= 862.5 \text{ W}$$

$$T_e = 42.31^\circ\text{C}$$

6-43

$$\rho = 1094 \quad c_p = 2518 \quad k = 0.258 \quad \text{Pr} = 72 \quad \nu = 6.72 \times 10^{-6}$$

$$\dot{m} = \frac{(1094)(10)\pi(0.03)^2}{4} = 7.733 \text{ kg/sec}$$

$$q = (7.733)(2518)(65 - 40) = 4.867 \times 10^5 \text{ W}$$

$$\text{Re} = \frac{(10)(0.03)}{6.72 \times 10^{-6}} = 4.464 \times 10^4 \quad \nu_w = 19.18 \times 10^{-6}$$

$$\bar{h} = \frac{0.258}{0.03} (0.027)(4.464 \times 10^4)^{0.8} (72)^{1/3} \left(\frac{6.72}{19.18} \right)^{0.14} = 4375 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$(4375)\pi(0.03)L(52.5 - 20) = 4.867 \times 10^5 \quad L = 36.3 \text{ m}$$

6-44

$$T = 20^\circ\text{C} = 293 \text{ K} \quad \mu = 1.91 \times 10^{-5} \quad \rho = \frac{7000}{(287)(293)} = 0.832$$

$$\text{Re} = \frac{(0.832)(15)(0.05)}{1.91 \times 10^{-5}} = 32,687 \quad C_D = 1.2$$

$$F_D = (1.2)(0.05)(0.832) \frac{(15)^2}{(2)(1.0)} = 5.62 \text{ N/m length}$$

6-45

$$T_f = \frac{450 + 325}{2} = 387.5 \text{ K} \quad \nu = 24.62 \times 10^{-6} \quad k = 0.0327$$

$$\text{Pr} = 0.69 \quad \text{Re} = \frac{(30)(0.025)}{24.62 \times 10^{-6}} = 30,463 \quad C = 0.193 \quad n = 0.618$$

$$\bar{h} = \frac{0.0327}{0.025} (0.193)(30,463)^{0.618} (0.69)^{1/3} = 131.6 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = \bar{h} \pi d (T_w - T_\infty) = (131.6)\pi(0.025)(450 - 325) = 1293 \text{ W/m}$$

6-46

$$T_w = 24^\circ\text{C} \quad T_\infty = 0^\circ\text{C} \quad u_\infty = 30 \text{ mi/h} = 13.4 \text{ m/s} \quad T_f = 285 \text{ K}$$

$$d = 0.3 \text{ m} \quad L = 1.8 \text{ m} \quad \nu = 14.3 \times 10^{-6} \text{ m}^2/\text{s} \quad k = 0.025 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\text{Pr} = 0.71$$

$$\text{Re}_d = \frac{(13.4)(0.3)}{14.3 \times 10^{-6}} = 2.82 \times 10^5 \quad C = 0.0266 \quad n = 0.805$$

$$\bar{h} = \frac{k}{d} C \text{Re}^n \text{Pr}^{1/3} = \frac{0.025}{0.3} (0.0266)(282,000)^{0.805} (0.71)^{1/3} = 48.3 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h} A (T_w - T_\infty) = (48.3)\pi(0.3)(1.8)(24 - 0) = 1967 \text{ W}$$

Chapter 6

6-48

$$\bar{T}_b = 21.11^\circ\text{C} \quad \rho = 997 \quad c_p = 4179 \quad k = 0.604 \quad \text{Pr} = 6.78$$

$$\mu = 9.8 \times 10^{-4}$$

$$\text{Re}_d = \frac{(997)(0.3)(0.002)}{9.8 \times 10^{-4}} = 610 < 2300$$

$$\text{Try fully developed } \text{Nu} = 3.66 \quad \bar{h} = \frac{(3.66)(0.604)}{0.002} = 1105$$

$$q = \dot{m}c_p\Delta T_b = (997)(0.3)\pi(0.001)^2(4179)(26.67 - 15.56) = 43.6 \text{ W}$$
$$= \bar{h}\pi dL(T_w - T_b)$$

$$43.6 = (1105)\pi(0.002)L(48.99 - 21.11) \rightarrow L = 0.225 \text{ m}$$

$$\text{Gz}^{-1} = \frac{0.225}{(610)(6.78)(0.002)} = 0.0272$$

$$\text{Fig. 6-5, } \bar{\text{Nu}} \sim 5.8 \rightarrow \bar{h} = 1751 \rightarrow L = 0.142$$

$$\text{Gz}^{-1} = 0.017 \rightarrow \bar{\text{Nu}} = 6.3$$

$$L = \frac{3.66}{6.3}(0.225) = 0.131 \rightarrow \text{Gz}^{-1} = 0.16$$

$$L \approx 0.13 \text{ m}$$

6-50

$$T_f = \frac{175 + (-30)}{2} = 72.5^\circ\text{C} = 345.5 \text{ K} \quad \rho = \frac{54,000}{(287)(345.5)} = 0.544$$

$$\mu = 2.07 \times 10^{-5} \quad k = 0.03 \quad \text{Pr} = 0.7$$

$$\text{Re} = \frac{(0.544)(0.00013)(230)}{2.07 \times 10^{-5}} = 786.6$$

$$\bar{h} = \frac{0.03}{0.00013}(0.683)(786.6)^{0.466}(0.7)^{1/3} = 3129 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (3129)\pi(0.00013)(0.0125)(175 + 30) = 3.275 \text{ W}$$

6-51

$$T_f = \frac{90 + 150}{2} = 120^\circ\text{C} = 393 \text{ K} \quad \rho = 0.899 \quad \mu = 2.256 \times 10^{-5}$$

$$k = 0.0331 \quad \text{Pr} = 0.69 \quad \text{Re} = \frac{(0.899)(0.0015)(6)}{2.256 \times 10^{-5}} = 359$$

$$\bar{h} = \frac{0.0331}{0.0015}(0.683)(359)^{0.466}(0.69)^{1/3} = 206.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (200.3)\pi(0.0015)(150 - 90) = 58.4 \text{ W/m}$$

6-52

$$d = 0.025 \text{ mm} \quad L = 0.15 \text{ m} \quad \rho_e = 70 \times 10^{-6} \Omega \cdot \text{cm}$$

$$a = 0.006^\circ\text{C}^{-1} \quad R = R_0[1 + a(T - T_0)] \quad R = \frac{E}{I}$$

$$u_\infty = 10 \text{ m/s} \quad T_\infty = 20^\circ\text{C} \quad T_w = 40^\circ\text{C}$$

$$R_0 = \frac{\rho_e L}{A} = \frac{(70 \times 10^{-6})(15)}{\pi(0.0125 \times 10^{-3})^2} = 2.14 \times 10^6 \Omega$$

$$\text{At } T = 40^\circ\text{C} \quad R = (2.14 \times 10^6)[1 + 0.006(40 - 20)] = 2.4 \times 10^6 \Omega$$

$$\text{At } T_f = 30^\circ\text{C} \quad \nu = 15.7 \times 10^{-6} \quad k = 0.027 \quad \text{Pr} = 0.7$$

$$\text{Re} = \frac{(10)(0.025 \times 10^{-3})}{15.7 \times 10^{-6}} = 15.92$$

$$\text{Nu} = C \text{Re}^n \text{Pr}^{1/3} \quad C = 0.911 \quad n = 0.385$$

$$\bar{h} = \frac{0.027}{0.025 \times 10^{-3}} (0.911)(15.92)^{0.385} (0.7)^{1/3} = 2536 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h} A (T_w - T_\infty) = I^2 R$$

$$I = \left[\frac{(2536)\pi(0.025 \times 10^{-3})(0.15)(40 - 20)}{2.4 \times 10^6} \right]^{1/2} = 4.99 \times 10^{-4} \text{ Amp}$$

$$E = IR = (4.99 \times 10^{-4})(2.4 \times 10^6) = 1197 \text{ Volts}$$

6-53

$$T_f = \frac{425 + 325}{2} = 375 \text{ K} \quad \nu = 181.4 \times 10^{-6} \quad k = 0.192 \quad \text{Pr} = 0.71$$

$$\text{Re} = \frac{(0.003)(9)}{181.4 \times 10^{-6}} = 148.8 \quad C = 0.683 \quad n = 0.618$$

$$\bar{h} = \frac{0.192}{0.003} (0.683)(148.8)^{0.618} (0.71)^{1/3} = 85.86 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = \bar{h} \pi d (T_w - T_\infty) = (85.86)\pi(0.003)(425 - 325) = 809 \text{ W/m}$$

Chapter 6

6-54

$$T_f = \frac{65 + 20}{2} = 42.5^\circ\text{C} = 315.5 \text{ K}$$

$$\text{Air: } \rho = \frac{1.0132 \times 10^5}{(287)(315.5)} = 1.119 \quad \mu = 2.012 \times 10^{-5} \quad k = 0.0274$$

$$\text{Pr} = 0.7 \quad C = 0.911 \quad n = 0.385$$

$$\text{Re} = \frac{(1.119)(6)(0.025 \times 10^{-3})}{2.012 \times 10^{-5}} = 8.342$$

$$h = \frac{0.0274}{0.025 \times 10^{-3}} (0.911)(8.342)^{0.385} (0.7)^{1/3} = 2006 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (2006)\pi(0.025 \times 10^{-3})(65 - 20) = 7.091 \text{ W/m}$$

$$\text{Water: } \rho = 991 \quad \mu = 6.2 \times 10^{-4} \quad k = 0.635$$

$$\text{Pr} = 4.1 \quad C = 0.683 \quad n = 0.466$$

$$\text{Re} = \frac{(991)(6)(0.025 \times 10^{-3})}{6.2 \times 10^{-4}} = 239.8$$

$$h = \frac{0.635}{0.025 \times 10^{-3}} (0.683)(239.8)^{0.466} (4.1)^{1/3} = 3.57 \times 10^5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (3.57 \times 10^5)\pi(0.025 \times 10^{-3})(65 - 20) = 1261 \text{ W/m}$$

6-52

$$\text{At } 90^\circ\text{C} \quad \text{Pr} = 1.978$$

$$\text{Eq. (6-17)} \quad \text{Nu} = C\text{Re}^n \text{Pr}^{1/3} \quad \text{Pr}^{1/3} = 1.255$$

$$\text{Eq. (6-18)} \quad \text{Nu} = (0.35 + 0.56\text{Re}^{0.52})\text{Pr}^{0.3} \quad \text{Pr}^{0.3} = 1.227$$

Re	C	n	Nu [Eq. (6-17)]	Nu [Eq. (6-18)]
10^3	0.683	0.466	21.44	25.38
10^4	0.193	0.618	71.81	83.04
10^5	0.0266	0.805	353.6	274.0

6-56

$$T_f = \frac{50 - 35}{2} = 7.5^\circ\text{C} = 280.5 \text{ K} \quad \text{Pr} = 0.71 \quad \mu = 1.79 \times 10^{-5}$$

$$\rho = \frac{1.0132 \times 10^5}{(287)(280.5)} = 1.259 \quad k = 0.0247 \quad \text{Re} = \frac{(1.259)(13)(0.5)}{1.79 \times 10^{-5}} = 457,000$$

$$C = 0.266 \quad n = 0.805$$

$$h = \frac{0.0247}{0.5} (0.0266)(457,000)^{0.805} (0.71)^{1/3} = 42.21 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (42.21)\pi(0.5)(50 + 35) = 5636 \text{ W/m}$$

6-57

$$T_f = \frac{50 + 27}{2} = 38.5^\circ\text{C} = 311.5 \text{ K} \quad \nu = 17.74 \times 10^{-6}$$

$$k = 0.02711 \quad \text{Pr} = 0.7 \quad \text{Re} = \frac{(20)(0.04)}{17.74 \times 10^{-6}} = 4.51 \times 10^4$$

$$\text{circ. tube: } h = \frac{0.02711}{0.04} (0.0266)(4.51 \times 10^4)^{0.805} (0.7)^{1/3} = 89.32 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{sq. tube: } h = \frac{0.02711}{0.04} (0.102)(4.51 \times 10^4)^{0.675} (0.7)^{1/3} = 85.04 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} (\text{circ.}) = (89.32)\pi(0.04)(50 - 27) = 258.1 \text{ W/m}$$

$$\frac{q}{L} (\text{sq.}) = (85.04)(4)(0.04)(50 - 27) = 312.9 \text{ W/m}$$

6-58

$$T_f = \frac{200 + 50}{2} = 125^\circ\text{C} = 398 \text{ K} \quad \nu = 14.35 \times 10^{-6}$$

$$k = 0.0246 \quad \text{Pr} = 0.74 \quad \text{Re} = \frac{u_\infty d}{\nu} = \frac{(40)(0.03)}{14.35 \times 10^{-6}} = 83,624$$

$$C = 0.0266 \quad n = 0.805$$

$$h = \frac{0.0246}{0.03} (0.0266)(83,624)^{0.805} (0.74)^{1/3} = 181 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d(T_w - T_\infty) = (181)\pi(0.03)(200 - 50) = 814 \text{ W/m}$$

Chapter 6

Compare Churchill Equation

$$Nu_d = 0.3 + \frac{(0.62)(83,624)^{1/2}(0.74)^{1/3}}{\left[1 + \left(\frac{0.4}{0.74}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{83,624}{282,000}\right)^{1/2}\right] = 220.8$$

$$h = \frac{(220.8)(0.0246)}{0.03} = 181 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Very close check. No need to use more complicated relation.

6-59

$$\mu = 6.82 \times 10^{-4} \quad k = 0.63 \quad \text{Pr} = 4.53 \quad c_p = 4174 \quad \bar{T}_b = 37.8^\circ\text{C}$$

$$Re_d = 100,000 = \frac{\rho u_m (0.0125)}{6.82 \times 10^{-4}} \quad \rho u_m = 5456$$

$$\dot{m} = \rho u_m A = \frac{(5456)\pi(0.0125)^2}{4} = 0.67 \text{ kg/sec}$$

$$\dot{m} c_p \Delta T_b = hA(T_w - \bar{T}_b)$$

$$\bar{h} = \frac{0.63}{0.0125} (0.023)(100,000)^{0.8} (4.53)^{0.4} = 21,200$$

$$(0.67)(4174)(\Delta T_b) = (21,200)\pi(0.0125)(1.5)(160 - 100) \left(\frac{5}{9}\right)$$

$$\Delta T_b = 14.89^\circ\text{C}$$

$$T_b(\text{exit}) = 37.8 + \left(\frac{1}{2}\right)(14.89) = 45.25^\circ\text{C}$$

6-61

$$T_f = \frac{100 + 20}{2} = 60^\circ\text{C} = 333 \text{ K} \quad \mu = 216 \times 10^{-7} \quad k = 0.159$$

$$\text{Pr} = 0.7 \quad \rho = \frac{150 \times 10^3}{(2078)(333)} = 0.217 \quad \text{Re} = \frac{(0.217)(50)(0.3)}{216 \times 10^{-7}} = 1.5 \times 10^5$$

$$C = 0.0266 \quad n = 0.805$$

$$h = \frac{0.159}{0.3} (0.0266)(1.5 \times 10^5)^{0.805} (0.7)^{1/3} = 184.3 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = h\pi dL(T_w - T_\infty) = (184.2)\pi(0.3)(6)(100 - 20) = 83,360 \text{ W}$$

Churchill Equation

$$Nu_d = 0.3 + \frac{(0.62)(1.5 \times 10^5)^{1/2}(0.7)^{1/3}}{\left[1 + \left(\frac{0.4}{0.7}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{1.5 \times 10^5}{282,000}\right)^{5/8}\right]^{4/5} = 323.3$$

$$h = \frac{(323.3)(0.159)}{0.3} = 171.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \text{ or about 7\% less.}$$

6-62

$$T_f = \frac{300 + 30}{2} = 115^\circ\text{C} = 388 \text{ K} \quad \nu = 13.62 \times 10^{-6} \quad k = 0.0236$$

$$\text{Pr} = 0.742 \quad \text{Re} = \frac{(0.25)(0.0254)(35)}{13.62 \times 10^{-6}} = 16,318 \quad C = 0.193 \quad n = 0.618$$

$$h = \frac{0.0236}{(0.25)(0.0254)} (0.193)(16,318)^{0.618} (0.742)^{1/3} = 260.6 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = h\pi dL(T_w - T_\infty) = (260.5)\pi(0.0254)(0.25)(4.5)(300 - 30) = 6316 \text{ W}$$

6-63

$$T_f = \frac{300 + 400}{2} = 350 \text{ K} \quad \nu = 11.19 \times 10^{-6} \quad k = 0.02047$$

$$\text{Pr} = 0.755 \quad \text{Re} = \frac{(50)(0.2)}{11.19 \times 10^{-6}} = 8.94 \times 10^5$$

Churchill Equation:

$$\text{Nu}_d = 0.3 + \frac{(0.62)(8.94 \times 10^{-5})^{1/2} (0.755)^{1/3} \left[1 + \left(\frac{8.94 \times 10^5}{282,000} \right)^{5/8} \right]^{4/5}}{\left[1 + \left(\frac{0.4}{0.755} \right)^{2/3} \right]^{1/4}} = 1151$$

$$h = \frac{(1151)(0.0247)}{0.2} = 117.8 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d(T_w - T_\infty) = (117.8)\pi(0.2)(400 - 300) = 7401 \text{ W/m}$$

6-64

$$T_f = \frac{20 + 85}{2} = 52.5^\circ\text{C} = 325.5 \text{ K} \quad \mu = 1.96 \times 10^{-5} \quad k = 0.0281$$

$$\text{Pr} = 0.7 \quad \rho = \frac{(0.6)(1.01 \times 10^5)}{(287)(325.5)} = 0.651 \text{ kg/m}^3 \quad C = 0.102$$

$$n = 0.675 \quad \text{Re} = \frac{(0.651)(12)(0.04)}{1.96 \times 10^{-5}} = 15,937$$

$$h = \frac{0.0281}{0.04} (0.102)(15,937)^{0.675} (0.7)^{1/3} = 43.68 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d(T_w - T_\infty) = (43.68)\pi(0.04)(85 - 20) = 356.7 \text{ W/m}$$

Chapter 6

6-65

At 38°C $\rho = 993$ $\mu = 6.82 \times 10^{-4}$ $k = 0.63$ $Pr = 4.53$
 At 93°C $\mu = 3.06 \times 10^{-4}$ $Re_{\infty} = \frac{(993)(0.003)(5)}{6.82 \times 10^{-4}} = 21,840$

Eq. 6-20 $h = \frac{0.63}{0.003} [1.2 + 0.53(21,840)^{0.54}] \left(\frac{6.82}{3.06}\right)^{0.25} (4.53)^{0.3}$

$h = 47,640 \frac{W}{m^2 \cdot ^\circ C}$

$q = (47,640)4\pi(0.0015)^2(93 - 38) = 74.08 \text{ W}$

6-66

$T_{\infty} = 293 \text{ K}$ $\nu = 15.96$ $k = 0.026$ $Pr = 0.71$ $T_w = 313 \text{ K}$
 $\nu = 17.86$ $Re = \frac{(6)(4)}{15.96 \times 10^{-6}} = 1.5 \times 10^6$

$h = \frac{0.026}{4.0} \left\{ 2 + [(0.4)(1.5 \times 10^6)^{1/2} + (0.06)(1.5 \times 10^6)^{2/3}] (0.71)^{0.4} \left(\frac{15.96}{17.86}\right)^{1/4} \right\}$
 $= 7.045 \frac{W}{m^2 \cdot ^\circ C}$

$q = (7.045)4\pi(2)^2(40 - 20) = 7082 \text{ W}$

6-68

At $T_{\infty} = 20^\circ C$ $\mu = 9.75 \times 10^{-4}$ $k = 0.6$ $Pr = 6.7$
 $\rho = 997$

At $T_w = 90^\circ C$ $\mu_w = 3.2 \times 10^{-4}$

$Nu Pr^{-0.3} \left(\frac{\mu_w}{\mu}\right)^{0.25} = 1.2 + 0.53 Re_d^{0.54}$

$Re = \frac{(997)(3.5)(0.03)}{9.75 \times 10^{-4}} = 1.073 \times 10^5$

$h = \frac{0.6}{0.03} [1.2 + 0.53(1.073 \times 10^5)^{0.54}] \left(\frac{9.75}{3.2}\right)^{0.25} (6.7)^{0.3} = 12,957 \frac{W}{m^2 \cdot ^\circ C}$

$q = h4\pi r^2(T_w - T_{\infty}) = (12,957)(4)\pi(0.015)^2(90 - 20) = 2564 \text{ W}$

6-69

$$T_f = \frac{220 + 20}{2} = 120^\circ\text{C} = 393 \text{ K} \quad \nu = 2.256 \times 10^{-5} \quad k = 0.0331$$

$$\text{Pr} = 0.69 \quad \text{Re} = \frac{u_\infty d}{\nu} = \frac{(20)(0.006)}{2.256 \times 10^{-5}} = 5319 \quad \frac{hd}{k} = 0.37 \text{Re}^{0.6}$$

$$h = \frac{0.0331}{0.006} (0.37)(5319)^{0.6} = 351.1 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = h4\pi r^2 (T_w - T_\infty) = (351.1)(4)\pi(0.003)^2(220 - 20) = 7.94 \text{ W}$$

6-70

$$T_f = \frac{200 + 30}{2} = 115^\circ\text{C} = 388 \text{ K} \quad \mu = 2.235 \times 10^{-5} \quad k = 0.0328$$

$$\text{Pr} = 0.69 \quad \rho = \frac{(3)(1.01 \times 10^5)}{(287)(388)} = 2.73 \text{ kg/m}^3$$

$$\text{Re} = \frac{(2.73)(75)(1)}{2.235 \times 10^{-5}} = 9.15 \times 10^6$$

$$\begin{aligned} \bar{h} &= \frac{k}{L} \text{Pr}^{1/3} (0.037 \text{Re}^{0.8} - 871) = \frac{0.0328}{1} (0.69)^{1/3} [(0.037)(9.15 \times 10^6)^{0.8} - 871] \\ &= 372 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \end{aligned}$$

$$q = \bar{h}A(T_w - T_\infty) = (372)(1)^2(200 - 30) = 6.33 \times 10^4 \text{ W}$$

6-71

$$\text{At } 38^\circ\text{C} \quad \rho = \frac{3.5 \times 10^6}{(287)(311)} = 39.2 \text{ kg/m}^3$$

$$\dot{m} = (39.2)(9)(1.5)(20)(0.025) = 264.7 \text{ kg/sec}$$

$$T_f \approx \frac{200 + 38}{2} = 119^\circ\text{C} = 392 \text{ K} \quad \rho_f = \frac{3.5 \times 10^6}{(287)(392)} = 31.1 \text{ kg/m}^3$$

$$\mu_f = 2.25 \times 10^{-5} \quad k_f = 0.0331 \quad \text{Pr}_f = 0.69 \quad c_p \approx 1010 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}$$

$$u_{\max} = u_\infty \left(\frac{S_n}{S_n - d} \right) = 9 \left(\frac{2.5}{2.5 - 1.25} \right) = 18 \text{ m/sec} \quad \frac{S_n}{d} = 2 \quad \frac{S_p}{d} = 3$$

$$\text{Re}_{\max} = \frac{(31.1)(18)(0.0125)}{2.25 \times 10^{-5}} = 311,000 \quad C = 0.488 \quad n = 0.562$$

$$h = \frac{0.331}{0.0125} (0.488)(311,000)^{0.562} (0.69)^{1/3} = 1395 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \dot{m}c_p\Delta T = hA(T_w - T_{\text{avg}})$$

Chapter 6

$$q = (264.7)(1010)(T_e - 38) = 1395(400)\pi(0.0125)(1.5)\left(200 - \frac{T_e - 38}{2}\right)$$

$$T_e = 56.76^\circ\text{C} \quad q = 5.016 \text{ MW}$$

6-72

$$\frac{S_n}{d} = \frac{1.9}{0.633} = 3 \quad \frac{S_p}{d} = 3 \quad u_\infty = 4.5 \text{ m/sec} \quad T_\infty = 293 \text{ K}$$

$$p = 1 \text{ atm} \quad \rho_\infty = 1.18 \text{ kg/m}^3 \quad T_f = \frac{90 + 20}{2} = 55^\circ\text{C} = 328 \text{ K}$$

$$\rho = 1.077 \quad \mu = 2.034 \times 10^{-5} \quad k = 0.0284 \quad \text{Pr} = 0.7 \quad c_p = 1007$$

$$u_{\max} = u_\infty \left(\frac{S_n}{S_n - d} \right) \quad u_{\max} = (4.5)(1.5) = 6.75 \text{ m/sec}$$

$$\text{Re} = \frac{(1.077)(6.75)(0.00633)}{2.034 \times 10^{-5}} = 2262 \quad C = 0.317 \quad n = 0.608$$

$$h = \frac{0.0284}{0.00633} (0.317)(2262)^{0.608} (0.7)^{1/3} (0.94) = 131.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (131.4)(6)(50)\pi(0.00633)\left(90 - \frac{T_e}{2} - \frac{20}{2}\right)$$

$$= (1.18)(50)(0.019)(4.5)(1007)(T_e - 20)$$

$$T_e = 30.03^\circ\text{C} \quad \frac{q}{L} = 50,944 \text{ W/m}$$

$$\text{Re}_{\max} = \frac{(7.27)(0.00633)}{2.034 \times 10^{-5}} = 2262$$

$$G_{\max} = (1.077)(6.75) = 7.27 \frac{\text{kg}}{\text{m}^2 \cdot \text{sec}} = 5361 \frac{\text{lbm}}{\text{ft}^2 \cdot \text{hr}}$$

$$\rho = 0.0737 \text{ lbm/ft}^3$$

$$f' = \left[0.044 + \frac{(0.08)(3)}{2^{0.807}} \right] (2262)^{-0.15} = 0.0569$$

$$\text{At } 90^\circ\text{C} \quad \mu_w = 2.17 \times 10^{-5}$$

$$\text{At } 20^\circ\text{C} \quad \mu = 1.98 \times 10^{-5}$$

$$\Delta p = \frac{(0.0569)(5361)^2(6)}{(0.0737)(2.09 \times 10^8)} \left(\frac{2.17}{1.98} \right)^{0.14} = 0.645 \text{ lbf/ft}^2$$

$$\Delta p = 30.89 \text{ N/m}^2$$

6-73

$$v = 15.69 \times 10^{-4} \quad k = 0.02624 \quad \text{Pr} = 0.71 \quad u_{\max} = (10) \left(\frac{4}{2} \right) = 20 \text{ m/s}$$

$$\text{Re}_d = \frac{(20)(0.02)}{15.69 \times 10^{-6}} = 25,494 \quad \frac{S_n}{d} = \frac{S_p}{d} = 2.0 \quad C = 0.254$$

$$n = 0.632$$

$$\bar{h} = \frac{0.02624}{0.02} (0.254)(25,494)^{0.632} (0.71)^{1/3} = 181 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

6-75

$$\frac{S_n}{d} = \frac{S_p}{d} = 1.5 \quad T_f = \frac{150 + 35}{2} = 92.5^\circ\text{C} = 365.5 \text{ K} \quad \rho = 5.226$$

$$\rho_f = \frac{(3)(1.0132 \times 10^5)}{(189)(365.5)} = 4.404 \quad \text{At } 35^\circ\text{C} = 308 \text{ K} \quad c_p = 921$$

$$\mu_f = 17.82 \times 10^{-6} \quad \text{Pr}_f = 0.75 \quad k_f = 0.0218$$

$$u_{\max} = (5) \left(\frac{1.875}{1.875 - 1.25} \right) = 15 \text{ m/s} \quad C = 0.278$$

$$\text{Re}_{\max} = \frac{(4.404)(15)(0.0125)}{17.82 \times 10^{-6}} = 46,339 \quad n = 0.620$$

$$h = \frac{0.0218}{0.0125} (0.278)(46,339)^{0.620} (0.75)^{1/3} = 344.2 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (344.2)(100)\pi(0.0125)(0.6) \left(150 - \frac{T_e - 35}{2} \right)$$

$$= (5.226)(10)(0.6)(0.01875)(5)(921)(T_e - 35)$$

$$T_e = 62.35^\circ\text{C} \quad q = 74,059 \text{ W}$$

Chapter 6

6-76

$$\begin{aligned}
 T_f &= 55^\circ\text{C} = 328 \text{ K} & u_\infty &= 12 \text{ m/s} & \text{Pr} &= 0.7 \\
 k &= 0.0284 & \nu &= 19.04 \times 10^{-6} & d &= 2.5 \text{ cm} \\
 u_{\max} &= (12) \frac{5}{5-2.5} = 24 \text{ m/s} & \text{Re}_{\max} &= \frac{(24)(0.025)}{19.04 \times 10^{-6}} = 3.15 \times 10^4 \\
 c &= 0.112 & n &= 0.702 & \bar{h} &= \frac{0.0284}{0.025} (0.112)(3.15 \times 10^4)^{0.702} (0.7)^{1/3} (0.96) \\
 h &= 156 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} & \frac{q}{L} &= (156)\pi(0.025)(15)(7)(90-20) = 9 \times 10^4 \text{ W/m} \\
 f' &= \left[0.044 + \frac{(0.08)(1.5)}{1} \right] (3.15 \times 10^4)^{-0.15} = 3.468 \times 10^{-2} \\
 p &= \frac{1.013 \times 10^5}{(287)(328)} = 1.076 & G_{\max} &= (1.076)(24) = 25.83 & \rho_\infty &= 1.205 \\
 \Delta p &= \frac{(2)(3.468 \times 10^{-2})(25.83)^2 (7) \left(\frac{2.12}{1.96} \right)^{0.14}}{1.205} = 272 \text{ N/m}^2 = 0.033 \text{ psi}
 \end{aligned}$$

6-77

$$\begin{aligned}
 T_f &= \frac{350+300}{2} = 325 \text{ K} & \nu &= 18.23 \times 10^{-6} & k &= 0.0281 & \text{Pr} &= 0.7 \\
 u_{\max} &= (10) \left(\frac{5}{2.5} \right) = 20 & \text{Re}_{\max} &= \frac{(20)(0.025)}{18.23 \times 10^{-6}} = 27,427 \\
 \frac{S_p}{d} &= \frac{S_n}{d} = \frac{5}{2.5} = 2.0 & C &= 0.254 & n &= 0.632 \\
 h &= \frac{0.0281}{0.025} (0.254)(27,427)^{0.632} (0.7)^{1/3} = 161.8 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \\
 \text{correction for 5 tubes} &= 0.92 \\
 h &= (161.8)(0.92) = 148.8 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \\
 \text{Zukauskas} & C = 0.27 & n &= 0.63 \text{ and } h = 166.9 \text{ correction for 5 tubes} = 0.92 \\
 h &= (166.9)(0.92) = 153.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \text{ only 3\% difference}
 \end{aligned}$$

6-78

$$T_f = \frac{90 + 20}{2} = 55^\circ\text{C} = 328 \text{ K} \quad \rho = \frac{1.01 \times 10^5}{(287)(328)} = 1.076$$

$$\mu = 2.035 \times 10^{-5} \quad k = 0.0284 \quad \text{Pr} = 0.7$$

$$\text{Re} = \frac{(1.076)(0.05)(15)}{2.035 \times 10^{-5}} = 39,656 \quad C = 0.102 \quad n = 0.675$$

$$h = \frac{0.0284}{0.05} (0.102)(39,656)^{0.675} (0.7)^{1/3} = 65.34 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (65.34)(4)(0.05)(90 - 20) = 915 \text{ W/m}$$

6-79

$$T_f = \frac{870 + 20}{2} = 445^\circ\text{C} = 718 \text{ K} \quad \text{Pr} = 0.685 \quad \mu = 3.386 \times 10^{-5}$$

$$\rho = \frac{1.01 \times 10^5}{(287)(718)} = 0.492 \quad k = 0.053 \quad \text{Re} = \frac{(0.492)(2)(0.006)}{3.386 \times 10^{-5}} = 174.37$$

$$C = 0.228 \quad n = 0.731 \quad (\text{Approximate values})$$

$$h = \frac{0.053}{0.006} (0.228)(174.37)^{0.731} (0.685)^{1/3} = 77.2 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (77.2)(7)(2)(0.006)(0.35)(870 - 20) = 1929 \text{ W}$$

This value is probably low because of the range of Table 6-2.

6-80

$$T_f = \frac{50 + 30}{2} = 40^\circ\text{C} = 313 \text{ K} \quad \mu = 2.007 \times 10^{-5} \quad k = 0.0272$$

$$\text{Pr} = 0.7 \quad \rho = \frac{1.01 \times 10^5}{(287)(313)} = 1.128 \quad \text{Re} = \frac{(1.128)(6)(0.3)}{2.007 \times 10^{-5}} = 101,165$$

$$C = 0.102 \quad n = 0.675$$

$$h = \frac{0.0272}{0.3} (0.102)(101,165)^{0.675} (0.7)^{1/3} = 19.63 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (19.63)(4)(0.3)(50 - 30) = 471 \text{ W/m}$$

$$\text{If velocity halved: } h_{1/2} = (19.63) \left(\frac{1}{2}\right)^{0.675} = 12.29 \quad q \text{ reduced by } 37.3\%$$

Chapter 6

6-81

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \alpha \frac{\partial^2 T}{\partial y^2}$$

$$u = u_\infty = \text{const} \quad T_\infty = \text{const}$$

$$u_\infty \frac{\partial T}{\partial x} = \alpha \frac{\partial^2 T}{\partial y^2}$$

$$\frac{\partial^2 T}{\partial y^2} = \frac{u_\infty}{\alpha} \frac{\partial T}{\partial x}$$

Analog to semi-infinite plate

$$y \sim x$$

$$x \sim \tau$$

$$\frac{u_\infty}{\alpha} \sim \frac{1}{\alpha}$$

Boundary Conditions

Solid

$$T(x, 0) = T_i$$

$$T(0, \tau) = T_0 \text{ for } \tau > 0$$

Solutions

Solid

$$\frac{T(x, \tau) - T_0}{T_i - T_0} = \text{erf}\left(\frac{x}{2\sqrt{\alpha\tau}}\right)$$

Boundary Layer

$$T(y, 0) = T_\infty$$

$$T(0, x) = T_w$$

Boundary Layer

$$\frac{T(y, x) - T_w}{T_\infty - T_w} = \text{erf}\left(\frac{y}{2\sqrt{\frac{\alpha\tau}{u_\infty}}}\right)$$

6-82

Bismuth at 400°C $\rho = 9950 \text{ kg/m}^3$ $\mu = 1.47 \times 10^{-3} \frac{\text{kg}}{\text{m} \cdot \text{sec}}$

$$c_p = 0.15 \frac{\text{kJ}}{\text{kg} \cdot \text{°C}} \quad k = 16.3 \quad \text{Pr} = 0.013 \quad \text{Re Pr} = 450.4$$

$$\text{Re} = \frac{(0.025)(1)(4)}{\pi(0.025)^2(1.47 \times 10^{-3})} = 34,645$$

$$h = \frac{16.3}{0.025} [5.0 + 0.025(450.4)^{0.8}] = 5423 \frac{\text{W}}{\text{m}^2 \cdot \text{°C}}$$

$$q = (1)(150)(T_e - 400) = (5423)\pi(0.025)(0.6) \left(450 - \frac{T_e - 400}{2}\right)$$

$$T_e = 445.98^\circ\text{C} \quad q = 6898 \text{ W}$$

6-83

Sodium at 134.5°C $\rho = 900$ $\mu = 0.45 \times 10^{-3}$ $c_p = 1345$

$k = 82$ $Pr = 0.08$ $q = (2.3)(1345)(149 - 120) = 151.6 \text{ kW}$

$$Re = \frac{(0.025)(2.3)(4)}{(0.025)^2(0.45 \times 10^{-3})} = 260,300 \quad Re Pr = 2082$$

$$h = \frac{8.2}{0.025} [4.82 + 0.01825(2082)^{0.8277}] = 49,500 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$151,600 = (49,500)\pi(0.025)L(200 - 149) \quad L = 0.765 \text{ m}$$

6-84

$$h = \frac{k}{x} 0.53 Re_x^{1/2} Pr^{1/2} = Cx^{-1/2}$$

$$\bar{h} = 2h_{x=L} \quad \frac{\bar{h}L}{k} = \bar{Nu}_L = 1.06 Re_L^{1/2} Pr^{1/2}$$

6-85

Air $T_f = \frac{93 + 15}{2} = 54^\circ\text{C} = 327 \text{ K}$ $\mu = 2.03 \times 10^{-5}$ $k = 0.028$

$Pr = 0.7$ $\rho = \frac{1.01 \times 10^5}{(287)(327)} = 1.08 \text{ kg/m}^3$

$$Re = \frac{(1.08)(15)(0.0516)}{2.03 \times 10^{-5}} = 41,163$$

$$h_a = \frac{0.028}{0.0516} (0.0266)(41,163)^{0.805} (0.7)^{1/3} = 66.44 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Water at 93°C $\mu = 3.06 \times 10^{-4}$ $k = 0.678$ $Pr = 1.90$

$$Re = \frac{(0.05)(0.8)(4)}{\pi(0.05)^2(3.06 \times 10^{-4})} = 66,574$$

$$h_w = \frac{(0.678)(0.023)(66,574)^{0.8} (1.9)^{0.4}}{0.5} = 2911 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = \frac{(93 - 15)\pi(1)}{\frac{1}{(66.44)(0.0516)} + \frac{1}{(2911)(0.05)}} = 821 \text{ W/m}$$

Chapter 6

6-86

$$G = \frac{\dot{m}}{A} = \frac{0.035}{\pi(0.0625)^2} = 2.852$$

Properties at 325 K $\mu = 1.96 \times 10^{-5} \frac{\text{kg}}{\text{m} \cdot \text{s}}$

$$k = 0.02813 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\text{Pr} = 0.7$$

$$\text{Re} = \frac{dG}{\mu} = \frac{(0.0125)(2.852)}{1.96 \times 10^{-5}} = 1819 \quad \text{Laminar}$$

$$\text{Re Pr} \frac{d}{L} = (1819)(0.7) \left(\frac{0.0125}{12} \right) = 1.33$$

$$h = \frac{0.02813}{0.0125} \left[3.66 + \frac{(0.0668)(1.33)}{1 + (0.04)(1.33)^{2/3}} \right] = 8.32 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \dot{m} c_p \Delta T_b = hA(T_w - \bar{T}_b) = (0.035)(1005)(T_e - 300) \\ = (8.32)\pi(0.0125)(12) \left(350 - 150 - \frac{T_e}{2} \right)$$

$$T_e = 305.3 \text{ K}$$

$$q = (0.035)(1005)(305.3 - 300) = 186 \text{ W}$$

6-87

$$T_f = \frac{77 + 20}{2} = 48.5^\circ\text{C} = 321.5 \text{ K}$$

Properties $\nu = 17.87 \times 10^{-6}$ $k = 0.028$ $\text{Pr} = 0.7$

$$\text{Re} = \frac{u_\infty d}{\nu} = \frac{(20)(0.05)}{17.87 \times 10^{-6}} = 55,960$$

$$C = 0.0266 \quad n = 0.805$$

$$h = \frac{0.028}{0.05} (0.0266)(55,960)^{0.805} (0.7)^{1/3} = 87.8 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d(T_w - T_\infty) = (87.8)\pi(0.05)(77 - 20) = 786 \text{ W/m}$$

6-88

Properties at 20°C $\nu = 0.0009 \text{ m}^2/\text{s}$ $\text{Pr} = 10,400$
 $k = 0.145 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$ $\rho = 888 \text{ kg}/\text{m}^3$ $c_p = 1880 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}$

$$G = \frac{(0.4)(4)}{\pi(0.02)^2} = 1273$$

$$\text{Re} = \frac{dG}{\mu} = \frac{(0.02)(1273)}{(888)(0.0009)} = 31.9$$

$$\text{Re Pr} \frac{d}{L} = (31.9)(10,400) \frac{0.02}{8} = 829 \quad \text{Gz}^{-1} = 1.21 \times 10^{-3}$$

From Fig. 6-5 $\bar{\text{Nu}} = 16$ $h = \frac{(16)(0.145)}{0.02} = 116 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$

$$q = \pi d L h (T_w - \bar{T}_b) = \dot{m} c_p \Delta T_b$$

$$= \pi(0.02)(8)(116) \left(80 - 10 - \frac{T_e}{2} \right) = (0.4)(1880)(T_e - 20)$$

$$19,120 = 781 T_e$$

$$T_e = 24.5^\circ\text{C}$$

6-89

at 325 K, properties $k = 0.02814 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$ $\nu = 18.23 \times 10^{-6} \text{ m}^2/\text{s}$

$$\text{Pr} = 0.7 \quad \mu = 1.96 \times 10^{-5} \quad \rho = 1.09 \text{ kg}/\text{m}^3$$

$$G = \frac{0.2}{(0.12)(0.2)} = 8.333 \quad D_H = \frac{(4)(0.12)(0.2)}{(2)(0.12 + 0.2)} = 0.15$$

$$\text{Re} = \frac{D_H G}{\mu} = \frac{(0.15)(8.333)}{1.96 \times 10^{-5}} = 63,770$$

$$h = \frac{0.028}{0.15} (0.023)(63,770)^{0.8} (0.7)^{0.4} = 26 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \dot{m} c_p \Delta T_b = h A (T_w - \bar{T}_b)$$

$$= (0.2)(1005)(T_e - 300) = 26(2)(0.12 + 0.2)(2.5) \left(400 - 150 - \frac{T_e}{2} \right)$$

$$5.382 T_e = 1700$$

$$T_e = 315.8 \text{ K}$$

$$q = 3175.8 \text{ W}$$

Chapter 6

6-90

constant temperature tube

$$Pr = 0.7 \quad d = 1.5 \text{ mm} \quad k = 0.02624 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$Re Pr = (1200)(0.7) = 840 \quad Re Pr d = 1.26$$

Use Fig. 6-5

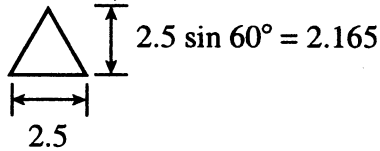
$x, \text{ m}$	$Gz^{-1} = \frac{x}{d} (Re Pr)$	\overline{Nu}_d	$\bar{h}, \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$
0.01	7.94×10^{-3}	7.9	138
0.1	7.94×10^{-2}	4.5	78.8
0.2	0.159	4.0	70
1.0	0.793	3.66	64.1

6-91

at 15°C $c_p = 4180$ $\rho = 999$ $\mu = 1.12 \times 10^{-3}$

$$k = 0.595 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad Pr = 7.88$$

$$Re = 50,000$$



$$A_c = \left(\frac{1}{2}\right)(2.165)(2.5) = 2.71 \text{ cm}^2$$

$$D_H = \frac{(4)(2.71)}{(3)(2.5)} = 1.443 \text{ cm} = 0.01443 \text{ m}$$

$$h = \frac{0.595}{0.01443} (0.023)(50,000)^{0.8} (7.88)^{0.4} = 12,438 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \dot{m} c_p \Delta T_b = hA(T_w - \bar{T}_b) \quad Re = \frac{D_H \dot{m}}{\mu}$$

$$\dot{m} = \frac{(50,000)(1.12 \times 10^{-3})(2.71)(10^{-4})}{0.01443} = 1.052 \text{ kg/sec}$$



$$q = (1.052)(4180)(10) = (12,438)(3)(0.025)L(15) = 43,961 \text{ W}$$

$$L = 3.14 \text{ m}$$

Checking Fig. 6-6 fully developed flow is present

6-92

$$\text{Re} = 10^4 \quad k = 0.026 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \text{Pr} = 0.7$$

Geom	C	n	Nu_d	h	A	$q \sim hA$
	0.193	0.618	50.8	$50.8 \frac{k}{d}$	πd	$159.6k$
	0.102	0.675	45.4	$45.4 \frac{k}{d}$	$4d$	$181.6k$

6-93

$$\begin{aligned} \text{Pr} = 0.7 \quad k = 0.026 \\ \text{Eq. (6-25)} \quad \text{Nu} = (0.37)(50,000)^{0.6} = 244 \\ \text{Eq. (6-26)} \quad \text{Nu} = 2 + [0.25 + (3 \times 10^{-4})(50,000)^{1.6}]^{1/2} = 101.5 \\ \text{Eq. (6-30)} \quad \text{Nu} = 2 + [0.4(50,000)^{1/2} + 0.06(50,000)^{2/3}](0.7)^{0.4} = 150.1 \end{aligned}$$

6-94

$$\begin{aligned} \text{at } 10^\circ\text{C} \quad \text{Pr} = 9.4 \quad \mu = 1.31 \times 10^{-3} \quad k = 0.585 \quad \rho = 999 \\ \text{at } 60^\circ\text{C} \quad \mu_w = 0.471 \times 10^{-3} \quad \text{Re} = \frac{(999)(4)(0.025)}{1.31 \times 10^{-3}} = 76,260 \end{aligned}$$

Use Eq. (6-29)

$$\text{Nu} = (9.4)^{0.3} \left(\frac{1.31}{0.471} \right)^{0.25} [1.2 + (0.53)(76,260)^{0.54}] = 584$$

$$h = \frac{(584)(0.585)}{0.025} = 13,647 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - T_\infty) = (13,647)4\pi \left(\frac{0.025}{2} \right)^2 (60 - 10) = 1340 \text{ W}$$

Chapter 6

6-95

$$u_{\max} = (6) \left(\frac{2}{2-1.5} \right) = 24 \text{ m/s}$$

$$\begin{array}{llll} \text{Take } T_f = 325 \text{ K} & \rho = 1.09 & \mu = 1.96 \times 10^{-5} & \rho_{\text{inlet}} = 1.18 \\ k = 0.02814 & \text{Pr} = 0.7 & c_p = 1005 & \end{array}$$

$$\text{Re} = \frac{\rho u_{\infty} d}{\mu} = \frac{(1.09)(24)(0.015)}{1.96 \times 10^{-5}} = 20,020$$

$$\frac{S_n}{d} = \frac{S_p}{d} = \frac{2}{1.5} = 1.33$$

From Table 6.4, by interpolation

$$n = 0.597 \quad C = 0.364$$

$$h = \frac{0.02814}{0.015} (0.364)(20,020)^{0.597} (0.7)^{1/3} = 224 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - \bar{T}_{\infty}) = \dot{m}c_p\Delta T_{\infty}$$

$$A = (144)\pi(0.015)(1.0) = 6.786 \text{ m}^2$$

$$\dot{m} = (1.18)(6)(12)(1.0)(0.02) = 1.69 \text{ kg/s}$$

$$(224)(6.786) \left(350 - 150 - \frac{T_e}{2} \right) = (1.69)(1005)(T_e - 300)$$

$$8.14 \times 10^5 = 2458T_e$$

$$T_e = 330.9 \text{ K}$$

$$q = 52,500 \text{ W}$$

6-96

$$k = 0.026 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \text{Pr} = 0.7$$

$$(a) \quad \bar{h} = \frac{0.026}{0.1} (0.0266)(50,000)^{0.805} (0.7)^{1/3} = 37.2 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$(b) \quad \bar{h} = \frac{0.026}{0.1} (0.023)(50,000)^{0.8} (0.7)^{0.4} = 29.8 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$(c) \quad \bar{h} = \frac{0.026}{0.1} (0.664)(50,000)^{1/2} (0.7)^{1/3} = 34.3 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

6-97

$$\rho = 999 \quad c_p = 4186 \quad \mu = 1.12 \times 10^{-3} \quad k = 0.595 \quad \text{Pr} = 7.88$$

$$\text{Re}_d = \frac{(999)(10)(0.3048)(0.025)}{1.12 \times 10^{-3}} = 67,967$$

$$\bar{h} = \frac{0.595}{0.025} (0.023)(67,967)^{0.8} (7.88)^{0.4} = 9178 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\dot{m} = \rho u_m A_c = (999)(10)(0.3048) \frac{\pi}{4} (0.025)^2 = 1.495 \text{ kg/s}$$

$$q = \dot{m} c_p \Delta T_b = \bar{h} A (T_w - \bar{T}_b)$$

$$(1.495)(4181)(10) = (9178)\pi(0.025)L(150 - 60) \left(\frac{5}{9}\right)$$

$$L = 1.74 \text{ m}$$

6-98

$$h = \frac{k}{d} (0.023) \left(\frac{mxd}{ud^2\mu} \right)^{0.8} \text{Pr}^{0.4}$$

$$\text{Pr} \sim \text{const} = 0.7$$

$$h = ck\mu^{-0.8}$$

T (K)	k	$\mu \times 10^5$	$k\mu^{-0.8}$
300	0.02624	1.8462	161
400	0.03365	2.286	174
500	0.04038	2.671	184
800	0.05779	3.625	206

Comment:

h varies approximately as $[T(\text{K})]^{0.25}$ for constant mass flow.

Chapter 6

6-99

Helium—Same relation as Prob. 6-92

T (K)	k	$\mu \times 10^5$	$k\mu^{-0.8}$
255	0.1357	1.817	842
477	0.197	2.75	877
700	0.251	3.475	927

Comment:

h varies approximately as $[T(\text{K})]^{0.1}$ for constant mass flow, i.e., not strongly dependent on temperature.

6-100

$$d = 5 \text{ mm} \quad \bar{T}_b = 300 \text{ K}$$

$$\text{Re}_d = 50,000 \quad L = 50 \text{ mm} \quad \frac{L}{d} = \frac{50}{5} = 10 \quad \text{Pr} = 0.708$$

$$k = 0.02624 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\text{Nu} = 0.036 \text{Re}^{0.8} \text{Pr}^{1/3} \left(\frac{d}{L}\right)^{0.055} = (0.036)(50,000)^{0.8} (0.708)^{1/3} (0.1)^{0.055} = 162.4$$

$$\bar{h} = \frac{(162.4)(0.02624)}{0.005} = 852 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

6-101

$$\begin{array}{llll} \text{Water} & d = 5 \text{ mm} & L = 50 \text{ mm} & \text{Pe} = 1000 = \text{Re Pr} \\ T_w = 49^\circ\text{C} = \text{const} & & \bar{T}_b = 15.6^\circ\text{C} & \rho = 999 \quad c_p = 4186 \end{array}$$

$$k = 0.595 \quad \mu = 1.12 \times 10^{-3} \quad \text{Pr} = 7.88$$

$$\text{Gz} = \text{Re Pr} \frac{d}{L} = (1000) \left(\frac{5}{50}\right) = 100 \quad \text{Gz}^{-1} = 0.01 \quad \bar{\text{Nu}}_d = 7.35$$

$$\bar{h} = \frac{(7.35)(0.595)}{0.005} = 874 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \text{Re} = \frac{\text{Pe}}{\text{Pr}} = \frac{1000}{7.88} = 128.2 = \frac{dG}{\mu}$$

$$G = \frac{(128.2)(0.00112)}{0.005} = 28.7 \frac{\text{kg}}{\text{m}^2 \cdot \text{s}}$$

$$\dot{m} = \frac{(28.7)\pi(0.005)^2}{4} = 5.64 \times 10^{-4} \text{ kg/s}$$

$$q = \bar{h} \pi d L (T_w - \bar{T}_b) = \dot{m} c_p \Delta T_b$$

$$\Delta T_b = \frac{(874)\pi(0.005)(0.05)(49 - 15.6)}{(5.64 \times 10^{-4})(4186)} = 9.71^\circ\text{C}$$

6-102

$$\text{At } 300 \text{ K: } u_m = 7.5 \text{ m/s} \quad L = 30 \text{ m} \quad T_w = 325 \text{ K}$$

$$k = 0.02624 \quad \rho = 1.006 \quad \text{Pr} = 0.706 \quad c_p = 1006$$

$$\mu = 1.8462 \times 10^{-5}$$

$$30 \times 60 \text{ cm; } D_H = \frac{(4)(30)(60)}{(2)(30+60)} = 40 \text{ cm} = 0.4 \text{ m}$$

$$\text{Re}_{D_H} = \frac{(1.006)(0.4)(7.5)}{1.846 \times 10^{-5}} = 1.63 \times 10^5 \text{ (turbulent)}$$

$$\dot{m} = \rho u_m A = (1.006)(7.5)(0.3)(0.6) = 1.358 \text{ kg/s}$$

$$\text{Nu} = 0.023 \text{Re}^{0.8} \text{Pr}^{0.4} = (0.023)(1.63 \times 10^5)^{0.8} (0.706)^{0.4} = 296$$

$$\bar{h} = \frac{(296)(0.02624)}{0.4} = 19.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad q = \bar{h}A(T_w - \bar{T}_b) = \dot{m}c_p\Delta T_b$$

$$\Delta T_b = \frac{(19.4)(30)(2)(0.3+0.6)(325-300)}{(1.358)(1006)} = 19.2^\circ\text{C}$$

6-103

Glycerine at 10°C

$$L = 1 \text{ m}$$

1 × 8 cm duct

$$\text{Re} = 250$$

$$T_w = \text{const}$$

$$D_H = \frac{(4)(1)(8)}{2(1+8)} = 1.78 \text{ cm} \quad \text{Pr} = 31.0 \times 10^3 \quad k = 0.284 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\frac{L}{D_H} = 56.2$$

$$\text{Gz} = \text{Re Pr} \frac{d}{L} = (250)(31,000) \left(\frac{0.0178}{1} \right) = 1.38 \times 10^5$$

$$\text{Nu} = 3.66 + \frac{(0.0668)(1.38 \times 10^5)}{1 + 0.04(1.38 \times 10^5)^{2/3}} = 88.8$$

$$\bar{h} = \frac{(88.8)(0.284)}{0.0178} = 1417 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

6-104

Air $T_\infty = 300 \text{ K}$ $T_w = 600 \text{ K}$ $d = 6 \text{ mm}$ $L = 50 \text{ cm}$ $\text{Re} = 15,000$

$$T_f = \frac{300+600}{2} = 450 \text{ K} \quad \text{Pr} = 0.683 \quad k = 0.03707$$

$$\text{Nu} = C \text{Re}^n \text{Pr}^{1/3} \quad C = 0.228 \quad n = 0.731$$

$$\text{Nu} = (0.228)(15,000)^{0.731} (0.683)^{1/3} = 227$$

$$\bar{h} = \frac{(227)(0.03707)}{0.006} = 1401 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (1401)(2)(0.006)(0.5)(600 - 300) = 2521 \text{ W}$$

Chapter 6

6-105

$$C = 0.102 \quad n = 0.675$$
$$\text{Nu} = (0.102)(15,000)^{0.675}(0.683)^{1/3} = 59.2$$
$$\bar{h} = \frac{(59.2)(0.03707)}{0.006} = 366 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$
$$q = \bar{h}A(T_w - T_\infty) = (366)(4)(0.006)(0.5)(600 - 300) = 1316 \text{ W}$$

6-106

$$\bar{\text{Nu}} = 0.664 \text{Re}^{1/2} \text{Pr}^{1/3} = 0.664(15,000)^{1/2}(0.683)^{1/3} = 71.6$$
$$\bar{h} = \frac{(71.6)(0.03707)}{0.006} = 442 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$
$$q = \bar{h}A(T_w - T_\infty) = (442)(2)(0.006)(0.5)(600 - 300) = 796 \text{ W}$$

6-107

$$d = 6 \text{ mm} \quad \text{in-line tube bank}$$
$$L = 50 \text{ cm} \quad 20 \times 20 \text{ tubes}$$
$$S_n = S_d = 9 \text{ mm} \quad T_\infty \text{ enter at } 300 \text{ K}$$
$$R_{\text{max}} \text{ at inlet} = 50,000 \quad T_w = 400 \text{ K} \quad T_f = 350 \text{ K} \quad k = 0.03003$$
$$\text{Pr} = 0.697 \quad \rho = 0.998 \quad \mu = 2.075 \times 10^{-5} \quad c_p = 1009$$
$$\frac{S_p}{d} = \frac{S_n}{d} = \frac{9}{6} = 1.50 \quad C = 0.278 \quad n = 0.62$$
$$\text{Nu} = (0.278)(50,000)^{0.62}(0.697)^{1/3} = 201.9$$
$$\bar{h} = \frac{(201.9)(0.03003)}{0.006} = 1011 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$
$$\text{Re}_{\text{max}} = \frac{\rho u_{\text{max}} d}{\mu}$$
$$u_{\text{max}} = \frac{(50,000)(2.075 \times 10^{-5})}{(0.998)(0.006)} = 173 \text{ m/s}$$
$$u_\infty = \left(\frac{9-6}{9}\right)(173) = 57.7 \text{ m/s}$$

For 1-m depth, $\dot{m} = \rho u_\infty A = (0.998)(57.7)(20)(0.009) = 10.76 \text{ kg/s}$

$$\text{Tube area} = (400)\pi(0.006)(1) = 7.54 \text{ m}^2$$
$$q = \bar{h}A \left[T_w - \left(300 + \frac{\Delta T}{2} \right) \right] = (10.36)(1009)\Delta T$$
$$\Delta T = 53.4^\circ\text{C}$$

6-108

$$u_{\infty} = 57.7 \text{ m/s} \quad \text{from Prob. 6-107}$$

$$\text{Diagonal dimension} = \left[\left(\frac{9}{2} \right)^2 + 9^2 \right]^{1/2} - 6 = 4.06 \text{ mm}$$

Normal space is still minimum flow area so $Re_{\max} = 50,000$

For staggered arrangement $C = 0.511$ $n = 0.562$

$$Nu = (0.511)(50,000)^{0.562} (0.697)^{1/3} = 198$$

$$\bar{h} = \frac{(198)(0.03003)}{0.006} = 992$$

Mass flow is same as before so energy balance is

$$(992)(7.54) \left[400 - \left(300 + \frac{\Delta T}{2} \right) \right] = (10.36)(1009)\Delta T$$

$$\Delta T = 52.8^{\circ}\text{C}$$

6-109

Air $Pr = 0.7$ at 300 K

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \quad (a)$$

$$Nu = 0.021(Re^{0.8} - 100) Pr^{0.4} \quad (b)$$

$$Nu = 0.012(Re^{0.87} - 280) Pr^{0.4} \quad (c)$$

Re	Nu
50,000	114.5 (a)
50,000	102.8 (b)
50,000	124.5 (c)
100,000	199.4 (a)
100,000	180.3 (b)
100,000	230.0 (c)

Chapter 6

6-110

Water Pr = 6.78 at 21°C

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \quad (a)$$

$$Nu = 0.021(Re^{0.8} - 100) Pr^{0.4} \quad (b)$$

$$Nu = 0.012(Re^{0.87} - 280) Pr^{0.4} \quad (c)$$

Re	Nu
50,000	284.0 (a)
50,000	254.9 (b)
50,000	308.8 (c)
100,000	494.5 (a)
100,000	447.1 (b)
100,000	570.4 (c)

6-111

$T_f = 350$ K Pr = 0.697

$$Nu = 0.0266 Re^{0.805} Pr^{1/3} \quad (a)$$

$$Nu = 0.3 + \frac{0.62 Re^{1/2} Pr^{1/3}}{\left[1 + \left(\frac{0.4}{Pr}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re}{282,000}\right)^{5/8}\right]^{4/5} \quad (b)$$

$$Nu = 0.3 + \frac{0.62 Re^{1/2} Pr^{1/3}}{\left[1 + \left(\frac{0.4}{Pr}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re}{282,000}\right)^{1/2}\right] \quad (c)$$

$$Nu = (0.4 Re^{0.5} + 0.06 Re^{2/3}) Pr_{\infty}^{0.4} \left(\frac{\mu_{\infty}}{\mu_w}\right)^{1/4} \quad (d)$$

Calculated values of Nu

Equation	Re = 50,000	Re = 100,000
a	143	249.8
b	136.5	213.8
c	153.5	243.6
d	141.5	211.1

Agreement within $\pm 7\%$

6-112

water $Pr_f = 5.842$ $Pr_\infty = 6.772$ $\mu_\infty = 9.789 \times 10^{-4}$

$$\mu_w = 7.629 \times 10^{-4}$$

Same equations as Problem 6-107

Calculated values of Nu

Equation	Re = 50,000	Re = 100,000
a	290.4	507.4
b	303.7	475.9
c	341.6	542.3
d	390.9	585.0

Agreement within $\pm 12\%$

6-113

0.5 × 0.5 m plate $L = 0.5$ $T_f = 42.5^\circ\text{C} = 315.5 \text{ K}$ $\rho = 1.12$

$k = 0.028$ $\mu = 1.91 \times 10^{-5}$ $Pr = 0.7$ $q = 850 \text{ W}$

$$q_w = \frac{850}{0.5^2} = 3400 \text{ W/m}^2 = \frac{3}{2} h_{x=L} (T_w - T_\infty)$$

$$h_{x=L} = \frac{(3400)(2)}{(3)(65 - 20)} = 50.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$Nu = \frac{hx}{k} = \frac{(50.4)(0.5)}{0.028} = 900$$

For $Re = 5 \times 10^5$ max Nu will be $Nu = 0.453(5 \times 10^5)^{1/2}(0.7)^{1/3} = 284$
so turbulent flow must be used and would be about same (+4%) as for const wall temperature

$$Nu = Pr^{1/3}(0.037 Re_L^{0.8} - 871) = 900, \text{ and } Re_L = 7.65 \times 10^5 = \frac{\rho u_\infty L}{\mu}$$

$$u_\infty = \frac{(7.65 \times 10^5)(1.91 \times 10^{-5})}{(1.12)(0.5)} = 26.1 \text{ m/s}$$

Radiation $T_w = 338 \text{ K}$ $T_\infty = 293 \text{ K}$

$$\frac{q}{A} = \sigma \epsilon (T_w^4 - T_\infty^4) = (5.668 \times 10^{-8})(1.0)(338^4 - 293^4) = 322 \text{ W/m}^2$$

$$q_{\text{conv}} = 3400 - 322 = 3078 \text{ W/m}^2$$

$$\text{Required } Nu = (900) \left(\frac{3078}{3400} \right) = 815 = (0.7)^{1/3} (0.037 Re_L^{0.8} - 871)$$

$$Re_L = 7.17 \times 10^5 = \frac{\rho u_\infty L}{\mu} \quad u_\infty = \frac{(7.17 \times 10^5)(1.91 \times 10^{-5})}{(1.12)(0.5)} = 24.5 \text{ m/s}$$

Chapter 6

6-114

Gas at 700 K $\rho = 0.503 \text{ kg/m}^3$ $\mu = 3.332 \times 10^{-5}$ Pr = 0.684

$k = 0.0523$ $Re = \frac{(0.025)(0.8)(4)}{\pi(0.025)^2(3.332 \times 10^{-5})} = 1.22 \times 10^6$

$h_g = \frac{(0.0523)(0.023)}{0.025} = (1.22 \times 10^6)^{0.8} (0.684)^{0.3} = 3176 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$

Water at 150°C = 423 K $\mu = 1.86 \times 10^{-4}$ $\rho = 918$ $k = 0.684$

Pr = 1.17 $D_H = 5 - 2.5 - 2(0.16) = 2.18 \text{ cm}$

$Re = \frac{(4)(1.5)}{\pi(0.05 + 0.0282)(1.86 \times 10^{-4})} = 1.313 \times 10^5$

$h_w = \frac{(0.684)(0.023)}{0.0218} (1.313 \times 10^5)^{0.8} (1.17)^{0.4} = 9555 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$

Neglect conduction resistance $q = 17.5 \text{ kW}$

$175,000 = \frac{700 - 423}{\frac{1}{h_g A_i} + \frac{1}{h_w A_o}} = \frac{(700 - 423)L}{\frac{1}{(3176)\pi(0.025)} + \frac{1}{(9555)\pi(0.0282)}}$

$L = 0.328 \text{ m}$

6-118

$\frac{\bar{h}d}{k} = \text{const} \left(\frac{\rho u_m d}{\mu} \right)^{0.8} \text{Pr}^{0.4}$

For constant mass flow and diameter

$\rho u_m = \text{const}$

For air as ideal gas Pr ~ const which implies $\mu \sim k$
over modest temperature range

$\mu \sim T^a$

$a = \text{const}$, $T = \text{abs. temp.}$

Thus, $\bar{h} = \text{const} \times T^a \left(\frac{1}{T^a} \right)^{0.8} = \text{const} \times T^{0.2a}$

For air at 300 K, $a = 0.74$ and $\bar{h} \sim \text{const} \times T^{0.148}$ or modest variation with temperature

6-119

One must recognize that significant amounts of energy are transmitted by radiation. For the radiation calculation assume that Eq. (1-12) is applicable and that the food has $\epsilon = 1.0$. The area for radiation transfer is the surface area of the food, the same as for convection. Although there are times when the radiant heaters in the oven are substantially above the control temperature for the oven, a reasonable assumption for the radiation temperature of the oven is probably at the control temperature because that is the temperature maintained by the walls which have the large area for radiation. A simple geometry to consider would be that of a sphere having the same mass as the turkey, for that part of the problem. For cooking pies or other "flat" objects some other assumption must be made. To make an assumption for the flow velocity, one might visit the oven display section of a local appliance store. In performing an analysis it is prudent to consider only a steady state operation of the oven, after it has reached the set point temperature.

Chapter 7

7-3

Show that $\beta = \frac{1}{T}$ for an ideal gas.

$$\beta = \frac{1}{V} \left(\frac{\partial V}{\partial T} \right)_p \quad pV = nRT \quad V = \frac{nRT}{p} \quad \left(\frac{\partial V}{\partial T} \right)_p = \frac{nR}{p}$$

$$\therefore \beta = \frac{1}{\frac{nRT}{p}} \left(\frac{nR}{p} \right) = \frac{1}{T}$$

7-4

$$T_f = 40^\circ\text{C} = 313 \text{ K} \quad \rho = 1.128 \quad L = 0.3048 \text{ m}$$

$$\mu = 1.906 \times 10^{-5} \quad \text{Pr} = 0.905 \quad \rho = 1.13 \quad k = 0.027$$

$$\beta = 0.00319 \quad \text{Gr} = 1.558 \times 10^8$$

$$\delta = L[0.393 \text{Pr}^{-1/2} (0.952 + \text{Pr})^{1/4} \text{Gr}^{-1/4}] = 0.014 \text{ m}$$

$$u = u_{\max} \text{ at } \frac{y}{\delta} = \frac{1}{3} = \frac{4}{27} u_x = 0.722 \text{ m/s}$$

$$\text{Nu} = 0.508 \text{Pr}^{1/2} (0.952 + \text{Pr})^{-1/4} \text{Gr}^{1/4} = 42.0$$

$$\bar{h} = \frac{4}{3} \text{Nu} \frac{k}{L} = 5.0 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad (\text{Free convection})$$

Forced Convection

$$\text{Re}_L = \frac{\rho u_{\max} L}{\mu} = 13,000 \quad \text{Laminar}$$

$$\bar{h} = 0.664 \text{Re}_L^{1/2} \text{Pr}^{1/3} \left(\frac{k}{L} \right) = 6.03 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{\bar{h} (\text{Forced})}{\bar{h} (\text{Free})} = \frac{6.03}{5.0} = 1.206$$

Conclusion

Heat transfer is strongly influenced by velocity of fluid over the heated surface

7-5

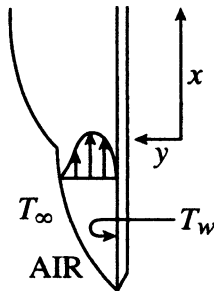
$$T_f = 325 \text{ K}, \quad \text{Pr} = 0.7; \quad v = 18.2 \times 10^{-6}; \quad \delta = 0.02 \text{ m}$$

$$\text{Gr}_x = (9.8)(1/3250950)x^3 / (18.2 \times 10^{-6})^2 = 4.455 \times 10^9 x^3$$

$$\text{Eq. (7-20a):} \quad 0.02 = (4.55 \times 10^9)^{-1/4} (3.93)(0.7)^{-1/2} (0.952 + 0.7)^{1/4} x^{1/4}$$

$$x = 0.9 \text{ m}$$

7-6



$$\frac{u}{u_x} = \left(\frac{y}{\delta}\right)\left(1 - \frac{y}{\delta}\right)^2$$

$$\frac{du}{dy} = u_x \left[\frac{y}{\delta} \left(-\frac{2}{\delta}\right) \left(1 - \frac{y}{\delta}\right) + \frac{1}{\delta} \left(1 - \frac{y}{\delta}\right)^2 \right] = 0$$

$$y = \frac{\frac{4}{\delta} \pm \sqrt{\left(\frac{16}{\delta^2}\right) - 4\left(\frac{3}{\delta^2}\right)}}{\frac{6}{\delta^2}}$$

$$y = \delta \quad y = \frac{\delta}{3} \quad \text{max } u \text{ occurs at } \frac{\delta}{3}$$

$$u_{\max} = u_x \left(\frac{y}{3y}\right) \left(1 - \frac{y}{3y}\right)^2 = \frac{4}{27} u_x = \frac{4}{27} C_1 x^m$$

7-7

Spacing $\sim 2\delta$

$$\frac{\delta}{L} = 3.93 \text{Pr}^{-1/2} (0.952 + \text{Pr})^{1/4} \text{Gr}_L^{-1/4}$$

$$T_f = \frac{65 + 25}{2} = 45^\circ\text{C} \quad L = 0.3 \text{ m} \quad \text{Pr} = 3.9$$

$$\text{Gr}_L = \frac{(4.5 \times 10^{10})(0.3)^3(65 - 25)}{3.9} = 1.25 \times 10^{10}$$

Outside of laminar range but use above equation for estimate of B.L. thickness

$$\delta = 0.3 \left(\frac{3.93}{3.9^{1/2}}\right) (0.952 + 3.9)^{1/4} (1.25 \times 10^{10})^{-1/4} = 0.0026 \text{ m}$$

Spacing should be at least 1 cm.

Chapter 7

7-8

$$T_f = 100^\circ\text{F} \quad k = 0.63$$

$$\text{Gr}_d \text{Pr} = (3.3 \times 10^{10})(0.02)^3(130 - 70)\left(\frac{5}{9}\right) = 8.8 \times 10^6$$

$$\text{Nu} = C(\text{Gr Pr})^n \quad C = 0.53 \quad n = \frac{1}{4}$$

$$h = \frac{(0.53)(8.8 \times 10^6)^{1/4}}{0.02} = 909 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = \bar{h} \pi d (T_w - T_\infty) = (909)\pi(0.02)(130 - 70)\left(\frac{5}{9}\right) = 1904 \text{ W/m}$$

7-9

$$L = 30 \text{ cm} \quad T_f = 57.5^\circ\text{C} = 330.5 \text{ K} \quad \nu = 19.23 \times 10^{-6}$$

$$\text{Gr}_L = \frac{(9.8)\left(\frac{1}{330.5}\right)(100 - 15)(0.3)^3}{19.23 \times 10^{-6}} = 1.84 \times 10^8$$

$$D = \frac{(0.3)(35)}{(1.84 \times 10^8)^{1/4}} = 9.01 \times 10^{-2} \text{ m} = 9.01 \text{ cm}$$

7-10

$$T_f = \frac{300 + 25}{2} = 162.5^\circ\text{C} = 436 \text{ K} \quad \nu = 30.1 \times 10^{-6} \quad k = 0.036$$

$$\text{Pr} = 0.68 \quad \text{Gr Pr} = \frac{(9.8)\left(\frac{1}{436}\right)(300 - 25)(1)^3(0.68)}{(30.1 \times 10^{-6})^2} = 4.64 \times 10^9$$

$$h = \frac{0.036}{1}(0.1)(4.64 \times 10^9)^{1/3} = 6.0 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - T_\infty) = (6.0)(1)^2(300 - 25) = 1650 \text{ W}$$

7-11

$$\delta \sim x^{1/4} \quad \frac{\delta_{24}}{\delta_{14}} = \left(\frac{24}{14}\right)^{1/4} \quad \delta_{24} = (1.0)\left(\frac{24}{14}\right)^{1/4} = 1.14 \text{ in.}$$

7-12

$$H = 0.2; W = 3.0 \quad T_f = 60^\circ\text{C} = 333 \text{ K}$$

$$\nu = 23.3 \times 10^{-6}; \text{Pr} = 0.7; k = 0.028; \rho = 1.06$$

$$\text{Gr}_x = 3.47 \times 10^7; \text{Eq. (7-20a)} \quad \delta = 0.0139$$

$$\text{Eq. (7-20b); } u_x = 2.74 \text{ m/s}$$

$$u_{\max} = (0.148)(2.74) = 0.41 \text{ m/s}$$

$$\dot{m} = (9/16)(1.06)(0.41)(0.0139) = 0.0034 \text{ kg/s}$$

$$\text{GrPr} = 2.43 \times 10^7; h = (0.028)(0.59/0.2)(2.43 \times 10^7)^{1/4} = 5.8$$

$$q = (6.8)((0.2)(3.0)(100 - 20)) = 278 \text{ W}$$

7-13

$$T_f = 300 \text{ K}; H = 0.1; W = 2.0; k = 0.61; \text{Pr} = 5.85; \rho = 996$$

$$\Delta T = 20^\circ\text{C}; \text{GrPr} = (1.91 \times 10^{10})(0.1)^3(20) = 3.82 \times 10^8$$

$$\text{Gr}_x = 6.53 \times 10^7$$

$$h = (0.61/0.1)(0.59)(3.82 \times 10^8)^{1/4} = 503$$

$$q = (503)(0.1)(1.0)(20) = 1006 \text{ W}$$

$$\text{Eq. (7-20a); } \delta = 0.00292 \text{ m}$$

$$\text{Eq. (7-20b); } \nu = 8.63 \times 10^{-7}$$

$$u_{\max} = (0.148)(8.63 \times 10^{-7}/0.1)(5.17)(0.952 + 5.85)^{-1/2}(6.53 \times 10^7)^{1/2}$$

$$= 0.02 \text{ m/s}$$

$$\dot{m} = (9/16)((996)(0.02)(0.00292)) = 0.0033 \text{ kg/s}$$

7-14

$$T_f = \frac{93 + 30}{2} = 61.5^\circ\text{C} = 334.5 \text{ K} \quad \beta = \frac{1}{334.5} = 2.99 \times 10^{-3}$$

$$\nu = 19.19 \times 10^{-6} \quad k = 0.0289 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.806)(2.99 \times 10^{-3})(93 - 30)(1.8)^3}{(19.19 \times 10^{-6})^2} (0.7) = 2.05 \times 10^{10}$$

$$h = \frac{0.0289}{1.8} (0.1)(2.05 \times 10^{10})^{1/3} = 4.394 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (4.394)\pi(0.075)(1.8)(93 - 30) = 117.4 \text{ W}$$

7-15

$$\frac{q}{A} = 1100 - 95 = 1005 \text{ W/m}^2 \text{ at } 300 \text{ K} \quad \beta = 3.33 \times 10^{-3}$$

$$\nu = 15.68 \times 10^{-6} \quad \text{Pr} = 0.7 \quad k = 0.02624$$

$$\text{Gr}^* = \frac{(9.806)(3.33 \times 10^{-3})(1005)(6)^4}{(15.68 \times 10^{-6})^2 (0.02624)} = 6.59 \times 10^{15}$$

$$h = \frac{0.02624}{6} (0.17)(6.59 \times 10^{15})^{1/3} = 6.7 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\Delta T = \frac{1005}{6.7} = 150^\circ\text{C} \quad T_{\text{wall}} \approx 150 + 20 = 170^\circ\text{C}$$

This does not take into account radiation which would lower the temperature substantially.

7-16

$$\Delta T = 24 - 20 = 4^\circ\text{C} \quad h = (0.95)(4)^{1/3} = 1.508 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (1.508)\pi(0.3)(2.0)(4.0) = 11.3 \text{ W}$$

Chapter 7

7-17

$$q_w = \frac{20}{(0.3)^2} = 222.2 \text{ W/m}^2 \quad \text{Take properties at 300 K}$$

$$k = 0.02624 \quad \beta = 3.33 \times 10^{-3} \quad \nu = 15.68 \times 10^{-6} \quad \text{Pr} = 0.71$$

$$\text{Gr}^* = \frac{(9.806)(3.33 \times 10^{-3})(222.2)(0.15)^4}{(0.02624)(15.68 \times 10^{-6})^2} = 5.694 \times 10^8 \text{ at 15 cm}$$

$$\text{Gr}^* = 9.11 \times 10^9 \text{ at 30 cm}$$

$$\text{at 15 cm} \quad h = \frac{0.02624}{0.15} (0.6)[(5.694 \times 10^8)(0.7)]^{1/5} = 5.51 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{at 30 cm} \quad h = \frac{0.02624}{0.3} (0.6)[(9.11 \times 10^9)(0.7)]^{1/5} = 4.796 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\bar{h} = \frac{5}{4} h_{x=L} = (1.25)(4.796) = 6.0 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

7-18

$$L = 0.3 \quad T_w = 55^\circ\text{C} \quad T_\infty = 20^\circ\text{C} \quad T_f = 37.5^\circ\text{C} = 310.5 \text{ K}$$

$$\nu = 16.7 \times 10^{-6} \quad k = 0.027 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{310.5}\right)(55 - 20)(0.3)^3(0.7)}{(16.7 \times 10^{-6})^2} = 7.48 \times 10^7$$

$$C = 0.59 \quad m = \frac{1}{4}$$

$$\bar{h} = \frac{0.027}{0.3} (0.59)(7.48 \times 10^7)^{1/4} = 4.94 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = 2hA(T_w - T_\infty) = (2)(4.94)(0.3)^2(55 - 20) = 31.1 \text{ W}$$

7-19

$$T_f = \frac{100 + 20}{2} = 60^\circ\text{C} = 333 \text{ K} \quad \mu = 2.16 \times 10^{-7}$$

$$\rho = \frac{(2)(1.01 \times 10^5)}{(333)(2078)} = 0.293 \text{ kg/m}^3 \quad k = 0.159 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{333}\right)(0.293)^2(100 - 20)(0.61)^3(0.7)}{(2.16 \times 10^{-7})^2} = 6.87 \times 10^7$$

$$h = \frac{(0.159)(0.59)(6.87 \times 10^7)^{1/4}}{0.61} = 14 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - T_\infty) = (14)(0.61)^2(100 - 20) = 417 \text{ W}$$

7-20

$$T_f = \frac{57 + 4}{2} = 30.5^\circ\text{C} = 303.5 \text{ K} \quad \nu = 16.1 \times 10^{-6}$$

$$k = 0.0265 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{303.5}\right)(57 - 4)(6.1)^3(0.7)}{(16.1 \times 10^{-6})^2} = 1.04 \times 10^{12}$$

$$\overline{\text{Nu}}^{1/2} = 0.825 + \frac{0.387 \text{Ra}^{1/4}}{\left[1 + \left(\frac{0.492}{\text{Pr}}\right)^{9/16}\right]^{8/27}} = 33.44$$

$$\text{Nu} = 1118 \quad h = \frac{(1118)(0.0265)}{6.1} = 4.86 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - T_\infty) = (4.86)(6.1)(1.22)(57 - 4) = 1907 \text{ W}$$

$$\text{Using } C = 0.1 \text{ and } m = \frac{1}{3}$$

$$\text{Nu} = 0.1(1.04 \times 10^{12})^{1/3} = 1012 \quad 9.5\% \text{ lower}$$

7-21

$$T_f = \frac{49 + 21}{2} = 35^\circ\text{C} = 308 \text{ K} \quad \nu = 16.5 \times 10^{-6} \quad k = 0.0268$$

$$\text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{308}\right)(49 - 21)(1)^3(0.7)}{(16.5 \times 10^{-6})^2} = 2.27 \times 10^9$$

$$\overline{\text{Nu}}^{1/2} = 0.825 + \frac{0.387 \text{Ra}^{1/4}}{\left[1 + \left(\frac{0.492}{\text{Pr}}\right)^{9/16}\right]^{8/27}} = 12.59 \quad \overline{\text{Nu}} = 158.1$$

$$h = \frac{(158.1)(0.0268)}{1} = 4.24 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - T_\infty) = (4.24)(1)^2(49 - 21) = 118 \text{ W}$$

$$\text{Using } C = 0.1 \text{ and } m = \frac{1}{3}$$

$$\text{Nu} = (0.1)(2.27 \times 10^9)^{1/3} = 131 \quad 17\% \text{ lower}$$

7-22

Take properties at 300 K

$$\nu = 15.69 \times 10^{-6} \quad k = 0.02624 \quad \text{Pr} = 0.7$$

$$10^{12} = \frac{(9.8)\left(\frac{1}{300}\right)(10)L^3(0.7)}{(15.69 \times 10^{-6})^2}$$

$$L = 10.35 \text{ m}$$

Chapter 7

7-23

Take properties at 15.56°C $k = 0.595$ $\frac{g\beta\rho^2 c_p}{\mu k} = 1.08 \times 10^{10}$

$$Gr^* Pr = \frac{(1.08 \times 10^{10})(1000)(0.25)^4}{0.595} = 7.09 \times 10^{10}$$

$$h_x = \frac{0.595}{0.25}(0.6)(7.09 \times 10^{10})^{1/5} = 211$$

$$\bar{h} = 1.25h_x = 264 \frac{W}{m^2 \cdot ^\circ C}$$

$$\overline{\Delta T} = \frac{q_w}{\bar{h}} = \frac{1000}{264} = 3.79^\circ C$$

$$\bar{T}_w = 3.79 + 15 = 18.79^\circ C \quad \text{it is very nearly isothermal.}$$

7-24

cylinder: $h = 1.32 \left(\frac{\Delta T}{d} \right)^{1/4}$

Vert. plate: $h = 1.42 \left(\frac{\Delta T}{L} \right)^{1/4}$

$\frac{1}{2}$ cyl: $q = \frac{1}{2}(1.32) \left(\frac{\Delta T}{d} \right)^{1/4} \pi d \Delta T = 2.073 d^{3/4} \Delta T^{5/4}$

Plate: $q = (1.42) \left(\frac{\Delta T}{L} \right)^{1/4} \frac{\pi d}{2} \Delta T = 1.992 d^{3/4} \Delta T^{5/4}$

Very close

7-25

$$T_f = \frac{200 + 120}{2} = 160^\circ\text{C} \quad \text{NaK, 22\% Na}$$

$$k = 24.4 \quad \text{Pr} = 0.019 \quad d = 0.02 \text{ m} \quad \mu = 0.4 \times 10^{-3} \quad L = 0.4 \text{ m}$$

$$\rho = 830$$

$$\beta \approx 690 \left(\frac{\frac{1}{690} - \frac{1}{830}}{760 - 93} \right) = 2.5 \times 10^{-4}$$

$$\text{Gr}_d \text{Pr} = \frac{(9.8)(2.5 \times 10^{-4})(830)^2(200 - 120)(0.02)^3(0.019)}{(0.4 \times 10^{-3})^2} = 1.28 \times 10^5$$

$$\text{Nu} = 0.36 + \frac{0.518(\text{GrPr})^{1/4}}{\left[1 + \left(\frac{0.559}{\text{Pr}} \right)^{9/16} \right]^{4/9}} = 0.36 + \frac{0.518(1.28 \times 10^5)^{1/4}}{\left[1 + \left(\frac{0.559}{0.019} \right)^{9/16} \right]^{4/9}} = 4.31$$

$$\bar{h} = \frac{(4.31)(24.4)}{0.02} = 5264 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (5264)\pi(0.02)(0.4)(200 - 120) = 10,580 \text{ W}$$

7-26

$$T_f = 299\text{K}; \quad L = 0.15; \quad W = 0.5; \quad p = 2.2 \text{ atm}; \quad \rho = 0.36$$

$$v = 128 \times 10^{-6} / 2.2 = 58 \times 10^{-6}; \quad k = 0.149; \quad \text{Pr} = 0.7; \quad \Delta T = 52^\circ\text{C}$$

$$\text{Gr} = (9.8)(1/299)(52)(0.15)^3 / (58 \times 10^{-6})^2 = 1 \times 10^6$$

$$\text{GrPr} = 7 \times 10^5$$

$$h = (0.149/0.15)(0.59)(7 \times 10^5)^{1/4} = 17$$

$$q = (17)(0.15)(0.5)(52) = 66.2 \text{ W}$$

$$\text{Eq. (7-20b); } u_{\max} = (58 \times 10^{-6} / 0.15)(0.148)(0.952 + 0.7)^{-1/2}(10^6)^{1/2} \quad (5.17)$$

$$= 0.23 \text{ m/s}$$

$$\text{Eq. (7-20a); } \delta = (0.15)(3.93)(0.7)^{-1/2}(0.952 + 0.7)^{1/4}(10^6)^{-1/4}$$

$$= 0.025 \text{ m}$$

$$\dot{m} = (9/16)(0.23)(0.025)(0.36) = 0.0016 \text{ kg/s}$$

7-27

$$T_f = \frac{70 + 20}{2} = 45^\circ\text{C} = 318 \text{ K} \quad \nu = 0.335 \times 10^{-6} \quad k = 0.485$$

$$\text{Pr} = 2.0 \quad \beta = 2.45 \times 10^{-3}$$

$$\text{Gr Pr} = \frac{(9.8)(2.45 \times 10^{-3})(70 - 20)(0.03)^3(2)}{(0.335 \times 10^{-6})^2} = 5.78 \times 10^8$$

$$C = 0.53 \quad m = \frac{1}{4}$$

$$h = \frac{0.485}{0.03} (0.53)(5.78 \times 10^8)^{1/4} = 1328 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = h\pi dL(T_w - T_\infty) = (1328)\pi(0.03)(1)(70 - 20) = 6260 \text{ W}$$

7-28

$$h = (1.32) \left(\frac{120 - 20}{0.075} \right)^{1/4} = 7.98 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = 29,300 \text{ W} = 7.98\pi(0.075)L(120 - 20)$$

$$L = 155.9 \text{ m}$$

Chapter 7

7-29

$$T_f = \frac{93 + 38}{2} = 65.5^\circ\text{C} \quad k = 0.659$$

$$\text{Gr Pr} = (7.62 \times 10^{10})(93 - 38)(0.0004)^3 = 268.2$$

$$\text{From Fig. 7-8} \quad \log \text{Nu} = 0.41 \quad \text{Nu} = 2.57$$

$$h = \frac{(2.57)(0.659)}{0.0004} = 4235 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (4235)\pi(0.0004)(0.1)(93 - 38) = 29.27 \text{ W}$$

7-30

Laminar:

$$h = 1.32 \left(\frac{85 - 20}{0.03} \right)^{1/4} = 9.006 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (9.006)\pi(0.03)(15)(85 - 20) = 827.6 \text{ W}$$

7-31

$$T_f = \frac{140 + 25}{2} = 82.5^\circ\text{C} = 356 \text{ K} \quad \nu = 2.54 \times 10^{-6} \quad k = 0.031$$

$$\text{Pr} = 0.697$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{356} \right) (140 - 25)(0.08)^3 (0.697)}{(21.1 \times 10^{-6})^2} = 2.54 \times 10^6$$

$$C = 0.53 \quad m = \frac{1}{4}$$

$$h = \frac{0.031}{0.08} (0.53)(2.54 \times 10^6)^{1/4} = 8.2 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d(T_w - T_\infty) = (8.2)\pi(0.08)(140 - 25) = 237 \text{ W/m}$$

7-32

$$h = 1.32 \left(\frac{250 - 20}{0.0125} \right)^{1/4} = 15.38 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (15.38)\pi(0.0125)(250 - 20) = 138.9 \text{ W/m}$$

7-33

$$T_f = \frac{150 + 93}{2} = 121.5^\circ\text{C} \quad \nu = 0.124 \times 10^{-4} \quad k = 0.135 \quad \text{Pr} = 175$$

$$\beta = 0.7 \times 10^{-3} \quad \text{Gr Pr} = \frac{(9.8)(0.7 \times 10^{-3})(150 - 93)(0.025)^3}{(0.124 \times 10^{-4})^2} = 6.96 \times 10^6$$

$$h = \frac{0.135}{0.025} (0.53)(6.96 \times 10^6)^{1/4} = 147 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (147)\pi(0.025)(150 - 93) = 658 \text{ W/m} = 200.6 \text{ W/ft}$$

7-34

$$0.3 \text{ m square duct} \quad T_w = 15.6^\circ\text{C} \quad T_\infty = 27^\circ\text{C} \quad \Delta T = 11.4^\circ\text{C}$$

$$\text{Bottom} \quad h = 1.32 \left(\frac{\Delta T}{L} \right)^{1/4} = (1.32) \left(\frac{11.4}{0.3} \right)^{1/4} = 3.28 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{Sides} \quad h = 1.42 \left(\frac{\Delta T}{L} \right)^{1/4} = (1.42) \left(\frac{11.4}{0.3} \right)^{1/4} = 3.53 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{Top} \quad h = 0.59 \left(\frac{\Delta T}{L} \right)^{1/4} = (0.59) \left(\frac{11.4}{0.3} \right)^{1/4} = 1.46 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \sum hA\Delta T = (0.3)(1)(11.4)[3.28 + (2)(3.53) + 1.46] = 40.4 \text{ W/m} \cdot \text{length}$$

7-35

$$T_f = \frac{240 + 10}{2} = 125^\circ\text{C} = 398 \text{ K} \quad \nu = 6.76 \times 10^{-5} \quad k = 0.178$$

$$\text{Pr} = 0.71$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{398} \right) (240 - 10) (2.54 \times 10^{-5})^3}{(6.76 \times 10^{-5})^2} (0.71) = 1.42 \times 10^{-5}$$

$$\text{Nu} = 0.36 + \frac{(0.518)(1.42 \times 10^{-5})^{1/4}}{\left[1 + \left(\frac{0.559}{0.7} \right)^{9/16} \right]^{4/9}} = 0.384$$

$$h = \frac{(0.384)(0.178)}{2.54 \times 10^{-5}} = 2691$$

$$\frac{q}{L} = (2691)\pi(2.54 \times 10^{-5})(240 - 10) = 49.4 \text{ W/m}$$

Chapter 7

7-36

He at 1 atm $L = 2$ m $d = 0.1$ m
 $T_w = 93^\circ\text{C} = 366$ K $T_\infty = -18^\circ\text{C} = 255$ K $T_f = 310.5$ K

$\nu = 134.6 \times 10^{-6}$ m²/s $k = 0.1524$ $\frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$ $\text{Pr} = 0.7$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{310.5}\right)(366 - 255)(0.1)^3(0.7)}{(134.6 \times 10^{-6})^2} = 1.356 \times 10^5$$

$C = 0.53$ $m = \frac{1}{4}$

$$\bar{h} = \frac{0.1524}{0.1} (0.53)(1.356 \times 10^5)^{1/4} = 15.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (15.5)\pi(0.1)(2)(366 - 255) = 1081 \text{ W}$$

7-37

$T_f = 135^\circ\text{C} = 408$ K $\nu = 26.83 \times 10^{-6}$ $k = 0.0342$ $\text{Pr} = 0.688$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{408}\right)(250 - 20)(3)^3(0.688)}{(26.83 \times 10^{-6})^2} = 1.43 \times 10^{11}$$

$$\text{Nu}^{1/2} = 0.6 + 0.387 \left\{ \frac{1.43 \times 10^{11}}{\left[1 + \left(\frac{0.559}{0.688}\right)^{9/16}\right]^{16/9}} \right\}^{1/6} = 23.78$$

$\text{Nu} = 565.3$ $h = \frac{(565.3)(0.0342)}{3.0} = 6.44$

$$\frac{q}{L} = (6.44)\pi(3.0)(250 - 20) = 13.97 \text{ kW/m}$$

7-38

$T_f = 40^\circ\text{C} = 313$ K $\nu = 0.00022$ $k = 0.286$

$\beta = 0.5 \times 10^{-3}$ $\text{Pr} = 2.45$

$$\text{Gr Pr} = \frac{(9.8)(0.5 \times 10^{-3})(60 - 20)(0.02)^3}{(0.00022)^2} (2.45) = 79.37$$

$$\text{Nu} = 0.36 + \frac{(0.518)(79.37)^{1/4}}{\left[1 + \left(\frac{0.559}{2.45}\right)^{9/16}\right]^{4/9}} = 1.677$$

$h = \frac{(1.677)(0.286)}{0.02} = 23.98$

$$q = (23.98)\pi(0.02)(0.6)(60 - 20) = 36.15 \text{ W}$$

7-39

$$\frac{q}{A} = 1500 \text{ W/m}^2 \quad \beta = \frac{1}{293} \quad \frac{q}{L} = (1500)\pi(0.035) = 165 \text{ W/m}$$

Properties at 350 K $\Delta T \approx 100^\circ\text{C}$ $\nu = 20.76 \times 10^{-6}$ $k = 0.03003$
 $\text{Pr} = 0.7$ $\theta = 65^\circ$ Take $L = 1 \text{ m}$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{293}\right)(100)(1.0)^3}{(20.76 \times 10^{-6})^2} (0.7) = 5.4 \times 10^9$$

$$\frac{1}{4} + \frac{1}{12} (\sin \theta)^{1.75} = 0.32$$

$$\text{Nu}_L = [0.6 - (0.488)(\sin 65^\circ)^{1.03}] (5.4 \times 10^9)^{0.32} = 206.9$$

$$h = \frac{(206.9)(0.03003)}{1} = 6.21 \quad h \text{ is insensitive to } L \text{ because of } 0.32 \text{ exponent.}$$

$$\Delta T = \frac{1500}{6.21} = 242^\circ\text{C}$$

With properties at 400 K and $\Delta T = 242$

$$\nu = 25.9 \times 10^{-6} \quad k = 0.03365 \quad \text{Nu}_L = 237.6$$

$$\text{Gr Pr} = 8.32 \times 10^9 \quad h = 8.0 \quad \Delta T = \frac{1500}{8} = 187.5^\circ\text{C}$$

$$T_w = 20 + 187.5 = 207.5^\circ\text{C} = 480.5 \text{ K}$$

$$T_f = 386 \text{ K} \quad \text{close enough}$$

7-40

$$T_f = \frac{25 + 20}{2} = 22.5^\circ\text{C} = 295.5 \text{ K} \quad \nu = 15.3 \times 10^{-6} \quad k = 0.0259$$

$$\text{Pr} = 0.7 \quad \text{Gr Pr} = \frac{(9.8)\left(\frac{1}{295.5}\right)(25 - 20)(0.3)^3(0.7)}{(15.3 \times 10^{-6})^2} = 1.34 \times 10^7$$

$$C = 0.53 \quad m = \frac{1}{4}$$

$$h = \frac{0.0259}{0.3} (0.53)(1.34 \times 10^7)^{1/4} = 2.77 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d(T_w - T_\infty) = (2.77)\pi(0.3)(25 - 20) = 13.04 \text{ W/m}$$

Chapter 7

7-41

$$T_f = \frac{260 + 20}{2} = 140^\circ\text{C} = 413 \text{ K} \quad d = 0.125 \text{ m} \quad \nu = 27.2 \times 10^{-6}$$

$$k = 0.035 \quad \text{Pr} = 0.687$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{413}\right)(260 - 20)(0.125)^3(0.687)}{(27.2 \times 10^{-6})^2} = 1.03 \times 10^7$$

$$C = 0.53 \quad m = \frac{1}{4}$$

$$\bar{h} = \frac{0.035}{0.125} (0.53)(1.03 \times 10^7)^{1/4} = 8.41 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = 37,000 \text{ W} = (8.71)\pi(0.125)L(260 - 20)$$

$$L = 46.7 \text{ m}$$

There will also be substantial radiation heating.

7-42

$$T_f = \frac{180 + 60}{2} = 120^\circ\text{F} \quad k = 0.644 \quad \frac{g\beta\rho^2 c_p}{\mu k} = 4.89 \times 10^{10}$$

$$\text{Gr Pr} = (4.89 \times 10^{10})(0.05)^3(180 - 60)\left(\frac{5}{9}\right) = 4.075 \times 10^8$$

$$C = 0.53 \quad m = \frac{1}{4}$$

$$h = \frac{0.644}{0.05} (0.53)(4.078 \times 10^8)^{1/4} = 970 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = h\pi dL(T_w - T_\infty) = (970)\pi(0.05)(3)(180 - 60)\left(\frac{5}{9}\right) = 3.047 \times 10^4 \text{ W}$$

7-43

$$T_f = \frac{77 + 27}{2} = 52^\circ\text{C} = 325 \text{ K} \quad \nu = 12.83 \times 10^{-6} \quad k = 0.0281$$

$$\text{Pr} = 0.7 \quad \text{Gr Pr} = \frac{(9.8) \left(\frac{1}{325}\right) (77 - 27) (2)^3 (0.7)}{(18.23 \times 10^{-6})^2} = 2.54 \times 10^{10}$$

$$\overline{\text{Nu}}^{1/2} = 0.6 + 0.387 \left\{ \frac{\text{Gr Pr}}{\left[1 + \left(\frac{0.559}{\text{Pr}}\right)^{9/16} \right]^{16/9}} \right\}^{1/6} = 17.998$$

$$\text{Nu} = 323.9$$

$$h = \frac{(323.9)(0.0281)}{2} = 4.55 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = h\pi dL(T_w - T_\infty) = (4.55)\pi(2)(20)(77 - 27) = 2.86 \times 10^4 \text{ W}$$

$$\text{Using } C = 0.13 \text{ and } m = \frac{1}{3}$$

$$\text{Nu} = (0.13)(2.54 \times 10^{10})^{1/3} = 293.7 \Rightarrow 9\% \text{ Lower}$$

7-44

$$T_f = \frac{90 + 20}{2} = 55^\circ\text{C} = 328 \text{ K} \quad \beta = 3.049 \times 10^{-3} \quad \nu = 18.52 \times 10^{-6}$$

$$k = 0.0284 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.806)(3.049 \times 10^{-3})(90 - 20)(0.3)^3}{(18.52 \times 10^{-6})^2} (0.7) = 1.153 \times 10^8$$

$$h = \frac{0.0284}{0.3} [2 + 0.43(1.153 \times 10^8)^{1/4}] = 4.407 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (4.407)\pi(4)(0.15)^2(90 - 20) = 87.23 \text{ W}$$

7-45

$$T_f = \frac{35 + 10}{2} = 22.5^\circ\text{C} \quad k = 0.604$$

$$\text{Gr Pr} = (1.46 \times 10^{10})(35 - 10)(0.025)^3 = 5.703 \times 10^6$$

$$h = \frac{0.604}{0.025} [2 + 0.43(5.703 \times 10^6)^{1/4}] = 556 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (556)4\pi(0.0125)^2(35 - 10) = 27.3$$

7-46

$$T_f = -25^\circ\text{C} = 248 \text{ K} \quad \rho = \frac{1400}{(287)(248)} = 1.967 \times 10^{-2} \quad \text{Pr} = 0.72$$

$$\mu = 1.488 \times 10^{-5} \quad \beta = 4.032 \times 10^{-3} \quad k = 0.0223$$

$$\text{Gr Pr} = \frac{(9.8)(4.032 \times 10^{-3})(1.967 \times 10^{-2})(50)(2.4)^3}{(1.488 \times 10^{-5})^2} (0.72) = 3.44 \times 10^7$$

$$h = \frac{0.0223}{2.4} [2 + 0.43(3.44 \times 10^7)^{1/4}] = 0.325 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (0.325)\pi(4)(1.2)^2(50) = 294 \text{ W}$$

Forced Convection:

$$\text{Re} = \frac{(1.967 \times 10^{-2})(0.3)(2.4)}{1.488 \times 10^{-5}} = 952$$

$$h = \frac{0.0223}{2.4} (0.37)(952)^{0.6} = 0.211 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (0.211)(4\pi)(1.2)^2(50) = 191 \text{ W}$$

7-47

$$T_f = \frac{38 + 15}{2} = 26.5^\circ\text{C} \quad k = 0.614$$

$$\text{Gr Pr} = (1.91 \times 10^{10})(38 - 15)(0.04)^3 = 2.81 \times 10^7$$

$$h = \frac{0.614}{0.04} [2 + 0.43(2.81 \times 10^7)^{1/4}] = 511 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (511)(4\pi)(0.02)^2(38 - 15) = 59.1 \text{ W}$$

7-48

$$L = \frac{\pi d}{2} \quad C = 0.52 \quad m = \frac{1}{4}$$

$$\frac{h\left(\frac{\pi d}{2}\right)}{k} = 0.52 \left[\text{const} \times \left(\frac{\pi d}{2}\right)^3 \right]$$

$$\frac{hd}{k} = \text{Nu}_d = (0.52) \left(\frac{2}{\pi}\right) \left[\left(\frac{\pi}{2}\right)^3\right]^{1/4} (\text{Gr}_d \text{Pr})^{1/4} = 0.464(\text{Gr}_d \text{Pr})^{1/4} \quad (\text{a})$$

Compare to

$$\text{Nu} = 2 + 0.43(\text{Gr}_d \text{Pr})^{1/4} \quad (\text{b})$$

GrPr	Nu (a)	Nu (b)
10^4	4.64	6.3
10^5	8.25	9.64
10^6	14.67	15.6

7-49

Flat plate

$$h = \frac{k}{L} (0.59)(\text{Gr Pr})^{1/4} = 1.42 \left(\frac{\Delta T}{L}\right)^{1/4}$$

Eq. (7-50)

$$h = 2 \frac{k}{d} + 0.43 \frac{k}{d} (\text{Gr Pr})^{1/4}$$

$$0.43 \frac{k}{d} (\text{Gr Pr})^{1/4} = (1.42) \frac{0.43}{0.59} \left(\frac{\Delta T}{d}\right)^{1/4} = 1.03 \left(\frac{\Delta T}{d}\right)^{1/4}$$

$$h = 2 \frac{k}{d} + 1.03 \left(\frac{\Delta T}{d}\right)^{1/4}$$

Chapter 7

7-50

$$T_f = \frac{204 + 93}{2} = 148.5^\circ\text{C} = 421.5 \text{ K} \quad \text{He at 3 atm}$$

$$\nu = \frac{221.5 \times 10^{-6}}{3} = 73.8 \times 10^{-6} \quad k = 0.183 \quad \text{Pr} = 0.71$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{421.5} \right) (204 - 93) (0.3)^3 (0.71)}{(73.8 \times 10^{-6})^2} = 9.08 \times 10^6$$

$$C = 0.53 \quad m = \frac{1}{4}$$

$$\bar{h} = \frac{0.183}{0.3} (9.08 \times 10^6)^{1/4} = 33.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h} \pi d L (T_w - T_\infty) = (33.5) \pi (0.3) (10.4) (204 - 93) = 36,435 \text{ W}$$

7-51

$$T_f = \frac{20 + 120}{2} = 70^\circ\text{C} = 343 \text{ K} \quad \nu = 20.05 \times 10^{-6} \quad k = 0.0295$$

$$\text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{343} \right) (120 - 20) (0.3)^3 (0.7)}{(20.05 \times 10^{-6})^2} = 1.34 \times 10^8 < 10^9$$

$$C = 0.53 \quad m = \frac{1}{4}$$

$$\bar{h} = \frac{0.0295}{0.3} (0.53) (1.34 \times 10^8)^{1/4} = 5.61 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h} A (T_w - T_\infty) = (5.61) \pi (0.3) (100) (120 - 20) = 52,847 \text{ W}$$

7-52

$$T_f = \frac{150 + 20}{2} = 85^\circ\text{C} = 358 \text{ K} \quad \beta = 2.793 \times 10^{-3} \quad \nu = 21.58 \times 10^{-6}$$

$$k = 0.0306 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.806) (2.793 \times 10^{-3}) (150 - 20) (0.15)^3}{(21.58 \times 10^{-6})^2} (0.7) = 1.806 \times 10^7$$

$$h = \frac{0.0306}{0.15} (0.15) (1.806 \times 10^7)^{1/3} = 8.03 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (8.03) \pi (0.075)^2 (150 - 20) = 18.4 \text{ W}$$

7-53

$$T_f = \frac{60 + 20}{2} = 40^\circ\text{C} \quad \nu = 0.00024 \quad k = 0.144$$

$$\text{Pr} = 2870 \quad \beta = 0.7 \times 10^{-3}$$

$$\text{Gr Pr} = \frac{(9.8)(0.7 \times 10^{-3})(60 - 20)(0.3)^3(2870)}{(0.00024)^2} = 3.69 \times 10^8$$

$$h = \frac{0.144}{0.3} (0.15)(3.69 \times 10^8)^{1/3} = 51.6 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (51.6)(0.3)^2(60 - 20) = 185.8 \text{ W}$$

7-54

$$\text{laminar:} \quad L = 6 \text{ mm} \quad \Delta T = 500 - 20 \quad q = 2 \text{ kW}$$

$$\text{Top:} \quad h = 1.32 \left(\frac{480}{0.006} \right)^{1/4} = 22.2 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{Bottom:} \quad h = 0.61 \left(\frac{480}{(0.006)^2} \right)^{1/5} = 16.23 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = 2000 = (16.23 + 22.2)(0.006)L(480) \quad L = 18.07 \text{ m}$$

7-55

$$T_f = \frac{25 + 28}{2} = 26.5^\circ\text{C} = 299.5 \text{ K} \quad \nu = 16.84 \times 10^{-6} \quad k = 0.02624$$

$$\text{Pr} = 0.71$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{299.5} \right) (3)(10)^3 (0.71)}{(16.84 \times 10^{-6})^2} = 2.42 \times 10^{11}$$

$$h = \frac{0.02624}{10} (0.15)(2.42 \times 10^{11})^{1/3} = 2.454$$

$$q = (2.454)(10)^2(3) = 736 \text{ W}$$

Chapter 7

7-56

$$T_f = \frac{15 + 50}{2} = 32.5^\circ\text{C} = 305.5 \text{ K} \quad \nu = 16.25 \times 10^{-6} \quad k = 0.0267$$

$$\text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{305.5} \right) (50 - 15) (4)^3 (0.7)}{(16.25 \times 10^{-6})^2} = 1.9 \times 10^{11}$$

$$\text{Upper:} \quad h_u = \frac{0.0267}{4} (0.15) (1.9 \times 10^{11})^{1/3} = 5.75 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{Lower:} \quad h_l = \frac{0.0267}{4} (0.27) (1.9 \times 10^{11})^{1/4} = 1.19 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (5.75 + 1.19) (4)^2 (50 - 15) = 3886 \text{ W}$$

7-57

$$T_f = \frac{400 + 300}{2} = 350 \text{ K} \quad \nu = 2.075 \times 10^{-6} \quad k = 0.03003$$

$$\text{Pr} = 0.697 \quad x = \frac{A}{P} = \frac{L \left(\frac{L}{2} \right)}{3L} = \frac{L}{6} = \frac{45}{6} = 7.5 \text{ cm}$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{350} \right) (400 - 300) (0.075)^3 (0.697)}{(2.075 \times 10^{-6})^2} = 1.91 \times 10^8$$

$$h = \frac{0.03003}{0.075} (0.15) (1.91 \times 10^8)^{1/3} = 34.58 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (34.58) \frac{(0.45)^2}{2} (400 - 300) = 350 \text{ W}$$

7-58

$$T_w = 40^\circ\text{C} \quad T_\infty = 20^\circ\text{C} \quad T_e = 40 - (0.25)(40 - 20) = 35^\circ\text{C} \quad k = 0.626$$

$$\text{Gr Pr} = (2.89 \times 10^{10}) (0.2)^3 (40 - 20) = 4.624 \times 10^9$$

$$\theta = 30^\circ \quad \bar{h} = \frac{0.626}{0.2} (0.56) [(4.624 \times 10^9) \cos 30^\circ]^{1/4} = 440 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (440) (0.2)^2 (40 - 20) = 352.7 \text{ W}$$

7-59

$$\theta = -30^\circ$$

$$\overline{\text{Nu}}_e = (0.14) [(4.624 \times 10^9)^{1/3} - (2 \times 10^9)^{1/3}] + 0.56 [(4.624 \times 10^9)^{1/3} \cos 30^\circ]^{1/4}$$

$$\overline{\text{Nu}}_e = 56.85 + 140.87 = 197.72$$

$$h = \frac{(0.626)(197.72)}{0.2} = 618.9 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (618.9) (0.2)^2 (40 - 20) = 495.1 \text{ W}$$

7-60

Assume $T = 20^\circ\text{C}$ inside

$$T_m = 20 + \frac{30}{2} = 35^\circ\text{C} = 308 \text{ K} \quad \beta = 3.247 \times 10^{-3}$$

$$\nu = 16.49 \times 10^{-6} \quad k = 0.0268 \quad \text{Pr} = 0.7$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)(3.247 \times 10^{-3})(30)(0.0125)^3}{(16.49 \times 10^{-6})^2} (0.7) = 4803$$

$$k_e \approx k \quad q = \frac{(0.0268)(1.8)(1.2)(30)}{0.0125} = 138.9 \text{ W}$$

7-61

$$T_m = \frac{160 + 40}{2} = 100^\circ\text{C} = 373 \text{ K} \quad \beta = 2.68 \times 10^{-3} \quad k = 0.0317$$

$$\text{Pr} = 0.69 \quad \rho = \frac{1.01 \times 10^4}{(287)(373)} = 0.0946 \quad \mu = 2.172 \times 10^{-5}$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)(2.68 \times 10^{-3})(0.946)^2(160 - 40)(0.08)^3(0.69)}{(2.172 \times 10^{-5})^2} = 2.11 \times 10^4$$

$$\theta = 20^\circ \quad C = 0.212 \quad n = \frac{1}{4}$$

$$\frac{k_e}{k} = (0.212)[(2.11 \times 10^4) \cos 20^\circ]^{1/4} = 2.516$$

$$q = (2.516)(0.0317)(1)^2(160 - 40) = 9.57 \text{ W}$$

7-62

$$q_w = 700 \text{ W/m}^2 \quad L = 1 \text{ m} \quad \theta = 60^\circ \text{ at } 30^\circ\text{C} \quad \nu = 15.98 \times 10^{-6}$$

$$\text{Pr} = 0.7 \quad k = 0.027 \quad \beta = 3.3 \times 10^{-3}$$

$$\text{Gr}^* = \frac{(9.8)(3.3 \times 10^{-3})(700)(1)^4}{(0.027)(15.98 \times 10^{-6})^2} = 3.286 \times 10^{12}$$

$$h = \frac{0.027}{1} (0.17)[(3.286 \times 10^{12})(0.7)]^{1/4} = 5.65 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\Delta T = \frac{700}{5.65} = 123.8^\circ\text{C} \quad T_w \approx 123.8 + 30 = 153.8^\circ\text{C}$$

7-63

$$\sigma \varepsilon A (T_w^4 - T_s^4) = hA(T_s - T_a)$$

$$(5.669 \times 10^{-8})(0.5)(308^4 - 303^4) = (6.5)(303 - T_a)$$

$$T_a = 300.5 \text{ K} = 27.5^\circ\text{C}$$

Chapter 7

7-64

$$T_e = 80 - \frac{1}{4}(80 - 20) = 65^\circ\text{C} = 338 \text{ K} \quad \beta = \frac{1}{308} \quad \nu = 19.54 \times 10^{-6}$$

$$k = 0.0291 \quad \text{Pr} = 0.7$$

Downward facing $\theta = 45^\circ$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{308}\right)(80 - 20)(0.1)^3(0.7)}{(19.54 \times 10^{-6})^2} = 3.5 \times 10^6$$

$$h_d = \frac{0.0291}{0.1}(0.56)(3.5 \times 10^6 \times 0.707)^{1/4} = 6.46 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Upward facing

$$\text{Gr}_c = 1.05 \times 10^9 \quad \text{Gr}_c \text{ Pr} = 7.35 \times 10^8$$

$$\text{Gr}_L < \text{Gr}_c \text{ so that } h_u = \frac{0.0291}{0.1}(0.56)(3.5 \times 10^6 \times 0.707)^{1/4} = 6.46 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (2)(6.46)(0.1)^2(80 - 20) = 7.752 \text{ W}$$

7-65

$$T_e = 50 - \frac{1}{4}(50 - 20) = 42.5^\circ\text{C} \quad \rho = 990 \quad \mu = 6.2 \times 10^{-4}$$

$$k = 0.635 \quad \text{Pr} = 0.41 \quad \theta = 30^\circ \quad \cos\theta = 0.866$$

$$\text{Gr Pr} = \frac{(9.8)(2.07 \times 10^{-4})(50 - 20)(0.05)^3(4.1)(990)^2}{(6.2 \times 10^{-4})^2} = 7.95 \times 10^7$$

$$h_d = \frac{0.635}{0.05}(0.56)(7.95 \times 10^7 \times 0.866)^{1/4} = 647.8 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Since $\text{Gr}_L < \text{Gr}_c$ $h_u = h_d$

$$q = (2)(647.8)(0.05)^2(50 - 20) = 97.2 \text{ W}$$

7-66

$$T_b = 38^\circ\text{C} = 311 \text{ K} \quad T_w = 540^\circ\text{C} \quad L = 30 \text{ cm}$$

$$d = 6.5 \text{ mm} \quad \frac{L}{d} = 46 \quad \text{fully developed}$$

$$\text{Air } u_m = 30 \text{ m/s} \quad \nu = 16.6 \times 10^{-6} \quad k = 0.028 \quad \text{Pr} = 0.7$$

$$\text{Re}_d = \frac{(30)(0.0065)}{16.6 \times 10^{-6}} = 11,750 \quad \text{turbulent}$$

$$\text{Nu} = 0.023 \text{Re}^{0.8} \text{Pr}^{0.4} = (0.023)(11,750)^{0.8}(0.7)^{0.4} = 35.95$$

$$\bar{h} = \frac{(35.95)(0.028)}{0.0065} = 155 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

7-67

$$T_f = \frac{100 + 15}{2} = 55^\circ\text{C} = 328 \text{ K} \quad \nu = 18.7 \times 10^{-6} \quad k = 0.0285$$

$$\text{Pr} = 0.7 \quad L = (2) \left(\frac{2.5}{2} \right) + 5 = 7.5 \text{ cm} = 0.075 \text{ m}$$

$$\text{Gr Pr} = \frac{(9.8)(328)(100 - 15)(0.075)^3(0.7)}{(18.7 \times 10^{-6})^2} = 2.15 \times 10^6$$

$$C = 0.52 \quad m = \frac{1}{4}$$

$$\bar{h} = \frac{0.0285}{0.075} (0.52)(2.15 \times 10^6)^{1/4} = 7.56 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$A = (2.5)^2(2) + (4)(2.5)(5) = 62.5 \text{ cm}^2$$

$$q = hA(T_w - T_\infty) = (7.56)(62.5 \times 10^{-4})(100 - 15) = 4.02 \text{ W}$$

7-68

$$A = \frac{1}{2}(40)^2 \sin 60^\circ = 692.8 \text{ cm}^2 \quad p = (3)(40) = 120 \text{ cm}$$

$$L = \frac{A}{p} = \frac{692.8}{120} = 5.77 \text{ cm} \quad T_f = \frac{55 + 25}{2} = 40^\circ\text{C} = 313 \text{ K}$$

$$\beta = 3.195 \times 10^{-3} \quad \nu = 17 \times 10^{-6} \quad k = 0.0272 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8)(3.195 \times 10^{-3})(55 - 25)(0.0577)^3}{(17 \times 10^{-6})^2} (0.7) = 4.37 \times 10^5$$

$$h = \frac{0.0272}{0.0577} (0.54)(4.37 \times 10^5)^{1/4} = 6.546 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (6.546)(0.0693)(55 - 25) = 13.61 \text{ W}$$

7-69

$$T_f = 40^\circ\text{C} = 313 \text{ K} \quad \beta = 3.195 \times 10^{-3} \quad \nu = 17 \times 10^{-6}$$

$$k = 0.0272$$

$$\text{Characteristic length} = \frac{A}{P} = \frac{d}{4} = 0.02 \text{ m}$$

$$\text{Pr} = 0.7 \quad \text{Gr Pr} = \frac{(9.8)(3.195 \times 10^{-3})(50 - 30)(0.02)^3(0.7)}{(17 \times 10^{-6})^2} = 1.21 \times 10^4$$

$$h = \frac{0.0272}{0.02} (0.54)(1.21 \times 10^4)^{1/4} = 7.71 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (7.71)\pi(0.04)^2(50 - 30) = 0.775 \text{ W}$$

Chapter 7

7-70

$$T_f = \frac{400 + 27}{2} = 213.5^\circ\text{C} = 486.5 \text{ K} \quad \nu = 36.23 \times 10^{-6} \quad k = 0.03948$$

$$\text{Pr} = 0.681 \quad \beta = \frac{1}{486.5} \quad \frac{1}{L} = \frac{1}{15} + \frac{1}{8} \quad L = 5.22 \text{ cm}$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{486.5} \right) (400 - 27) (0.0522)^3 (0.681)}{(36.23 \times 10^{-6})^2} = 5.54 \times 10^5$$

$$h = \frac{0.03948}{0.0522} (0.6) (5.54 \times 10^5)^{1/4} = 12.38 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$A = (2)(15)^2 + (4)(15)(8) = 930 \text{ cm}^2$$

$$q = (12.38)(930 \times 10^{-4})(400 - 27) = 429 \text{ W}$$

7-71

$$\frac{1}{L} = \frac{1}{0.15} + \frac{1}{0.15} \quad L = 0.075 \text{ m} \quad \nu = 17 \times 10^{-6} \quad k = 0.027$$
$$\text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{300} \right) \Delta T (0.075)^3 (0.7)}{(17 \times 10^{-6})^2} = 3.34 \times 10^4 \Delta T$$

$$A = 6(0.15)^2 = 0.135 \text{ m}^2$$

$$h = \frac{0.027}{0.075} (0.6) (3.34 \times 10^4)^{1/4} \Delta T^{1/4} = 2.92 \Delta T^{1/4}$$

$$50 = (2.92)(0.135)(\Delta T)^{5/4} \quad \Delta T = 48.2^\circ\text{C}$$

$$T_w = 48.2 + 20 = 68.2^\circ\text{C}$$

7-72

$$\sigma \varepsilon (T_i^4 - T_w^4) = h(T_a - T_i)$$

$$(5.669 \times 10^{-8})(0.95)(303^4 - 283^4) = 5(T_a - 303)$$

$$T_a = 325 \text{ K} = 52^\circ\text{C}$$

7-73

$$L = 30 + 15 = 45 \text{ cm} \quad T_f = \frac{45 + 20}{2} = 32.5^\circ\text{C} = 306 \text{ K}$$

$$\nu = 16.5 \times 10^{-6} \quad k = 0.0268 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{306} \right) (45 - 20) (0.45)^3 (0.7)}{(16.5 \times 10^{-6})^2} = 1.88 \times 10^8$$

$$C = 0.52 \quad m = \frac{1}{4}$$

$$h = \frac{0.0268}{0.45} (0.52) (1.88 \times 10^8)^{1/4} = 3.62 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h \frac{A}{L} (T_w - T_\infty) = (3.62)(2)(0.3 + 0.15)(45 - 20) = 81.5 \text{ W/m}$$

7-74

$$T_m = \frac{38 + 60}{2} = 49^\circ\text{C} \quad k = 0.644 \quad \text{Pr} = 3.64$$

$$\text{Gr}_\delta \text{Pr} = (4.89 \times 10^4)(60 - 38)(0.0125)^3 = 2.1 \times 10^6$$

$$\frac{k_e}{k} = (0.42)(2.1 \times 10^6)^{1/4} (3.64)^{0.012} \left(\frac{30}{1.25} \right)^{-0.3} = 6.26$$

$$q = \frac{(6.26)(0.644)(60 - 38)(0.3)^2}{0.0125} = 638.5 \text{ W}$$

7-75

$$T_m = \frac{80 + 20}{2} = 50^\circ\text{C} = 323 \text{ K} \quad k = 0.156$$

$$\nu = \frac{143.3 \times 10^{-6}}{1.3} = 1.102 \times 10^{-4} \quad \text{Pr} = 0.7$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8) \left(\frac{1}{323} \right) (80 - 20) (0.02)^3 (0.7)}{(1.102 \times 10^{-4})^2} = 839$$

$$k_e = k$$

$$q = \frac{(0.156)(0.4)^2(80 - 20)}{0.02} = 74.88 \text{ W}$$

Chapter 7

7-76

$$T_m = 30^\circ\text{C}$$

$$k = 0.62$$

$$\text{Gr}_\delta \text{Pr} = (2.25 \times 10^{10})(40 - 20)(0.02)^3 = 3.6 \times 10^6$$

$$C = 0.40 \quad n = 0.20 \quad \frac{k_e}{k} = (0.40)(3.6 \times 10^6)^{0.2} = 8.191$$

$$q = \frac{(2\pi)(8.191)(0.62)(1)(40 - 20)}{\ln\left(\frac{10}{8}\right)} = 2860 \text{ W}$$

7-77

$$T_m = \frac{30 - 10}{2} = 10^\circ\text{C} = 283 \text{ K} \quad \rho = \frac{(0.05)(1.01 \times 10^5)}{(287)(283)} = 0.0624$$

$$k = 0.0249 \quad \beta = 3.53 \times 10^{-3} \quad \mu = 1.814 \times 10^{-5} \quad \text{Pr} = 0.71$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)(0.0624)^2(3.53 \times 10^{-3})(40)(0.05)^3}{(1.814 \times 10^{-5})^2} (0.71) = 1454$$

$$\frac{k_e}{k} = (0.228)(1454)^{0.226} = 1.182$$

$$q = \frac{4\pi(1.182)(0.0249)(1)(1.05)(40)}{1.05 - 1} = 310.7 \text{ W}$$

7-78

$$T_m = \frac{400 + 140}{2} = 270^\circ\text{F} = 132.2^\circ\text{C} = 405 \text{ K} \quad \nu = 26.2 \times 10^{-6}$$

$$k = 0.034 \quad \beta = 2.47 \times 10^{-3} \quad \text{Pr} = 0.7$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)(2.47 \times 10^{-3})(400 - 140)\left(\frac{5}{9}\right)(0.03)^3}{(26.2 \times 10^{-6})^2} (0.7) = 9.63 \times 10^4$$

$$C = 0.197 \quad n = \frac{1}{4} \quad m = -\frac{1}{9}$$

$$\frac{k_e}{k} = (0.197)(9.63 \times 10^4)^{1/4} \left(\frac{35}{3}\right)^{-1/9} = 2.64$$

$$\frac{q}{A} = \frac{(2.64)(0.034)(400 - 140)\left(\frac{5}{9}\right)}{0.03} = 432 \text{ W/m}^2$$

7-79

$$T_m = \frac{200 + 90}{2} = 145^\circ\text{C} = 418 \text{ K} \quad \nu = 26.97 \times 10^{-6} \quad k = 0.0349$$

$$\beta = 2.39 \times 10^{-3} \quad \text{Pr} = 0.685$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)(2.39 \times 10^{-3})(200 - 90)(0.025)^3(0.685)}{(26.97 \times 10^{-6})^2} = 3.79 \times 10^4$$

$$C = 0.197 \quad n = \frac{1}{4} \quad m = -\frac{1}{9}$$

$$\frac{k_e}{k} = (0.197)(3.79 \times 10^4)^{1/4} \left(\frac{30}{2.5}\right)^{-1/9} = 2.086$$

$$q = (2.086)(0.0349)(0.3)^2 \left(\frac{200 - 90}{0.025}\right) = 28.83 \text{ W}$$

7-80

$$T_m = 90 + \frac{165}{2} = 172.5^\circ\text{C} = 445.5 \text{ K} \quad \text{Pr} = 0.684$$

$$\beta = 2.245 \times 10^{-3} \quad \nu = 28.59 \times 10^{-6} \quad k = 0.0368$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)(2.245 \times 10^{-3})(165)(0.0016)^3}{(28.59 \times 10^{-6})^2} (0.684) = 12.45$$

$$k_e = k \quad \frac{q}{A} = \frac{(0.0368)(165)}{0.0016} = 3795 \text{ W/m}^2$$

7-81

$$\text{at } 172.5^\circ\text{C} \quad k = 0.669 \quad \text{Gr}_\delta \text{Pr} = (10.11 \times 10^{10})(165)(0.0016)^3$$

$$\text{Gr}_\delta \text{Pr} = 6.83 \times 10^4 \quad C = 0.13 \quad n = 0.3 \quad m = 0$$

$$\frac{k_e}{k} = (0.13)(6.83 \times 10^4)^{0.3} = 3.67$$

$$k_e = (3.67)(0.669) = 2.453 \quad \frac{q}{A} = \frac{(2.453)(165)}{0.0016} = 2.53 \times 10^5 \text{ W/m}^2$$

Chapter 7

7-83

$$T_m = \frac{50 + 20}{2} = 35^\circ\text{C} \quad \rho = 994 \quad \mu = 7.2 \times 10^{-4} \quad k = 0.626$$

$$\text{Pr} = 4.82 \quad \frac{g\beta\rho^2 c_p}{\mu k} = 2.89 \times 10^{10}$$

$$\text{Gr}_\delta \text{Pr} = (2.89 \times 10^{10})(0.04)^3(30) = 5.55 \times 10^7$$

$$\frac{k_e}{k} = (0.046)(5.55 \times 10^7)^{1/3} = 17.55$$

$$q = (17.55)(0.626)(0.5)^2 \left(\frac{50 - 20}{0.04} \right) = 2060 \text{ W}$$

7-84

$$\frac{k_e}{k} = (0.057)(5.55 \times 10^7)^{1/3} = 21.74$$

$$q = (21.74)(0.626)(0.5)^2 \left(\frac{50 - 20}{0.04} \right) = 2552 \text{ W}$$

7-87

Assume 20°C inside

$$T_m = 20 + \frac{17}{2} = 28.5^\circ\text{C} = 302 \text{ K} \quad \beta = 3.32 \times 10^{-3} \quad \text{Pr} = 0.71$$

$$\nu = 15.68 \times 10^{-6} \quad k = 0.0262$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)(3.32 \times 10^{-3})(17)(0.1)^3(0.71)}{(15.68 \times 10^{-6})^2} = 1.598 \times 10^6$$

$$C = 0.073 \quad n = \frac{1}{3} \quad m = -\frac{1}{9}$$

$$\frac{k_e}{k} = (0.073)(1.598 \times 10^6)^{1/3} \left(\frac{2}{0.1} \right)^{-1/9} = 6.118$$

$$\frac{q}{A} = \frac{(6.118)(0.0262)(17)}{0.1} = 27.25 \text{ W/m}^2$$

7-88

$$T_m = 350 \text{ K} \quad v = \frac{20.76 \times 10^{-6}}{2} \quad k = 0.03003 \quad p = 2 \text{ atm} \quad \text{Pr} = 0.7$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)\left(\frac{1}{350}\right)(400 - 300)(0.06)^3(0.7)(2)^2}{(20.76 \times 10^{-6})^2} = 3.93 \times 10^6$$

$$C = 0.073 \quad m = \frac{1}{3} \quad n = -\frac{1}{9}$$

$$k_e = (0.03003)(0.073)(3.93 \times 10^6)^{1/3} \left(\frac{3}{0.06}\right)^{-1/9} = 0.224 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$q = k_e A \frac{\Delta T}{\delta} = (0.224)(3)(2) \left(\frac{400 - 300}{0.06}\right) = 2240 \text{ W}$$

7-90

$$T_m = \frac{100 + 20}{2} = 60^\circ\text{C} = 333 \text{ K} \quad v = 19.04 \times 10^{-6} \quad k = 0.0287$$

$$\text{Pr} = 0.7$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)\left(\frac{1}{333}\right)(100 - 20)(0.08)^3(0.7)}{(19.04 \times 10^{-6})^2} = 2.33 \times 10^6$$

$$C = 0.073 \quad n = \frac{1}{3} \quad m = -\frac{1}{9}$$

$$\frac{k_e}{k} = (0.073)(2.33 \times 10^6)^{1/3} \left(\frac{1}{0.08}\right)^{-1/9} = 7.304$$

$$q = \frac{(0.0287)(7.304)(1)^2(100 - 20)}{0.08} = 209.6 \text{ W}$$

Chapter 7

7-91

Take properties at 300 K $\nu = 15.69 \times 10^{-6}$ $k = 0.02624$ $Pr = 0.7$

$$Gr_{\delta} Pr = \frac{(9.8)\left(\frac{1}{300}\right)(30)(0.01)^3(0.7)}{(15.69 \times 10^{-6})^2} = 2787$$

For horizontal plate $C = 0.059$ $n = 0.4$

$$\frac{k_e}{k} = (0.059)(2787)^{0.4} = 1.41$$

$$q = \frac{(1.41)(0.02624)(0.3)^2(30)}{0.01} = 9.98 \text{ W}$$

For 30 cm vertical plate

$$Gr Pr = (2787)\left(\frac{30}{1}\right)^3 = 7.52 \times 10^7 \quad C = 0.59 \quad m = \frac{1}{4}$$

$$h = \frac{0.02624}{0.3} (0.59)(7.52 \times 10^7)^{1/4} = 4.806 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA(T_w - T_\infty)(4.806)(0.3)^2(30) = 129.8 \text{ W}$$

the 9.98 W is a reduction of 93%

7-92

$$T_m = \frac{120 + 20}{2} = 70^\circ\text{C} = 343 \text{ K} \quad \mu = 2.04 \times 10^{-5} \quad k = 0.0295$$

$$Pr = 0.7 \quad \delta = 1 \text{ cm}$$

$$Gr_{\delta} = 1700 = \frac{\rho^2(9.8)\left(\frac{1}{343}\right)(120 - 20)(0.01)^3(0.7)}{(2.04 \times 10^{-5})^2}$$

$$\rho^2 = 0.3537 \quad \rho = 0.595$$

$$\text{At 1 atm} \quad \rho = 1.023$$

$$\text{Thus at } \delta = 1 \text{ cm} \quad p = \frac{0.595}{1.023} = 0.582 \text{ atm (58.96 kPa)}$$

For the other spacings:

δ (cm)	ρ^2	ρ	p (atm, kPa)
2	0.0442	0.2103	0.2056, 20.83
5	0.00283	0.0532	0.052, 5.27
10	3.537×10^{-3}	0.0188	0.0184, 1.86

7-94

$$q = h\pi dL\Delta T \quad h = 1.32\left(\frac{\Delta T}{d}\right)^{1/4} \quad q \sim \Delta T^{5/4}$$

$$\frac{q_{83}}{175} = \left(\frac{83-27}{55-27}\right)^{5/4} \quad q_{83} = 416 \text{ W}$$

7-95

$$T_f = \frac{140 + 70}{2} = 105^\circ\text{F} = 40.6^\circ\text{C} = 314 \text{ K}$$

$$\nu = 17.11 \times 10^{-6} \text{ m}^2/\text{s} \quad k = 0.0273 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = 10^9 = \frac{(9.8)\left(\frac{1}{314}\right)(140-70)\left(\frac{5}{9}\right)x^3}{(17.11 \times 10^{-6})^2} \quad (0.7)$$

$$x = 0.701 \text{ m}$$

$$h = \frac{0.0273}{0.701}(0.59)(10^9)^{1/4} = 4.09 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{A} = h\Delta T = (4.09)(140-70)\left(\frac{5}{9}\right) = 159 \text{ W/m}^2$$

$$u = u_{\max} \text{ at } y = \frac{\delta}{3} = 0.148u_x$$

$$u_x = C_1 x^{1/2}$$

$$C_1 = (5.17)(17.11 \times 10^{-6})\left(\frac{20}{21} + 0.7\right)^{-1/2} \left[\frac{(9.8)\left(\frac{1}{314}\right)(70)\left(\frac{5}{9}\right)}{(17.11 \times 10^{-6})^2} \right]^{1/2} = 4.43$$

$$u_x = (4.43)(0.701)^{1/2} = 3.71$$

$$u_{\max} = (0.148)(3.71) = 0.55 \text{ m/s}$$

Chapter 7

7-96

$$\delta = 0.025 \text{ m} \quad T_f = 50^\circ\text{C} = 323 \text{ K} \quad \nu = 18.02 \times 10^{-6} \text{ m}^2/\text{s}$$

$$k = 0.02798 \quad \text{Pr} = 0.7$$

$$\text{Gr}_\delta \text{Pr} = \frac{(9.8)\left(\frac{1}{323}\right)(70 - 30)(0.025)^3(0.7)}{(18.02 \times 10^{-6})^2} = 40,878$$

$$\frac{k_e}{k} = (0.212)(40,878)^{1/4} = 3.014$$

$$k_e = 0.0843 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\frac{q}{A} = (0.0843)\left(\frac{70 - 30}{0.025}\right) = 135 \text{ W/m}^2$$

$$\text{For } \delta = 0.01 \text{ m} \quad \text{Gr}_\delta \text{Pr} = 2616$$

$$\frac{k_e}{k} = 0.059(2616)^{0.4} = 1.374$$

$$\frac{q}{A} = (1.374)(0.02798)\left(\frac{70 - 30}{0.01}\right) = 154 \text{ W/m}^2$$

7-97

$$\text{Gr}_\delta \text{Pr} = 1700 = 40,878 \left(\frac{p}{1 \text{ atm}}\right)^2 \quad \text{since } \rho = \frac{p}{RT} \quad p = 0.204 \text{ atm}$$

7-98

$$T_f = \frac{120 + 80}{2} = 100^\circ\text{F} = 37.8^\circ\text{C} = 311 \text{ K}$$

$$\text{(a) Air} \quad \nu = 16.81 \times 10^{-6} \quad k = 0.02707 \quad \text{Pr} = 0.7$$

$$\text{GrPr} = \frac{(9.8)\left(\frac{1}{311}\right)(120 - 80)\left(\frac{5}{9}\right)(0.025)^3(0.7)}{(16.81 \times 10^{-6})^2} = 27,100$$

$$h = \frac{0.02707}{0.025} [2 + 0.43(27,100)^{1/4}] = 8.14 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA\Delta T = (8.14)4\pi(0.0125)^2(40)\left(\frac{5}{9}\right) = 0.36 \text{ W}$$

$$(b) \text{ Water } \frac{g\beta\rho^2 c_p}{\mu k} = 3.3 \times 10^{10} \quad k = 0.630$$

$$\text{Gr Pr} = (3.3 \times 10^{10})(0.025)^3(120 - 80)\left(\frac{5}{9}\right) = 1.146 \times 10^7$$

$$h = \frac{0.63}{0.025} [2 + 0.50(1.146 \times 10^7)^{1/4}] = 783 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA\Delta T = (783)4\pi(0.0125)^2(40)\left(\frac{5}{9}\right) = 34.2 \text{ W}$$

7-99

$$T_f = 350 \text{ K} \quad \nu = 20.76 \times 10^{-6} \quad k = 0.03003 \quad \text{Pr} = 0.7$$

$$r_i = 0.04 \quad r_o = 0.05 \quad \delta = 0.01$$

$$\text{Gr}_\delta \text{ Pr} = \frac{(9.8)\left(\frac{1}{350}\right)(400 - 300)(0.01)^3(0.7)}{(20.76 \times 10^{-6})^2} = 4548$$

$$\frac{k_e}{k} = (0.228)(4548)^{0.226} = 1.53$$

$$k_e = (0.03003)(1.53) = 0.0459$$

$$q = \frac{4\pi(0.0459)(0.04)(0.05)(100)}{0.05 - 0.04} = 11.54 \text{ W}$$

7-100

$$d = L = 0.08 \text{ m} \quad C = 0.775 \quad m = 0.21 \quad T_f = 287.5 \text{ K}$$

$$\nu = 14.6 \times 10^{-6} \quad k = 0.0252 \quad \text{Pr} = 0.71$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{287.5}\right)(300 - 275)(0.08)^3(0.71)}{(14.6 \times 10^{-6})^2} = 1.45 \times 10^6$$

$$h = \frac{0.0252}{0.08} (0.775)(1.45 \times 10^6)^{0.21} = 4.81 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$hA = (4.81)[2\pi(0.04)^2 + \pi(0.08)(0.08)] = 0.1452$$

$$\rho c V = (999)(4180)\pi(0.04)^2(0.08) = 1679$$

$$\frac{hA}{\rho c V} = \frac{0.1452}{1679} = 8.65 \times 10^{-5}$$

$$\frac{290 - 275}{300 - 275} = \exp[-8.65 \times 10^{-5} \tau]$$

$$\tau = 5905 \text{ sec} = 1.64 \text{ hr}$$

Chapter 7

7-101

$$L = \frac{A}{\rho} = \frac{\pi d^2}{4\pi d} = \frac{d}{4}$$

$$T_f = \frac{120 + 80}{2} = 100^\circ\text{F} = 37.8^\circ\text{C}$$

$$\frac{g\beta\rho^2 c_p}{\mu k} = 3.3 \times 10^{10} \quad k = 0.63$$

$$\text{Gr Pr} = (3.3 \times 10^{10}) \left(\frac{0.05}{4}\right)^3 (120 - 80) \left(\frac{5}{9}\right) = 1.43 \times 10^6$$

Upper surface $C = 0.54$ $m = \frac{1}{4}$

$$h = \frac{0.63}{0.05/4} (0.54)(1.43 \times 10^6)^{1/4} = 942 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (942)\pi(0.025)^2(40) \left(\frac{5}{9}\right) = 41.1 \text{ W}$$

Lower surface $C = 0.27$ $m = \frac{1}{4}$

$$h = 471 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = 20.6 \text{ W}$$

7-102

$$\theta = 45^\circ \quad L = 0.1 \text{ m} \quad T_f = 350 \text{ K}$$

$$T_e = 400 - 0.25(400 - 300) = 375 \text{ K}$$

$$\nu = 23.33 \times 10^{-6} \quad k = 0.0318 \quad \text{Pr} = 0.69$$

$$\text{Gr}_e \text{Pr}_e \cos\theta = \frac{(9.8) \left(\frac{1}{350}\right) (400 - 300) (0.1)^3 (0.7) (0.707)}{(23.33 \times 10^{-6})^2} = 2.54 \times 10^6$$

Eq. (7-43)

$$h = \frac{0.0318}{0.1} (0.56)(2.54 \times 10^6)^{1/4} = 7.11 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA\Delta T = (7.11)(0.1)^2(400 - 300) = 7.11 \text{ W}$$

7-103

Upward facing surface

Because $\text{Gr}_e < \text{Gr}_c$ 1st term of Eq. (7-46) drops out and the result is the same as in Prob. (7-98).

7-104

$$\frac{D}{L} \geq \frac{35}{Gr_L^{1/4}} \quad L = 50 \text{ cm} = 0.5 \text{ m} \quad T_f = 350 \text{ K}$$

$$\nu = 20.76 \times 10^{-6} \quad k = 0.03003 \quad Pr = 0.7$$

$$Gr_L = \frac{(9.8)\left(\frac{1}{350}\right)(400 - 300)(0.5)^3}{(20.76 \times 10^{-6})^2} = 8.12 \times 10^8$$

$$d_{\min} = (0.5)(35)(8.12 \times 10^8)^{-1/4} = 0.104 \text{ m}$$

7-108

$$\text{Const heat flux, } T_w = 65^\circ\text{C} = 338 \text{ K} \quad T_\infty = 20^\circ\text{C} = 293 \text{ K}$$

$$L = 0.5 \text{ m}$$

$$T_f = \frac{65 + 20}{2} = 42.5^\circ\text{C} = 316 \text{ K}$$

$$\nu = 17.3 \times 10^{-6} \quad Pr = 0.7 \quad k = 0.0275$$

$$\text{For laminar } \bar{h} = \frac{5}{4} h_{x=L}$$

$$Gr Pr = \frac{(9.8)\left(\frac{1}{316}\right)(65 - 20)(0.5)^3(0.7)}{(17.3 \times 10^{-6})^2} = 4.08 \times 10^8$$

$$Nu_x = 0.6(Gr_x Nu_x Pr)^{1/5} = 75.05$$

$$h_{x=L} = \frac{(75.05)(0.0275)}{0.5} = 4.13 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\bar{h} = \left(\frac{5}{4}\right)(4.13) = 5.16 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q_{\text{conv}} = \bar{h}A(T_w - T_\infty) = (5.16)(2)(0.5)^2(65 - 20) = 116.1 \text{ W}$$

$$q_{\text{rad}} = \sigma \epsilon A(T_w^4 - T_\infty^4) = (5.668 \times 10^{-8})(2)(0.5)^2(338^4 - 293^4) = 161 \text{ W}$$

$$q_{\text{total}} = 116.1 + 161 = 277.1 \text{ W}$$

7-109

$$L = 0.2 \text{ m} \quad T_w = 30^\circ\text{C} \quad T_\infty = 10^\circ\text{C} \quad T_f = \frac{30 + 10}{2} = 20^\circ\text{C}$$

$$\nu = 0.00118 \quad k = 0.286 \quad Pr = 12.5 \times 10^3 \quad \beta = 0.5 \times 10^{-3}$$

$$Gr Pr = \frac{g\beta\Delta TL^3}{\nu^2} Pr = \frac{(9.8)(0.5 \times 10^{-3})(30 - 10)(0.2)^3(12.5 \times 10^3)}{(0.00118)^2} = 7.038 \times 10^6$$

$$Nu = C(Gr Pr)^m = (0.59)(7.038 \times 10^6)^{1/4} = 30.39$$

$$\bar{h} = \frac{(30.39)(0.286)}{0.2} = 43.46 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (43.46)(2)(0.2)^2(30 - 10) = 69.53 \text{ W}$$

Chapter 7

7-110

$$T_w = 43.3^\circ\text{C} \quad T_\infty = 10^\circ\text{C} \quad T_f = 26.65^\circ\text{C} \quad L = d = 0.3 \text{ m}$$

$$\frac{g\beta\rho^2 c_p}{\mu k} = 1.91 \times 10^{10} \quad \text{Pr} = 5.85 \quad k = 0.614$$

$$\text{Gr}_L \text{Pr} = (1.91 \times 10^{10})(0.3)^2(43.3 - 10) = 1.72 \times 10^{10}$$

$$\text{Gr}_L = \frac{1.72 \times 10^{10}}{5.85} = 2.94 \times 10^9 = \text{Gr}_d$$

$$\frac{35}{\text{Gr}_L^{1/4}} = 0.15 \quad \frac{d}{L} = 1.0 > 0.15$$

Treat as vertical plate

Sides $C = 0.1 \quad m = \frac{1}{3}$

$$\bar{h} = \frac{0.614}{0.3} (0.1)(1.72 \times 10^{10})^{1/3} = 528 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (528)\pi(0.3)(0.3)(43.3 - 10) = 4974 \text{ W}$$

Top and Bottom $L = \frac{A}{P} = \frac{d}{4} = 0.075 \text{ m}$

$$\text{Gr}_L \text{Pr} = \frac{1.72 \times 10^{10}}{(4)^3} = 2.69 \times 10^8$$

Top $C = 0.15 \quad m = \frac{1}{3}$

Bottom $C = 0.27 \quad m = \frac{1}{4} \quad A = \frac{\pi d^2}{4}$

$$h(\text{Top}) = \frac{0.614}{0.075} (0.15)(2.69 \times 10^8)^{1/3} = 792 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$h(\text{Bottom}) = \frac{0.614}{0.075} (0.27)(2.69 \times 10^8)^{1/4} = 283 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q(\text{Top} + \text{Bottom}) = (792 + 283) \frac{\pi(0.3)^2}{4} (43.3 - 10) = 2530 \text{ W}$$

$$q(\text{Total}) = 4974 + 2530 = 7504 \text{ W}$$

Second Method

Treat solid as vertical plate with characteristic dimension $= L + (2)\left(\frac{d}{2}\right) = 0.6 \text{ m}$

$$\text{Gr Pr} = (1.72 \times 10^{10}) \left(\frac{0.6}{0.3}\right)^3 = 1.38 \times 10^{11}$$

$$C = 0.1 \quad m = \frac{1}{3}$$

$$\text{Nu} = (0.1)(1.38 \times 10^{11})^{1/3} = 516$$

$$\bar{h} = \frac{(516)(0.614)}{0.6} = 528 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$A(\text{total}) = \pi dL + 2\left(\frac{\pi d^2}{4}\right) = \pi \left[(0.3)(0.3) + \frac{(0.3)^2}{2} \right] = 0.424 \text{ m}^2$$

$$q(\text{total}) = \bar{h} A_{\text{total}} (T_w - T_\infty) = (528)(0.424)(43.3 - 10) = 7457 \text{ W}$$

Good agreement between the two methods

7-111

$$T_f = 350 \text{ K} \quad v = \frac{20.8 \times 10^{-6}}{1.5}$$

$$\text{O}_2 \quad k = 0.0307 \quad \text{Pr} = 0.702$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{350}\right)(400 - 300)(0.01)^3(0.702)}{(20.8 \times 10^{-6})^2} = 10,222$$

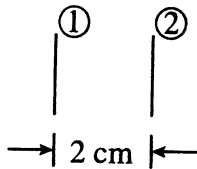
$$C = 0.53 \quad m = \frac{1}{4}$$

$$\bar{h} = \frac{0.0307}{0.01} (0.53)(10,222)^{1/4} = 16.36 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h} A (T_w - T_\infty) = (16.36)\pi(0.01)(1.25)(400 - 300) = 64.25 \text{ W}$$

Chapter 7

7-112



$$\lambda = 2 \text{ cm} = 0.02 \text{ m} = L$$

$$T_1 = 400 \text{ K} \quad \varepsilon_1 = 0.1$$

$$T_2 = 300 \text{ K} \quad \varepsilon_2 = 0.15$$

$$\alpha_1 = \alpha_2 = 0.9$$

$$k = 0.03003 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \text{Pr} = 0.7 \quad \gamma = 1.4$$

$$\Delta T = \frac{2 - \alpha}{\alpha} \frac{2\gamma}{\gamma + 1} \frac{\lambda}{\text{Pr}} \frac{T_1 - T_2 - 2\Delta T}{L} = \left(\frac{1.1}{0.9}\right) \left(\frac{2.8}{2.4}\right) \left(\frac{0.02}{0.7}\right) \left(\frac{400 - 300 - 2\Delta T}{0.02}\right)$$

$$= 40.15^\circ\text{C}$$

$$\left. \frac{q}{A} \right|_{\text{cond}} = k \left(\frac{T_1 - T_2 - 2\Delta T}{L} \right) = (0.03003) \left[\frac{400 - 300 - (2)(40.15)}{0.02} \right] = 29.59 \text{ W/m}^2$$

$$\left. \frac{q}{A} \right|_{\text{rad}} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = \frac{(5.668 \times 10^{-8})(400^4 - 300^4)}{\frac{1}{0.1} + \frac{1}{0.15} - 1} = 63.31 \text{ W/m}^2$$

$$\left. \frac{q}{A} \right|_{\text{Total}} = 29.59 + 63.31 = 92.89 \text{ W/m}^2$$

7-113

$$T_w = 400 \text{ K} \quad T_\infty = 20^\circ\text{C} = 293 \text{ K} \quad d = 0.4 \text{ m}$$

$$T_f = \frac{400 + 293}{2} = 347 \text{ K}$$

$$\nu = 20.5 \times 10^{-6} \quad k = 0.03 \quad \text{Pr} = 0.7$$

$$\text{Gr Pr} = \frac{(9.8) \left(\frac{1}{347}\right) (400 - 293) (0.4)^3 (0.7)}{(20.5 \times 10^{-6})^2} = 3.23 \times 10^8$$

$$\text{Nu} = 2 + 0.5(\text{Gr Pr})^{1/4} = 2 + (0.5)(3.23 \times 10^8)^{1/4} = 69.0$$

$$\bar{h} = \frac{(69)(0.03)}{0.4} = 5.18 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (5.18)4\pi(0.2)^2(400 - 293) = 279 \text{ W}$$

$$q_{\text{rad}} = \sigma \varepsilon A (T_w^4 - T_\infty^4) = (5.668 \times 10^{-8})(0.9)(4\pi)(0.2)^2(400^4 - 293^4) = 467 \text{ W}$$

7-114

$$L = 0.2 \text{ m} \quad T_1 = 350 \text{ K} \quad T_2 = 400 \text{ K} \quad \delta = 0.02 \text{ m}$$

$$\bar{T} = \frac{350 + 400}{2} = 375 \text{ K}$$

Helium at $p = 2 \text{ atm}$

$$\nu = \frac{181 \times 10^{-6}}{2} = 90.5 \times 10^{-6} \quad k = 0.171 \quad \text{Pr} = 0.71$$

$$\text{Gr}_\delta \text{Pr} = \frac{g\beta\Delta T\delta^3}{\nu^2} \text{Pr} = \frac{(9.8)\left(\frac{1}{375}\right)(400 - 350)(0.02)^3(0.71)}{(90.5 \times 10^{-6})^2} = 906 < 2000$$

$$\text{Therefore} \quad \frac{k_e}{k} = 1.0 \quad q = k_e A \frac{\Delta T}{\delta} = (0.171)(0.2)^2 \left(\frac{400 - 350}{0.02}\right) = 17.1 \text{ W}$$

7-115

$$T_w = 125^\circ\text{C} = 398 \text{ K} \quad T_\infty = 25^\circ\text{C} = 298 \text{ K} \quad T_f = 348 \text{ K}$$

$$\nu = 20.7 \times 10^{-6} \quad k = 0.03 \quad \text{Pr} = 0.7$$

$$\text{Characteristic} = \frac{A}{P} = \frac{L^2}{4L} = \frac{L}{4} = 0.075 \text{ m}$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{348}\right)(125 - 25)(0.075)^3(0.7)}{(20.7 \times 10^{-6})^2} = 1.94 \times 10^6$$

$$\text{Top} \quad C = 0.54 \quad m = \frac{1}{4}$$

$$\text{Bottom} \quad C = 0.27 \quad m = \frac{1}{4}$$

$$\text{Top} \quad \bar{h} = \frac{0.03}{0.075} (0.54)(1.94 \times 10^6)^{1/4} = 8.06 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{Bottom} \quad \bar{h} = \frac{0.27}{0.54} (8.06) = 4.03 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q(\text{total}) = (8.06 + 4.03)(0.3)^2(125 - 25) = 108.8 \text{ W}$$

Chapter 7

7-116

$$T_w = 134^\circ\text{C} = 407 \text{ K} \quad T_\infty = 20^\circ\text{C} = 293 \text{ K} \quad d = 0.001 \text{ m}$$

$$T_f = 350 \text{ K} \quad k = 0.03003 \quad \text{Pr} = 0.697 \quad \nu = 20.76 \times 10^{-6}$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{350}\right)(134 - 20)(0.001)^3(0.697)}{(20.76 \times 10^{-6})^2} = 5.16$$

$$C = 1.02 \quad m = 0.148 \quad \text{Nu} = C(\text{Gr Pr})^m = (1.02)(5.16)^{0.148} = 1.3$$

$$\bar{h} = \frac{(1.3)(0.03003)}{0.001} = 39.05 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (39.05)\pi(0.001)(1)(134 - 20) = 15.21 \text{ W} = \dot{q}V = \dot{q}\left(\frac{\pi d^2}{4}\right)L$$

$$\dot{q} = \frac{(15.21)(4)}{\pi(0.001)^2(1)} = 1.94 \times 10^7 \text{ W/m}^3$$

$$\text{From chap. 2} \quad T_0 - T_\infty = \frac{\dot{q}r^2}{4k} = \frac{(1.94 \times 10^7)(0.0005)^2}{(4)(16)} = 0.076^\circ\text{C}$$

$$T_0 = 134.076^\circ\text{C}$$

$$R_{\text{elec}} = \rho_e \frac{L}{A} = \frac{(70 \times 10^{-6})(100)(4)}{\pi(0.1)^2} = 0.89 \Omega$$

$$q = \frac{E^2}{R} = 15.21 \text{ W}$$

$$E = [(15.21)(0.89)]^{1/2} = 3.68 \text{ Volts}$$

7-117

$$L = 0.3 \text{ m} \quad d = 0.105 \text{ m} \quad T_\infty = 15^\circ\text{C} = 288 \text{ K}$$

$$T_w = 100^\circ\text{C} = 373 \text{ K} \quad T_f = 330.5 \text{ K} \quad \nu = 18.7 \times 10^{-6}$$

$$k = 0.029 \quad \text{Pr} = 0.7$$

$$\text{Gr}_L = \frac{(9.8)\left(\frac{1}{330.5}\right)(100 - 15)(0.3)^3}{(18.7 \times 10^{-6})^2} = 1.95 \times 10^8$$

$$\frac{d}{L} = \frac{0.105}{0.3} = 0.35 \quad \frac{35}{\text{Gr}_L^{1/4}} = 0.296 < 0.35 \quad \text{treat as vertical plate}$$

$$\text{Gr}_L \text{Pr} = (1.95 \times 10^8)(0.7) = 1.365 \times 10^8$$

$$C = 0.59 \quad m = \frac{1}{4} \quad \text{Nu} = C(\text{Gr Pr})^m = (0.59)(1.365 \times 10^8)^{1/4} = 63.77$$

$$\bar{h} = \frac{(63.77)(0.029)}{0.3} = 6.16 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (6.16)\pi(0.105)(0.3)(100 - 15) = 51.9 \text{ W}$$

7-118

$$T_w = 865 \text{ K} \quad T_\infty = 300 \text{ K} \quad d = 0.025 \text{ mm} \quad T_f = 582.5 \text{ K}$$

$$v = 48.9 \times 10^{-6} \quad k = 0.0455 \quad \text{Pr} = 0.683$$

$$\text{Gr Pr} = \frac{g\beta\Delta T d^3 \text{Pr}}{v^2} = \frac{(9.8)\left(\frac{1}{582.5}\right)(865 - 300)(0.025 \times 10^{-3})^3(0.683)}{(48.9 \times 10^{-6})^2} = 4.24 \times 10^{-5}$$

$$C = 0.675 \quad m = 0.058 \quad \text{Nu} = C(\text{Gr Pr})^m = (0.675)(4.24 \times 10^{-5})^{0.058} = 0.376$$


$$\bar{h} = \frac{(0.376)(0.0455)}{0.025 \times 10^{-3}} = 685 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q_{\text{conv}} = \bar{h}A(T_w - T_\infty) = (685)\pi(0.025 \times 10^{-3})(865 - 300) = 30.4 \text{ W/m} \cdot \text{length}$$

$$q_{\text{rad}} = \sigma A \varepsilon (T_w^4 - T_\infty^4) = (5.668 \times 10^{-8})\pi(0.025 \times 10^{-3})(0.9)(865^4 - 300^4) \\ = 2.21 \text{ W/m} \cdot \text{length}$$

7-119

$$T_w = 400 \text{ K} \quad T_\infty = 300 \text{ K} \quad T_f = 350 \text{ K} \quad v = 20.76 \times 10^{-6} \quad k = 0.03003$$



$$\text{Pr} = 0.697 \quad A = \frac{1}{2}L\left(\frac{\sqrt{3}}{2}L\right) = \frac{\sqrt{3}}{4}L^2 \quad L = 0.2 \text{ m}$$

$$\text{characteristic dimension} = \frac{A}{P} = \frac{\frac{\sqrt{3}}{4}L^2}{3L} = \frac{L}{4\sqrt{3}} = 0.144L = 0.0288 \text{ m}$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{350}\right)(400 - 300)(0.0288)^3(0.697)}{(20.76 \times 10^{-6})^2} = 1.09 \times 10^5$$

$$C = 0.54 \quad m = \frac{1}{4} \quad \text{Nu} = C(\text{Gr Pr})^m = (0.54)(1.09 \times 10^5)^{1/4} = 9.81$$

$$\bar{h} = \frac{(9.81)(0.03003)}{0.0288} = 10.23 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (10.23)(0.2)^2 \frac{\sqrt{3}}{4}(400 - 300) = 17.7 \text{ W}$$

Chapter 7

7-120

$$\text{Water} \quad d = 10 \text{ cm} \quad T_w = 49^\circ\text{C} \quad T_\infty = 10^\circ\text{C} \quad T_f = 29.5^\circ\text{C}$$

$$\text{characteristic dim} = \frac{A}{P} = \frac{d}{4} = 0.025 \text{ m}$$

$$\frac{g\beta\rho^2 c_p}{\mu k} = 2.2 \times 10^{10} \quad k = 0.618$$

$$\text{Gr Pr} = (2.2 \times 10^{10})(0.025)^3(49 - 10) = 1.34 \times 10^7$$

$$C = 0.15 \quad m = \frac{1}{3} \quad \text{Nu} = C(\text{Gr Pr})^m = (0.15)(1.34 \times 10^7)^{1/3} = 35.6$$

$$\bar{h} = \frac{(35.6)(0.618)}{0.025} = 881 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h}A(T_w - T_\infty) = (881)\pi(0.05)^2(49 - 10) = 270 \text{ W}$$

7-125

$$T_f = \frac{15 - 10}{2} = 2.5^\circ\text{C} = 276 \text{ K} \quad \nu = 13.5 \times 10^{-6} \text{ m}^2/\text{s} \quad k = 0.0243$$

$$\text{Pr} = 0.71 \quad \delta = 0.025 \text{ m} \quad L = 1.0 \text{ m}$$

$$\text{Gr}_\delta \text{ Pr} = \frac{(9.8)\left(\frac{1}{276}\right)(0.025)^3(0.71)(15 + 10)}{(13.5 \times 10^{-6})^2} = 54,231$$

$$C = 0.197 \quad n = \frac{1}{4} \quad m = -\frac{1}{9}$$

$$\frac{k_e}{k} = (0.197)(54,231)^{1/4} \left(\frac{1}{0.025}\right)^{-1/9} = 1.995$$

$$k_e = 0.0485 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\frac{q}{A} = \frac{\Delta T}{R} = \frac{\Delta T}{\delta/k_e}$$

$$R = \frac{\delta}{k_e} = \frac{0.025}{0.0485} = 0.516$$

$$\text{For fiberglass blanket, } k = 0.04 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$R = \frac{0.025}{0.04} = 0.625$$

7-126
2

$$\text{For } \frac{k_e}{k} = 1.0 \quad \text{Gr}_\delta \text{ Pr} < 2000$$

$$\text{Worst condition} \quad \Delta T = 200^\circ\text{C}$$

$$v \sim 20 \times 10^{-6} \quad \beta = \frac{1}{373} \quad \text{Pr} = 0.7$$

$$\text{Gr}_\delta \text{ Pr} = \frac{g\beta\Delta T\delta^3 \text{Pr}}{v^2} = 2000$$

$$\frac{(9.8)\left(\frac{1}{373}\right)(200)\delta^3(0.7)}{(20 \times 10^{-6})^2} = 2000$$

$$\delta = 0.006 \text{ m}$$

For smaller values of ΔT (multiple layers) the spacing would be larger.

7-127

The apparent "leakage" of the window in the winter is in reality the downward free convection flow of cool air from the vertical window surface. In the summer, the free convection flow is upward so Aunt Maude feels no draft. An estimate of the draft velocity may be made by calculating the free convection velocity at the bottom of a vertical plate under typical winter conditions. The window might be about 3 ft high and a typical temperature difference might be 20°C , although it would obviously depend on weather conditions.

7-128

Neglect resistance of steel duct. Also, forced convection h is much larger than free convection h so that $T_w \approx 5^\circ\text{C}$

$$T_f = \frac{5 + 20}{2} = 12.5^\circ\text{C} = 286 \text{ K} \quad d = 0.18 \text{ m} \quad v = 14.5 \times 10^{-6}$$

$$\text{Pr} = 0.71 \quad k = 0.0251 \quad L = 30 \text{ m}$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{286}\right)(20 - 5)(0.18)^3(0.71)}{(14.5 \times 10^{-6})^2} = 9.98 \times 10^6$$

$$C = 0.53 \quad m = \frac{1}{4} \quad \text{Nu} = C(\text{Gr Pr})^m = (0.53)(9.98 \times 10^6)^{1/4} = 29.79$$

$$\bar{h} = \frac{(29.79)(0.0251)}{0.18} = 4.15 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \dot{m}c_p(T_2 - T_1) = \bar{h}A\left(T_\infty - \frac{T_1 + T_2}{2}\right)$$

$$\dot{m} = \rho A_c u_m (1.27)\pi(0.09)^2(7.5) = 0.242 \text{ kg/s}$$

$$(0.242)(1005)(T_2 - 5) = (4.15)\pi(0.18)(30)\left(20 - \frac{5 + T_2}{2}\right)$$

$$T_2 = 8.8^\circ\text{C}$$

Chapter 7

7-129

$d = 5 \text{ mm}$ and 50 mm range

$\Delta T \sim 30$ to 210°C

$$\beta \approx \frac{1}{373} \quad \text{Pr} = 0.7 \quad \nu \approx 20 \times 10^{-6}$$

Low limit

$$\text{Gr Pr} = \frac{g\beta\Delta T d^3 \text{Pr}}{\nu^2} = \frac{(9.8)(20)\left(\frac{1}{373}\right)(0.005)^3(0.7)}{(20 \times 10^{-6})^2} = 115$$

High limit

$$\text{Gr Pr} = \frac{(9.8)(210)\left(\frac{1}{373}\right)(0.05)^3(0.7)}{(20 \times 10^{-6})^2} = 1.21 \times 10^6$$

7-130

The general idea in this problem is to determine the surface temperature necessary to dissipate the same amount of energy in forced convection as in free convection. Because the forced convection value of h is larger than the value for free convection a lower surface temperature is required, and thereby produces the wind chill effect. The key assumption required is that of the surface temperature under still air conditions, and that obviously depends on the clothing the person is wearing! Although body temperature is about 98.6°F , the skin temperature can be much cooler; certainly when exposed to winter weather. Take 75°F as a first assumption for skin temperature, and then work through for other assumed values.

Chapter 8

8-1

- (a) $T = 800^\circ\text{C} = 1073 \text{ K}$ $\lambda_1 T = (0.2)(1073) = 214.6$
 $\lambda_2 T = (4)(1073) = 4292$ $E_{bo-\lambda_1} = 0$ $E_{bo-\lambda_2} = 0.53131$
 $E_b = (5.669 \times 10^{-8})(1073)^4 = 7.515 \times 10^4 \text{ W/m}^2$
 $q_{\text{trans}} = (0.53131)(0.9)(7.515 \times 10^4) = 35,933 \text{ W/m}^2$
- (b) $T = 550^\circ\text{C} = 823 \text{ K}$ $\lambda_2 T = (4)(823) = 3292$
 $E_b = (5.669 \times 10^{-8})(823)^4 = 26,007$ $E_{bo-\lambda_2} = 0.33834$
 $E_{bo-\lambda_1} = 0$
 $q_{\text{trans}} = (0.33834)(0.9)(26,007) = 7919 \text{ W/m}^2$
- (c) $T = 250^\circ\text{C} = 523 \text{ K}$ $\lambda_2 T = (4)(523) = 2092$
 $E_b = (5.669 \times 10^{-8})(523)^4 = 4241$ $E_{bo-\lambda_2} = 0.08182$
 $q_{\text{trans}} = (0.08182)(0.9)(4241) = 312.3 \text{ W/m}^2$
- (d) $T = 70^\circ\text{C} = 343 \text{ K}$ $\lambda_2 T = (4)(343) = 1372$
 $E_b = (5.669 \times 10^{-8})(343)^4 = 784.7$ $E_{bo-\lambda_2} = 0.0069$
 $q_{\text{trans}} = (0.0069)(0.9)(784.7) = 4.87 \text{ W/m}^2$

8-2

- (a) $\lambda_2 T = (5.5)(1073) = 5901.5$ $E_{bo-\lambda_2} = 0.72921$
 $q_{\text{trans}} = (0.72921)(0.85)(75,150) = 46,580 \text{ W/m}^2$
- (b) $\lambda_2 T = (5.5)(823) = 4527$ $E_{bo-\lambda_2} = 0.5684$
 $q_{\text{trans}} = (0.5684)(0.85)(26,007) = 12,565 \text{ W/m}^2$
- (c) $\lambda_2 T = (5.5)(523) = 2877$ $E_{bo-\lambda_2} = 0.24497$
 $q_{\text{trans}} = (0.24497)(0.85)(4241) = 883 \text{ W/m}^2$
- (d) $\lambda_2 T = (5.5)(343) = 1887$ $E_{bo-\lambda_2} = 0.05059$
 $q_{\text{trans}} = (0.05059)(0.85)(784.7) = 33.74 \text{ W/m}^2$

Chapter 8

8-3

- (a) $\lambda_2 T = (52)(1073) = 55,796$ $E_{bo-\lambda_2} = 1.0$
 $q_{\text{trans}} = (1.0)(0.92)(75,150) = 69,138 \text{ W/m}^2$
- (b) $\lambda_2 T = (52)(823) = 42,796$ $E_{bo-\lambda_2} = 0.998$
 $q_{\text{trans}} = (0.998)(0.92)(26,007) = 23,880 \text{ W/m}^2$
- (c) $\lambda_2 T = (52)(523) = 27,196$ $E_{bo-\lambda_2} = 0.993$
 $q_{\text{trans}} = (0.993)(0.92)(4241) = 3874 \text{ W/m}^2$
- (d) $\lambda_2 T = (52)(343) = 17,836$ $E_{bo-\lambda_2} = 0.97912$
 $q_{\text{trans}} = (0.97912)(0.92)(784.7) = 706.8 \text{ W/m}^2$

8-4

$$\lambda_1 T = (4)(560) = 2240 \mu \cdot ^\circ\text{R} \qquad \lambda_2 T = (15)(560) = 8400 \mu \cdot ^\circ\text{R}$$

$$\frac{E_b(0-\lambda_1)}{E_b(0-\infty)} = 0.00306 \qquad \frac{E_b(0-\lambda_2)}{E_b(0-\infty)} = 0.5890$$

$$E_b(\lambda_1-\lambda_2) = (1.714 \times 10^{-9})(560)^4(0.5890 - 0.00306) = 98.9 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2}$$

$$E(\lambda_1-\lambda_2) = (0.6)(98.9) = 59.3 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} = 187 \text{ W/m}^2$$

8-6

λ	α	$T = 300 \text{ K}$		$T = 1000 \text{ K}$		$T = 5000 \text{ K}$	
		λT	frac	λT	frac	λT	frac
0	0.05	0	0	0	0	0	0
1.2	0.5	360	0	1200	0.0021	6000	0.7377
3	0.4	900	0.74×10^{-4}	3000	0.273	15,000	0.969
6	0.2	1800	0.039	6000	0.7377	30,000	0.995
20	0	6000	0.7377	20,000	0.9855	100,000	1.0
∞	0	—	—	—	—	—	—

λ	α	Frac $\alpha \times \text{frac}$	$T = 300 \text{ K}$	$T = 1000 \text{ K}$	$T = 5000 \text{ K}$
0-1.2	0.05	0	0.0021	0.7377	
1.2-3	0.5	0.74×10^{-4}	0.271	0.231	
3-6	0.4	0.039	0.465	0.026	
6-20	0.2	0.699	0.248	0.005	
20- ∞	0	0	0	0	
$\sum \alpha \text{Frac} =$			0.155	0.371	0.164

8-7

$T = 5795 \text{ K}$

λ	λT	Frac	λ	Frac contained
0	0		0-0.2	0.0015
0.2	1159	0.0015	0.2-0.4	0.1235
0.4	2318	0.125	0.4-1.0	0.596
1.0	5795	0.721	1.0-2.0	0.219
2.0	11,590	0.94	over 2.0	0.06
∞		1.0		<hr/> 1.0

8-10

$T = 1073 \text{ K}$

λ	$\lambda T (\mu - k)$	fraction $0 - \lambda T$	fraction $\lambda_1 T - \lambda_2 T$
1	1073	7.74×10^{-4}	—
2	2146	9.13×10^{-2}	8.35×10^{-3}
3	3219	0.32233	0.23103
4	4292	0.53131	0.20898
5	5365	0.67651	0.1452
6	6348	0.76538	0.08887

Chapter 8

8-11

$T = 1373 \text{ K}$

fraction	λT	$\lambda(\mu)$
0.25	2897	2.11
0.5	4100	2.99
0.75	6149	4.48
0.98	18,222	13.27

8-12

$E_b = \sigma(1400)^4 = 2.177 \times 10^5 \text{ W/m}^2$

λ	λT	Fraction
0.6	840	0.00008
5	7000	0.80807

$$E = (2.177 \times 10^5)[(0.08)(0.00008) + (0.4)(0.80807 - 0.00008) + (0.7)(1 - 0.80807)]$$

$$= 1.000 \times 10^5 \text{ W/m}^2$$

8-13

$E = \int_0^\infty \epsilon_\lambda E_{b\lambda} d\lambda$
 $T = 2000 \text{ K}$
 $E_b = 9.07 \times 10^5$
 $T^5 = 3.2 \times 10^{16}$

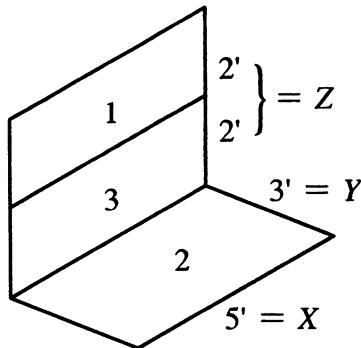
λ	λT	ϵ_λ	$E_{b\lambda}$	$\epsilon_\lambda E_{b\lambda}$
0	0	0	0	0
0.5	1000	0.25	6752	1688
1.0	2000	0.5	281,145	140,573
1.5	3000	0.5	410,384	205,192
2.0	4000	0.5	329,366	164,683
2.5	5000	0.5	228,371	114,186
3.0	6000	0.4	153,907	61,563
3.5	7000	0.3	104,573	31,372
4.0	8000	0.2	22,467	14,493
4.5	9000	0.1	19,363	1936
5.0	10,000	0		0

$$E = \int_0^{10} \epsilon_\lambda E_{b\lambda} d\lambda = \Delta\lambda \sum \epsilon_\lambda E_{b\lambda} = (0.5)(735,686) = 367,843 \text{ W/m}^2$$

$$\epsilon \text{ (avg.)} = \frac{E}{E_b} = \frac{3.678}{9.07} = 0.406$$

8-14

(a)

Find F_{1-2}

$$\frac{Y}{X} = \frac{3}{5} = 0.6 \quad \frac{Z}{X} = \frac{4}{5} = 0.8$$

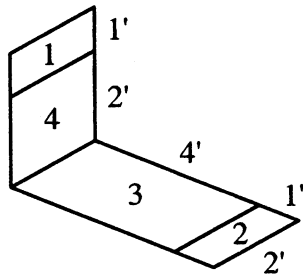
$$F_{2-3,1} = F_{2-3} + F_{2-1} = 0.25$$

$$F_{2-3} = 0.17$$

$$F_{2-1} = F_{2-3,1} - F_{2-3} = 0.08$$

$$A_1 F_{1-2} = A_2 F_{2-1} \quad \therefore F_{1-2} = 0.105$$

(b)

Find F_{1-2}

$$F_{1-2} = \frac{1}{A_1} [A_{1,4} (F_{1,4-3,2} - F_{1,4-3}) + A_4 (F_{4-3} - F_{4-3,2})]$$

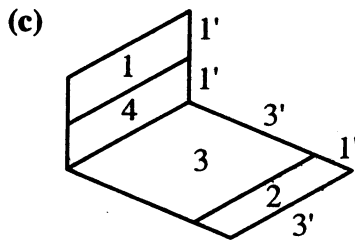
$$\frac{Y_{4-1}}{X} = \frac{3}{2} = 1.5 \quad \frac{Z_{32}}{X} = \frac{5}{2} = 2.25 \quad \frac{Y_{14}}{X} = 1.5$$

$$\frac{Z_3}{X} = 2 \quad \frac{Y_4}{X} = 1 \quad \frac{Z_3}{X} = 2 \quad \frac{Z_{32}}{X} = \frac{5}{2} = 2.25$$

$$F_{1,4} = 0.19 \quad F_{1,4-3} = 0.18 \quad F_{4-3} = 0.23 \quad F_{4-3,2} = 0.24$$

$$F_{1-2} = \frac{1}{2} [6(0.19 - 0.18) + 4(0.23 - 0.24)] = 0.01$$

Chapter 8

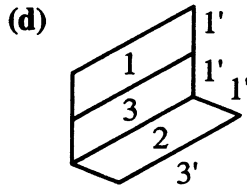


$$F_{1-2} = \frac{1}{A_1} [A_{1,4}(F_{1,4-3,2} - F_{1,4-3}) + A_4(F_{4-3} - F_{4-3,2})]$$

$$\frac{Y_{3,2}}{X} = 1.33 \quad \frac{Z_{1,4}}{X} = 0.666 \quad \frac{Y_3}{X} = 1 \quad \frac{Z_4}{X} = \frac{1}{3}$$

$$F_{1,4-3} = 0.26 \quad F_{4-3} = 0.35 \quad F_{4-3,2} = 0.36 \quad F_{1,4-3,2} = 0.27$$

$$F_{1-2} = \frac{1}{3} [6(0.27 - 0.26) + 3(0.36 - 0.35)] = 0.03$$



$$F_{2-3,1} = F_{2-3} + F_{2-1} \quad \frac{Y_2}{X} = \frac{1}{3} \quad \frac{Z_{3,1}}{X} = 0.666 \quad \frac{Z_3}{X} = \frac{1}{3}$$

$$F_{2-3,1} = 0.32 \quad F_{2-3} = 0.26 \quad F_{2-1} = 0.06$$

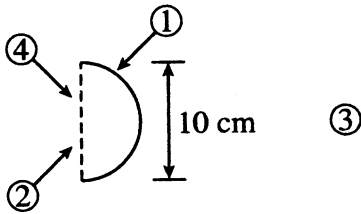
$$A_2 F_{2-1} = A_1 F_{1-2} \quad F_{1-2} = 0.06$$

8-15

$$r_1 = 5 \text{ cm} \quad r_2 = 2.5 \text{ cm} \quad L = 10 \text{ cm} \quad \frac{r_2}{L} = 0.25 \quad \frac{L}{r_1} = 2.0$$

$$\frac{r_1}{r_2} = 2.0 \quad F_{12} = 0.06 \quad F_{21} = F_{12} \frac{r_1}{r_2} = 0.12$$

8-16



$$F_{21} = 1.0 \quad A_1 = 2\pi r^2 = (2)\pi(12.5)^2 = 981.7 \quad A_2 = \pi r^2 = \pi(5)^2 = 78.5$$

$$F_{12} = (1.0)\left(\frac{78.5}{981.7}\right) = 0.08 \quad A_4 = \pi(12.5^2 - 5^2) = 412.3$$

$$F_{41} = 1.0 \quad F_{14} = F_{13} = 1.0\left(\frac{412.3}{981.7}\right) = 0.42$$

$$F_{12} + F_{11} + F_{13} = 1.0 \quad F_{11} = 1.0 - 0.08 - 0.42 = 0.50$$

Summary

$$F_{11} = 0.50 \quad F_{12} = 0.08 \quad F_{13} = 0.42 \quad F_{21} = 1.0 \quad F_{23} = 0$$

$$F_{31} = F_{32} = 0 \quad F_{33} = 1.0$$

8-17

$$r_1 = 5.0 \text{ cm} \quad r_2 = 12.5 \text{ cm} \quad L = 7 \text{ cm}$$

open ends = 3 & 4

$$\frac{L}{r_2} = 0.56 \quad \frac{r_1}{r_2} = 0.4 \quad F_{22} = 0.18 \quad F_{21} = 0.19$$

$$A_3 = A_4 = \pi(12.5^2 - 5.0^2) = 412.3 \text{ cm}^2$$

$$A_2 = \pi(25)(7) = 549.8 \text{ cm}^2$$

$$A_1 = \pi(10)(7) = 219.9 \text{ cm}^2$$

$$F_{21} + F_{22} + F_{23} + F_{24} = 1.0 \quad F_{23} = F_{24}$$

$$F_{23} = \frac{1 - 0.19 - 0.18}{2} = 0.315$$

$$F_{12} = 0.19\left(\frac{25}{10}\right) = 0.475$$

$$F_{12} + F_{13} + F_{14} = 1.0 \quad F_{13} = F_{14} \quad F_{13} = \frac{1 - 0.475}{2} = 0.263$$

$$F_{31} = (0.263)\left(\frac{A_1}{A_3}\right) = (0.263)\left(\frac{220}{412}\right) = 0.140$$

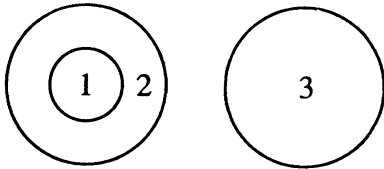
$$F_{32} = (0.315)\left(\frac{A_2}{A_1}\right) = (0.315)\left(\frac{550}{412}\right) = 0.421$$

$$F_{31} + F_{32} + F_{34} = 1.0$$

$$F_{34} = 1 - 0.140 - 0.421 = 0.439$$

Chapter 8

8-19



$$d_1 = 20 \quad d_2 = d_3 = 50 \quad L = 10$$

$$\text{Two large disks } \frac{d}{x} = \frac{50}{10} = 5.0$$

$$F_{3-21} = 0.65 = F_{21-3}$$

$$\text{Large disk to hole } \frac{r_1}{L} = \frac{10}{10} = 1.0 \quad \frac{L}{r_3} = \frac{10}{25} = 0.4$$

$$A_2 = \pi(25^2 - 10^2) \quad A_3 = \pi(25^2)$$

$$F_{31} = 0.15 \quad F_{31} + F_{32} = F_{3-21} \quad F_{32} = 0.65 - 0.15 = 0.5$$

$$F_{23} = F_{32} \left(\frac{A_3}{A_2} \right) = (0.5) \left(\frac{25^2}{25^2 - 10^2} \right) = 0.595$$

8-20

(a) $F_{21} = 1.0$

$$F_{12} = \frac{A_2}{A_1} = \frac{d}{\pi \frac{d}{2}} = \frac{2}{\pi} = 0.637$$

$$F_{11} = 1 - \frac{A_2}{A_1} = 1 - \frac{2}{\pi} = 0.363$$

(b) $F_{12} = \frac{A_1}{A_{\text{opening}}} = 0.637$

$$F_{11} = 1 - 0.637 = 0.363$$

$$F_{21} \approx 0 \text{ because } A_2 \rightarrow \infty$$

(c) Parallel disk $\frac{d}{x} = \frac{2}{1} = 2$ bottom = 2

$$F_{23} = 0.37 \quad F_{21} = 1 - 0.37 = 0.63 \quad A_2 F_{21} = A_1 F_{12}$$

$$F_{12} = \frac{\pi(1)^2(0.63)}{\pi(2)(1)} = 0.315 = F_{13}$$

$$F_{11} + F_{12} + F_{13} = 1.0 \quad F_{11} = 1 - 0.63 = 0.37$$

(d) $F_{12} = 1.0$ $F_{13} = 0$

$$A_1 = \pi(0.5)^2 = \frac{\pi}{4} \quad A_2 = 2\pi(1.5)^2 = 4.5\pi \quad A_2 F_{21} = A_1 F_{12}$$

$$F_{21} = \frac{\left(\frac{\pi}{4}\right)(1.0)}{4.5\pi} = 0.0555$$

$$A_{\text{open}} = \pi(1.5)^2 = 2.25\pi \quad F_{\text{open-2}} = 1.0$$

$$A_{\text{open}} F_{\text{open-2}} = A_2 F_2 - \text{open}$$

$$F_2 \text{ open} = \frac{(2.25)(1)}{4.5} = 0.5 = F_{21} + F_{23}$$

$$F_{23} = 0.5 - 0.0555 = 0.4444$$

$$F_{21} + F_{22} + F_{23} = 1.0$$

$$F_{22} = 0.5$$

(e) Parallel Disks

$$r_1 = 0.5 \quad r_3 = 1.5 \quad L = 2.0 \quad \frac{r_3}{L} = 0.75$$

$$\frac{L}{r_1} = 4.0$$

$$F_{13} = 0.35 \quad F_{12} = 1 - 0.35 = 0.65 \quad A_1 = \pi(0.5)^2 = \frac{\pi}{4}$$

$$A_2 = \pi(3)(2) = 6\pi \quad A_3 = \pi(1.5)^2 = 2.25\pi$$

$$F_{33} = 0.28 \quad \text{Top} = \text{surface 3'} \quad \frac{d}{x} = \frac{3}{2}$$

$$F_{32} = 1 - 0.28 = 0.72$$

$$A_3 - F_{32} = A_2 F_{23}$$

$$F_{23} = \left(\frac{2.25}{6}\right)(0.72) = 0.27 = F_{2-\text{bottom}}$$

$$A_1 F_{12} = A_2 F_{21}$$

$$F_{21} = \frac{\pi/4}{6\pi}(0.65) = 0.0271$$

$$F_{21} + F_{22} + F_{23} = 1.0$$

$$F_{23} = 0.27 + 0.27 - 0.0271 = 0.513$$

$$F_{22} = 1 - 0.0271 - 0.513 = 0.46$$

(f) $F_{12} = 0.5$
 $F_{21} \rightarrow 0$ because $A_2 \rightarrow \infty$

Chapter 8

(g) $A_1 = \sqrt{2}(1.5) = 2.121$ A_3 for opening = 2.121 $A_2 = 3.0$
 By symmetry $F_{21} = F_{23} = 0.5$ $A_1 F_{12} = A_2 F_{21}$
 $F_{12} = \frac{3}{2.121}(0.5) = 0.707$

(h) Perpendicular Rectangles

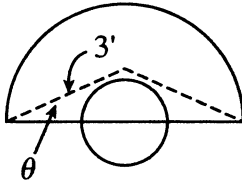
$$\frac{Y}{X} = \frac{Z}{X}$$

$\frac{Y}{X}$	F_{12}
0.6	0.23
0.4	0.25
0.2	0.27
0.1	0.285

$$F_{12} = 0.293 = F_{21}$$

$$F_{13} = F_{23} = 1 - 0.293 = 0.707$$

(i) $A_2 = 4\pi(0.5)^2 = \pi$ $A_1 = 2\pi(1.5)^2 = 4.5\pi$
 $F_{21} = 0.5$ $A_1 F_{12} = A_2 F_{21}$ $F_{12} = \frac{0.5}{4.5} = 0.1111$
 $A_3 =$ tangential frustrum of cone plus portion of sphere top



$$\sin \theta = \frac{0.5}{1.5} \quad \theta = 19.47^\circ \quad \text{tangent} = 1.5 \cos \theta = 1.414$$

$$r \text{ at tangent} = 0.5 \sin \theta = 0.1667$$

$$\text{cone area} = 2\pi \left(\frac{1.5 + 0.1667}{2} \right) (1.414) = 7.404$$

$$\text{Portion of sphere area} = 4\pi(0.5)^2 (2) \left(\frac{19.47}{360} \right) = 0.3398$$

$$A_3 = 7.404 + 0.3398 = 7.744$$

$$F_{3-1} = 1.0 \quad A_3 F_{3-1} = A_1 F_{1-3}$$

$$F_{1-3} = \frac{(1.0)(7.744)}{4.5\pi} = 0.548 = F_{12} + F_{13}$$

$$F_{13} = 0.548 - 0.1111 = 0.4369$$

$$F_{11} + F_{12} + F_{13} = 1.0$$

$$F_{11} = 1 - 0.1111 - 0.4369 = 0.452$$

8-21

$$F_{ii} = 0$$

$$\text{Perpendicular sides} \quad F_{ij} = 0.2$$

$$\text{Parallel sides} \quad F_{ij} = 0.2$$

8-22

$$F_{ii} = 0 \quad F_{ij} = \frac{1}{3}$$

8-23

$$T_1 = 260^\circ\text{C} = 533 \text{ K}$$

$$E_{b_1} = 4575 \text{ W/m}^2$$

$$T_2 = 90^\circ\text{C} = 363 \text{ K}$$

$$E_{b_2} = 984$$

$$A_1 = A_2 = 16$$

$$F_{12} = 0.27$$

$$\varepsilon_1 = \varepsilon_2 = 1.0$$

$$q = \frac{(16)(4575 - 984)}{(16+6) - (2)(16)(0.27)} = 36,485 \text{ W}$$

$$16 - (16)(0.27)^2$$

8-24

$$A_1 = A_2 = (1.2)^2 = 1.44 \text{ m}^2$$

$$T_1 = 800 \text{ K}$$

$$T_2 = 500 \text{ K}$$

$$E_{b_1} = 23,220 \text{ W/m}^2$$

$$E_{b_2} = 3543 \text{ W/m}^2$$

$$F_{12} = 0.2$$

$$q_{12} = (1.44)(0.2)(23,220 - 3543) = 5667 \text{ W}$$

8-25

$$T_1 = 540^\circ\text{C} = 813 \text{ K}$$

$$T_2 = 300^\circ\text{C} = 573 \text{ K}$$

$$\varepsilon_1 = 0.7$$

$$\varepsilon_2 = 0.5 \quad T_3 = 100^\circ\text{C} = 373 \text{ K}$$

$$A_1 = A_2 = 0.2827 \text{ m}^2$$

$$F_{12} = 0.6 \quad F_{13} = F_{23} = 0.4$$

$$E_{b_1} = 24,767 \text{ W/m}^2$$

$$E_{b_2} = 6111$$

$$E_{b_3} = 1097 = J_3$$

$$\frac{1 - \varepsilon_1}{\varepsilon_1 A_1} = 1.516$$

$$\frac{1 - \varepsilon_2}{\varepsilon_2 A_2} = 3.537$$

$$\frac{1}{A_1 F_{12}} = 5.896$$

$$\frac{1}{A_1 F_{13}} = \frac{1}{A_2 F_{23}} = 8.843$$

$$\frac{24,767 - J_1}{1.516} + \frac{J_2 - J_1}{5.896} + \frac{1097 - J_1}{8.843} = 0$$

$$\frac{J_1 - J_2}{5.896} + \frac{1097 - J_2}{8.843} + \frac{6111 - J_2}{3.537} = 0$$

$$J_1 = 19,089 \text{ W/m}^2 \quad J_2 = 9002 \text{ W/m}^2$$

$$q_1 = \frac{24,767 - 19,089}{1.516} = 3745 \text{ W} \quad q_2 = \frac{6111 - 9001}{3.537} = -817 \text{ W}$$

Chapter 8

8-26

$$J_{2D} = \varepsilon_2 E_{b_2} = 3.056 \quad \rho_{23} = 0.5 \quad \frac{1}{A_1 F_{12}(1 - \rho_{23})} = 11.79$$

$$\frac{1}{A_2 F_{23}(1 - \rho_{23})} = 17.69 \quad \frac{24,767 - J_1}{1.516} + \frac{\frac{3.056}{0.5} - J_1}{11.79} + \frac{478 - J_1}{8.843} = 0$$

$$J_1 = 19,719 \text{ W/m}^2 \quad q_1 = \frac{24,767 - 19,719}{1.516} = 3330 \text{ W}$$

$$q_2 = \frac{6111 - 19,719}{11.79} + \frac{6111 - 478}{17.69} = -836 \text{ W}$$

8-27

$$E_{b_1} = 459 \text{ W/m}^2 \quad E_{b_2} = 401 \text{ W/m}^2 \quad F_{12} = 0.25 \quad A_1 = A_2 = 9$$

$$\varepsilon_1 = 0.8 \quad \varepsilon_2 = 0.8$$

$$q = \frac{(9)(459 - 401)}{\frac{9+9-(2)(9)(0.25)}{9-(9)(0.25)^2} + (2)\left(\frac{1}{0.8} - 1\right)} = 248.6 \text{ W}$$

From symmetry $J_3 = \frac{1}{2}(E_{b_1} + E_{b_2}) = E_{b_3} = 430$

$$T_3 = \left(\frac{E_{b_3}}{\sigma}\right)^{1/4} = 295 \text{ K} = 22.1^\circ\text{C}$$

8-28

$$T_1 = 800^\circ\text{C} = 1073 \text{ K} \quad E_{b_1} = \sigma T_1^4 = 75,146 \text{ W/m}^2$$

$$\varepsilon_1 = 0.8 \quad \varepsilon_2 = 0.1 \quad T_3 = 300 \text{ K} \quad E_{b_3} = \sigma T_3^4 = 459$$

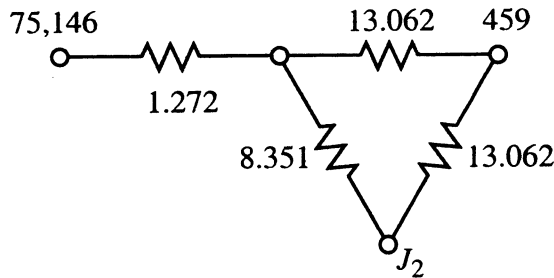
$$d = 50 \text{ cm} \quad x = 12.5 \text{ cm} \quad \frac{d}{x} = 4$$

$$F_{12} = 0.61 = F_{21} \quad F_{13} = 0.39 = F_{23}$$

$$A_1 = A_2 = \pi(0.25)^2 = 0.1963 \text{ m}^2$$

$$\frac{1 - \varepsilon_1}{\varepsilon_1 A_1} = \frac{0.2}{(0.8)(0.1963)} = 1.273 \quad \frac{1}{A_1 F_{12}} = \frac{1}{(0.1963)(0.61)} = 8.351$$

$$\frac{1}{A_1 F_{13}} = \frac{1}{(0.1963)(0.39)} = 13.062 = \frac{1}{A_2 F_{23}} \quad \frac{1 - \varepsilon_3}{\varepsilon_3 A_3} \rightarrow 0$$



$$q = \frac{75,146 - 459}{1.272 + \frac{1}{\frac{1}{13.062} + \frac{1}{13.062 + 8.351}}} = \frac{74,687}{9.385} = 7958 \text{ W}$$

8-29

$$T_f = 350 \text{ K} \quad T_r = 22^\circ\text{C} = 295 \text{ K} \quad p = 1.7 \text{ atm}$$

$$v = \frac{20.76 \times 10^{-6}}{1.7} \quad k = 0.03003 \quad \text{Pr} = 0.697 \quad \varepsilon = 1.0$$

$$\text{Gr Pr} = \frac{(9.8)\left(\frac{1}{350}\right)(127 - 27)(0.5)^3(0.697)(1.7)^2}{(20.76 \times 10^{-6})^2} = 1.64 \times 10^9$$

$$c = 0.1 \quad m = \frac{1}{3}$$

$$\bar{h} = \frac{0.03003}{0.5} (0.1)(1.64 \times 10^9)^{1/3} = 7.07 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q_{\text{conv}} = hA(T_w - T_\infty) = (7.07)(2)(0.5)^2(127 - 27) = 353.6 \text{ W}$$

$$q_{\text{rad}} = \sigma A \varepsilon (T_w^4 - T_r^4) = (5.669 \times 10^{-8})(2)(0.5)^2(1.0)(400^4 - 295^4) = 510.9 \text{ W}$$

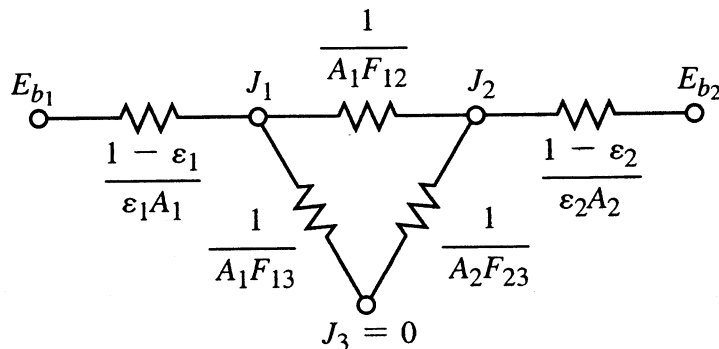
$$q_{\text{total}} = 864.5 \text{ W}$$

8-30

$$A_1 = A_2 = (1.5)^2 = 2.25 \text{ m}^2 \quad T_1 = 800^\circ\text{C} = 1073 \text{ K} \quad T_2 = 553 \text{ K}$$

$$\varepsilon_1 = 0.5 \quad \varepsilon_2 = 0.8 \quad T_3 = 0 \text{ K} \quad F_{12} = 0.7 \quad F_{13} = F_{23} = 0.3$$

$$E_{b_1} = 75,146 \text{ W/m}^2 \quad E_{b_2} = 5302 \text{ W/m}^2$$



Chapter 8

Node J_1

$$\frac{75,146 - J_1}{0.4444} + \frac{J_2 - J_1}{0.6349} + \frac{0 - J_1}{1.481} = 0$$

Node J_2

$$\frac{J_1 - J_2}{0.6349} + \frac{0 - J_2}{1.481} + \frac{5302 - J_2}{0.1111} = 0$$

$$J_1 = 41,070 \text{ W/m}^2 \quad J_2 = 9992 \text{ W/m}^2$$

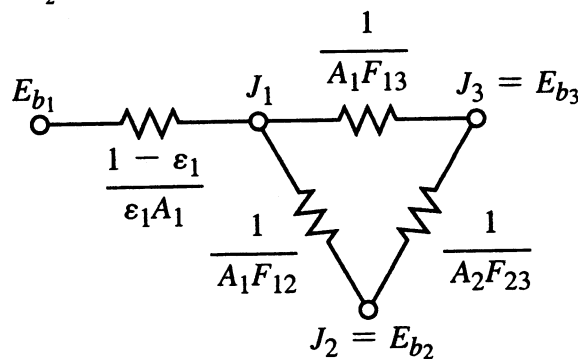
$$q_1 = \frac{75,146 - 41,070}{0.4444} = 76,671 \text{ W}$$

$$q_2 = \frac{5302 - 9992}{0.1111} = -42,210 \text{ W}$$

8-31

$$A_1 = A_2 = (0.9)(0.6) = 0.54 \text{ m}^2 \quad \epsilon_1 = 0.6 \quad E_{b_1} = 23,220 \text{ W/m}^2$$

$$E_{b_2} = 401 \text{ W/m}^2 \quad A_3 \rightarrow \infty \quad F_{12} = 0.25 \quad F_{13} = 0.75 = F_{23}$$



$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = 1.235$$

$$\frac{1}{A_1 F_{13}} = \frac{1}{A_2 F_{23}} = 2.469$$

$$\frac{1}{A_1 F_{12}} = 7.407$$

$$q = \frac{23,220 - 401}{1.235 + \frac{1}{\frac{1}{2.469} + \frac{1}{2.469} + 7.407}}} = 7108 \text{ W} = \frac{23,220 - J_1}{1.235}$$

$$J_1 = 14,441 \text{ W/m}^2$$

$$\frac{14,441 - J_2}{7.407} = \frac{J_2 - 401}{2.469}$$

$$J_2 = 3911 = E_{b_2} = \sigma T_2^4$$

$$T_2 = 512.5 \text{ K} = 239.5^\circ\text{C}$$

8-32

$$\frac{q}{L} = (5.669 \times 10^{-8})\pi(0.05)(0.6)(366^4 - 293^4) = 56.5 \text{ W/m} = 17.22 \text{ W/ft}$$

8-33

$$\Delta T = 100 - 27 = 73^\circ\text{C}; k = 0.04; W = 0.05; r = 0.0125; L = 2.0$$

$$\text{Table 3-1; } S = 2\pi(2)/\ln[0.54(0.05)/0.0125] = 1.632$$

$$R_{\text{ins}} = 1/kS = 15.318$$

$$R_{\text{conv}} = 1/hA = 1/(5.1)(4)(0.05)(2) = 0.49$$

$$h_{\text{rad}} = \sigma(T+300)(T^2+300^2)$$

$$h_{\text{tot}} = h_{\text{rad}} + 5.1$$

$$q = (373 - T)(0.04)(1.632) = (T - 300)(5.1 + h_r)(4)(0.05)(2)$$

Solve by iteration for T. The result is: T = 301 K

$$q = 4.69 \text{ W}$$

8-34

$$q = \sigma A \varepsilon (T_1^4 - T_2^4) = (5.669 \times 10^{-8})(0.6)(0.3)(0.8)(368^4 - 293^4) = 89.55 \text{ W}$$

8-35

$$T_w = 150^\circ\text{C} = 423 \text{ K} \quad T_\infty = 20^\circ\text{C} = 293 \text{ K} \quad T_r = 38^\circ\text{C} = 311 \text{ K}$$

$$d = 0.125 \text{ m} \quad L = 6 \text{ m}$$

Free convection

$$h = 1.32 \left(\frac{\Delta T}{d} \right)^{1/4} = (1.32) \left(\frac{150 - 20}{0.125} \right)^{1/4} = 7.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q(\text{conv}) = hA(T_w - T_\infty) = (7.5)\pi(0.125)(6)(150 - 20) = 2296 \text{ W}$$

Radiation

$$q(\text{rad}) = \sigma \epsilon A (T_w^4 - T_r^4) = (5.669 \times 10^{-8})\pi(0.125)(6)(423^4 - 311^4) = 3027 \text{ W}$$

$$q(\text{total}) = 2296 + 3027 = 5323 \text{ W}$$

8-36

$$A_1 = \text{heater} \quad A_2 = \text{side walls} \quad A_4 = \text{room} \rightarrow \infty \quad A_3 = \text{belt}$$

$$J_2 = E_{b_2} \quad T_1 = 698 \text{ K} \quad T_3 = 393 \text{ K} \quad T_4 = 298 \text{ K}$$

$$E_{b_1} = 13,456 \text{ W/m}^2 \quad E_{b_3} = 1352 \quad E_{b_4} = 447$$

$$\epsilon_1 = 0.7 \quad \epsilon_3 = 0.8 \quad A_1 = A_3 = 3 \text{ m}^2 \quad A_2 = 1.8 \text{ m}^2$$

$$F_{12} = F_{32} = 0.28 \quad F_{31} = F_{13} = 0.67 \quad F_{14} = F_{34} = 1 - 0.67 - 0.28 = 0.05$$

$$F_{24} = (0.04)(2) = 0.08 \quad \frac{1}{A_3 F_{32}} = 1.19 \quad \frac{1}{A_1 F_{13}} = 0.4975$$

$$\frac{1}{A_1 F_{12}} = 1.19 \quad \frac{1}{A_2 F_{24}} = 6.944 \quad \frac{1}{A_1 F_{14}} = 6.667$$

$$\frac{1}{A_3 F_{34}} = 6.667 \quad \frac{1 - \epsilon_1}{\epsilon_1 A_1} = 0.1429 \quad \frac{1 - \epsilon_3}{A_3 \epsilon_3} = 0.0833$$

$$\frac{13,456 - J_1}{0.1429} + \frac{J_2 - J_1}{1.19} + \frac{J_3 - J_1}{0.4975} + \frac{447 - J_1}{6.667} = 0$$

$$\frac{J_1 - J_2}{1.19} + \frac{J_3 - J_2}{1.19} + \frac{447 - J_2}{6.944} = 0$$

$$\frac{J_1 - J_3}{0.4975} + \frac{J_2 - J_3}{1.19} + \frac{1352 - J_3}{0.0833} + \frac{447 - J_3}{6.667} = 0$$

$$\text{Solving:} \quad J_1 = 10,515 \quad J_2 = 6185 \quad J_3 = 2841$$

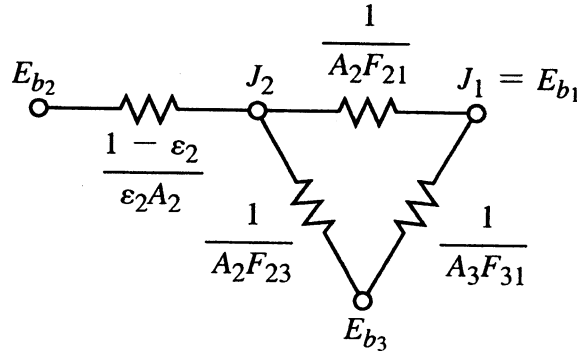
$$q_1 = \frac{13,456 - 10,515}{0.1429} = 20,580 \text{ W}$$

Chapter 8

8-37

$$T_2 = 1200 \text{ K} \quad \epsilon_2 = 0.75 \quad \epsilon_3 = 0.3 \quad q_3 = 0 \quad T_1 = 293 \text{ K}$$

$$E_{b_2} = \sigma T_2^4 = 1.176 \times 10^5 \quad E_{b_1} = \sigma T_1^4 = 417.8$$



$$\frac{1 - \epsilon_2}{\epsilon_2 A_2} = 42.44 \quad \frac{1}{A_2 F_{23}} = 167.53 \quad \frac{1}{A_2 F_{21}} = 530.52$$

$$\frac{1}{A_3 F_{31}} = 361.84$$

$$\text{Req.} = 42.44 + \frac{1}{\frac{1}{530.52} + \frac{1}{167.53 + 361.84}} = 307.44$$

$$q = \frac{1.176 \times 10^5 - 477.8}{307.4} = 382 \text{ W} = \frac{1.176 \times 10^5 - J_2}{42.44} \quad J_2 = 1.014 \times 10^5$$

$$\frac{1.014 \times 10^5 - E_{b_3}}{167.53} = \frac{1.014 \times 10^5 - 477.8}{167.53 + 361.84} \quad E_{b_3} = 6.946 \times 10^4$$

$$T_3 = 1052 \text{ K}$$

8-38

$$A_1 = \pi(0.02) = 0.06283 \quad A_2 = \pi(0.06) = 0.1884$$

$$E_{b_1} = \sigma T_1^4 = 32,922 \text{ W/m}^2 \quad E_{b_3} = \sigma T_3^4 = 459 \quad F_{12} = 1.0$$

$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = \frac{0.6}{(0.4)(0.06283)} = 23.874 \quad \frac{1 - \epsilon_2}{\epsilon_2 A_2} = \frac{0.8}{(0.2)(0.1884)} = 21.231$$

$$\frac{1}{A_1 F_{12}} = 15.916 \quad \frac{1}{A_2 F_{23}} = 5.308$$

$$q_1 = \frac{32,922 - 459}{23.874 + 15.916 + (2)(21.231) + 5.308} = 371.6 \text{ W/m}$$

$$= \frac{32,922 - E_{b_2}}{23.874 + 15.916 + 21.231} = \frac{32,922 - E_{b_2}}{61.021}$$

$$E_{b_2} = 10,317 \text{ W/m}^2 \quad T_2 = 653 \text{ K} = 380^\circ\text{C}$$

8-39

$$L = 30 \text{ cm} \quad r_1 = 4 \text{ cm} \quad F_{12} = 0.8 \quad r_2 F_{21} = r_1 F_{12}$$

Iteration Solution

r_2	$\frac{r_1}{r_2}$	$\frac{L}{r_2}$	F_{21}	$F_{12} = F_{21} \frac{r_2}{r_1}$	$0.8 - F_{12}$
8	0.5	3.75	0.45	0.9	-0.1
10	0.4	3.0	0.35	0.87	-0.07
12	0.33	2.5	0.27	0.81	-0.01
16	0.25	1.875	0.18	0.72	+0.08
12.44	0.3215	2.41	Interpolated		0

8-40

$$E_{b1} = 117500$$

$$E_{b2} = 3543$$

$$E_{b3} = 459; \quad A_1 = A_2 = \pi(0.3)^2/4 = 0.0707; \quad d/x = 3.0$$

$$\text{Fig. 8-13 } F_{12} = 0.52; \quad F_{13} = F_{23} = 0.48$$

$$q_{12} = (0.0707)(0.52)(117500 - 3543) = 4190 \text{ W}$$

$$q_{13} = (0.0707)(0.48)(117500 - 459) = 3971$$

$$q_1 = 8161 \text{ W}$$

$$q_{21} = -4190$$

$$q_{23} = (0.0707)(0.48)(3543 - 459) = 105 \text{ W}$$

$$q_2 = 14085 \text{ W}; \quad \text{Check } q_1 + q_2 + q_3 = 0$$

8-41

$$(E_{b1} - E_{b2})(0.52) = (0.48)(E_{b2} - E_{b3}) + (1.0)(E_{b2} - E_{b3})$$

$$E_{b2} = 30890; \quad T_2 = 859 \text{ K}$$

$$q_1 = 0.0707[(0.52)(117500 - 30890) + (0.48)(117500 - 459)]$$

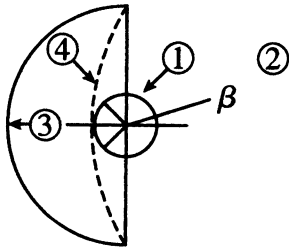
$$= 7456 \text{ W}$$

8-42

$$\begin{aligned}
d &= 75 \text{ cm} & x &= 50 \text{ cm} & \frac{d}{x} &= 1.5 & \frac{q}{A_1} &= 7000 & \epsilon_1 &= 0.8 \\
\epsilon_2 &= 0.6 & T_2 &= 400 \text{ K} & F_{12} &= F_{21} &= 0.3 & F_{13} &= F_{23} &= 0.7 \\
E_{b_2} &= 1451 & A_1 &= A_2 &= \pi \left(\frac{0.75}{2} \right)^2 &= 0.4418 & A_3 &= \pi(0.5)(0.75) &= 1.178 \\
F_{31} &= F_{32} &= 0.263 & F_{33} &= 1 - (0.2)(0.263) &= 0.474 \\
\frac{1 - \epsilon_1}{\epsilon_1 A_1} &= 0.5659 & \frac{1 - \epsilon_2}{\epsilon_2 A_2} &= 1.509 & \frac{1}{A_1 F_{12}} &= 7.545 \\
\frac{1}{A_1 F_{13}} &= \frac{1}{A_2 F_{23}} &= 3.234 \\
J_1 - (F_{12} J_2 + F_{13} J_3) &= 7000 & J_2 - 0.4(F_{21} J_1 + F_{23} J_3) &= 871 \\
J_3(1 - 0.474) - (F_{31} J_1 + F_{32} J_2) &= 0 \\
J_1 &= 7000 + 0.3 J_2 + 0.7 J_3 = 16,795 \text{ W/m}^2 \\
J_2 &= 871 + 0.12 J_1 + 0.28 J_3 = 6075 \text{ W/m}^2 \\
J_3 &= 0.498 J_1 + 0.498 J_2 = 11,389 = E_{b_3} = \sigma T_3^4 \\
T_3 &= 669 \text{ K} & \frac{E_{b_1} - 16,795}{\frac{1 - 0.8}{0.8}} &= 7000 \\
E_{b_1} &= 18,545 = \sigma T_1^4 & T_1 &= 756 \text{ K}
\end{aligned}$$

Chapter 8

8-43



$$T_1 = 1253 \text{ K} \quad T_2 = 288 \text{ K} \quad F_{13} = 0.5 \quad F_{12} = 0.5$$

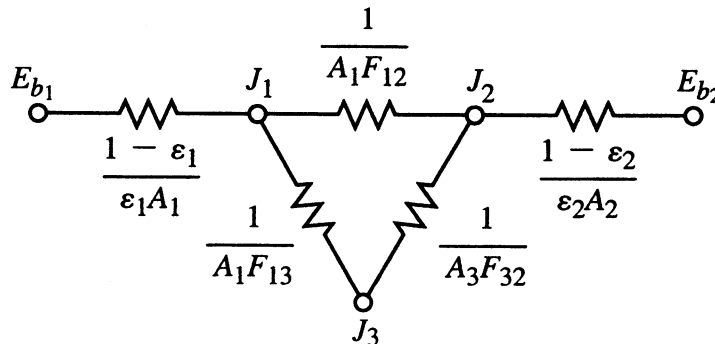
$$\beta = 2\alpha \quad \sin \alpha = \frac{3.75}{25} \quad \alpha = 8.627^\circ \quad \beta = 17.25^\circ$$

$$A_4 = 2(0.25 \cos \alpha) + \pi(0.075) \left(\frac{2\alpha}{360} \right) = 0.5056 \quad F_{43} = 1.0$$

$$A_3 = \pi(0.25) = 0.7854 \quad F_{34} = F_{31} + F_{32} = \frac{(0.5056)(1.0)}{0.7854} = 0.6437$$

$$A_1 = \pi(0.025) = 0.2356 \quad F_{31} = \frac{(0.2356)(0.5)}{0.7854} = 0.15$$

$$F_{32} = 0.6437 - 0.15 = 0.4937$$



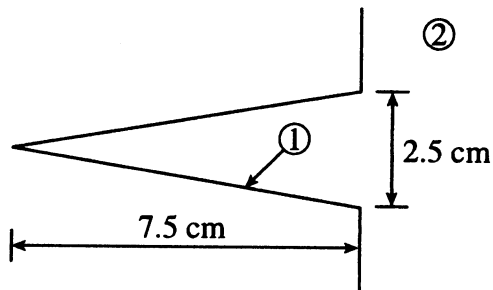
$$\frac{1-\epsilon_1}{\epsilon_1 A_1} = 1.061 \quad \frac{1}{A_1 F_{12}} = 8.489 \quad \frac{1}{A_3 F_{32}} = 2.579 \quad \frac{1}{A_1 F_{13}} = 8.489$$

$$E_{b1} = 139,736 \text{ W/m}^2 \quad E_{b2} = 390 \text{ W/m}^2$$

$$q = \frac{139,736 - 390}{1.061 + \frac{1}{8.489 + \frac{1}{8.489 + 2.579}}} = 23,758 \text{ W/m}$$

$$q \text{ w/o reflector} = \epsilon_1 A_1 (E_{b1} - E_{b2}) = 26,264 \text{ W/m}$$

8-40



$$T_1 = 823 \text{ K} \quad \epsilon_1 = 0.5 \quad T_2 = 0 \text{ K}$$

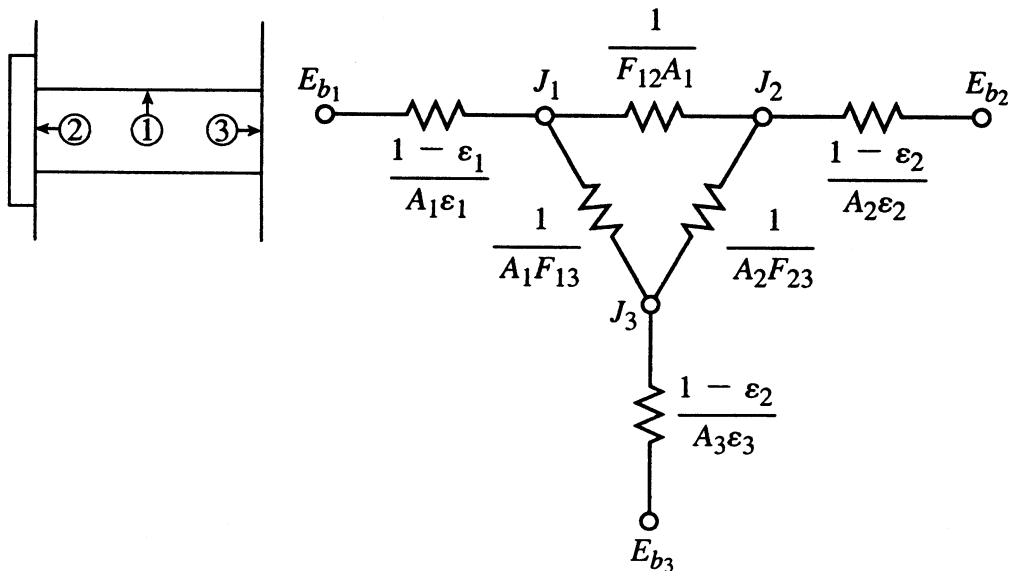
$$A_1 = \pi(1.25)(1.25^2 + 7.5^2)^{1/2} = 29.86 \text{ cm}^2$$

$$A_2 = \pi(1.25)^2 = 4.91 \text{ cm}^2 \quad F_{21} = 1.0$$

$$q = \frac{(5.669 \times 10^{-8})(823)^4 - 0}{\frac{1-0.5}{(0.5)(0.002986)} + \frac{1}{4.91 \times 10^{-4}} + 0} = 10.97 \text{ W}$$

$$\epsilon_{\text{app}} = \frac{10.97}{(5.669 \times 10^{-8})(823)^4 (4.9 \times 10^{-4})} = 0.859$$

8-45



$$T_1 = 260^\circ\text{C} = 533 \text{ K} \quad T_2 = 425^\circ\text{C} = 698 \text{ K}$$

$$\epsilon_3 = 1.0 \quad \epsilon_2 = 0.5 \quad \epsilon_1 = 0.07 \quad T_3 = 0 \text{ K} \quad F_{23} = 0.04$$

$$F_{21} = 0.96 \quad A_1 = \pi(2.5)(7.5) = 58.9 \text{ cm}^2$$

$$A_2 = A_3 = \pi(1.25)^2 = 4.91 \text{ cm}^2 \quad F_{12} = F_{13} = \frac{A_2}{A_1} F_{21} = (0.96) \left(\frac{4.91}{58.9} \right) = 0.08$$

$$E_{b1} = 4575 \quad E_{b2} = 13,456$$

Chapter 8

Node J₁

$$\frac{4575 - J_1}{2256} + \frac{J_2 - J_1}{2121} + \frac{0 - J_1}{2122} = 0$$

Node J₂

$$\frac{13,456 - J_2}{2037} + \frac{J_1 - J_2}{2121} + \frac{0 - J_2}{50,916} = 0$$

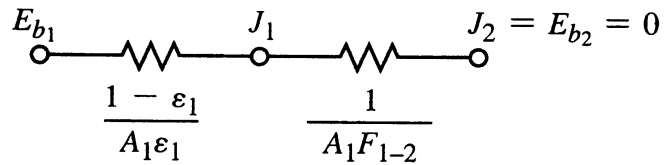
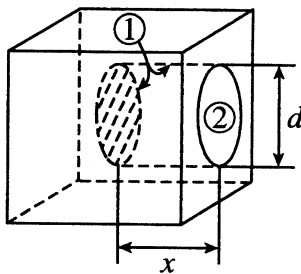
$$J_1 = 4484 \quad J_2 = 8879$$

$$q_1 = \frac{4575 - 4484}{2256} = 0.0403$$

$$q_2 = \frac{13,456 - 8879}{2037} = 2.247$$

$$q_3 = 2.287 \text{ W}$$

8-46

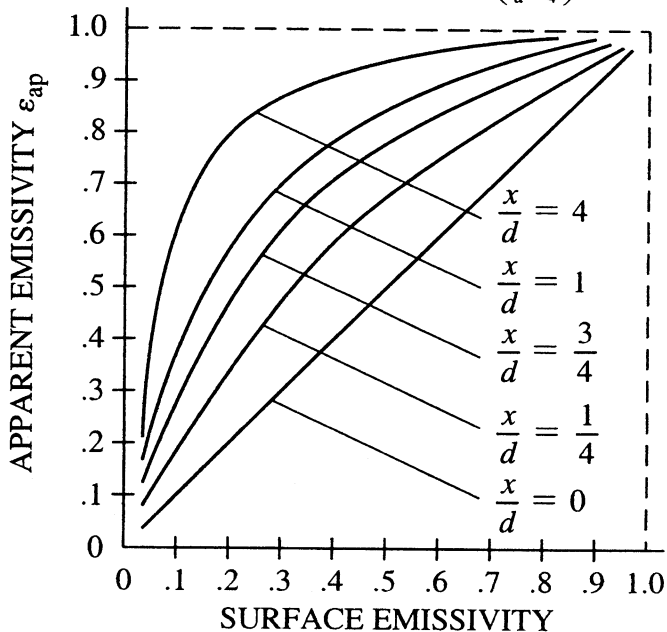


Plot apparent emissivity ϵ_{ap} vs $\frac{x}{d}$ and ϵ .

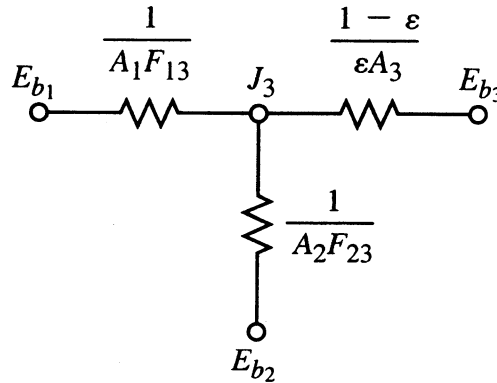
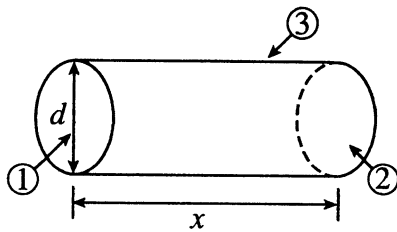
$$q_{1-2} = \frac{E_{b1} - 0}{\frac{1 - \epsilon_1}{A_1 \epsilon_1} + \frac{1}{A_2}}$$

$$A_1 F_{1-2} = A_2 F_{2-1} = A_2 \quad F_{2-1} = 1$$

$$\epsilon_{ap} = \frac{q_{1-2}}{(q_2)_b} = \frac{E_{b1}}{\left[\frac{(1 - \epsilon_1) A_2 + A_1 \epsilon_1}{A_1 A_2 \epsilon_1} \right] E_{b1} A_2} = \frac{4}{\left(\frac{1}{\frac{x}{d} + 1} \right) \left(\frac{1 - \epsilon_1}{\epsilon_1} \right) + 4}$$



8-47



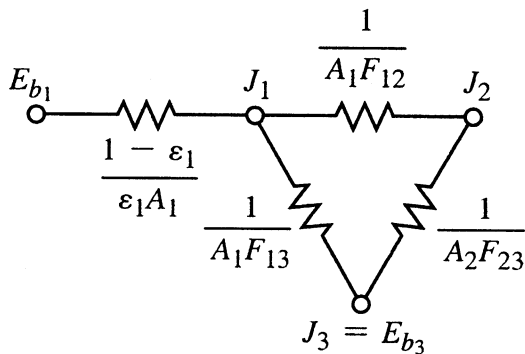
$$\begin{aligned} \epsilon_3 &= \epsilon & E_{b1} &= E_{b2} = 0 & \epsilon_2 &= \epsilon_1 = 1.0 & F_{13} &= F_{23} = 1 - F_{12} \\ A_2 &= A_1 = \frac{\pi d^2}{4} & A_3 &= \pi x d & q_1 &= \frac{\frac{1}{2}(E_{b3} - 0)}{\frac{1-\epsilon_3}{\epsilon_3 A_3} + \frac{1}{A_1(1-F_{12})+A_2(1-F_{12})}} \\ \epsilon_{app1} &= \frac{q_1}{A_1 E_{b3}} & \epsilon_{app1} &= \epsilon_{app2} = \frac{\frac{1}{2}}{\left(\frac{1-\epsilon}{\epsilon}\right)\left(\frac{d}{4x}\right) + \frac{1}{2(1-F_{12})}} \end{aligned}$$

F_{12} is obtained from Fig. 8-13. Note that ϵ_{app} approaches 1.0 as $\frac{x}{d} \rightarrow \infty$.

As $\frac{x}{d} \rightarrow 0$ $\epsilon_{app} \rightarrow 0$

8-48

$$\begin{aligned} r_1 &= 0.5 & L &= 1.0 & r_2 &= 1.0 & q_2 &= 0 & T_1 &= 800 \text{ K} \\ T_3 &= 300 \text{ K} & \epsilon_1 &= 0.65 & \frac{r_1}{r_2} &= 0.5 & \frac{L}{r_2} &= 1.0 & F_{21} &= 0.35 \\ F_{22} &= 0.23 & F_{23} &= 1 - 0.35 - 0.23 = 0.42 & F_{12} &= F_{21} \left(\frac{A_2}{A_1}\right) &= 0.7 \\ F_{13} &= 1 - 0.7 = 0.3 & A_1 &= \pi(1)(1) = 3.142 & A_2 &= 2\pi = 6.284 \end{aligned}$$



Chapter 8

$$\begin{aligned} E_{b_1} &= \sigma T_1^4 = 23,216 \text{ W/m}^2 & E_{b_3} &= \sigma T_3^4 = 459 \text{ W/m}^2 \\ \frac{1 - \epsilon_1}{\epsilon_1 A_1} &= 0.1714 & \frac{1}{A_1 F_{13}} &= 1.061 & \frac{1}{A_1 F_{12}} &= 0.455 \\ \frac{1}{A_2 F_{23}} &= 0.379 \\ q &= \frac{23,216 - 459}{0.1714 + \frac{1}{\frac{1}{1.061} + 0.379 + 0.455}}} = 35,650 \text{ W} \end{aligned}$$

8-49

$$L = 0.1 \text{ m} \quad h_1 = (1.42)(100/0.1)^{1/4} = 7.99$$

$$h_2 = (1.42)[(T_2 - 300)/0.1]^{1/4}$$

Fig. 8-12; $F_{12} = 0.4$ $F_{13} = 0.6$

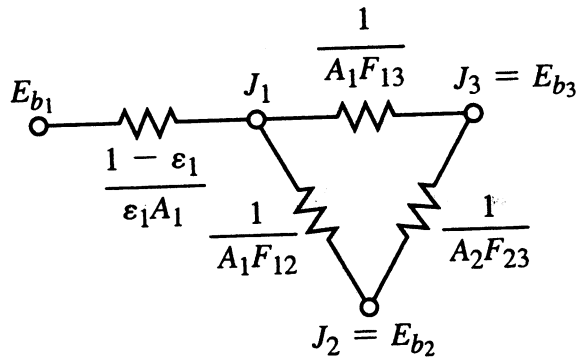
$$(0.1)^2 \sigma (400^4 - T^4)(0.4) = (0.1)^2 [\sigma (T^4 - 300^4)(0.6 + 1.0) + (1.42)(2)(T - 300)^{1/4} / 0.1^{1/4}]$$

Solve for T by iteration; $T = 327.5 \text{ K}$

$$\begin{aligned} q_1 &= (0.1)^2 [\sigma (400^4 - T^4)(0.4) + 0.6 \sigma (400^4 - 300^4) + (7.99)(400 - 300)] \\ &= 17.1 \text{ W} \end{aligned}$$

8-50

- $T_1 = 973 \text{ K}$ $E_{b1} = 50,811 \text{ W/m}^2$ $\epsilon_1 = 0.8$ $A_1 = (2)(3) = 6 \text{ m}^2$
 (2) Surface = side walls $A_2 = (10)(2) = 20 \text{ m}^2$
 (3) room $T_3 = 303 \text{ K}$ $E_{b3} = 478 \text{ W/m}^2$



$$\frac{X}{D} = 1.0 \quad \frac{Y}{D} = 1.5 \quad F_{13} = 0.25 \quad F_{12} = 0.75$$

$$F_{21} = \frac{6}{20}(0.75) = 0.225 \quad F_{23} = 0.225$$

$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = 4.1666 \times 10^{-2} \quad \frac{1}{A_1 F_{13}} = 0.6667 \quad \frac{1}{A_1 F_{12}} = 0.2222$$

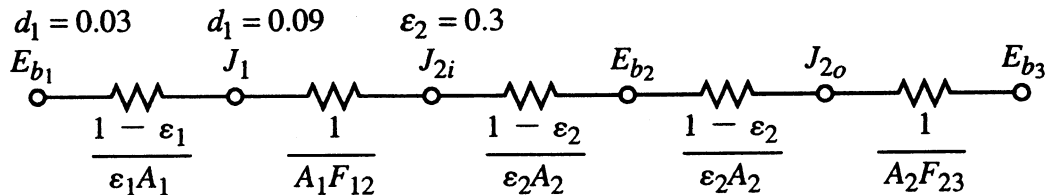
$$\frac{1}{A_2 F_{23}} = 0.2222$$

$$q = \frac{50,811 - 478}{0.0417 + \frac{1}{0.6667 + 0.2222 + 0.2222}} = 1.633 \times 10^5 \text{ W}$$

8-51

$T_1 = 1273 \text{ K}$ $E_{b_1} = 1.489 \times 10^5 \text{ W/m}^2$ $\epsilon_1 = 0.6$ $T_3 = 303 \text{ K}$

Surface (2) is sphere in radiant balance. $E_{b_3} = 478 \text{ W/m}^2$



$A_1 = 4\pi r_1^2 = 2.83 \times 10^{-3} \text{ m}^2$

$A_2 = 4\pi r_2^2 = 0.0254 \text{ m}^2$

$F_{12} = 1.0$ $F_{23} = 1.0$ $\frac{1-\epsilon_1}{\epsilon_1 A_1} = 235.6$ $\frac{1}{A_1 F_{12}} = 353.4$

$\frac{1-\epsilon_2}{\epsilon_2 A_2} = 91.86$ $\frac{1}{A_2 F_{23}} = 39.37$

$q = \frac{AE_b}{\sum R} = \frac{148,900 - 478}{235.6 + 353.4 + (2)(91.86) + 39.37} = 182.7 \text{ W}$

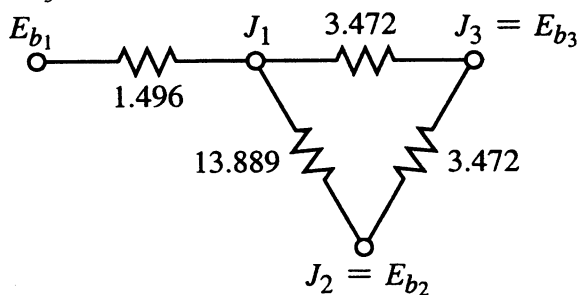
8-52

$T_1 = 873$ $\epsilon_1 = 0.65$ $q_2 = 0$ $T_3 = 303 \text{ K}$ $F_{12} = 0.2$

$F_{13} = F_{23} = 0.8$ $A_1 = A_2 = (0.6)^2 = 0.36$ $\frac{1-\epsilon_1}{\epsilon_1 A_1} = 1.496$

$\frac{1}{A_1 F_{13}} = 3.472 = \frac{1}{A_2 F_{23}}$ $\frac{1}{A_1 F_{12}} = 13.889$ $E_{b_1} = 32,928$

$E_{b_3} = 478$



$q = \frac{32,928 - 478}{1.496 + \frac{1}{\frac{1}{3.472} + \frac{1}{13.889 + 3.472}}} = 7393 \text{ W} = \frac{32,928 - J_1}{1.496}$

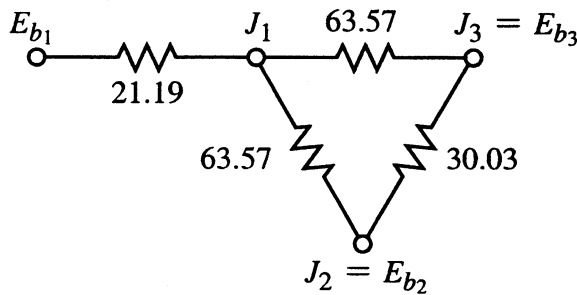
$J_1 = 21,868 \text{ W/m}^2$ $\frac{21,868 - J_2}{13.889} = \frac{21,868 - 478}{13.889 + 3.472}$

$J_2 = 4756 = E_{b_2}$ $T_2 = 538 \text{ K}$

Chapter 8

8-53

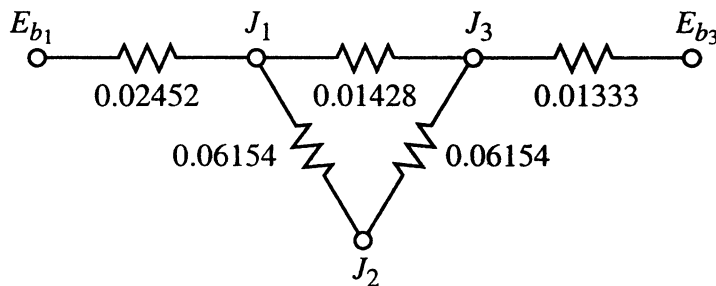
$$\begin{aligned}
 r_1 &= 5 \text{ cm} & r_2 &= 10 \text{ cm} & L &= 10 \text{ cm} & T_1 &= 973 \text{ K} & T_3 &= 303 \text{ K} \\
 \epsilon_1 &= 0.6 & \epsilon_2 &= 0.7 & q_2 &= 0 & \frac{r_1}{r_2} &= 0.5 & \frac{L}{r_2} &= 1.0 \\
 F_{21} &= 0.25 & F_{12} &= 0.50 & F_{22} &= 0.22 & F_{13} &= 0.5 & F_{23} &= 0.53 \\
 A_1 &= \pi(0.1)^2 = 0.03146 & A_2 &= \pi(0.2)(0.1) = 0.06283 & & & & & \frac{1-\epsilon_1}{\epsilon_1 A_1} &= 21.19 \\
 \frac{1}{A_1 F_{12}} &= 63.57 & \frac{1}{A_1 F_{13}} &= 63.57 & \frac{1}{A_2 F_{23}} &= 30.03 & & & &
 \end{aligned}$$



$$q = \frac{50,811 - 478}{21.19 + \frac{1}{\frac{1}{63.57} + \frac{1}{63.57 + 30.03}}} = 852 \text{ W}$$

8-54

$$\begin{aligned}
 A_1 &= A_3 = 25 \text{ m}^2 & A_2 &= (4)(5)(4) = 80 \text{ m}^2 & T_1 &= 301 \text{ K} & T_3 &= 293 \text{ K} \\
 E_{b1} &= 465.3 & E_{b3} &= 417.8 \text{ W/m}^2 & \epsilon_1 &= 0.62 & \epsilon_3 &= 0.75 \\
 \frac{X}{D} &= \frac{Y}{D} = 1.25 & F_{13} &= 0.35 & F_{12} &= 0.65 & \frac{1-\epsilon_1}{\epsilon_1 A_1} &= 0.02452 \\
 \frac{1-\epsilon_3}{\epsilon_3 A_3} &= 0.01333 & \frac{1}{A_1 F_{12}} &= 0.06154 = \frac{1}{A_3 F_{32}} & \frac{1}{A_1 F_{13}} &= 0.01428 & &
 \end{aligned}$$



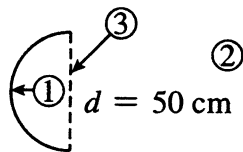
$$q = \frac{465.3 - 417.8}{0.02452 + \frac{1}{\frac{0.01428}{2} + 2(0.06154)}} + 0.01333 = 489.1 \text{ W} = \frac{E_{b1} - J_1}{0.02452} = \frac{J_3 - E_{b3}}{0.01333}$$

$$J_1 = 453.3 \text{ W/m}^2 \quad J_3 = 424.3 \text{ W/m}^2$$

$$\text{From Symmetry: } J_2 = \frac{J_1 + J_3}{2} = 438.8 \text{ W/m}^2 = \sigma T_2^4$$

$$T_2 = 296.6 \text{ K} = 23.6^\circ\text{C}$$

8-55



$$T_1 = 1000 \text{ K} \quad T_2 = 300 \text{ K} \quad \epsilon_1 = 0.7 \quad F_{31} = 0.5$$

$$F_{13} = F_{12} = 0.5 \frac{A_3}{A_1} = 0.5 \left(\frac{d}{\pi \frac{d}{2}} \right) = 0.3183$$

$$E_{b1} = 56,690 \text{ W/m}^2 \quad E_{b2} = 459 \text{ W/m}^2$$

$$\text{For unit length } A_1 = \pi d = 1.571$$

$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = 0.2728 \quad \frac{1}{A_1 F_{12}} = 2.0$$

$$\frac{q}{L} = \frac{56,690 - 459}{0.2728 + 2.0} = 2.47 \times 10^4 \text{ W}$$

8-56

$$E_{b1} = \sigma(673)^4 = 11,630 \quad E_{b3} = \sigma(873)^4 = 32,928 \text{ W/m}^2$$

$$\frac{1 - \epsilon_1}{\epsilon_1} = \frac{1 - 0.6}{0.6} = 0.6667 = \frac{1 - \epsilon_3}{\epsilon_3} \quad \frac{1 - \epsilon_2}{\epsilon_2} = \frac{0.9}{0.1} = 9$$

$$\frac{1}{F_{12}} = \frac{1}{F_{23}} = 1.0$$

For unit area

$$q = \frac{32,928 - 11,630}{0.6667 + 1 + (2)(9) + 1 + 0.6667} = 998.3 \text{ W/m}^2$$

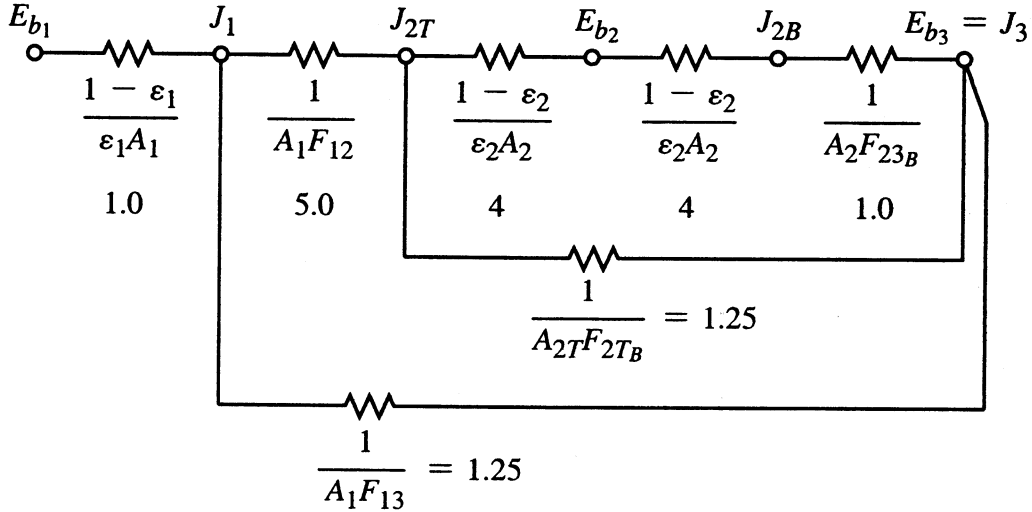
Chapter 8

8-57

$$A_1 = A_2 = 1.0 \quad A_3 \rightarrow \infty$$

$$E_{b_1} = 23,216 \text{ W/m}^2 \quad E_{b_3} = 459 \text{ W/m}^2$$

$$F_{12} = 0.2 \quad F_{13} = 0.8 = F_{23_{\text{Top}}} \quad F_{23_B} = 1.0$$



$$q = \frac{E_{b_1} - E_{b_3}}{\sum R} = \frac{23,216 - 459}{1.0373} = 11,170 \text{ W}$$

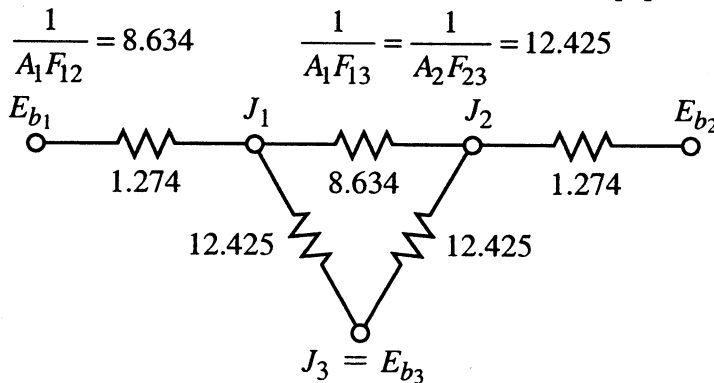
8-58

$$\frac{d}{x} = \frac{50}{12.5} = 4.0 \quad F_{12} = 0.59 \quad F_{13} = F_{23} = 0.41$$

$$A_1 = A_2 = \pi(0.25)^2 = 0.1963 \text{ m}^2 \quad \epsilon_1 = \epsilon_2 = 0.8 \quad T_1 = 1000 \text{ K}$$

$$T_2 = 500 \text{ K} \quad T_3 = 300 \text{ K} \quad E_{b_1} = 56,690$$

$$E_{b_2} = 3543 \text{ W/m}^2 \quad E_{b_3} = 459 \quad \frac{1 - \epsilon_1}{\epsilon_1 A_1} = \frac{1 - \epsilon_2}{\epsilon_2 A_2} = 1.274$$



$$\frac{56,690 - J_1}{1.274} + \frac{J_2 - J_1}{8.634} + \frac{459 - J_1}{12.425} = 0$$

$$\frac{J_1 - J_2}{8.634} + \frac{459 - J_2}{12.425} + \frac{3543 - J_2}{1.274} = 0$$

$$J_1 = 46,373 \text{ W/m}^2 \quad J_2 = 8346 \text{ W/m}^2$$

$$q_1 = \frac{56,690 - J_1}{1.274} = 8098 \text{ W} \quad q_2 = \frac{3543 - J_2}{1.274} = -3770 \text{ W}$$

8-59

Disk = (1) Shield = (2) Room = (3) $\frac{d}{x} = \frac{50}{25} = 2.0$ $F_{13} = 0.28$

$F_{12} = 0.72$ $T_1 = 873 \text{ K}$ $\epsilon_1 = 0.55$ $\epsilon_2 = 0.1$ $T_3 = 30^\circ\text{C}$

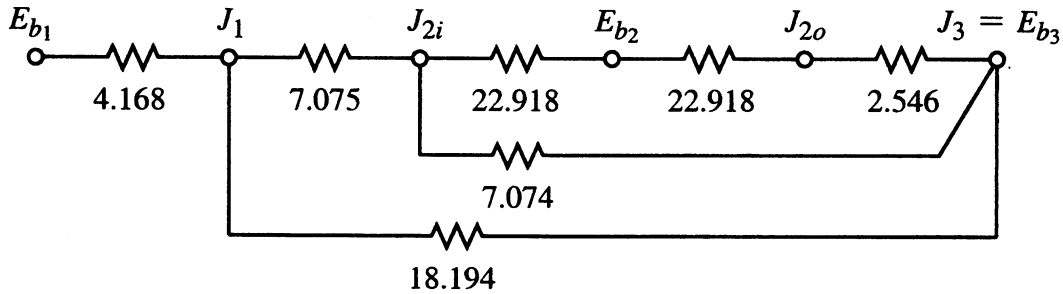
$E_{b_1} = 32,928 \text{ W/m}^2$ $E_{b_3} = 478 \text{ W/m}^2$ $A_1 = \pi(0.25)^2 = 0.1963 \text{ m}^2$

$A_2 = \pi(0.5)(0.25) = 0.3927 \text{ m}^2$ $F_{21} = F_{12} \frac{A_1}{A_2} = 0.36 = F_{23}$ (inside)

F_{23} (inside) = 1.0 $\frac{1 - \epsilon_1}{\epsilon_1 A_1} = 4.168$ $\frac{1 - \epsilon_2}{\epsilon_2 A_2} = 22.918$

$\frac{1}{A_1 F_{12}} = 7.075$ $\frac{1}{A_1 F_{13}} = 18.194$ $\frac{1}{A_2 F_{23}}$ = 7.074 (inside)

$\frac{1}{A_2 F_{23}}$ = 2.546 (outside)



$$q = \frac{E_{b_1} - E_{b_3}}{\sum R} \quad \frac{1}{R_1} = \frac{1}{(22.918)(2) + 2.546} + \frac{1}{7.074}$$

$$\frac{1}{R_2} = \frac{1}{R_1 + 7.025} + \frac{1}{18.194} \quad \sum R = 4.168 + R_2 \quad R_1 = 6.1716$$

$R_2 = 7.648$ $\sum R = 11.817$

$$q = \frac{32,928 - 478}{11.817} = 2746 \text{ W} = \frac{32,928 - J_1}{4.168} \quad J_1 = 21,482 \text{ W/m}^2$$

$$\frac{21,482 - J_{2i}}{7.075} = \frac{J_{2i} - 478}{6.1716} \quad J_{2i} = 10,264 \text{ W/m}^2 \quad J_{2o} = 993$$

$$\frac{J_{2i} - J_{2o}}{(2)(22.918)} = \frac{J_{2i} - 478}{48.382} \quad E_{b_2} = \frac{J_{2i} + J_{2o}}{2} = 5628 \text{ W/m}^2 = \sigma T_2^4$$

$T_2 = 561 \text{ K} = 288^\circ\text{C}$

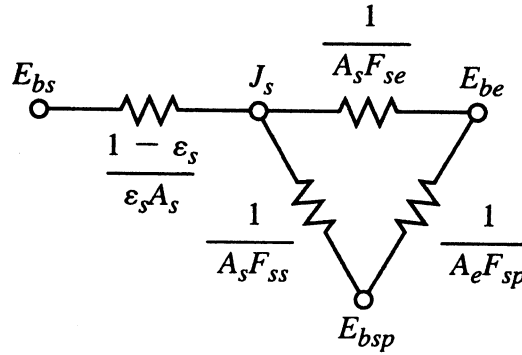
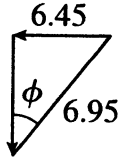
Chapter 8

8-61

$$1500\alpha = \epsilon\sigma T^4 \quad \epsilon = \alpha \quad T = 403.3 \text{ K} = 130.3^\circ\text{C}$$

8-62

(a) Dark Side



at equilibrium $J_s = E_{bs}$

$$\begin{aligned} \sin \phi &= \frac{6.45}{6.95} \\ \phi &= 70.3^\circ \\ \cos \phi &= 0.3367 \end{aligned}$$

$$\text{solid angle} = \frac{1 - \cos \phi}{2} = 0.3316 = F_{se} \quad F_{ss} = 0.6684 \quad F_{esp} \approx 1.0$$

$$A_s = \pi(1)^2 = \pi \text{ m}^2 \quad E_{be} = (5.669 \times 10^{-8})(288)^4 = 390 \text{ W/m}^2$$

$$E_{bsp} = 0 \quad \frac{390 - J_s}{1/0.3316} + \frac{0 - J_s}{1/0.6684} = 0 \quad J_s = 129.3 = E_s = \sigma T_s^4$$

$$T_s = 218.5 \text{ K} = -54.5^\circ\text{C}$$

(b) Bright Side

$$A_{\text{view}} = \pi \left(\frac{1}{2} \right)^2 = \frac{\pi}{4} \text{ for sun}$$

For polished Aluminum $t = 0.048$

$$q \text{ absorbed} = (0.048) \left(\frac{\pi}{4} \right) (1400) = 52.779 \text{ W}$$

$$\frac{E_{bs} - J_s}{\frac{1 - \epsilon_s}{\epsilon_s A_s}} = 52.779 \quad 52.779 + \frac{390 - J_s}{\frac{1}{\pi(0.3316)}} + \frac{0 - J_s}{\frac{1}{\pi(0.6684)}} = 0$$

$$J_s = 146.1 \quad E_{bs} = 146.1 + \frac{(52.779)(1 - 0.048)}{(0.048)\pi} = 479.3 \text{ W/m}^2$$

$$T_s = \left(\frac{479.3}{5.669 \times 10^{-8}} \right)^{1/4} = 303.2 \text{ K} = 30.2^\circ\text{C}$$

8-63

$$d = 0.02; \quad x = 0.03$$

$$A_1 = \pi[(0.02)(0.03) + (0.02)^2/4]$$

$$A_o = \pi(0.02)^2/4; \quad A_o/A_1 = 0.143$$

Table A-10; $\epsilon = 0.44$ freshly turned

Fig. 8-32; $\epsilon_a = 0.88$

Heat to $930^\circ\text{C} = 1700^\circ\text{F}$, $\epsilon_i \approx 0.65$

Fig 8-32 $\epsilon_a = 0.94$

8-64

Black shiny lacquer, $\epsilon_i \approx 0.88$; $\epsilon_a = 0.99$

8-65

$$A_1 = A_2 = 0.09 \text{ m}^2$$

$$T_1 = 423 \text{ K}$$

$$\epsilon_1 = \epsilon_2 = 0.8$$

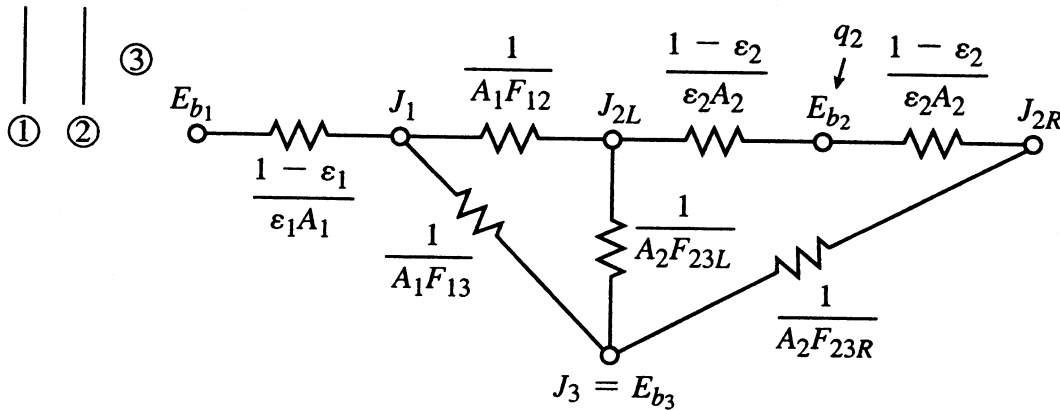
$$T_3 = 293 \text{ K}$$

$$h = 1.42 \left(\frac{\Delta T}{L} \right)^{1/4}$$

$$F_{12} = 0.55$$

$$F_{13} = F_{23L} = 0.45$$

$$F_{23R} = 1.0$$



$$-q_2 \text{ net rad} = q_2 \text{ conv}$$

$$\frac{J_{2L} - E_{b2} - J_{2R} - E_{b2}}{\frac{1-\epsilon_2}{\epsilon_2 A_2}} = 2hA_2(T_2 - 293)$$

$$\frac{1-\epsilon_1}{\epsilon_1 A_1} = 2.778$$

$$\frac{1}{A_1 F_{12}} = 20.20$$

$$\frac{1-\epsilon_2}{\epsilon_2 A_2} = 2.778$$

$$\frac{1}{A_1 F_{13}} = 24.69$$

$$= \frac{1}{A_2 F_{23L}}$$

$$\frac{1}{A_2 F_{23R}} = 11.11$$

$$E_{b1} = 1815 \text{ W/m}^2$$

$$E_{b3} = 418 \text{ W/m}^2$$

$$\frac{J_{2R} - E_{b2}}{\frac{1-\epsilon_2}{\epsilon_2 A_2}} = \epsilon_2 A_2 (418 - E_{b2})$$

$$(J_1) \quad \frac{1815 - J_1}{2.778} + \frac{J_{2L} - J_1}{20.20} + \frac{418 - J_1}{24.69} = 0$$

$$(J_2) \quad \frac{J_1 - J_{2L}}{20.20} + \frac{418 - J_{2L}}{24.69} + \frac{E_{b2} - J_{2L}}{2.778} = 0$$

$$J_1 = 1489.5 + 0.11J_{2L}$$

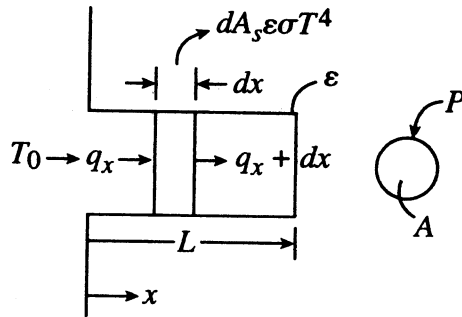
$$J_{2L} = 0.11J_1 + 334.4 + \frac{E_{b2}}{2.778} = 504.34 + 0.3644E_{b2}$$

$$\frac{504.34 - 0.6356E_{b2}}{2.778} + (0.8)(0.09)(418 - E_{b2}) = (2)(1.42) \left(\frac{1}{0.3} \right)^{1/4} (T - 293)^{5/4}$$

Solution by iteration: $E_{b2} = \sigma T_2^4$ $T_2 = 304.8 \text{ K} = 31.8^\circ\text{C}$

Chapter 8

8-66



$$q_x = q_{x+dx} + dA_s \epsilon \sigma T^4 \quad -kA \frac{dT}{dx} = -kA \left(\frac{dT}{dx} + \frac{d^2T}{dx^2} dx \right) + P dx \epsilon \sigma T^4$$

$$kA \frac{d^2T}{dx^2} - P \epsilon \sigma T^4 = 0 \quad \frac{d^2T}{dx^2} - \frac{P \epsilon \sigma}{kA} T^4 = 0$$

Boundary conditions

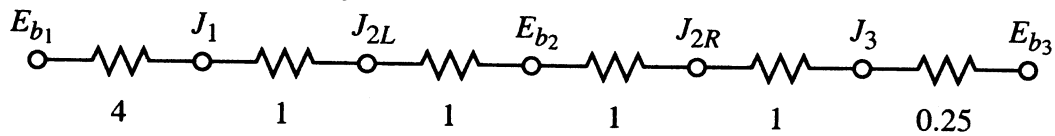
- (1) at $x=0$ $T = T_0$
 (2) at $x=L$ $-kA \frac{dT}{dx} = A \epsilon \sigma T^4$

8-67

$$T_1 = 1200 \text{ K} \quad T_3 = 300 \text{ K} \quad E_{b1} = 1.1755 \times 10^5 \quad E_{b3} = 459$$

$$\epsilon_1 = 0.2 \quad \epsilon_2 = 0.5 \quad \epsilon_3 = 0.8 \quad F_{12} = F_{23} = 1.0 \quad \frac{1 - \epsilon_1}{\epsilon_1} = 4.0$$

$$\frac{1 - \epsilon_2}{\epsilon_2} = 1.0 \quad \frac{1 - \epsilon_3}{\epsilon_3} = 0.25$$



$$\frac{117,550 - E_{b2}}{4 + 1 + 1} = \frac{117,550 - 459}{4 + 1 + 1 + 1 + 1 + 0.25}$$

$$E_{b2} = 32,393 \text{ W/m}^2 = \sigma T_2^4 \quad T_2 = 869 \text{ K}$$

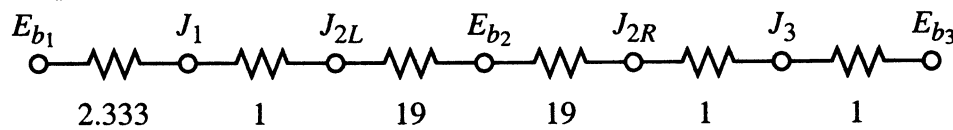
8-68

$$T_1 = 900 \text{ K} \quad \epsilon_1 = 0.3 \quad T_3 = 400 \text{ K} \quad \epsilon_3 = 0.5 \quad \epsilon_2 = 0.05$$

$$E_{b_1} = 37,194 \quad E_{b_3} = 1451 \text{ W/m}^2$$

(a) $\frac{q}{A}$ (w/o shield) = $\frac{37,194 - 1451}{\frac{1}{0.3} + \frac{1}{0.5} - 1} = 8248 \text{ W/m}^2$

$$\frac{1 - \epsilon_1}{\epsilon_1} = 2.333 \quad \frac{1 - \epsilon_2}{\epsilon_2} = 19 \quad \frac{1 - \epsilon_3}{\epsilon_3} = 1.0$$

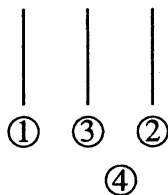


(b) $q = \frac{37,194 - 1451}{42.333} = 844.3 \text{ W/m}^2$ a reduction of 90%

(c) $q = \frac{37,194 - E_{b_2}}{2.333 + 1 + 19} = 844.3$

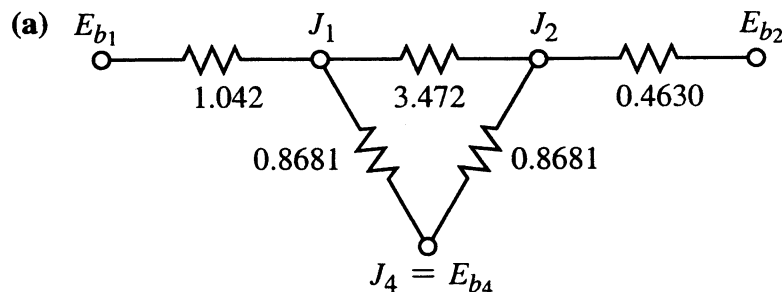
$$E_{b_2} = 18,338 \text{ W/m}^2 = \sigma T_2^4 \quad T_2 = 754 \text{ K}$$

8-69



$$A_1 = A_2 = A_3 = 1.44 \text{ m}^2 \quad \epsilon_1 = 0.4 \quad \epsilon_2 = 0.6 \quad A_4 \rightarrow \infty$$

$$T_1 = 1033 \text{ K} \quad T_2 = 573 \text{ K} \quad \epsilon_3 = 0.05 \quad T_4 = 313 \text{ K}$$



$$E_{b_1} = 64,552 \quad E_{b_2} = 6111 \quad E_{b_4} = 544$$

$$F_{12} = 0.2 \quad F_{14} = F_{24} = 0.8$$

Chapter 8

Node J_1

$$\frac{64,552 - J_1}{1.042} + \frac{J_2 - J_1}{3.472} + \frac{544 - J_1}{0.8681} = 0$$

$$J_1 = 26,791 \text{ W/m}^2$$

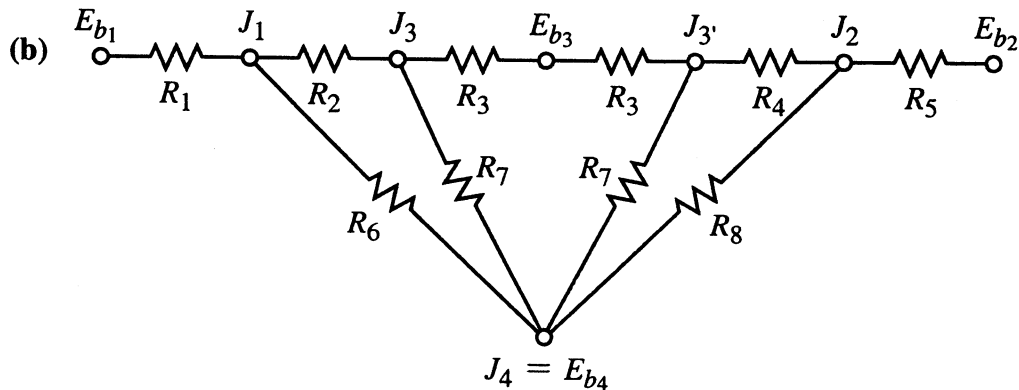
Node J_2

$$\frac{J_1 - J_2}{3.472} + \frac{544 - J_2}{0.8681} + \frac{6111 - J_2}{0.4630} = 0$$

$$J_2 = 5984 \text{ W/m}^2$$

$$q_1 = \frac{64,552 - 26,791}{1.042} = 36,239 \text{ W}$$

$$q_2 = \frac{6111 - 5984}{0.463} = 274 \text{ W}$$



$$F_{12} = 0.42$$

$$F_{23} = 0.42$$

$$F_{14} = F_{24} = 0.58$$

$$R_1 = 1.042$$

$$R_2 = 1.653$$

$$R_4 = 1.653$$

$$R_6 = R_7 = R_8 = 1.197$$

$$R_3 = 13.194$$

$$R_5 = 0.4630$$

$$J_1: \frac{64,552 - J_1}{1.042} + \frac{J_3 - J_1}{1.653} + \frac{544 - J_1}{1.197} = 0$$

$$J_1 = 28,895$$

$$J_3: \frac{J_1 - J_3}{1.653} + \frac{J_3 - J_3}{(2)(13.194)} + \frac{544 - J_3}{1.197} = 0$$

$$J_3 = 11,602$$

$$J_3': \frac{J_3 - J_3'}{(2)(13.194)} + \frac{J_2 - J_3'}{1.653} + \frac{544 - J_3'}{1.197} = 0$$

$$J_3' = 1855$$

$$J_2: \frac{J_3 - J_2}{1.653} + \frac{6111 - J_2}{0.4630} + \frac{544 - J_2}{1.197} = 0$$

$$J_2 = 4195$$

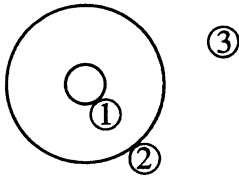
$$q_1 = \frac{64,552 - 28,895}{1.042} = 34,220 \text{ W}$$

$$q_2 = \frac{6111 - 4195}{0.463} = 4138 \text{ W}$$

$$E_{b_3} = \frac{J_3 + J_3'}{2} = 6729 = \sigma T_3^4$$

$$T_3 = 587 \text{ K} = 314^\circ\text{C}$$

8-70



$$T_1 = 773 \text{ K} \quad T_1 = 298 \text{ K} \quad \epsilon_1 = 0.8 \quad \epsilon_2 = 0.2 \quad \frac{A_1}{L} = 0.07854$$

$$\frac{A_2}{L} = 0.9425 \quad E_{b_1} = 20,241 \text{ W/m}^2 \quad E_{b_3} = 447 \quad \frac{1 - \epsilon_1}{\epsilon_1 A_1} = 3.183$$

$$\frac{1 - \epsilon_2}{\epsilon_2 A_2} = 4.244 \quad \frac{1}{A_1 F_{12}} = 12.732 \quad \frac{1}{A_2 F_{23}} = 1.061$$

$$\frac{1 - \epsilon_3}{\epsilon_3 A_3} \rightarrow 0 \quad \text{w/o shield} \quad \frac{q}{L} = \frac{20,241 - 447}{3.183 + 12.732} = 1244 \text{ W/m}$$

$$\text{w/ shield:} \quad \frac{q}{L} = \frac{20,241 - 447}{3.183 + 12.732 + (2)(4.244) + 1.061} = 777 \text{ W/m}$$

$$\frac{20,241 - E_{b_2}}{20,241 - 447} = \frac{3.183 + 12.732 + 4.244}{3.183 + 12.732 + (2)(4.244) + 1.061} \quad E_{b_2} = 4571$$

$$4571 = \sigma T_2^4 \quad T_2 = 533 \text{ K} = 260^\circ\text{C}$$

8-71

$$T_1 = 1073 \text{ K} \quad T_3 = 373 \text{ K} \quad \epsilon_1 = 0.8 \quad \epsilon_3 = 0.4$$

$$d_1 = 4 \text{ cm} \quad d_3 = 8 \text{ cm} \quad d_2 = 6 \text{ cm} \quad \epsilon_2 = 0.3$$

$$E_{b_1} = 75,146 \text{ W/m}^2 \quad E_{b_3} = 1097 \text{ W/m}^2$$

w/o shield

$$A_1 = \pi d_1 = 0.1257 \text{ (per unit length)}$$

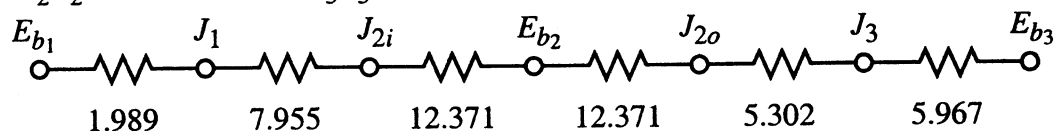
$$q = \frac{0.1257(75,146 - 1097)}{\frac{1}{0.8} + 0.5\left(\frac{1}{0.4} - 1\right)} = 4654 \text{ W/m}$$

with shield

$$A_2 = 0.1886 \quad A_3 = 0.2514 \text{ m}^2/\text{m} \quad F_{12} = F_{23} = 1.0$$

$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = 1.989 \quad \frac{1}{A_1 F_{12}} = 7.955 \quad \frac{1}{A_2 F_{23}} = 5.302$$

$$\frac{1 - \epsilon_2}{\epsilon_2 A_2} = 12.371 \quad \frac{1 - \epsilon_3}{\epsilon_3 A_3} = 5.967$$



$$\frac{q}{L} = \frac{E_{b_1} - E_{b_3}}{\sum R} = \frac{75,146 - 1097}{45.953} = 1611 \text{ W/m} \quad \text{a reduction of 65\%}$$

Chapter 8

8-73

$$E_{b_1} = \sigma(1073)^4 = 75,133 \quad E_{b_2} = \sigma(673)^4 = 11,628 \quad E_{b_3} = \sigma(23)^4 \sim 0$$

$$A_1 = 0.1963 \quad A_2 = \frac{A_1}{4} = 0.0491 \quad A_3 \rightarrow \infty \quad \epsilon_1 = 0.6 \quad \epsilon_2 = 0.4$$

$$r_1 = 0.25 \quad r_2 = 0.125 \quad L = 0.25 \quad \frac{L}{r_1} = 1.0 \quad \frac{r_2}{L} = 0.5$$

$$F_{12} = 0.12 \quad F_{13} = 0.88 \quad F_{21} = (4)F_{12} = 0.48 \quad F_{23} = 1 - 0.48 = 0.52$$

$$J_1 - (1 - 0.6)[0.12J_2 + 0.88(0)] = 0.6(75,133)$$

$$J_2 - (1 - 0.4)[0.48J_1 + 0.52(0)] = 0.4(11,628)$$

$$J_1 = 45,938$$

$$J_2 = 17,881 \text{ W/m}^2$$

$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = 3.396$$

$$q = \frac{E_{b_1} - J_1}{\frac{1 - \epsilon_1}{\epsilon_1 A_1}} = \frac{75,133 - 45,938}{3.396} = 8597 \text{ W}$$

8-75

$$d = 0.03; \quad x = 0.06$$

$$d/x = 0.5, \quad F = 12+ = 0.021; \quad T_1 = 373 \text{ K}; \quad T_2 = 273 \text{ K}; \quad T_3 = 264 \text{ K}$$

$$A = \pi(0.03)^2/4 = 0.000707$$

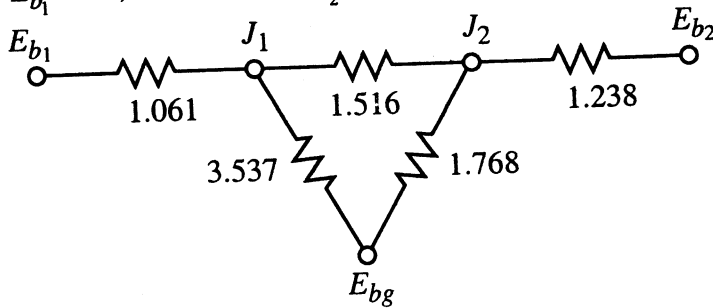
$$q_{21} = (0.000707)(0.021)\sigma(273^4 - 373^4) = -0.01162 \text{ W}$$

$$q_{23} = (0.000707)(0.979)\sigma(273^4 - 263^4) = 0.03022$$

$$q_{2 \text{ tot}} = 0.0186 \text{ W}; \quad 1 \text{ percent} = 0.186 \text{ mW}$$

8-77

$$\begin{aligned}
 d_1 &= 0.3 & d_2 &= 0.6 & \epsilon_1 &= 0.5 & \epsilon_2 &= 0.3 & T_1 &= 1033 \text{ K} \\
 T_2 &= 643 \text{ K} & A_1 &= \pi(0.3) = 0.9425 & \tau_g &= 0.7 \\
 A_2 &= \pi(0.6) = 1.885 & \alpha_g &= \epsilon_g = 0.3 & F_{12} &= 1.0 \\
 F_{1g} &= F_{2g} = 1.0 & \text{Resistance shown on figure} \\
 E_{b_1} &= 64,552 & E_{b_2} &= 9691
 \end{aligned}$$



$$q = \frac{64,552 - 9691}{1.061 + \frac{1}{\frac{1}{5.16} + \frac{1}{3.537 + 1.768}} + 1.238} = 15,773 \text{ W/m}$$

$$15,773 = \frac{64,552 - J_1}{1.061} = \frac{J_2 - 9691}{1.238}$$

$$J_1 = 47,816$$

$$J_2 = 29,218$$

$$\frac{47,816 - E_{bg}}{47,816 - 29,218} = \frac{3.537}{3.537 + 1.768}$$

$$E_{bg} = 35,416 = \sigma T_g^4$$

$$T_g = 889 \text{ K} = 616^\circ\text{C}$$

8-79

$$T_1 = 1033 \text{ K} \quad T_2 = 643 \text{ K} \quad E_{b_1} = 64,550 \quad E_{b_2} = 9690$$

$$\epsilon_1 = 0.5 \quad \epsilon_2 = 0.3 \quad F_{12} = 1.0 \quad F_{1g} = 1.0 \quad F_{2g} = 1.0$$

$$\alpha_g = \epsilon_g = 0.3 \quad \tau_g = 0.7$$

Consider per unit area, $A_1 = A_g = A_2 = 1.0$

$$\frac{1 - \epsilon_1}{\epsilon_1} = 1.0 \quad \frac{1 - \epsilon_2}{\epsilon_2} = 2.333 \quad \frac{1}{F_{12}(1 - \epsilon_g)} = \frac{1}{0.7} = 1.429$$

$$\frac{1}{F_{1g}\epsilon_g} = \frac{1}{F_{2g}\epsilon_g} = \frac{1}{0.3} = 3.333$$

$$q = \frac{E_{b_1} - E_{b_2}}{\frac{1 - \epsilon_1}{\epsilon_1} + \frac{1 - \epsilon_2}{\epsilon_2} + \frac{1}{\frac{1}{F_{1g}\epsilon_g} + \frac{1}{F_{2g}\epsilon_g}} + F_{12}(1 - \epsilon_g)}$$

$$= \frac{64,550 - 9690}{1 + 2.333 + \frac{1}{(2)(3.333) + 0.7}}$$

$$= \frac{54,860}{4.5097} = 12,160 \text{ W}$$

$$q = 12,160 = \frac{64,550 - J_1}{1.0} = \frac{J_2 - 9690}{2.333} \quad J_1 = 52,385 \quad J_2 = 38,063$$

$$E_{bg} = \frac{J_1 + J_2}{2} = 45,224 = \sigma T_g^4 \quad T_g = 945 \text{ K} = 672^\circ\text{C}$$

8-80

$$\text{Same network as 8-61} \quad \text{Re} = \frac{(1.6)(6)(0.6 - 0.3)}{5.4 \times 10^{-5}} = 53,330$$

$$\text{Pr} = \frac{(1670)(5.4 \times 10^{-5})}{0.11} = 0.82$$

$$h_1 = \frac{0.11}{0.3} (0.023)(53,330)^{0.8} (0.82)^{0.4} = 47.11$$

$$h_2 = \frac{1}{2} h_1 = 23.55 \quad T_g = 1373 \text{ K} \quad E_{bg} = 2.015 \times 10^5$$

$$(J_1) \quad \frac{64,552 - J_1}{1.061} + \frac{J_2 - J_1}{1.516} + \frac{2.015 \times 10^5 - J_1}{3.537} = 0 \quad J_1 = 95,980$$

$$(J_2) \quad \frac{J_1 - J_2}{1.516} + \frac{2.015 \times 10^5 - J_2}{1.768} + \frac{9691 - J_2}{1.238} = 0 \quad J_2 = 91,051$$

Inner Surface:

$$\text{cooling} = \frac{95,980 - 64,552}{1.061} + (47.11)\pi(0.3)(1373 - 1033) = 44,717 \text{ W/m}$$

Chapter 8

Outer Surface:

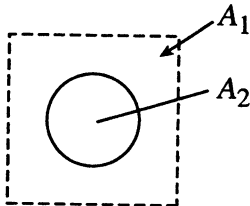
$$\text{cooling} = \frac{91,051 - 9691}{1.238} + (23.55)\pi(0.6)(1373 - 643) = 98,124 \text{ W/m}$$

8-81

$$\begin{aligned} E_{b_1} &= 37,194 & E_{b_2} &= 14,513 & \frac{A_1}{L} &= 0.1571 & \frac{A_2}{L} &= 0.3142 \\ \frac{1 - \epsilon_1}{\epsilon_1 A_1} &= 9.548 & \frac{1 - \epsilon_2}{\epsilon_2 A_2} &= 2.122 & \frac{1}{A_1 F_{2g} \epsilon_g} &= 42.44 \\ \frac{1}{A_2 F_{2g} \epsilon_g} &= 21.22 & \frac{1}{A_1 F_{12}(1 - \epsilon_g)} &= 7.489 \\ R &= 9.548 + \frac{1}{\frac{1}{7.489} + \frac{1}{42.44 + 21.22}} = 18.37 \\ q &= \frac{37,194 - 14,513}{18.37} = 1235 \text{ W/m} \cdot \text{length} = \frac{37,194 - J_1}{9.548} = \frac{J_2 - 14,513}{21.22} \\ J_1 &= 25,406 & J_2 &= 17,134 \\ E_{bg} &= 17,134 + \frac{1}{3}(25,406 - 17,134) = 19,891 & T_g &= 770 \text{ K} \end{aligned}$$

8-82

Assume large number of pins so that array behaves like single pin



$$\begin{aligned} \text{cavity area} &= A_3 & A_2 &= \pi(1)^2 = \pi \text{ mm}^2 = 3.416 \\ A_1 &= (4)^2 - \pi = 16 - \pi = 12.858 & A_3 &= A_1 + (4)(4)(12) + \pi(2)(12) = 472.256 \\ \epsilon_{a_1} &= \frac{\epsilon A_3}{A_1 + \epsilon(A_3 - A_1)} = \frac{472.256\epsilon}{12.858 + 459.398\epsilon} \\ \text{Energy emitted / area} &= \frac{\epsilon_{a_1} A_1 + \epsilon A_2}{A_1 + A_2} E_b \\ \epsilon_{\text{eff}} &= \frac{\epsilon_{a_1} A_1 + \epsilon A_2}{A_1 + A_2} = \frac{\left[\frac{(472.256)(12.858)}{12.858 + 459.398(0.3)} \right] (0.3)}{16} = 0.8145 \end{aligned}$$

8-83

Assume array behaves same as single cell

$$A_o = (6)(6) = 36$$

$$A_i = 36 + (4)(6)(10) = 276$$

$$\varepsilon_i = 0.1$$

$$\varepsilon_a = \frac{\varepsilon_i A_i}{A_o + \varepsilon_i (A_i - A_o)} = \frac{(0.1)(276)}{36 + (0.1)(240)} = 0.46$$

8-84

$$A_o = \pi(12.5)^2 = 490.87 \text{ mm}^2 \quad x = \text{depth}$$

$$A_i = \pi(3)^2 + \pi(3+12.5)[x^2 + (12.5-3)^2]^{1/2} = \pi[9 + 15.5(x^2 + 90.25)^{1/2}]$$

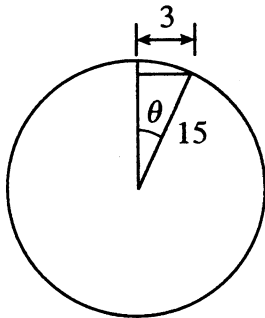
$$\varepsilon_a = \frac{\varepsilon_i A_i}{A_o + \varepsilon_i (A_i - A_o)} \quad \varepsilon_a = 0.98 \quad \varepsilon_i = 0.9$$

$$0.98 = \frac{0.9 A_i}{490.87 + (0.9)(A_i - 490.87)}$$

$$A_i = 2672.52 = \pi[9 + 15.5(x^2 + 90.25)^{1/2}]$$

$$x = 53.46 \text{ mm}$$

8-85



$$\sin \theta = \frac{3}{15} = 0.2 \quad \theta = 11.537^\circ \quad A_o = \pi(3)^2 = 28.274$$

$$\varepsilon_i = 0.5$$

$$A_i = 4\pi r^2 - 4\pi r^2 (1 - \cos \theta) = 4\pi r^2 \cos \theta = 4\pi(15)^2 \cos(11.537^\circ) = 2770$$

$$\varepsilon_a = \frac{\varepsilon_i A_i}{A_o + \varepsilon_i (A_i - A_o)} = \frac{(0.5)(2770)}{28.274 + (0.5)(2770 - 28.274)} = 0.9899$$

Chapter 8

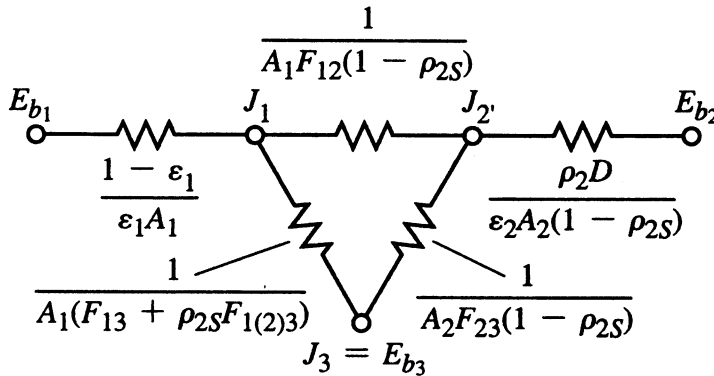
8-86

$$\tau_o = 0.5 \quad \epsilon_o = 0.4 \quad \rho_o = 0.1 \quad \epsilon_i = 0.6 \quad A_o = (25)^2 = 625 \text{ cm}^2$$

$$A_i = 625 + (4)(25)(10) = 1625 \quad k = \frac{\epsilon_i}{\tau_o + \frac{\epsilon_o}{2}} = \frac{0.6}{0.5 + 0.2} = 0.85714$$

$$\epsilon_a = \frac{(\tau_o + \frac{\epsilon_o}{2})k}{\left(\frac{A_o}{A_i}\right)(1 - \epsilon_i) + k} = \frac{\epsilon_i}{\left(\frac{A_o}{A_i}\right)(1 - \epsilon_i) + k} = \frac{0.6}{\left(\frac{625}{1625}\right)(1 - 0.6) + 0.85714} = 0.5934$$

8-87



$$T_1 = 813 \text{ K} \quad \epsilon_1 = 0.3 \quad T_2 = 533 \text{ K} \quad T_3 = 293 \text{ K} \quad \rho_{D2} = 0.2$$

$$F_{1(2)2} = 0.6 \quad F_{1(2)1} = 0.37 \quad F_{1(2)3} = 0.23 \quad \rho_{S2} = 0.4 \quad \epsilon_2 = 1 - \rho_2 = 0.4$$

$$A_1 = A_2 = \pi(0.05)^2 = 7.854 \times 10^{-3} \text{ m}^2 \quad F_{23} = 0.4 \quad F_{13} = 0.4$$

$$E_{b1} = 24,767 \text{ W/m}^2 \quad E_{b2} = 4575 \quad E_{b3} = 418 \quad \frac{1 - \epsilon_1}{\epsilon_1 A_1} = 297.1$$

$$\frac{1}{A_1 F_{12} (1 - \rho_{2s})} = 3537 \quad \frac{1}{A_1 (F_{13} + \rho_{2s} F_{1(2)3})} = 258.8$$

$$\frac{\rho_{2D}}{\epsilon_2 A_2 (1 - \rho_{2s})} = 106.1 \quad \frac{1}{A_2 F_{23} (1 - \rho_{2s})} = 530.5$$

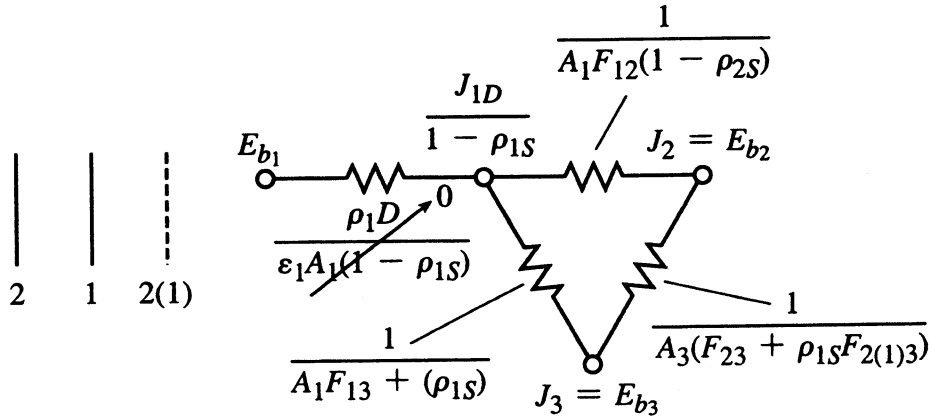
$$J_2 = \frac{J_{D2}}{1 - \rho_{2s}}$$

$$\frac{24,767 - J_1}{297.1} + \frac{J_2 - J_1}{353.7} + \frac{418 - J_1}{258.8} = 0 \quad J_1 = 9878 \text{ W/m}^2$$

$$\frac{J_1 - J_2}{353.7} + \frac{418 - J_2}{530.5} + \frac{4575 - J_2}{106.1} = 0 \quad J_2 = 5081 \text{ W/m}^2$$

$$q_1 = \frac{24,767 - 9878}{297.1} = 50.11 \text{ W} \quad q_2 = \frac{4575 - 5081}{106.1} = -4.76 \text{ W}$$

8-88



$$T_1 = 823 \text{ K} \quad \epsilon_1 = 0.6 \quad T_3 = 283 \text{ K} \quad \rho_{1D} = 0 \quad \rho_{1S} = 0.4$$

$$A_1 = A_2 = 0.54 \text{ m}^2 \quad F_{12} = F_{21} = 0.25 \quad F_{13} = 0.75 \quad J_{1D} = \epsilon_1 E_{b1} = 15,604$$

$$\frac{J_{1D}}{1 - \rho_{1S}} = 26,007 \text{ W/m}^2 \quad \frac{1}{A_1 F_{12} (1 - \rho_{1S})} = 12.346 \quad \frac{1}{A_1 F_{13} (1 - \rho_{1S})} = 4.15$$

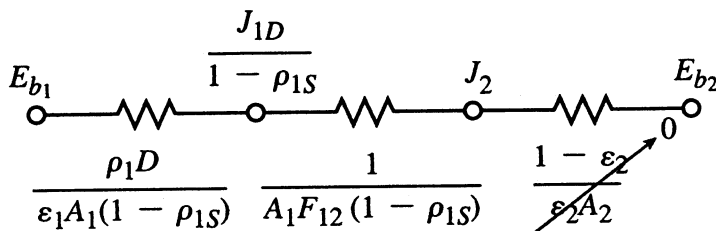
$$\frac{1}{A_2 (F_{23} + \rho_{1S} F_{2(1)3})} = 2.281$$

$$q = \frac{26,007 - 363.6}{\frac{1}{4.15 + 12.346 + 2.281}} = 7985 \text{ W}$$

$$\frac{26,007 - J_2}{26,007 - 363.6} = \frac{12.346}{12.346 + 2.281} \quad J_2 = 4362 = \sigma T_2^4$$

$$T_2 = 526.7 \text{ K} = 253.7^\circ\text{C}$$

8-89'



$$F_{12} = 1$$

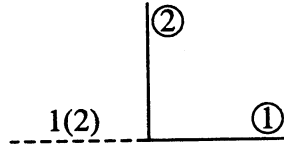
$$q = \frac{E_{b1} - E_{b2}}{\sum R} = \epsilon_1 A_1 (E_{b1} - E_{b2}) = \frac{\sigma (T_1^4 - T_2^4)}{\frac{\rho_{1D}}{\epsilon_1 A_1 (1 - \rho_{1S})} + \frac{1}{A_1 (1 - \rho_{1S})}}$$

$$= \frac{A_1 \sigma (1 - \rho_{1S}) (T_1^4 - T_2^4)}{\frac{\rho_{1D}}{\epsilon_1} + 1}$$

Same answer with diffuse

Chapter 8

8-90



$$T_1 = 643 \text{ K} \quad \epsilon_1 = 0.6 \quad A_1 = (0.3)(0.6) = 0.18 \text{ m}^2 \quad T_3 = 363 \text{ K}$$

$$\rho_{2S} = 0.7 \quad \rho_{2D} = 0.1 \quad \epsilon_2 = 0.2 \quad F_{12} = F_{21} = 0.25 \quad F_{13} = 0.75$$

$$F_{23L} = 1.0 \quad F_{23R} = 0.75 \quad F_{1(2)3} = F_{12} = 0.25 \quad \frac{1 - \epsilon_1}{\epsilon_1 A_1} = 3.704$$

$$\frac{1}{A_1 F_{12} (1 - \rho_{2S})} = 74.07$$

$$\frac{\rho_{2D}}{\epsilon_2 A_2 (1 - \rho_{2S})} = 9.259$$

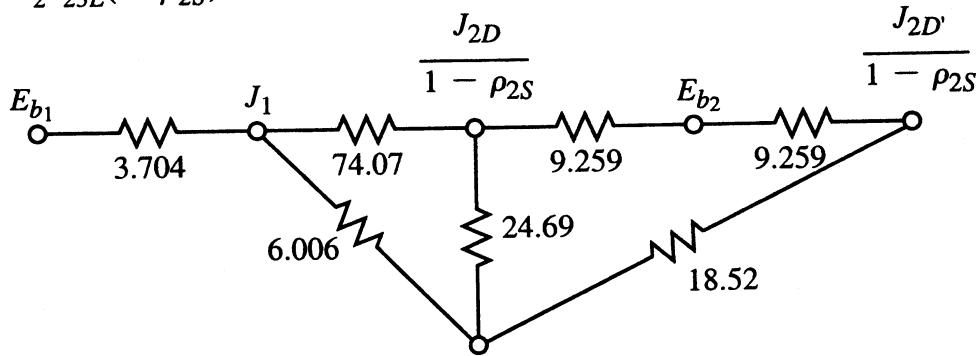
$$\frac{1}{A_1 (F_{13} + \rho_{2S} F_{1(2)3})} = 6.006$$

$$\frac{1}{A_2 F_{23R} (1 - \rho_{2S})} = 24.69$$

$$\frac{1}{A_2 F_{23L} (1 - \rho_{2S})} = 18.52$$

$$E_{b_1} = 9691 \text{ W/m}^2$$

$$E_{b_3} = 984 \text{ W/m}^2$$



$$q = \frac{E_{b_1} - E_{b_3}}{\sum R} = \frac{9691 - 984}{9.33} = 933 \text{ W}$$

w/o Reflector: $q = (0.6)(0.18)(9691 - 984) = 940.4 \text{ W}$

$$\frac{9691 - J_1}{9691 - 984} = \frac{3.704}{9.33}$$

$$J_1 = 6234 \text{ W/m}^2$$

$$\frac{6234 - \frac{J_{2D}}{1 - \rho_{2S}}}{6234 - 984} = \frac{74.07}{74.07 + 14.84}$$

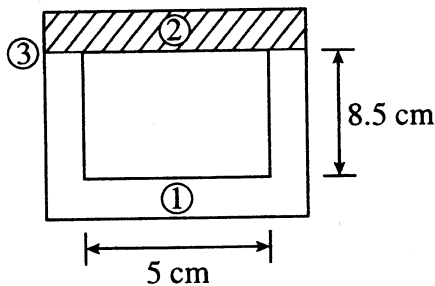
$$\frac{J_{2D}}{1 - \rho_{2S}} = 1859$$

$$\frac{1859 - E_{b_2}}{1859 - 984} = \frac{9.259}{37.038}$$

$$E_{b_2} = 1640 = \sigma T_2^4$$

$$T_2 = 412 \text{ K} = 139^\circ\text{C}$$

8-91



$$T_1 = 533 \text{ K} \quad \epsilon_1 = 0.6 \quad \rho_{2S} = 0.1 \quad T_3 = 293 \text{ K} \quad \rho_{2D} = 0.1$$

$$\tau_{2D} = 0.3 \quad \tau_{2S} = 0.3 \quad \epsilon_2 = 0.2 \quad E_{b1} = 4575 \text{ W/m}^2$$

$$E_{b2} = 418 \text{ W/m}^2$$

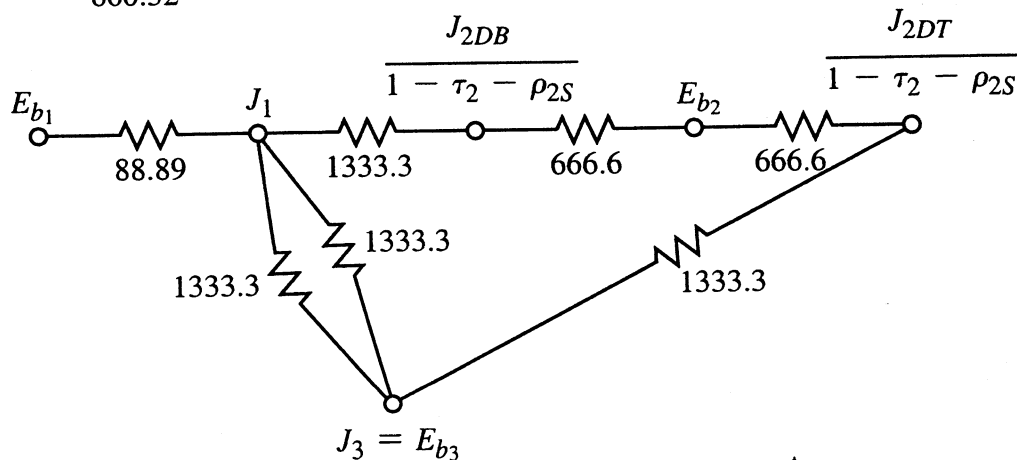
$$A_1 = 75 \text{ cm}^2 = 7.5 \times 10^{-3} \text{ m}^2 \quad A_2 = 25 \text{ cm}^2 = 2.5 \times 10^{-3} \text{ m}^2$$

$$A_3 \rightarrow \infty \quad F_{21} = 1.0 \quad F_{12} = \frac{25}{75} = 0.3333 = F_{13} \quad \frac{1 - \epsilon_1}{\epsilon_1 A_1} = 88.89$$

$$\frac{1}{A_2 F_{23T} (1 - \tau_2 - \rho_{2S})} = 1333.3 \quad \frac{1}{A_1 F_{13} \tau_{2S}} = 1333.33 = \frac{1}{A_1 F_{12} F_{23T} \tau_{2D}}$$

$$\frac{1}{A_1 F_{12} (1 - \tau_2 - \rho_{2S})} = 1333.3 \quad \frac{\rho_{2D}}{\epsilon_2 A_2 (1 - \tau_2 - \rho_{2S})} = 666.6$$

$$q = \frac{4575 - 418}{660.32} = 6.295 \text{ W} \quad \text{w/o window: } q = \frac{4575 - 418}{88.89 + 400} = 8.503 \text{ W}$$



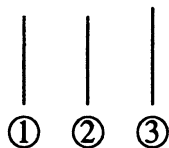
8-92

$$\frac{1}{A_1 F_{13} \tau_{2S}} = 666.6 \quad \frac{1}{A_1 F_{12} (1 - \tau_2 - \rho_{2S})} = 1000 \quad \frac{\rho_{2D}}{\epsilon_2 A_2 (1 - \tau_2 - \rho_{2S})} = 1000$$

$$\frac{1}{A_2 F_{23T} (1 - \tau_2 - \rho_{2S})} = 1000 \quad q = \frac{4575 - 418}{660.32} = 6.295 \text{ W}$$

Chapter 8

8-95



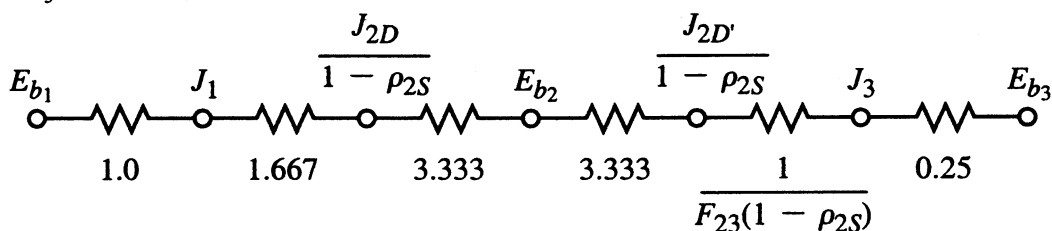
① ② ③

$$T_1 = 1073 \text{ K} \quad T_3 = 308 \text{ K} \quad \epsilon_1 = 0.5 \quad \epsilon_3 = 0.8 \quad \rho_{2D} = 0.4$$

$$\epsilon_2 = 0.2 \quad F_{12} = F_{23} = 1.0 \quad \text{etc.} \quad \frac{1 - \epsilon_1}{\epsilon_1} = 1.0 \quad \frac{1}{F_{12}(1 - \rho_{2S})} = 1.67$$

$$\frac{\rho_{2D}}{\epsilon_2(1 - \rho_{2S})} = 3.333 \quad \frac{1 - \epsilon_3}{\epsilon_3} = 0.25 \quad E_{b_1} = 75,146 \text{ W/m}^2$$

$$E_{b_3} = 510 \text{ W/m}^2$$



with shield: $\frac{q}{A} = \frac{75,146 - 510}{1 + 1.667 + (2)(3.333) + 1.667 + 0.25} = 6634 \text{ W/m}^2$

w/o shield: $\frac{q}{A} = \frac{75,146 - 510}{1 + 1 + 0.25} = 33,172 \text{ W/m}^2$

same for diffuse shield

8-96

$$F_{12} = 1.0 \quad F_{21} = \frac{A_1}{A_2} \quad F_{11} = 0 \quad F_{22} = 1 - \frac{A_1}{A_2}$$

$$J_1(1 - 0) - (1 - \epsilon_1)(F_{12}J_2) = \epsilon_1 E_{b_1}$$

$$J_2 \left[1 - \left(1 - \frac{A_1}{A_2} \right) (1 - \epsilon_2) \right] - (1 - \epsilon_1)(F_{21}J_1) = \epsilon_2 E_{b_2}$$

For $A_2 \rightarrow \infty$, $F_{22} \rightarrow 1.0$, and $F_{21} \rightarrow 0$, and

$$J_1 - (1 - \epsilon_1)J_2 = \epsilon_1 E_{b_1} \quad J_2[1 - (1 - \epsilon_2)] - (1 - \epsilon_2)(0)J_1 = \epsilon_2 E_{b_2}$$

Thus, $J_2 = E_{b_2}$

$$J_1 = (1 - \epsilon_1)E_{b_2} + \epsilon_1 E_{b_1}$$

$$q = \frac{\epsilon_1 A_1}{1 - \epsilon_1} (E_{b_1} - J_1) = \frac{\epsilon_1 A_1}{1 - \epsilon_1} [E_{b_1} - \epsilon_1 E_{b_1} - (1 - \epsilon_1)E_{b_2}] = \epsilon_1 A_1 (E_{b_1} - E_{b_2})$$

This agrees with Eq. (8-43a)

8-100

$$d_1 = d_2 = 30 \text{ cm} \quad x = 5 \text{ cm} \quad \frac{d}{x} = 6 \quad F_{12} = F_{21} = 0.7$$

$$F_{13} = F_{23} = 0.3 \quad T_3 = 293 \text{ K} \quad \frac{q_1}{A} = 1 \times 10^5 \text{ W/m}^2$$

$$\epsilon_1 = 0.9 \quad \epsilon_2 = 0.5 \quad J_1 - F_{12}F_{2T} = 10^5$$

$$J_{2T} - (1 - 0.5)(F_{23}E_{b_3} + F_{21}J_1) = 0.5E_{b_2}$$

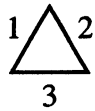
$$J_{2B} - (1 - 0.5)(E_{b_3}) = 0.5E_{b_2} \quad E_{b_2} = \frac{J_{2T} + J_{2B}}{2}$$

$$\text{Solution: } E_{b_2} = 4678 \quad T_2 = 953 \text{ K} \quad J_{2T} = 69,961$$

$$J_1 = 1.49 \times 10^5 \quad 10^5 = \frac{E_{b_1} - 1.49 \times 10^5}{\frac{1-0.9}{0.9}} \quad E_{b_1} = 10.49 \times 10^5$$

$$T_1 = 2074 \text{ K}$$

8-101



$$T_1 = 900 \text{ K} \quad \epsilon_1 = 0.6 \quad T_2 = 1500 \text{ K} \quad \epsilon_2 = 0.8$$

$$\frac{q}{A_3} = 1000 \text{ W/m}^2 \quad \epsilon_3 = 0.7$$

$$F_{12} = F_{13} = F_{21} = F_{23} = F_{31} = F_{32} = 0.5 \quad E_{b_1} = 37,190 \quad E_{b_2} = 2.87 \times 10^5$$

$$J_1 - 0.4(F_{12}J_2 + F_{13}J_3) = 0.6E_{b_1} \quad J_1 = 111,479$$

$$J_2 - 0.2(F_{21}J_1 + F_{23}J_3) = 0.8E_{b_2} \quad J_2 = 259,391$$

$$J_3 - (F_{31}J_1 + F_{32}J_2) = 1000 \quad J_3 = 186,435$$

$$\frac{q}{A_1} = \frac{37,190 - 111,479}{\frac{1-0.6}{0.6}} = -1.115 \times 10^5$$

$$\frac{q}{A_2} = \frac{287,000 - 259,391}{\frac{1-0.8}{0.8}} = +1.105 \times 10^5$$

$$1000 = \frac{E_{b_3} - 186,435}{\frac{1-0.7}{0.7}} \quad E_{b_3} = 1.888 \times 10^5 \quad T_3 = 1350 \text{ K}$$

Chapter 8

8-102

$$\begin{aligned}
 A_1 = A_2 = 1 \text{ m}^2 & \quad T_1 = 573 \text{ K} & \quad \varepsilon_1 = 0.5 & \quad E_{b_1} = 6111 \\
 q_2 = 0 & \quad \varepsilon_2 = 0.7 & \quad T_3 = 303 \text{ K} & \quad E_{b_3} = 478 \\
 F_{12} = F_{21} = 0.2 & \quad F_{13} = F_{23} = 0.8 & \quad F_{11} = F_{22} = 0 & \quad F_{31} = F_{32} = 0 \\
 F_{33} \cong 1.0 & \quad E_{b_3} = J_3 & & \\
 J_1 - (1 - 0.5)(0.2J_2 + 0.8E_{b_3}) = 0.5E_{b_1} & & & \\
 J_2 - (0.2J_1 + 0.8E_{b_3}) = 0 & & &
 \end{aligned}$$

Solution:

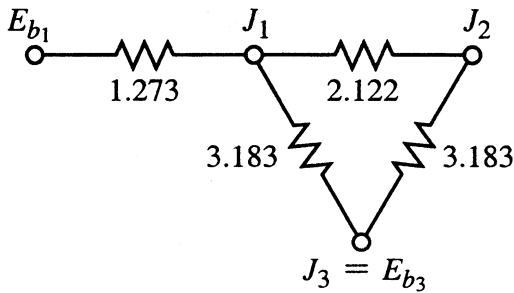
$$\begin{aligned}
 J_1 = 3352 \text{ W/m}^2 & \quad J_2 = 1053 = \sigma T_2^4 & \quad T_2 = 369 \text{ K} \\
 q_1 = \frac{E_{b_1} - J_1}{\frac{1 - \varepsilon_1}{\varepsilon_1 A_1}} = \frac{(0.5)(6111 - 478)(1)}{1 - 0.5} = 5633 \text{ W}
 \end{aligned}$$

8-103

$$\begin{aligned}
 d_1 = d_2 = 60 \text{ cm} & \quad x = 15 \text{ cm} & \quad T_1 = 813 \text{ K} & \quad T_2 = 573 \text{ K} & \quad \varepsilon_1 = 0.7 \\
 \varepsilon_2 = 0.5 & \quad T_3 = 303 \text{ K} & \quad A_1 = A_2 = 0.2827 \text{ m}^2 & \quad F_{12} = 0.6 = F_{21} \\
 F_{13} = F_{31} = 0.4 & \quad E_{b_1} = 24,767 \text{ W/m}^2 & \quad E_{b_2} = 6111 \\
 F_{11} = F_{22} = 0 & \quad F_{31} = F_{32} = 0 & \quad F_{34} \rightarrow 1.0 & \quad E_{b_3} = J_3 = 478 \\
 J_1 = (1 - 0.7)(0.6J_2 + 0.4E_{b_3}) + 0.7E_{b_1} & \quad J_1 = 18,980 \text{ W/m}^2 \\
 J_2 = (1 - 0.5)(0.6J_1 + 0.4E_{b_3}) + 0.5E_{b_2} & \quad J_2 = 8840 \text{ W/m}^2 \\
 q_1 = \frac{\varepsilon_1 A_1 (E_{b_1} - J_1)}{1 - \varepsilon_1} = \frac{(0.7)(0.2827)(24,767 - 18,980)}{0.3} = 3817 \text{ W} \\
 q_2 = \frac{\varepsilon_2 A_2 (E_{b_2} - J_2)}{1 - \varepsilon_2} = \frac{(0.5)(0.2827)(6111 - 8840)}{0.5} = -771 \text{ W}
 \end{aligned}$$

8-104

$$\begin{aligned}
 d_1 = d_2 = 1 \text{ m} & & x = 0.25 & & \frac{d}{x} = 4 & & F_{12} = F_{21} = 0.6 \\
 F_{13} = F_{23} = 0.4 & & A_1 = A_2 = \pi(0.5)^2 = 0.7854 & & T_1 = 573 \text{ K} \\
 T_3 = 303 \text{ K} & & \varepsilon_1 = 0.5 & & E_{b_1} = 6111 & & E_{b_3} = 478 \\
 \frac{1 - \varepsilon_1}{\varepsilon_1 A_1} = 1.273 & & \frac{1}{A_1 F_{12}} = 2.122 & & \frac{1}{A_1 F_{13}} = \frac{1}{A_2 F_{23}} = 3.183
 \end{aligned}$$



$$q = \frac{6111 - 478}{1.273 + \frac{1}{\frac{1}{3.183} + 2.122 + 3.183}}} = 1727 \text{ W}$$

8-105

$$\begin{aligned}
 d_1 = d_2 = 50 \text{ cm} & & x = 10 \text{ cm} & & F_{12} = F_{21} = 0.65 & & F_{13} = F_{23} = 0.35 \\
 T_1 = 350 \text{ K} & & \varepsilon_1 = \varepsilon_2 = 0.6 & & E_{b_1} = 850.7
 \end{aligned}$$

$$\left. \frac{q}{A_2} \right| = 10,000 \text{ W/m}^2 \quad \left. \frac{q}{A_3} \right| = 0 \quad F_{11} = F_{22} = 0 \quad F_{33} \rightarrow 1.0$$

$$A_1 = A_2 = \pi(0.25)^2 = 0.1963 \text{ m}^2 \quad A_3 = \pi(0.5)(0.1) = 0.1571 \text{ m}^2$$

$$F_{31} = F_{32} = 0.35 \left(\frac{A_1}{A_3} \right) = 0.4373 \quad F_{33} = 1 - (2)(0.4373) = 0.125$$

$$J_1 = (1 - 0.6)(0.65J_2 + 0.35J_3) + 0.6E_{b_1} \quad J_1 = 7514.31 \text{ W/m}^2$$

$$J_2 = (0.65J_1 + 0.35J_3) + 10,000 \quad J_2 = 19,632.83 \text{ W/m}^2$$

$$J_3 = \frac{1}{1 - 0.125} (0.4373J_1 + 0.4373J_2) \quad J_3 = 13,566.78 \text{ W/m}^2$$

$$J_3 = E_{b_3} \quad T_3 = \left(\frac{J_3}{5.669 \times 10^{-8}} \right)^{1/4} = 699.4 \text{ K}$$

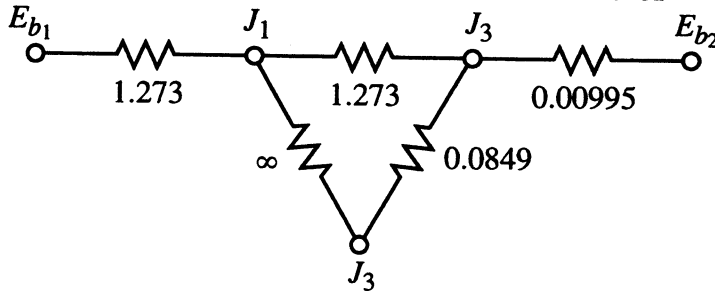
$$E_{b_2} = J_2 + \left(\frac{1 - 0.6}{0.6} \right) (10,000) = 26,299.5 \text{ W/m}^2$$

$$T_2 = \left(\frac{E_{b_2}}{5.669 \times 10^{-8}} \right)^{1/4} = 825.3 \text{ K}$$

Chapter 8

8-106

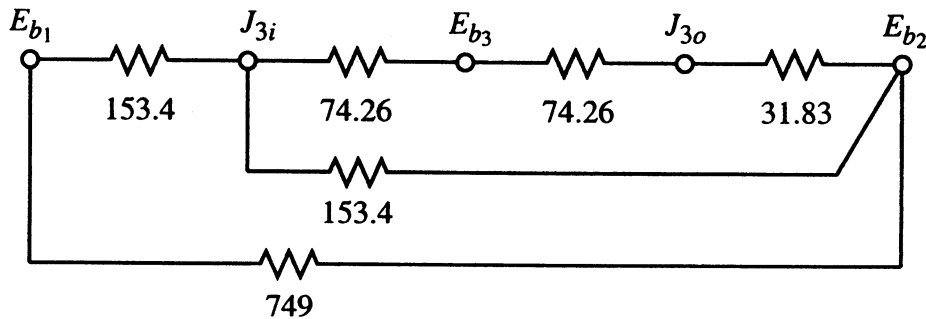
$$\begin{aligned}
 T_1 &= 900 \text{ K} & \epsilon_1 &= 0.5 & E_{b_1} &= 37,194 & A_1 &= \pi(0.5)^2 = 0.7854 \\
 A_2 &= 2\pi(2)^2 = 25.13 \text{ m}^2 & T_2 &= 300 \text{ K} & \epsilon_2 &= 0.8 & E_{b_2} &= 459 \\
 q_3 &= 0 & A_3 &= \pi(2^2 - 0.5^2) = 11.781 \text{ m}^2 & F_{12} &= F_{32} = 1.0 \\
 F_{21} &= 1.0 \left(\frac{A_1}{A_2} \right) = 0.0313 & F_{23} &= 1.0 \left(\frac{A_3}{A_2} \right) = 0.4688 & \frac{1-\epsilon_1}{\epsilon_1 A_1} &= 1.273 \\
 \frac{1-\epsilon_2}{\epsilon_2 A_2} &= 0.00995 & \frac{1}{A_1 F_{12}} &= 1.273 & \frac{1}{A_3 F_{32}} &= 0.0849 & \frac{1}{A_1 F_{13}} &= \infty
 \end{aligned}$$



$$\begin{aligned}
 q &= \frac{37,194 - 459}{1.273 + 1.273 + 0.00995} = 14,372 \text{ W} \\
 q &= \frac{J_2 - E_{b_2}}{0.00995} & J_2 &= 602 \text{ W/m}^2 \\
 q &= A_2(G_2 - J_2) & G_2 &= 1174 \text{ W/m}^2
 \end{aligned}$$

8-107

$$\begin{aligned}
 \frac{d}{x} &= 1.0 & F_{12} &= 0.17 & (1) \text{ disk} & (2) \text{ room} & (3) \text{ shield} \\
 F_{13} &= 0.83 & \epsilon_1 &= 1.0 & \epsilon_3 &= 0.3 & T_1 &= 773 \text{ K} & E_{b_1} &= 20,241 \text{ W/m}^2 \\
 T_2 &= 313 \text{ K} & E_{b_2} &= 544 & A_1 &= \pi(0.05)^2 = 0.007854 \text{ m}^2 \\
 A_3 &= \pi(0.1)(0.1) = 0.03142 & F_{31} &= 0.83 \left(\frac{A_1}{A_3} \right) = 0.2075 = F_{32} \\
 \frac{1-\epsilon_1}{\epsilon_1 A_1} &= 0 & \frac{1-\epsilon_3}{\epsilon_3 A_3} &= 74.26 & \frac{1}{A_1 F_{12}} &= 749 & \frac{1}{A_1 F_{13}} &= 153.4 \\
 \frac{1}{A_3 F_{32}} &= 153.4 & F_{32} \text{ (out)} &= 1.0 & \frac{1}{A_3 F_{32}} \text{ (outside)} &= 31.83
 \end{aligned}$$



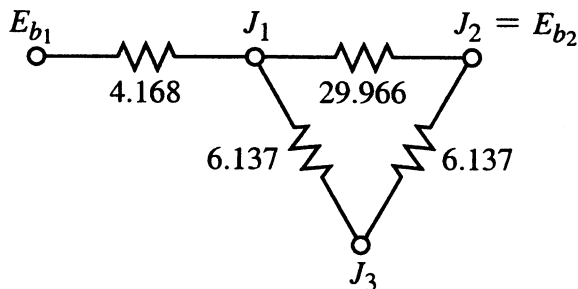
$$\frac{1}{R_1} = \frac{1}{153.4} + \frac{1}{74.26 + 74.26 + 31.83} \quad R_1 = 82.89 \quad \frac{1}{R} = 5.5671 \times 10^{-3}$$

$$q = \frac{E_{b1} - E_{b2}}{\sum R} = (5.5671 \times 10^{-3})(20,241 - 544) = 109.7 \text{ W}$$

8-108

$$\begin{aligned} \frac{d}{x} &= 1.0 & F_{12} &= 0.17 & (1) \text{ disk} & (2) \text{ room} & T_1 &= 1273 \text{ K} \\ T_2 &= 293 \text{ K} & \epsilon_1 &= 0.55 & E_{b1} &= 1.489 \times 10^5 & E_{b2} &= 418 \text{ W/m}^2 \\ F_{13} &= 0.83 & A_1 &= \pi(0.25)^2 = 0.1963 & A_3 &= \pi(0.5)^2 = 0.7854 \\ F_{31} = F_{32} &= \frac{0.83}{4} = 0.2075 & \frac{1 - \epsilon_1}{\epsilon_1 A_1} &= 4.168 & \frac{1}{A_1 F_{12}} &= 29.966 \end{aligned}$$

$$\frac{1}{A_1 F_{13}} = \frac{1}{A_3 F_{32}} = 6.137$$



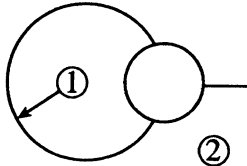
$$q = \frac{148,900 - 418}{4.168 + \frac{1}{\frac{1}{29.966} + 2(6.137)}} = 11,532 \text{ W}$$

Chapter 8

8-109

$$E_{b_1} = \sigma T_1^4 = 23,200 \text{ W/m}^2$$

$$E_{b_2} = 459$$



$$A_3 = \frac{\pi(7.1)^2}{4} = 39.6 \text{ cm}^2$$

$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = \frac{0.55}{(0.45)(0.0156)} = 78.35$$

$$F_{13} = F_{12}$$

$$A_1 F_{13} = A_3 F_{31} = A_3$$

$$q = \frac{23,220 - 459}{78.35 + \frac{1}{0.00396}} = 68.79 \text{ W}$$

8-110

Bottom = (1) Sides = (2) Room = (3) $A_1 = 7.854 \times 10^{-5}$

$$A_2 = \pi(0.005 + 0.01)[(0.01^2 - 0.005^2) + 0.03^2]^{1/2} = 0.001433$$

$$T_1 = 773 \text{ K} \quad E_{b_1} = 20,241 \quad E_{b_3} = 478 = J_3 \quad T_3 = 303 \text{ K}$$

$$\epsilon_1 = 0.6$$

For figure: $\frac{r_2}{L} = 0.167$

$$\frac{L}{r_1} = 3$$

open hole $A_3 = 3.142 \times 10^{-4}$

$$F_{13} = (0.05)(2)^2 = 0.8$$

$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = 8488$$

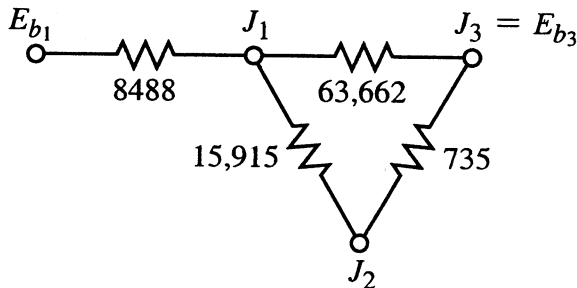
$$F_{23} = 1 - 0.05 = 0.95$$

$$F_{12} = 1 - 0.2 = 0.8$$

$$\frac{1}{A_1 F_{13}} = 63,662$$

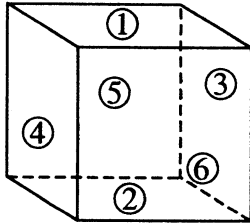
$$\frac{1}{A_1 F_{12}} = 15,915$$

$$\frac{1}{A_2 F_{23}} = 735$$



$$q = \frac{20,241 - 478}{8488 + \frac{1}{\frac{1}{63,662} + \frac{1}{15,915 + 735}}} = 0.911 \text{ W}$$

8-111



$$\begin{aligned}
 T_1 &= 373 \text{ K} & T_2 &= 313 \text{ K} & \epsilon_1 &= 0.7 & \epsilon_2 &= 0.5 \\
 \epsilon_3 &= \epsilon_4 = \epsilon_5 = \epsilon_6 = 0.6 & T_3 &= T_4 = 343 \text{ K} & T_5 &= T_6 = 60^\circ\text{C} = 333 \text{ K} \\
 E_{b_1} &= 1097 \text{ W/m}^2 & E_{b_2} &= 544 & E_{b_3} &= E_{b_4} = 785 & E_{b_5} &= E_{b_6} = 735 \\
 F_{12} &= 0.2 & F_{13} &= F_{14} = F_{15} = F_{16} = 0.2 & \text{All shape factors are } 0.2 \\
 A_{ij} &= 0 & \text{From symmetry} & & J_3 &= J_4 & J_5 &= J_6 \\
 J_1 - (1 - 0.7)(0.2)(J_2 + 2J_3 + 2J_5) &= (0.7)(1097) \\
 J_2 - (1 - 0.5)(0.2)(J_1 + 2J_3 + 2J_5) &= (0.5)(544) \\
 J_3 - (1 - 0.6)(0.2)(J_1 + J_2 + J_3 + 2J_5) &= (0.6)(785) \\
 J_5 - (1 - 0.6)(0.2)(J_1 + J_2 + J_5 + 2J_3) &= (0.6)(735)
 \end{aligned}$$

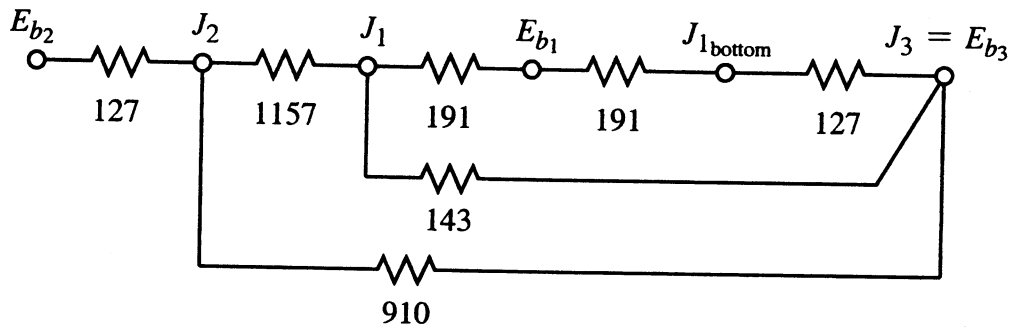
Solving:

$$\begin{aligned}
 J_1 &= 995.215 \text{ W/m}^2 & J_2 &= 682.195 \text{ W/m}^2 & J_3 &= J_4 = 790.51 \\
 J_5 &= J_6 = 762.68 \text{ W/m}^2 \\
 \frac{1 - \epsilon_1}{\epsilon_1 A_1} &= 0.4286 & \frac{1 - \epsilon_2}{\epsilon_2 A_2} &= 1.0 & \frac{1 - \epsilon_3}{\epsilon_3 A_3}, \text{ etc.} &= 0.6667 \\
 q_1 &= \frac{E_{b_1} - J_1}{0.4286} = 238 \text{ W} & q_2 &= \frac{E_{b_2} - J_2}{1.0} = -138 \text{ W} \\
 q_3 &= q_4 = \frac{E_{b_3} - J_3}{0.6667} = -8.3 \text{ W} & q_5 &= q_6 = \frac{E_{b_5} - J_5}{0.6667} = -41.5 \text{ W}
 \end{aligned}$$

8-112

$$\begin{aligned}
 r_1 &= 10 \text{ cm} & r_2 &= 5 \text{ cm} & L &= 10 \text{ cm} & \frac{r_2}{L} &= 0.5 & \frac{L}{r_1} &= 1.0 \\
 F_{12} &= 0.11 & \text{(3) room} & & F_{13} &= 1 - 0.11 = 0.89 & F_{13_{\text{bottom}}} &= 1.0 \\
 T_2 &= 700 \text{ K} & \epsilon_2 &= 0.8 & \epsilon_1 &= 0.4 & T_3 &= 298 \text{ K} \\
 F_{21} &= (0.11)(2)^2 = 0.44 & E_{b_2} &= 13,611 & E_{b_3} &= 447 \\
 F_{23} &= 1 - 0.44 = 0.56 & A_1 &= 0.007854 & A_2 &= 0.001963 \text{ m}^2 \\
 \frac{1 - \epsilon_1}{\epsilon_1 A_1} &= 191 & \frac{1 - \epsilon_2}{\epsilon_2 A_2} &= 127 & \frac{1}{A_3 F_{23}} &= 910 & \frac{1}{A_1 F_{12}} &= 1157 \\
 \frac{1}{A_1 F_{13}} &= 143 & \frac{1}{A_1 F_{13_{\text{bot}}}} &= 127
 \end{aligned}$$

Chapter 8



$$\frac{1}{R_1} = \frac{1}{143} + \frac{1}{(2)(191) + 127} = 0.008958 \quad R_1 = 111.6$$

$$\frac{1}{R_2} = \frac{1}{910} + \frac{1}{1157 + R_1} \quad R_2 = 529.9 \quad R = 127 + R_2 = 656.9$$

$$q_2 = \frac{E_{b_2} - E_{b_3}}{R} = \frac{13,611 - 447}{656.9} = 20.04 \text{ W}$$

8-113

$$T_1 = 873 \text{ K} \quad \varepsilon_1 = 0.63 \quad r_1 = r_2 = 25 \text{ cm} \quad q_2 = 80 \text{ kW/m}^2$$

$$\varepsilon_2 = 0.75 \quad d = 12.5 \text{ cm} \quad T_3 = 303 \text{ K} \quad E_{b_1} = 32,928 \text{ W/m}^2$$

$$E_{b_3} = 478 = J_3 \quad F_{12} = 0.6 \quad F_{13} = 0.4$$

$$A_1 = A_2 = \pi(0.25)^2 = 0.1963 \text{ m}^2 \quad F_{21} = 0.6 \quad F_{23} = 0.4$$

$$J_1 - (1 - 0.63)[0.6J_2 + (0.4)(478)] = (0.63)(32,928) \quad J_1 = 44,552 \text{ W/m}^2$$

$$J_2 - [0.6J_2 + (0.4)(478)] = 80,000 \quad J_2 = 106,900$$

$$q_1 = \frac{\varepsilon_1 A_1}{1 - \varepsilon_1} (E_{b_1} - J_1) = -3885 \text{ W} \quad q_2 = \frac{\varepsilon_2 A_2}{1 - \varepsilon_2} (E_{b_2} - J_2) = 15,700 \text{ W}$$

$$E_{b_2} = 1.3356 \times 10^5 = \sigma T_2^4 \quad T_2 = 1239 \text{ K} = 966^\circ\text{C}$$

$$q(\text{room}) = q_1 + q_2 = 11,815 \text{ W}$$

8-114

$$J_1 - [0.6J_2 + (0.4)(478)] = 100,000 \quad J_2 - [0.6J_1 + (0.4)(478)] = 80,000$$

Solution

$$J_1 = 2.317 \times 10^5 \text{ W/m}^2 \quad J_2 = 2.192 \times 10^5 \text{ W/m}^2$$

$$q_1 = \frac{\varepsilon_1 A_1}{1 - \varepsilon_1} (E_{b_1} - J_1) = 19,630 \text{ W} \quad E_{b_1} = 2.904 \times 10^5 \text{ W/m}^2 = \sigma T_1^4$$

$$T_1 = 1504 \text{ K} = 1231^\circ\text{C}$$

$$q_2 = \frac{\varepsilon_2 A_2}{1 - \varepsilon_2} (E_{b_2} - J_2) = 15,704 \text{ W} \quad E_{b_2} = 2.459 \times 10^5 \text{ W/m}^2 = \sigma T_2^4$$

$$T_2 = 1413 \text{ K} = 1170^\circ\text{C}$$

$$q(\text{room}) = q_1 + q_2 = 35,064 \text{ W}$$

8-115

Heater surface (3) Room is (4) $d_1 = 10 \text{ cm}$ $\epsilon_1 = 0.4$ $d_2 = 20 \text{ cm}$

$\epsilon_2 = 0.6$ $L = 10 \text{ cm}$ $\epsilon_3 = 0.8$ $\frac{q}{A_3} = 90 \text{ kW/m}^2$ $T_4 = 303 \text{ K}$

$$A_1 = \pi(0.1)^2 = 0.03142 \text{ m}^2$$

$$A_2 = 0.06283 \text{ m}^2$$

$$A_3 = \pi(0.1^2 - 0.05^2) = 0.02356 \text{ m}^2$$

$$F_{21} = 0.32 \quad F_{22} = 0.23$$

$$F_{24} + F_{23} = 1 - 0.32 - 0.23 = 0.45$$

$$F_{24i} = F_{23} = 0.225$$

$$F_{12} = (2)(0.32) = 0.64$$

$$F_{13} = F_{14i} = \frac{1}{2}(1 - 0.64) = 0.18$$

$$F_{32} = 0.6$$

$$F_{34} = 0.4 \quad F_{31} = 0.24$$

Both inside and outside of cylinder exchange heat with room and are in radiant balance

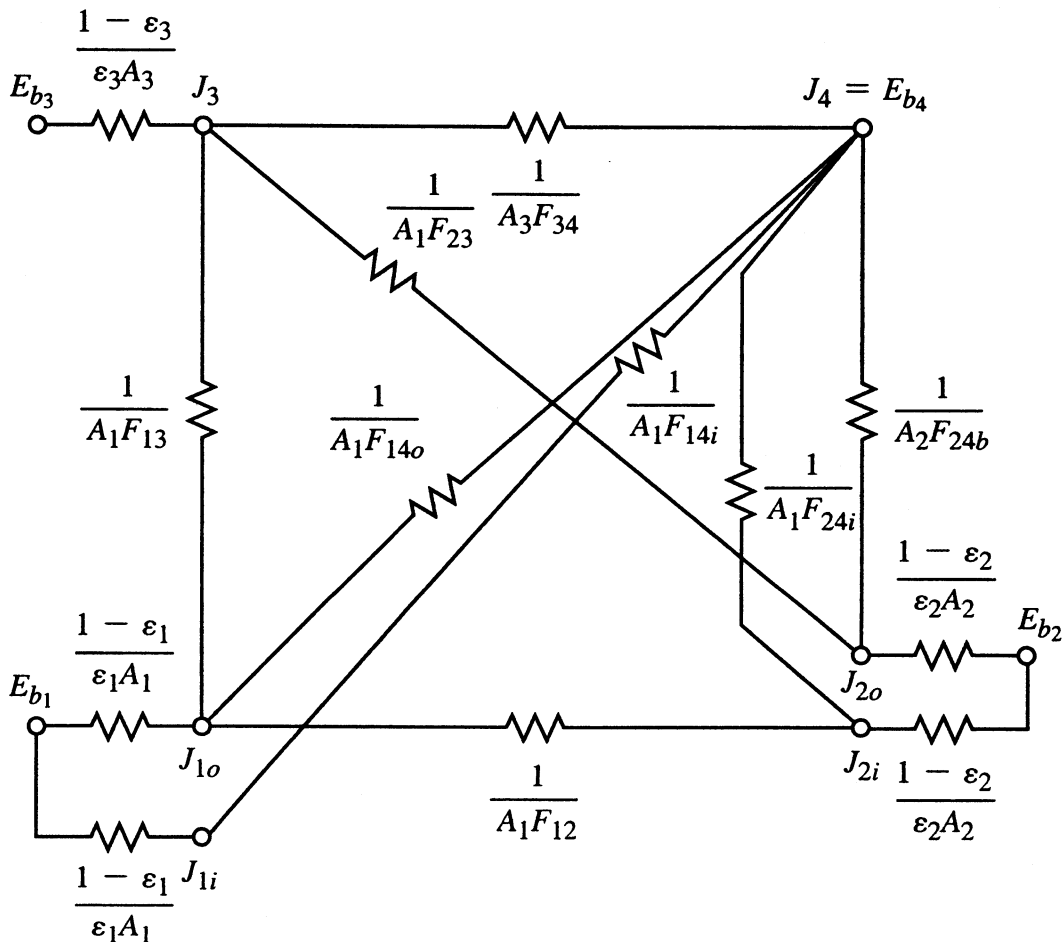
open ends of (1) $F = 0.175$ $A_{\text{end}} = 0.007854 \text{ m}^2$

$$F_{\text{end}-(1)} = 0.825$$

$$F_{(1)\text{-end}} = 0.2065$$

$$F_{14i} = (2)(0.206) = 0.413$$

$$E_{b_4} = 478 \text{ W/m}^2$$



Chapter 8

$$\begin{array}{lll} \frac{1-\varepsilon_1}{\varepsilon_1 A_1} = 47.74 & \frac{1-\varepsilon_2}{\varepsilon_2 A_2} = 10.61 & \frac{1}{A_1 F_{13}} = 176.8 \\ \frac{1}{A_2 F_{23}} = 70.74 & \frac{1}{A_1 F_{14o}} = 176.8 & \frac{1}{A_1 F_{14i}} = 77.06 & \frac{1}{A_1 F_{12}} = 49.73 \\ \frac{1}{A_3 F_{34}} = 106.1 & \frac{1}{A_2 F_{24i}} = 70.74 & \frac{1}{A_2 F_{24o}} = 15.92 \end{array}$$

$$q_3 = \left(\frac{q}{A}\right) A_3 = (90,000)(0.02356) = 2120 \text{ W}$$

Node J_3

$$2120 + \frac{J_{1o} - J_3}{176.8} + \frac{J_{2i} - J_3}{70.74} + \frac{478 - J_3}{106.1} = 0$$

Node J_{1o}

$$\frac{J_{1i} - J_{1o}}{(2)(47.74)} + \frac{J_3 - J_{1o}}{176.8} + \frac{478 - J_{1o}}{176.8} + \frac{J_{2i} - J_{1o}}{49.73} = 0$$

Node J_{1i}

$$\frac{J_{1o} - J_{1i}}{(2)(47.74)} + \frac{478 - J_{1i}}{77.06} = 0$$

Node J_{2o}

$$\frac{J_{2i} - J_{2o}}{(2)(10.61)} + \frac{478 - J_{2o}}{15.92} = 0$$

Node J_{2i}

$$\frac{J_{2o} - J_{2i}}{(2)(10.61)} + \frac{J_{1o} - J_{2i}}{49.73} + \frac{J_3 - J_{2i}}{70.74} + \frac{478 - J_{2i}}{70.74} = 0$$

Solution

$$J_{1o} = 81,792 \text{ W/m}^2 \quad J_{1i} = 36,584 \text{ W/m}^2 \quad J_{2o} = 47,927 \text{ W/m}^2$$

$$J_{2i} = 111,173 \text{ W/m}^2 \quad J_3 = 142,337 \text{ W/m}^2$$

$$\text{then } E_{b_1} = \frac{J_{1o} + J_{1i}}{2} = \sigma T_1^4 = 59,188 \text{ W/m}^2 \quad T_1 = 1011 \text{ K}$$

$$E_{b_2} = \frac{J_{2o} + J_{2i}}{2} = \sigma T_2^4 = 79,550 \text{ W/m}^2 \quad T_2 = 1088 \text{ K}$$

$$q_3 = 2120 = \frac{E_{b_3} - 142,337}{\frac{1-0.8}{(0.8)(0.02356)}} \quad E_{b_3} = 1.648 \times 10^5 = \sigma T_3^4 \quad T_3 = 1306 \text{ K}$$

8-116

$$GA\alpha_{\text{solar}} = \varepsilon_{\text{low temp}} A \sigma (T^4 - T_{\infty}^4)$$

$$(1500)(0.15) = (0.04)(5.669 \times 10^{-8}) T^4$$

$$T = 561 \text{ K} = 288^\circ\text{C}$$

8-117.

$$T_{\infty} = -70^{\circ}\text{C} = 203 \text{ K} \quad \alpha_{\text{solar}} = 0.46 \quad \alpha_{\text{low temp}} = 0.95$$

$$(1070)(0.46) = (0.95)(5.669 \times 10^{-8})(T^4 - 203^4) \quad T = 322.6 \text{ K} = 49.6^{\circ}\text{C}$$

8-118

$$\alpha_s(950) = \sigma\epsilon(T^4 - 300^4) + 12(T - 300)$$

$$f(T) = 0 = -902.5 + (0.6)(5.669 \times 10^{-8})(T^4 - 300^4)$$

T	$f(T)$
350	-67.6
360	+113.3
$T = 353.7$	0

8-119

$$\alpha_{\text{solar}} = 0.94 \quad \alpha_{\text{low temp}} = 0.21$$

$$(800)(0.94) = (0.21)(5.669 \times 10^{-8})(T^4 - 298^4)$$

$$T = 516 \text{ K} = 243^{\circ}\text{C}$$

8-120

$$hA(T_{\infty} - T_t) + \sigma\epsilon A(T_r^4 - T_t^4) = 0$$

$$T_{\infty} = 105^{\circ}\text{C} = 378 \text{ K} \quad T_t = 98^{\circ}\text{C} = 371 \text{ K}$$

$$\text{Solving } T_r = 305 \text{ K} = 32^{\circ}\text{C}$$

8-121

$$T_t = 443 \text{ K} \quad T_w = 698 \text{ K} \quad \epsilon_t = 0.43 \quad h = 150 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$$

$$(5.669 \times 10^{-8})(0.43)(698^4 - 443^4) = (150)(443 - T_g)$$

$$T_g = 410.7 \text{ K} = 137.7^{\circ}\text{C}$$

8-122

$$T_s = -40^{\circ}\text{C} = 233 \text{ K} \quad \epsilon = 0.8$$

$$hA(T_w - T_{aw})_{\text{lam}} + hA(T_w - T_{aw})_{\text{turb}} = -\sigma A\epsilon(T_w^4 - T_s^4)$$

laminar: $h = 56.26 \quad x_c = 0.222 \text{ m} \quad T_{aw} = 584 \text{ K}$

turbulent: $h = 87.45 \quad 0.222 \text{ to } 0.7 \text{ m} \quad T_{aw} = 605 \text{ K}$

$$(56.26)(0.222)(T_w - 584) + (87.45)(0.7 - 0.222)(T_w - 605)$$

$$= -(5.669 \times 10^{-8})(0.7)(0.8)(T_w^4 - 233^4)$$

$$T_w = 549 \text{ K} = 276^{\circ}\text{C}$$

Chapter 8

8-123

$$(28)A(T_a - 273) = (5.669 \times 10^{-8})A(1.0)(273^4 - 203^4)$$

$$T_a = 280.8 \text{ K} = 7.8^\circ\text{C}$$

8-124

$$h = 1.32 \left(\frac{\Delta T}{d} \right)^{1/4} \quad T_f = 650^\circ\text{C} = 923 \text{ K} \quad T_a = 560^\circ\text{C} = 833 \text{ K}$$

$$\frac{q}{A}_{\text{conv}} = 1.32(\Delta T)^{5/4} \left(\frac{1}{d} \right)^{1/4}$$

$$(5.669 \times 10^{-8})(0.6)(923^4 - T_i^4) = 1.32 \left(\frac{1}{0.0032} \right)^{1/4} (T_i - 833)^{5/4}$$

$$3.4014 \times 10^{-8} T_i^4 + 5.55(T_i - 833)^{5/4} - 24,687 = 0 \quad T_i = 911 \text{ K} = 638^\circ\text{C}$$

8-125

$$T_\infty = 20^\circ\text{C} = 293 \text{ K} \quad T_r = 32^\circ\text{C} = 305 \text{ K} \quad d = 0.0032 \text{ m}$$

$$\varepsilon = 0.6 \quad h = 1.32 \left(\frac{\Delta T}{d} \right)^{1/4} = 1.32 \left(\frac{T_i - T_\infty}{d} \right)^{1/4}$$

$$\frac{q}{A}_{\text{conv}} = 1.32(\Delta T)^{5/4} \left(\frac{1}{d} \right)^{1/4} \quad \frac{q}{A}_{\text{conv}} = \frac{q}{A}_{\text{rad}}$$

$$(5.669 \times 10^{-8})(0.6)(305^4 - T_i^4) = (1.32)(T_i - 293)^{5/4} \left(\frac{1}{0.0032} \right)^{1/4}$$

$$T_i = 297 \text{ K} = 24^\circ\text{C}$$

8-126

$$T_w = 373 \text{ K} \quad T_{\text{sun}} = 673 \text{ K} \quad \varepsilon_w = 0.6 \quad \text{assume } T_f = 350 \text{ K}$$

$$\rho = 0.998 \quad \mu = 2.075 \times 10^{-5} \quad k = 0.03003 \quad \text{Pr} = 0.7$$

$$\text{Re} = \frac{(0.998)(7)(0.003)}{2.075 \times 10^{-5}} = 1010 \quad C = 0.683 \quad n = 0.466$$

$$h = \frac{0.03003}{0.003} (0.683)(1010)^{0.466} (0.7)^{1/3} = 152.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$(0.6)(5.669 \times 10^{-8})(673^4 - 373^4) = (152.5)(373 - T_g)$$

$$T_g = 331.5 \text{ K} = 58.5^\circ\text{C} \quad T_f = 352 \text{ K}$$

8-127

$$A_1 F_{12} = A_2 F_{21} \quad F_{21} = (0.86) \left(\frac{1}{2} \right) = 0.43 \quad F_{22} = 1 - 0.43 - 0.24 = 0.33$$

$$J_1 - (1 - \epsilon_1)(F_{12} J_{2i} + F_{13} E_{b_3}) = \epsilon_1 E_{b_1}$$

$$J_{2i}[1 - F_{22}(1 - \epsilon_2)] - (1 - \epsilon_2)(F_{21} J_1 + F_{23i} E_{b_3}) = \epsilon_2 E_{b_2}$$

$$J_{2o} - (1 - \epsilon_2)(F_{23o} E_{b_3}) = \epsilon_2 E_{b_2}$$

$$h A_2 (T_3 - T_2) = \frac{E_{b_2} - J_{2o}}{\frac{1 - \epsilon_2}{\epsilon_2 A_2}} + \frac{E_{b_2} - J_{2i}}{\frac{1 - \epsilon_2}{\epsilon_2 A_2}}$$

$$h(T_3 - T_2) = \frac{2\epsilon_2}{1 - \epsilon_2} E_{b_2} - \frac{\epsilon_2}{1 - \epsilon_2} (J_{2o} + J_{2i})$$

Solution yields:

$$T_2 = 406 \text{ K} \quad E_{b_2} = 1540 \quad J_{2i} = 23,644 \quad J_{2o} = 675$$

$$J_1 = 4943$$

$$q_1 = \frac{56,690 - 4943}{\frac{1 - 0.8}{0.8(0.06283)}} = 1824 \text{ W}$$

8-128

$$T_f = 973 \text{ K} \quad h = 20 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad T_\infty = 923 \text{ K}$$

$$(5.669 \times 10^{-8})(0.7)(T_f^4 - 973^4) = (20)(973 - 923)$$

$$T_f = 980 \text{ K} = 707^\circ\text{C}$$

8-129

$$T_f = 328 \text{ K} \quad h = 30 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad T_w = 363 \text{ K} \quad \epsilon = 0.94$$

$$(5.669 \times 10^{-8})(0.94)(363^4 - 328^4) = (30)(328 - T_a)$$

$$T_a = 318 \text{ K} = 45^\circ\text{C}$$

Chapter 8

8-130

$$T_f = \frac{20 + 150}{2} = 85^\circ\text{C} = 358 \text{ K} \quad v = 21.58 \times 10^{-6} \quad k = 0.0306$$

$$\text{Pr} = 0.7 \quad \text{Re} = \frac{(25)(0.5)}{21.58 \times 10^{-6}} = 5.792 \times 10^5$$

$$\text{Nu}_d = 0.3 + \frac{(0.62)(5.79 \times 10^5)^{1/2}(0.7)^{1/3}}{\left[1 + \left(\frac{0.4}{0.7}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{5.79 \times 10^5}{282,000}\right)^{5/8}\right]^{4/5} = 601.7$$

$$h = \frac{(601.7)(0.0306)}{0.5} = 36.82 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q_c = (36.82)\pi(0.5)(150 - 20) = 7519 \text{ W/m}$$

$$q_r = (5.669 \times 10^{-8})(0.7)\pi(0.5)(423^4 - 293^4) = 1536 \text{ W/m}$$

$$q_{\text{total}} = 7519 + 1536 = 9055 \text{ W/m}$$

8-131

$$\lambda_1 T = (0.4)(3400) = 1360 \mu \cdot \text{K} = 2448 \mu \cdot ^\circ\text{R}$$

$$\lambda_2 T = (0.7)(3400) = 2380 \mu \cdot \text{K} = 4284 \mu \cdot ^\circ\text{R}$$

$$E_b = (0 - \lambda_1 T) = 0.00644$$

$$E_b = (0 - \lambda_2 T) = 0.13626$$

$$\text{Fraction between } 0.4 \text{ and } 0.7 \mu = 0.12982$$

8-132

$$E_b = 5.669 \times 10^{-8} (3400)^4 = 7.576 \times 10^6 \text{ W/m}^2$$

$$\text{Between } 0.4 \text{ and } 0.7 \mu = (7.576 \times 10^6)(0.12982) = 9.835 \times 10^5$$

$$400 \text{ W} = A(7.576 \times 10^6)$$

$$A = 5.286 \times 10^{-5} \text{ m}^2 = 0.5286 \text{ cm}^2$$

8-133

$$E_b = 5.669 \times 10^{-8} (3400)^4 = 4.592 \times 10^6 \text{ W/m}^2$$

λ	ϵ	λT	Fraction
0		0	
2	0.6	6000	0.73777
8	0.2	24,000	0.99075

$$E = (4.592 \times 10^6)[(0.6)(0.73777) + (0.2)(0.99075 - 0.73777)]$$

$$= 2.265 \times 10^6 \text{ W/m}^2$$

8-135

8-125

$$T = 5800 \text{ K}$$

λ	λT	Fraction
0.25	1450	0.0099
0.5	2900	0.25055
1.5	8700	0.88066
2.5	14,500	0.96604

$$\text{Fraction transmitted through plain glass} = (0.9)(0.96604 - 0.0099) = 0.86053$$

$$\text{Fraction transmitted through tinted glass} = (0.9)(0.88066 - 0.25055) = 0.56710$$

8-136

$$h = 12 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad T_\infty = 400 \text{ K}$$

$$\text{For } T_w = 510 \text{ K} \quad E = 1100 \text{ W/m}^2$$

$$E_{bw} = \sigma T_w^4 = 3835 \quad \varepsilon = \frac{E}{E_b} = 0.287$$

$$A(G - J) = hA(T_w - 400) \quad G = 2200 \text{ W/m}^2 \quad J = 450 + \varepsilon \sigma T_w^4$$

$$2200 - 450 - (0.289)\sigma T_w^4 = 12(T_w - 400) \quad T_w = 475 \text{ K}$$

$$J = 450 + (0.287)(5.669 \times 10^{-8})(475) = 1278 \text{ W/m}^2$$

8-137

$$T_1 = 550 \text{ K} \quad \varepsilon_1 = 0.5 \quad T_2 = 300 \text{ K} \quad \varepsilon_2 = 0.7$$

$$A_1 = A_2 = (3)^2 = 9 \quad F_{12} = 0.2$$

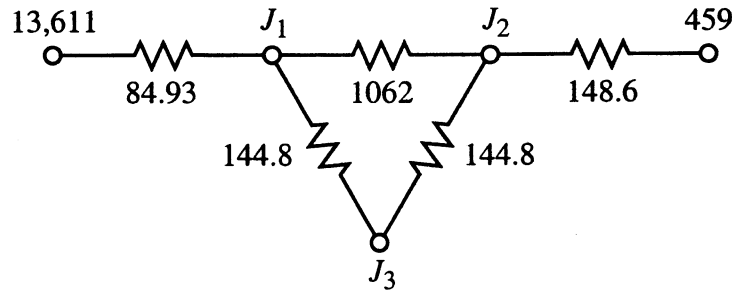
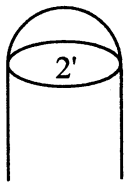
Eq. (8-41)

$$q = \frac{(5.669 \times 10^{-8})(9)(550^4 - 300^4)}{\frac{18(1-0.2)}{9(1-0.2^2)} + \left(\frac{1}{0.5} - 1\right)\left(\frac{1}{0.7} - 1\right)} = \frac{42,555}{3.095} = 13,750 \text{ W}$$

Chapter 8

8-138

$$\begin{aligned}
 T_1 &= 700 \text{ K} & \epsilon_1 &= 0.6 & A_1 &= \pi(0.05)^2 = 7.85 \times 10^{-3} \text{ m}^2 \\
 T_2 &= 300 \text{ K} & \epsilon_2 &= 0.3 & A_2 &= 2\pi(0.05)^2 = 0.0157 \text{ m}^2 \\
 E_{b_1} &= \sigma T_1^4 = 13,611 & E_{b_2} &= \sigma T_2^4 = 459 \text{ W/m}^2 \\
 \frac{d}{x} &= \frac{10}{15} = \frac{2}{3} & F_{12} &= 0.12 & F_{13} &= 1 - 0.12 = 0.88 \\
 \frac{1 - \epsilon_1}{\epsilon_1 A_1} &= 84.93 & \frac{1 - \epsilon_2}{\epsilon_2 A_2} &= 148.6 & \frac{1}{A_1 F_{12}} &= 1062 & \frac{1}{A_1 F_{13}} &= 144.8 \\
 \frac{1}{A_2 F_{23}} &= 144.8 & F_{2-2'} &= 1.0 & F_{2-2'} &= 0.5 & F_{22} &= 0.5 \\
 F_{21} &= \frac{1}{2}(0.12) = 0.06 & F_{23} &= 1 - 0.5 - 0.06 = 0.44
 \end{aligned}$$



$$q = \frac{13,611 - 459}{84.93 + \frac{1}{\frac{1}{1062} + (2)(144.8)}} = 28.5 \text{ W}$$

8-139

$$\begin{aligned}
 E_{b_1} &= 23,220 & E_{b_2} &= 459 \text{ W/m}^2 \\
 \text{Per Unit Length:} \\
 \frac{q}{L} &= \pi(0.05)(0.7)(23,220 - 459) = 2503 \text{ W/m} \\
 \text{with shield, as surface 3, } F_{13} &= 1.0 & \epsilon_3 &= 0.2 \\
 \frac{1 - \epsilon_1}{\epsilon_1 \pi(0.05)} &= 2.73 & \frac{1}{\pi(0.05)(1.0)} &= 6.37 & \frac{1 - \epsilon_3}{\epsilon_3 \pi(0.1)} &= 12.73 \\
 \frac{1}{\pi(0.1)} &= 3.18 \\
 q \text{ with shield per unit length} \\
 \frac{q}{L} &= \frac{23,220 - 459}{2.73 + 6.37 + (2)(12.73) + 3.18} = 603 \text{ W} \\
 \text{Reduced by } &76\%
 \end{aligned}$$

8-140

$$T_1 = 450 \text{ K} \quad \epsilon_1 = 0.5 \quad A_1 = \pi(0.25)^2 = 0.1963 \text{ m}^2 = A_2$$

$$T_2 = 600 \text{ K} \quad \epsilon_2 = 0.6$$

$$T_3 = 1000 \text{ K} \quad \epsilon_3 = 0.7 \quad A_3 = \pi(0.5)(0.5) = 0.7854 \text{ m}^2$$

$$\frac{d}{x} = 1.0 \quad F_{12} = 0.17 = F_{21} \quad F_{13} = 0.83 = F_{23}$$

$$F_{31} = F_{32} = (0.83) \left(\frac{0.1963}{0.7854} \right) = 0.2075 \quad F_{33} = 1 - (2)(0.2075) = 0.585$$

$$E_{b_1} = 2325 \text{ W/m}^2 = E_{b_2} = 7347 \text{ W/m}^2 \quad E_{b_3} = 56,690 \text{ W/m}^2$$

$$\left. \begin{aligned} J_1 - 0.5[0.17J_2 + 0.83J_3] &= 0.5(2325) \\ J_2 - 0.4[0.17J_1 + 0.83J_3] &= 0.6(7347) \\ J_3[1 - 0.585(0.3)] - 0.3(0.2075J_1 + 0.2075J_2) &= 0.7(56,690) \end{aligned} \right\}$$

$$\left. \begin{aligned} J_1 - 0.085J_2 - 0.415J_3 &= 1162.5 \\ -0.068J_1 + J_2 - 0.332J_3 &= 4408.2 \\ -0.06225J_1 - 0.06225J_2 + 0.8245J_3 &= 39,683 \end{aligned} \right\}$$

Solving,

$$J_1 = 24,614 \text{ W/m}^2 \quad J_2 = 23,261 \quad J_3 = 51,744$$

$$q_1 = \frac{0.5}{0.5} (0.1963)(2325 - 24,614) = -4375 \text{ W} = 0.1963(J_1 - G_1)$$

$$G_1 = 46,901 \text{ W/m}^2$$

$$q_2 = \frac{0.6}{0.4} (0.1963)(7347 - 23,261) = -4686 \text{ W} = 0.1963(J_2 - G_2)$$

$$G_2 = 47,133 \text{ W/m}^2$$

$$q_3 = \frac{0.7}{0.3} (0.7854)(56,690 - 51,744) = 9064 \text{ W} = 0.7854(J_3 - G_3)$$

$$G_3 = 40,203 \text{ W/m}^2$$

Chapter 8

8-141

Behaves as if $T_2 = 300 \text{ K}$ $G_2 = 1.0$ $E_{b_2} = 459 \text{ W/m}^2 = J_2$

Do not need Eqn. for surface 2. Inserting $J_2 = 459$ in Eqns. for 1 and 3 gives

$$J_1 - 0.415J_3 = 1201.5 \quad -0.06225J_1 + 0.8245J_3 = 39,712$$

Solving, $J_1 = 21,875$ $J_3 = 49,817$

$$q_1 = \frac{0.5}{0.5}(0.1963)(2325 - 21,875) = -3838 \text{ W} = 0.1963(J_1 - G_1)$$

$$G_1 = 41,427 \text{ W/m}^2$$

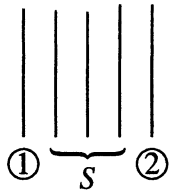
$$q_3 = \frac{0.7}{0.3}(0.7854)(56,690 - 49,817) = 12,595 \text{ W} = 0.7854(J_3 - G_3)$$

$$G_3 = 33,781 \text{ W/m}^2$$

$$q_2 = -12,595 + 3838 = -8757 \text{ W}$$

$$G_2 \rightarrow 0 \text{ because } A_2 \rightarrow \infty$$

8-142



$$T_1 = 300 \text{ K} \quad T_2 = 85 \text{ K} \quad \epsilon_1 = \epsilon_2 = 0.11 \quad \epsilon_s = 0.04$$

All F factors = 1.0

Work problem per unit area

$$\frac{1 - \epsilon_1}{\epsilon_1} = \frac{1 - \epsilon_2}{\epsilon_2} = 8.091 \quad \frac{1 - \epsilon_s}{\epsilon_s} = \frac{0.96}{0.04} = 24$$

4 space resistances = 1.0

$$\text{Total resistance} = (2)(8.091) + (4)(1.0) + (6)(24) = 164.2$$

$$q = \frac{(5.669 \times 10^{-8})(300^4 - 85^4)}{164.2} = 2.779 \text{ W/m}^2 = k_{\text{eff}} \frac{300 - 85}{0.008}$$

$$k_{\text{eff}} = 1.034 \times 10^{-4} \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad R = 77.4 \frac{^\circ\text{C} \cdot \text{m}^2}{\text{W}}$$

8-143

$$\begin{aligned}
 T_1 &= 750 \text{ K} & \varepsilon_1 &= 0.75 & A_1 &= \pi(0.2)^2 = 0.1256 \\
 T_2 &= 600 \text{ K} & \varepsilon_2 &= 0.4 & A_2 &= \pi(0.2^2 - 0.1^2) = 0.09425 \\
 q_3 &= 0 & A_3 &= \pi(0.4)(0.3) = 0.377 \text{ m}^2 & A_{\text{hole}} &= \pi(0.1)^2 = 0.03146 \\
 \frac{d_1}{x} &= \frac{40}{30} = 1.33 & F_{1-2} &= 0.25 \\
 \text{To hole} & \frac{30}{20} = 1.5 & \frac{10}{30} &= \frac{1}{3} & F_{1-\text{hole}} &= 0.07 = F_{14} \\
 F_{12} &= 0.25 - 0.07 = 0.18 & F_{13} &= 1 - 0.25 = 0.75 \\
 T_4 &= \text{room} = 300 \text{ K} \\
 F_{31} &= \frac{(0.75)(0.1256)}{0.337} = 0.25 & F_{33} &= 1 - (2)(0.25) = 0.5 \\
 F_{21} &= \frac{(0.1256)(0.18)}{0.09425} = 0.24 & F_{\text{hole}-1} &= \frac{(0.1256)(0.07)}{0.03146} = 0.28 \\
 F_{\text{hole}-3} &= 1 - 0.28 = 0.72 & F_{3-\text{hole}} &= F_{34} = \frac{(0.72)(0.03146)}{0.377} = 0.06 \\
 F_{32} &= 0.25 - 0.06 = 0.19 & F_{23} &= \frac{(0.19)(0.377)}{0.09425} = 0.76 \\
 E_{b_1} &= 17,937 \text{ W/m}^2 & E_{b_2} &= 7347 & E_{b_4} &= 459 = J_4 \\
 \left. \begin{aligned}
 & \left[J_1 - 0.25[0.18J_2 + (0.07)(459) + 0.75J_3] = 0.75(17,937) \right] \\
 & \left[J_3(1 - 0.5) - [0.25J_1 + 0.19J_2 + (0.06)(459)] = 0 \right] \\
 & \left[J_2 - 0.6(0.24J_1 + 0.76J_3) = 0.4(7347) \right]
 \end{aligned} \right\} \\
 \left. \begin{aligned}
 & \left[J_1 - 0.045J_2 - 0.1875J_3 = 13,461 \right] \\
 & \left[-0.25J_1 - 0.19J_2 + 0.5J_3 = 27.54 \right] \\
 & \left[-0.144J_1 + J_2 - 0.456J_3 = 2939 \right]
 \end{aligned} \right\} \\
 \text{Solving,} \\
 J_1 &= 16,264 \text{ W/m}^2 & J_2 &= 10,904 \text{ W/m}^2 \\
 J_3 &= 12,330 \text{ W/m}^2 = G_3 & J_3 &= E_{b_3} = \sigma T_3^4 & T_3 &= 683 \text{ K} \\
 q_1 &= \frac{(0.75)(0.1256)}{0.25} (17,937 - 16,264) = 630.4 \text{ W} = 0.1256(J_1 - G_1) \\
 G_1 &= 11,245 \text{ W/m}^2 \\
 q_2 &= \frac{(0.4)(0.09425)}{0.6} (7347 - 10,904) = -223.5 \text{ W} = 0.09425(J_2 - G_2) \\
 G_2 &= 13,275 \text{ W/m}^2 \\
 q_4 &= 630.4 - 223.5 = 406.9 \text{ W}
 \end{aligned}$$

Chapter 8

8-144

$$\frac{q}{A} = E\sigma(T_1^4 - T_2^4) = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$E = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$\varepsilon_1 = \varepsilon_2$	E
0.9	0.818
0.8	0.667
0.5	0.333
0.2	0.111
0.1	0.0526
0.05	0.0256

8-145

For large plates, $\frac{A_2}{A_1} \rightarrow 1.0$ and $F_{12} \rightarrow 1.0$. Substituting these values gives the desired result.

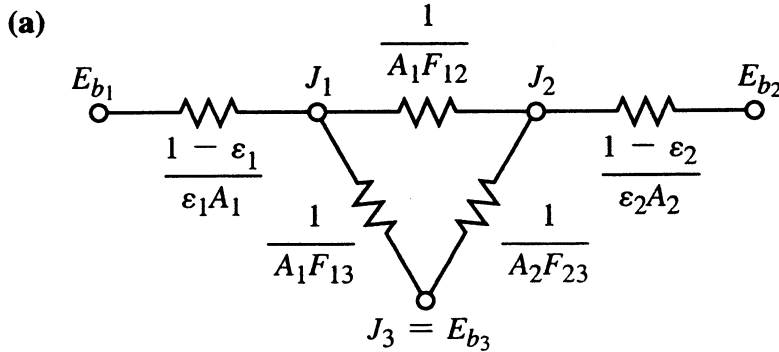
8-146

$$\begin{array}{llll} r_1 = 0.15 & r_2 = 0.5 & L = 2 & \varepsilon_1 = 0.2 \quad \varepsilon_2 = 0.4 \\ T_1 = 800 \text{ K} & T_2 = 400 \text{ K} & & (3) \text{ is room} \quad T_3 = 300 \text{ K} \\ \frac{r_1}{r_2} = 0.3 & \frac{L}{r_2} = 4.0 & F_{22} = 0.55 & F_{21} = 0.265 \end{array}$$

$$F_{12} = \frac{0.5}{0.15}(0.265) = 0.883 \quad F_{13} = 1 - 0.883 = 0.117$$

$$F_{23} = 1 - 0.55 - 0.265 = 0.185 \quad F_{11} = 0$$

Assume only inner surfaces exchange heat



$$A_1 = \pi(0.3)(2) = 1.885 \quad A_2 = \pi(1)(2) = 6.283$$

$$E_{b1} = \sigma T_1^4 = 23,216 \text{ W/m}^2 \quad E_{b2} = \sigma T_2^4 = 1451 \text{ W/m}^2$$

$$E_{b3} = \sigma T_3^4 = 459 \text{ W/m}^2$$

$$J_1 = (1 - \epsilon_1)(F_{12}J_2 + F_{13}J_3) + \epsilon_1 E_{b1}$$

$$J_2 = \frac{1}{1 - F_{22}(1 - \epsilon_2)} [(1 - \epsilon_1)(F_{12}J_1 + F_{23}J_3) + \epsilon_2 E_{b2}]$$

$$J_3 = E_{b3} = 459$$

$$J_1 = 0.7064 J_2 + 4686$$

$$J_2 = (1.4925)(0.159 J_1 + 631)$$

Which have the solution:

$$J_1 = 6428 \text{ W/m}^2 \quad J_2 = 2467 \text{ W/m}^2$$

$$q_1 = \frac{\epsilon_1 A_1}{1 - \epsilon_1} (E_{b1} - J_1) = \frac{(0.2)(1.885)}{1 - 0.2} (23,216 - 6428) = 7911 \text{ W}$$

$$q_2 = \frac{\epsilon_2 A_2}{1 - \epsilon_2} (E_{b2} - J_2) = \frac{(0.4)(6.283)}{1 - 0.4} (1451 - 2467) = -4256 \text{ W}$$

(b) Ends insulated, J_3 floats and $\neq E_{b3}$

$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = 2.122 \quad \frac{1 - \epsilon_2}{\epsilon_2 A_2} = 0.2387$$

$$\frac{1}{A_1 F_{12}} = 0.6008 \quad \frac{1}{A_1 F_{13}} = 4.534 \quad \frac{1}{A_2 F_{23}} = 0.8603$$

$$q = \frac{23,216 - 1451}{2.122 + \frac{1}{0.6008 + 4.534 + 0.8603} + 0.2387} = 7502 \text{ W}$$

Chapter 8

8-147

$$d_1 = 20 \text{ cm} \quad d_2 = 10 \text{ cm} \quad T_1 = 500 \text{ K} \quad \varepsilon_1 = 0.6 \quad T_2 = 700 \text{ K}$$

$$\varepsilon_2 = 0.2$$

Surface 3 = sides, $\varepsilon_3 = 0.8$

$$A_1 = 0.03142 \quad A_2 = 0.007853 \quad A_3 = 0.05269$$

$$F_{12} = 0.12 \quad F_{11} = 0 \quad F_{13i} = 0.88 \quad F_{21} = 0.48 \quad F_{22} = 0$$

$$F_{23i} = 0.52 \quad F_{3i-1} = 0.525 \quad F_{3i-2} = 0.0775 \quad F_{3i-3i} = 0.397$$

$$F_{3o-4} = 1.0 \quad E_{b_1} = 3543 \quad E_{b_2} = 13,609 \quad E_{b_4} = 459$$

$$J_1 = (1 - \varepsilon_1)(F_{12}J_2 + F_{13i}J_{3i}) + \varepsilon_1 E_{b_1} \quad (\text{a})$$

$$J_2 = (1 - \varepsilon_2)(F_{21}J_1 + F_{23i}J_{3i}) + \varepsilon_2 E_{b_2} \quad (\text{b})$$

Energy balance on surface 3

$$(A_1 F_{1-3i})(J_1 - J_{3i}) + (A_2 F_{23i})(J_2 - J_{3i}) = \frac{E_{b_4} - J_{3i}}{(2)\left(\frac{1-\varepsilon_3}{\varepsilon_3 A_3}\right) + \frac{1}{A_3 F_{34o}}} = 0 \quad (\text{c})$$

Solution of equations is

$$J_1 = 2960 \quad J_2 = 4585 \quad J_{2i} = 1745 \text{ W/m}^2$$

$$q_1 = \frac{\varepsilon_1 A_1}{1 - \varepsilon_1} (E_{b_1} - J_1) = 27.48 \text{ W} \quad q_2 = \frac{\varepsilon_2 A_2}{1 - \varepsilon_2} (E_{b_2} - J_2) = 17.72 \text{ W}$$

$$q \text{ (total)} = 27.48 + 17.72 = 45.2 \text{ W}$$

8-148

See problem 8-137. Equations (a) and (b) remain the same, convection loss term must be added to Eq. (c) for surface 3o. (outside of cone)

$$q_{\text{conv}} = hA_{3o}(T_4 - T_3) \quad h = 25 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

The energy balance on surface 3 is then

$$(A_1 F_{13i})(J_1 - J_3) + (A_2 F_{23i})(J_2 - J_{3i}) + (A_{3o} F_{3o-4})(E_{b_4} - J_{3o}) + hA_{3o}(T_4 - T_3) = 0 \quad (\text{c})$$

$$\text{In addition, we have } T_3 = \left(\frac{E_{b_3}}{\sigma}\right)^{1/4} \quad (\text{d})$$

$$\text{and } hA_{3o}(T_4 - T_3) = \frac{\varepsilon_3 A_3}{1 - \varepsilon_3} (E_{b_3} - J_{3o} - J_{3i}) \quad (\text{e})$$

The original two equations are

$$J_1 - (1 - \varepsilon_1)(F_{12}J_2 + F_{1-3i}J_{3i}) - \varepsilon_1 E_{b_1} = 0 \quad (\text{a})$$

$$J_2 - (1 - \varepsilon_2)(F_{21}J_1 + F_{2-3i}J_{3i}) - \varepsilon_2 E_{b_2} = 0 \quad (\text{b})$$

The solution to the nonlinear set of equations may be obtained with Excel solver.

$$\text{The results are } J_1 = 2677 \quad J_{3i} = 1009 \quad E_{b_3} = 727 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$J_2 = 4155 \quad J_{3o} = 673 \quad T_3 = \left(\frac{E_{b3}}{\sigma} \right)^{1/4} = 337 \text{ K}$$

The heat transfer rates are thus

$$q_1 = \frac{\epsilon_1 A_1}{1 - \epsilon_1} (E_{b1} - J_1) = 40.81 \text{ W} \quad q_2 = \frac{\epsilon_2 A_2}{1 - \epsilon_2} (E_{b2} - J_2) = 18.56 \text{ W}$$

$$q \text{ (total)} = 59.37 \text{ W}$$

As a check this value must equal the energy lost by convection and radiation from the outside of surface 3.

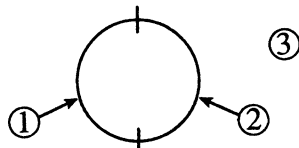
$$q_{3o, \text{ rad}} = \frac{\epsilon_3 A_3}{1 - \epsilon_3} (E_{b3} - J_{3o}) = 11.38 \text{ W}$$

$$q_{3o, \text{ conv}} = h A_{3o} (T_3 - T_4) = (25)(0.05269)(337 - 300) = 48.74 \text{ W}$$

$$q \text{ (total)} = 60.1 \text{ W}$$

The difference in the two values for total heat transfer results from roundoff in the solution.

8-149



$$T_1 = T_2 = 800^\circ\text{C} = 1073 \text{ K} \quad T_3 = 20^\circ\text{C} = 293 \text{ K}$$

$$\epsilon_1 = 0.5 \quad \epsilon_2 = 0.8 \quad d = 10 \text{ cm}$$

$$A_1 = A_2 = \frac{4\pi r^2}{2} = 2\pi(0.05)^2 = 0.01571 \text{ m}^2$$

$$q = \sigma \epsilon A (T^4 - T_3^4)$$

$$q_1 = (5.668 \times 10^{-8})(0.5)(0.01571)(1073^4 - 293^4) = 587 \text{ W}$$

$$q_2 = (5.668 \times 10^{-8})(0.8)(0.01571)(1073^4 - 293^4) = 939 \text{ W}$$

$$q_{\text{tot}} = 587 + 939 = 1526 \text{ W}$$

8-150

$$\alpha \text{ (solar)} = 0.94 \quad T_{\text{surr}} = 25^\circ\text{C} = 298 \text{ K} \quad \alpha \text{ (low temp)} = 0.21 = \epsilon$$

$$G \text{ (solar)} = 700 \text{ W/m}^2$$

$$G \text{ (solar)} \alpha \text{ (solar)} = \sigma \epsilon (T^4 - 298^4)$$

$$(700)(0.94) = (5.668 \times 10^{-8})(0.21)(T^4 - 298^4)$$

$$T = 501 \text{ K} = 228^\circ\text{C}$$

Chapter 8

8-151

$$G(\text{solar})\alpha(\text{solar}) = q_{\text{rad}} + q_{\text{conv}}$$
$$(700)(0.94) = (0.21)(5.668 \times 10^{-8})(T^4 - 298^4) + (7.5)(T - 298)$$

Solving, $T = 369 \text{ K} = 96^\circ\text{C}$

8-152

copper sphere $\rho = 8954$ $c = 383$ $\varepsilon = 0.8$ $d = 5 \text{ cm}$

$$A = 4\pi(0.0025)^2 = 7.85 \times 10^{-3} \text{ m}^2$$
$$V = \frac{4}{3}\pi(0.025)^3 = 6.54 \times 10^{-5} \text{ m}^3$$
$$T_r = 0^\circ\text{C} = 273 \text{ K} \quad \sigma\varepsilon A(T_r^4 - T^4) = \rho c V \frac{dT}{d\tau}$$

$$T^{p+1} = \Delta\tau \left(\frac{\sigma\varepsilon A}{\rho c V} \right) (T_r^4 - T^p) + T^p$$

$$T(\text{initial}) = 300^\circ\text{C} = 573 \text{ K} \quad T(\text{final}) = 50^\circ\text{C} = 323 \text{ K}$$

$$\frac{\sigma\varepsilon A}{\rho c V} = \frac{(5.668 \times 10^{-8})(0.8)(7.85 \times 10^{-3})}{(8954)(383)(6.54 \times 10^{-5})} = 1.586 \times 10^{-12}$$

Choose $\Delta\tau = 100 \text{ sec}$

$$T^{p+1} = 1.586 \times 10^{-10} (273^4 - T^p) + T^p$$

At $T = 200^\circ\text{C} = 473 \text{ K}$ 9 time increments = 900 sec
At $T = 100^\circ\text{C} = 373 \text{ K}$ 34 time increments = 3400 sec
At $T = 50^\circ\text{C} = 323 \text{ K}$ 70 time increments = 7000 sec

Excel printout follows on next page.

8-153

$T_\infty = 293 \text{ K}$; $T_{\text{wall}} = 313 \text{ K}$; $u_\infty = 3 \text{ m/s}$; Assume $\varepsilon_{\text{glass}} = 1.0$
Assume $d = 0.006 \text{ m}$

$$\nu = 15 \times 10^{-6}; \quad k = 0.026; \quad \text{Re} = (3)(0.006)/15 \times 10^{-6} = 1200$$

$$h = (0.026/0.006)(0.683)(1200)^{0.618} = 24$$

Assume half radiation to wall; half to surroundings

$$(24)(T_i - 293) = 0.5\sigma(313^4 + 293^4 - 2T_i^4)$$

Solve by iteration; $T_i = 295 \text{ K} = 22^\circ\text{C}$

Time incr. (100 sec)	Temp, K
0	573
1	556.7839
2	542.4226
3	529.574
4	517.9809
5	507.4447
6	497.8094
7	488.9505
8	480.7665
9	473.1744
10	466.105
11	459.5002
12	453.3107
13	447.4945
14	442.0155
15	436.8423
16	431.9476
17	427.3075
18	422.9007
19	418.7088
20	414.715
21	410.9046
22	407.2642
23	403.7819
24	400.4469
25	397.2496
26	394.1809
27	391.2328
28	388.3981
29	385.6698
30	383.0419
31	380.5087
32	378.0649
33	375.7056
34	373.4265
35	371.2234
36	369.0925
37	367.03
38	365.0329
39	363.0978

40	361.222
41	359.4028
42	357.6375
43	355.9238
44	354.2595
45	352.6425
46	351.0708
47	349.5425
48	348.0559
49	346.6093
50	345.2011
51	343.8299
52	342.4944
53	341.193
54	339.9246
55	338.688
56	337.4821
57	336.3057
58	335.1578
59	334.0375
60	332.9439
61	331.8759
62	330.8329
63	329.8139
64	328.8182
65	327.8451
66	326.8939
67	325.9638
68	325.0542
69	324.1645
70	323.2942
71	322.4425
72	321.6091
73	320.7933
74	319.9947
75	319.2127
76	318.4469
77	317.6969
78	316.9621
79	316.2423

Chapter 8

8-159

$$T_1 = 600 \text{ K} \quad F_{12} = 1.0 \quad E_{b_1} = 7347 \text{ W/m}^2 \quad \epsilon_1 = 0.75$$

$$(3) \text{ room} \quad E_{b_3} = 447 \text{ W/m}^2 \quad \epsilon_2 = 0.8 \quad T_3 = 298 \text{ K}$$

$$\text{Per unit length: } A_1 = \pi(0.02) = 0.06283 \quad A_2 = 0.1571 \quad T_\infty = 308 \text{ K}$$

$$\frac{1 - \epsilon_1}{\epsilon_1 A_1} = 5.305 \quad \frac{1}{A_1 F_{12}} = 15.916 \quad \frac{1 - \epsilon_2}{\epsilon_2 A_2} = 1.591$$

$$\frac{1}{A_2 F_{23}} = 6.365$$

$$q = \frac{(5.669 \times 10^{-8})(600^4 - T_2^4)}{5.305 + 15.916 + 1.591}$$

$$= \frac{(5.669 \times 10^{-8})(T_2^4 - 298^4)}{1.591 + 6.365} + \pi(0.05)(180)(T_2 - 308)$$

By iteration: $T_2 = 318 \text{ K} \quad q = 297 \text{ W/m}$

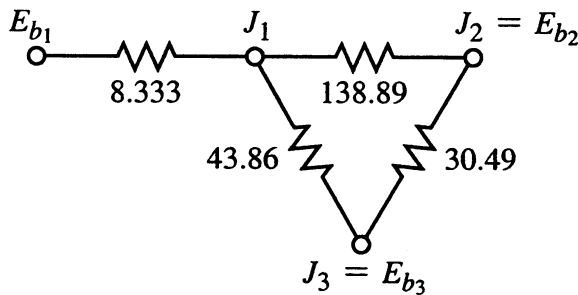
8-160

$$T_1 = 500 \text{ K} \quad T_3 = 300 \text{ K} \quad \epsilon_1 = 0.8 \quad \epsilon_2 = 0.4 \quad E_{b_1} = 3543 \text{ W/m}^2$$

$$A_1 = 0.03 \quad A_2 = 0.04 \quad E_{b_3} = 459 \text{ W/m}^2 \quad F_{21} = 0.18 \quad F_{23} = 0.82$$

$$F_{13} = 0.76 \quad \frac{1 - \epsilon_1}{\epsilon_1 A_1} = 8.333 \quad \frac{1}{A_1 F_{12}} = 138.89 \quad \frac{1}{A_1 F_{13}} = 43.86$$

$$\frac{1}{A_2 F_{23}} = 30.49$$



$$q = \frac{3543 - 459}{8.333 + \frac{1}{\frac{1}{43.86} + \frac{1}{138.89 + 30.49}}} = 71.44 \text{ W} = \frac{E_{b_1} - J_1}{8.333} \quad J_1 = 2948 \text{ W/m}^2$$

$$\frac{2948 - J_2}{138.89} = \frac{2948 - 459}{138.89 + 30.49} \quad J_2 = 907 \text{ W/m}^2 = E_{b_2} = \sigma T_2^4$$

$$T_2 = 356 \text{ K} = 83^\circ\text{C}$$

8-163

$$Re = 34,562 \quad T_{\infty} = 27^{\circ}\text{C} = 300 \text{ K}$$

$$\bar{h} = \frac{(0.664)(0.02749)}{0.3} (34,562)^{1/2} (0.7)^{1/3} = 10.04 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$$

$$(1100)(0.6) = (10.04)(T - 300) + (0.09)(5.669 \times 10^{-8})(T^4 - 300^4)$$

$$T = 316.5 \text{ K} = 43.5^{\circ}\text{C}$$

8-167

The temperature of the walls obviously depends on the wall insulation. The radiation exchange also depends on sunlight through the windows if applicable. For comparison purposes any sunlight load should be neglected. To start the analysis some worst case conditions might be assumed with a winter wall temperature of 5°C and a summer wall temperature of 30°C . Regardless of the paint the walls will act as a blackbody enclosure. The people may be assumed to also radiate as black surfaces for worst case conditions. Assume a body surface temperature of 75°F for the radiant and convection exchange to compute the total heat loss/gain. Other assumptions may be made to examine the effects of different temperatures. The radiation shape factor from the people to the cool/hot walls depends on interception by other people, but for the worst case may be taken as 1.0.

8-169

Assume some convenient size of building wall (5 m high by 30 m long). The concrete slab might be assumed to be insulated or part of a semi infinite solid having the properties of concrete. The shape factor between the wall and concrete slab is that for a perpendicular rectangle with a common edge. Convection from the building might be assumed to have $h = 15 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$ as a first approximation, with a like value from the concrete slab. Worst case conditions will be experienced with a black building and ε is about 0.6 for concrete. Solar irradiation might be taken as about 650 W/m^2 , although it could be higher. For the grass, assume that the temperature is substantially lower than for the concrete. Assume summer conditions for air temperature at about 33°C . Recall that the irradiation is calculated from the emissive power and the radiosity from $G = E_b - J$.

Chapter 8

8-170

The open side of the box should be assumed to be a black surface with temperature equal to the room temperature. The maximum exchange per unit heater surface area is obtained with no walls at all and this fact may be used to set an upper limit to the size of the heater surface (area). As higher and higher walls are added the net heat transfer with the room will decrease and the surface area must be increased to maintain the net exchange value of 15 kW. The configuration of the heater surface (long and slim, square, etc.) may be a factor in a final design selection because it can influence the radiant coverage in the warehouse floor space. If time permits you may wish to influence the radiant coverage in the warehouse floor space. If time permits you may wish to examine several configurations with this fact in mind.

8-171

While there will be temperature gradients in the electronics package itself, there is no information given to determine these gradients. Therefore, one should just assume an outside temperature for the package as 80°C. The package will lose heat by both radiation and free convection to the surrounding enclosure space and containing box. The best case for radiation transfer is for black surfaces so that should be assumed (because they can be painted black). To start the design assume typical values of h for free convection from the outside of the package, to the inside of the enclosing box, and outside of the box. $h = 7 - 10 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$ might be reasonable. From these assumptions an estimate may be made for the size (area) of the enclosing box. One can then work backward, refine the values for h using the relations of Chap. 7, and make a new determination of the area and shape of the enclosing box. The calculations may be refined further by assuming different values for ε for the electronics package and enclosing box in the event that black surfaces cannot be obtained. If interested, the calculation might also be made for forced convection dissipation from the outside of the box, but that is not asked for in the problem.

8-172

Designate the black panel as surface 1, the shield as surface 2, and the room as surface 3. It is reasonable to assume that the shields will occupy a view area equal to the projection parallel to the black surface. For the inside of the shield

$F_{21} = 1.0$ and the value of F_{12} is obtained by reciprocity. Then $F_{13} = 1 - F_{12}$.

Using either a network approach or numerical formulation the problem may be treated as one with four surfaces (1) the black plate, (2) the inside of the shield, (3) the outside of the shield and (4) the room which may be treated as black because $A_3 \rightarrow \infty$. Only two equations for the inside and outside shield surfaces are required because of the black conditions for surfaces 1 and 3. For the conditions where free convection must be considered, assume some average value of h which might be experienced with a vertical flat plate as calculated from the relations of chapter 7. Non-linear equations for the free convection case will result. The radiant heat transfer is calculated from the usual relations once values of the radiosity are determined. All of the radiant energy lost by the black panel is eventually delivered to the room, whether by direct radiation, radiation from the shield, or free convection from the shield. The convection loss from the black panel is dissipated directly, independent of the radiant loss.

8-173

Best conditions can be represented when all the solar energy is trapped inside the collector, i.e., no transmission out through the glass. The solar irradiation may be taken as about 650 W/m^2 for an initial calculation. You will need to consult chapter 9 for condensation coefficients but a value of $h = 10,000 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$ might be reasonable. The energy to evaporate unit mass of water is the enthalpy of vaporization which may be taken as about $2.3 \times 10^6 \text{ J/kg}$.

8-174

Because of the shadowing effect of the fins the assembly will probably radiate as if it had a surface area equal to that of a surface enclosing the outer periphery of the fins. The apparent emissivity of the assembly will then be given by the relation in Prob. 8-129, which will turn out to be close to that of a blackbody. The assembly may be assumed to convect with an area equal to the total area exposed to the air. The assembly may be heated and allowed to cool as a lumped capacity in room air. By a transient numerical procedure the value of h may be obtained as a function of surface temperature during the cooling process. The behavior will depend on orientation of the assembly but the convection might be expected to follow a relation like

$$h = \text{const} \times (T_{\text{surface}} - T_{\text{room}})^n$$

where the constant and exponent n are obtained from a plot of $\log h$ vs ΔT .

Correlation in terms of Grashof and Nusselt numbers is difficult because of the uncertain characteristic dimension of the fin assembly surface.

Chapter 8

8-175

From the problem statement the radiation shape factor from the person to each of the walls is taken as $1/6$. The outside wall temperatures (interior surface temperature) will probably be rather cold; about 10°C . The two interior walls and floor should be assumed at the room air temperature. A reasonable value for h

from the person to air will be about $7 - 10 \frac{\text{W}}{\text{m}^2 \cdot ^{\circ}\text{C}}$. Because the room area is

large compared to the person, it will behave as a black surface. The objective is to obtain the same energy transfer to the person by radiation as would be obtained by convection in a typical forced air heating situation. Note that the net radiation to the person is that received from the ceiling less that dissipated to the floor and walls. Note that only the radiation exchange with the person is to be considered for comfort. The heating requirements for the space would also have to take account of losses to the outside from the exterior walls, etc.

8-176

The total energy dissipated to the room will be influenced by the free convection loss from the outside surface of the covering. The radiant loss to the room is also governed by the temperature of the surface cover. Minimum energy transfer will be obtained at the cavity low temperature limit of 350 K. A value of $\tau = 1$ might be selected for this condition with decreasing values as the cavity temperature is increased. No information is given as to the balance between α , ρ , and τ for the cover. The easiest design is one for which $\rho = 0$. Zero transmissivity then becomes that for $\alpha = 1$. Assume $\varepsilon = \alpha$. The calculation can then be performed for the minimum value of τ at the high temperature of 500 K. Variation of radiation properties between the temperature limits may then be determined. The calculation may be refined by assuming different values of surface reflectivity. It is suggested that the initial analysis be made neglecting the free convection losses because of the non linear factors introduced into the equations.

8-179

This problem obviously involves the assumption that $\varepsilon = 1.0$ for both heater surfaces. Otherwise the analysis is the same as Problem 8 - 161.

8-180

The total heat lost is obviously a strong function of the strip temperature. If a large value of the strip temperature is selected the major portion of heat loss will be by radiation. As a start choose a rather high temperature of 800°C and a strip width of 6 mm. Compute the convection loss using the relations of Chap. 5 (flow will be laminar). Be sure to compute convection for both sides of strip. Calculate radiation as if exchange is by openings between strips to large room. Select ϵ for strip as about 0.6. (Material with other value may be selected from appendix.) Large room behaves as a blackbody. These calculations will yield a heat transfer value per unit length of strip(s). Then choose a configuration of strips (height and length) based on a total length required to dissipate 3 kW. Refine the calculation by taking account of fact that outer surfaces of top and bottom strips will exchange more heat than inner surfaces. Various values of strip temperatures and material properties may be examined as desired, as well as different strip widths. The wider the strip, the less heat that will be dissipated by the inner surfaces by radiation with the room.

8-181

$$T_m = 25^\circ\text{C} = 298 \text{ K} \quad T_a = 20^\circ\text{C} = 293 \text{ K} \quad h = 8 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\epsilon_m \sim 1.0$$

(a) $T_r = 0^\circ\text{C} = 273 \text{ K}$

$$\left. \frac{q}{A} \right|_{\text{conv}} = h\Delta T = (8)(25 - 20) = 40 \text{ W/m}^2$$

$$\left. \frac{q}{A} \right|_{\text{rad}} = \epsilon\sigma(T_m^2 - T_r^4) = (5.668 \times 10^{-8})(298^4 - 273^4) = 132 \text{ W/m}^2$$

$$\left. \frac{q}{A} \right|_{\text{Total}} = 40 + 132 = 172 \text{ W/m}^2$$

(b) $T_r = 20^\circ\text{C} = 293 \text{ K}$

$$\left. \frac{q}{A} \right|_{\text{conv}} = 40 \text{ W/m}^2$$

$$\left. \frac{q}{A} \right|_{\text{rad}} = (5.668 \times 10^{-8})(298^4 - 293^4) = 29.3 \text{ W/m}^2$$

$$\left. \frac{q}{A} \right|_{\text{Total}} = 40 + 29.3 = 69.3 \text{ W/m}^2$$

(c) Because wall is large $A \rightarrow \infty$ and $\frac{1-\epsilon}{\epsilon A} \rightarrow 0$ so same result as for large value of ϵ_{wall} .

Chapter 8

(d) If emissivity of man reduced to $\varepsilon = 0.1$

$$\text{At } T_r = 273 \text{ K} \quad \left. \frac{q}{A} \right|_{\text{rad}} = (0.1)(132) = 13.2 \text{ W/m}^2$$

$$\left. \frac{q}{A} \right|_{\text{Total}} = 40 + 13.2 = 53.2 \text{ W/m}^2$$

$$\text{At } T_r = 293 \text{ K} \quad \left. \frac{q}{A} \right|_{\text{rad}} = (0.1)(29.3) = 2.93 \text{ W/m}^2$$

$$\left. \frac{q}{A} \right|_{\text{Total}} = 40 + 2.93 = 42.93 \text{ W/m}^2$$

Chapter 9

9-1

$$\bar{h} \left(\frac{\mu_f^2}{k_f^2 \rho_f^2 g} \right)^{1/3} = 0.0077 \text{Re}_f^{0.4} \quad \text{Re}_f = \frac{4\bar{h}L(T_g - T_w)}{h_{fg}\mu_f}$$

$$\bar{h} \left(\frac{\mu_f^2}{k_f^2 \rho_f^2 g} \right)^{1/3} = 0.0077 \left[\frac{4\bar{h}L(T_g - T_w)}{h_{fg}\mu_f} \right]^{-0.4}$$

$$\bar{h} = \frac{(0.0077)^{1/0.6} \left[\frac{4L(T_g - T_w)}{h_{fg}\mu_f} \right]^{2/3}}{\left(\frac{\mu_f}{k_f^3 \rho_f^2 g} \right)^{1/1.8}}$$

$$\frac{\bar{h}L}{k_f} = \overline{\text{Nu}} = \frac{(0.0077)^{1/0.6} L \left[\frac{4L(T_g - T_w)}{h_{fg}\mu_f} \right]^{2/3}}{\left(\frac{\mu_f}{k_f^3 \rho_f^2 g} \right)^{1/1.8}}$$

$$\overline{\text{Nu}} = \frac{(0.0077)^{1/0.6} L^{5/3} k_f^{2/3} [4(T_g - T_w)]^{2/3} (\rho_f^2 g)^{5/9}}{\mu_f^{1.22} h_{fg}^{2/3}}$$

9-2

Flat plate

$$\text{Re}_f = \frac{4\dot{m}}{\mu_f} \quad \dot{m} = \frac{\rho_f^2 \delta^3}{3\mu_f} \quad \delta^3 = \left[\frac{4\mu_f k L (T_g - T_w)}{g h_{fg} \rho_f^2} \right]^{3/4}$$

$$\text{Re}_f = \frac{4\rho_f^2 g}{3\mu_f^2} \left[\frac{4\mu_f k L (T_g - T_w)}{g h_{fg} \rho_f^2} \right]^{3/4}$$

$$\text{Re}_f = 3.77 \left[\frac{\rho_f^2 g k_f^3 L^3 (T_g - T_w)^3}{\mu_f^5 h_{fg}^3} \right]^{1/4}$$

Chapter 9

9-3

Turbulent Film

$$\bar{h} = \frac{0.0077 \text{Re}_f^{0.4}}{\left(\frac{\mu_f^2}{k_f^3 \rho_f^2 g}\right)^{1/3}} \quad \text{Re}_f = \frac{4\dot{m}}{W\mu_f}$$

$$\dot{m} = \frac{\bar{h}A(T_g - T_w)}{h_{fg}} = \frac{\bar{h}LW(T_g - T_w)}{h_{fg}} \quad \bar{h} = \frac{\dot{m}h_{fg}}{LW(T_g - T_w)}$$

$$\frac{\dot{m}h_{fg}}{LW(T_g - T_w)} = \frac{0.0077\left(\frac{4\dot{m}}{W\mu_f}\right)^{0.4}}{\left(\frac{\mu_f^2}{k_f^3 \rho_f^2 g}\right)^{1/3}}$$

$$\dot{m} = \left[\frac{0.0077(4)^{0.4} LW^{0.6} (T_g - T_w) k_f (\rho_f^2 g)^{1/3}}{\mu_f^{1.07}} \right]^{5/3}$$

9-5

$$T_f = \frac{80 + 100}{2} = 90^\circ\text{C} \quad L = 1.2 \quad \rho_f = 964 \quad \mu_f = 3.15 \times 10^{-4}$$

$$k_f = 0.676 \quad h_{fg} = 2255 \text{ kJ/kg}$$

$$\bar{h} = 1.13 \left[\frac{(964)^2 (9.806) (2.255 \times 10^6) (0.676)^3}{(1.2)(3.15 \times 10^{-4})(100 - 80)} \right]^{1/4} = 6082 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (6082)(1.2)(0.3)(100 - 80) = 43,790 \text{ W}$$

$$\dot{m} = \frac{43,790}{2.255 \times 10^6} = 0.0195 \text{ kg/sec} = 69.9 \text{ kg/hr}$$

9-6

$$L = 0.4 \text{ m} \quad \phi = 90 - 30 = 60^\circ \quad T_w = 98^\circ\text{C} \quad T_g = 100^\circ\text{C} \quad \rho = 960$$

$$h_{fg} = 2.255 \times 10^6 \quad k = 0.68 \quad \mu = 2.82 \times 10^{-4}$$

$$\bar{h} = 1.13 \left[\frac{(960)^2 (9.806) (2.255 \times 10^6) (0.68)^3 \sin 60^\circ}{(0.4)(2.82 \times 10^{-4})(2)} \right]^{1/4} = 14,152 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (14,152)(0.4)^2 (2) = 4528 \text{ W} \quad \dot{m} = 2.008 \times 10^{-3} \text{ kg/sec} = 7.23 \text{ kg/hr}$$

9-7

$$k = 0.684 \quad \mu = 3.0 \times 10^{-4} \quad \rho = 962$$

$$\bar{h} = 1.13 \left[\frac{(962)^2 (9.8) (2.255 \times 10^6) (0.684)^3}{(0.5)(3 \times 10^{-4})(100 - 95)} \right]^{1/4} = 10,930 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (10,930)(0.5)^2 (100 - 95) = 136,510 \text{ W}$$

$$\dot{m} = \frac{136,510}{2.255 \times 10^6} = 0.0606 \text{ kg/sec} = 217.9 \text{ kg/hr}$$

9-8

$$T_f = 47.5^\circ\text{F} \quad k = 0.583 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \mu = 1.37 \times 10^{-3} \quad \rho = 999$$

$$h = 1.13 \left[\frac{(999)^2 (9.8) (2.376 \times 10^6) (0.583)^3}{(1.5)(1.37 \times 10^{-3})(15)\left(\frac{5}{9}\right)} \right]^{1/4} = 4576 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (4576)(1.5)^2 (15) \left(\frac{5}{9}\right) = 8.58 \times 10^4$$

$$\dot{m} = \frac{q}{h_{fg}} = 0.0361 \text{ kg/sec} = 130 \text{ kg/hr}$$

9-9

$$T_g = 38^\circ\text{C} \quad T_f = \frac{38 + 30}{2} = 34^\circ\text{C} \quad \rho = 590 \quad \nu = 0.345 \times 10^{-6}$$

$$h_{fg} = 1111 \text{ kJ/kg} \quad k = 0.501$$

$$h = 1.13 \left[\frac{(590)(9.8)(1.111 \times 10^6)(0.501)^3}{(0.4)(0.345 \times 10^{-6})(8)} \right]^{1/4} = 5877 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA\Delta T = (5877)(0.4)^2 (8.0) = 7522 \text{ W}$$

$$\dot{m} = \frac{q}{h_{fg}} = 0.00677 \text{ kg/sec} = 24.38 \text{ kg/hr}$$

Chapter 9

9-11

Assume laminar condensation $T_{\text{sat}} = 328^\circ\text{F}$ $h_{fg} = 889 \text{ Btu/lbm}$

$p_{\text{sat}} = 100 \text{ psia}$ $T_w = 280^\circ\text{F}$ $T_f = 304^\circ\text{F}$ $\rho_p = 57.29 \text{ lbm/ft}^3$

$\mu = 0.44 \frac{\text{lbm}}{\text{hr} \cdot \text{ft}}$ $k = 0.395 \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot ^\circ\text{F}}$ $\text{Pr} = 1.15$

$\rho_f > \rho_r \therefore \rho_f(\rho_f - \rho_r) = \rho_p^2$

$$\bar{h} = 0.725 \left[\frac{\rho_f^2 g h_{fg} k^3}{\mu d (T_g - T_w)} \right]^{1/4} = 1855 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$$

$$\dot{m} = \frac{q}{h_{fg}} = \frac{\bar{h} \pi d L (T_{\text{sat}} - T_w)}{h_{fg}} \quad \frac{\dot{m}}{L} = \frac{(1855)\pi(1)(48)}{(12)(889)} = 26.31 \frac{\text{lbm}}{\text{hr} \cdot \text{ft}}$$

9-12

$35^\circ\text{C} = 95^\circ\text{F}$ $p_g = 0.8237 \text{ psia}$ $p_r = (0.8)(0.8237) = 0.659 \text{ psia}$

$T_g = 88^\circ\text{F} = 31.1^\circ\text{C}$ $h_{fg} = 1043 \text{ Btu/lbm} = 2426 \text{ kJ/kg}$

$T_f = \frac{31.1 + 2}{2} = 16.55^\circ\text{C}$ $\rho = 998$ $\mu_f = 1.1 \times 10^{-3}$ $k_f = 0.596$

$\text{Pr}_f = 7.8$

$$\bar{h} = 0.725 \left[\frac{(998)^2 (9.8) (2.426 \times 10^6) (0.596)^3}{(1.1 \times 10^{-3}) (0.05) (31.1 - 2)} \right]^{1/4} = 5425 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (5425)\pi(0.05)(7.5)(31.1 - 2) = 185,970$$

$$\dot{m} = \frac{185,970}{2.426 \times 10^6} = 0.0767 \text{ kg/sec} = 276 \text{ kg/hr}$$

9-13

Assume laminar film and heat transfer area = 1 ft^2

\bar{h}_1 : $T_f = 154^\circ\text{F}$ $\rho_f = 61.1$ $\mu_f = 1.02$ $k_f = 0.382$

$$\bar{h}_1 = 873 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$$

\bar{h}_2 : $T_f = 177^\circ\text{F}$ $\rho_f = 60.6$ $h_{fg} = 992.1$ $\mu_f = 0.86$ $k_f = 0.388$

$$\bar{h}_2 = 838 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$$

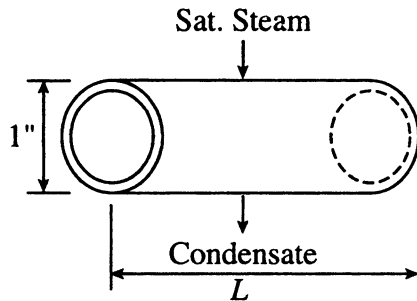
$$q_1 = \bar{h}_1 A \Delta T = 1.02 \times 10^5 \text{ Btu/hr} \quad q_2 = \bar{h}_2 A \Delta T = 1.37 \times 10^5 \text{ Btu/hr}$$

$$\frac{q_2 - q_1}{q_1} = 0.344 \quad 34.4\% \text{ increase}$$

9-14

$$p_{\text{sat}} = 690 \text{ kPa} \quad h_{fg} = 2.07 \times 10^6 \text{ J/kg} \quad T_g = 164^\circ\text{C} \quad T_w = 138^\circ\text{C}$$

$$T_f = 151^\circ\text{C} \quad \rho_f = 915 \quad \mu_f = 1.86 \times 10^{-4} \quad k_f = 0.683$$



Assume laminar flow:

$$\bar{h} = 0.725 \left[\frac{\rho^2 g h_{fg} k_f^3}{\mu_f d (T_g - T_w)} \right]^{1/4} = 10,450 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \text{Check } Re_f = 73.6$$

 \therefore Laminar

$$q = \bar{h} A (T_g - T_w) = 22,231 \text{ W/m}$$

$$\dot{m} = \frac{q}{h_{fg}} = 38.7 \frac{\text{kg}}{\text{sec} \cdot \text{m length}}$$

9-15

$$k = 0.684 \quad \mu = 3.0 \times 10^{-4} \quad \rho = 962$$

$$\bar{h} = 0.725 \left[\frac{(962)^2 (9.8) (2.255 \times 10^6) (0.684)^3}{(3 \times 10^{-4}) (0.3) (5)} \right]^{1/4} = 7962 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = h \pi d L (T_g - T_w) = (7962) \pi (0.3) (15) (5) = 5.628 \times 10^5 \text{ W}$$

$$\dot{m} = \frac{q}{h_{fg}} = 0.2496 \text{ kg/sec} = 898 \text{ kg/hr}$$

Chapter 9

9-16

$$\text{CO}_2 \quad h_{fg} = 153.2 \text{ kJ/kg at } 20^\circ\text{C} \quad d = 0.1 \text{ m} \quad L = 1.0 \text{ m}$$

$$T_w = 15^\circ\text{C} \quad T_g = 20^\circ\text{C} \quad T_f = 17.5^\circ\text{C} \quad \rho = 795 \text{ kg/m}^3$$

$$k = 0.0897 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \nu = 0.0935 \times 10^{-6}$$

$$\mu = (735)(0.0935 \times 10^{-6}) = 6.87 \times 10^{-5} \quad \text{Pr} = 3.78$$

$$\bar{h} = 0.725 \left[\frac{(795)^2 (9.8) (153.2 \times 10^3) (0.0897)}{(6.87 \times 10^{-5}) (0.1) (20 - 15)} \right]^{1/4} = 1532 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (1532)\pi(0.1)(1.0)(20 - 15) = 2406 \text{ W}$$

$$= \dot{m} h_{fg} = \dot{m} (153.2 \times 10^3)$$

$$\dot{m} = 0.0157 \text{ kg/sec} = 56.5 \text{ kg/hr}$$

9-17

$$n = 20 \quad T_f = \frac{88 + 100}{2} = 94^\circ\text{C} \quad \rho_f = 963.2$$

$$d = 0.25 \text{ in.} = 0.00635 \text{ m} \quad \mu_f = 3.06 \times 10^{-4} \quad k_f = 0.627$$

$$h_{fg} = 2255 \text{ kJ/kg}$$

$$\bar{h} = 0.725 \left[\frac{(963)^2 (9.8) (2.255 \times 10^6) (0.627)^3}{(3.06 \times 10^{-4}) (20) (0.00635) (100 - 88)} \right]^{1/4} = 7845 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (400)\pi(0.00635)(7845)(100 - 88) = 7.51 \times 10^5 \text{ W/m}$$

$$\dot{m} = \frac{7.51 \times 10^5}{2.255 \times 10^6} = 0.333 \text{ kg/sec} = 1200 \frac{\text{kg}}{\text{hr} \cdot \text{m}}$$

9-18

$$d = 0.05 \quad T_g = 100^\circ\text{C} \quad T_w = 98^\circ\text{C} \quad L = 1.5 \text{ m} \quad \rho = 960$$

$$k = 0.68 \quad \mu = 2.82 \times 10^{-4} \quad h'_{fg} \approx h_{fg} = 2.255 \times 10^6$$

$$\bar{h} = 0.555 \left[\frac{(960)^2 (9.8) (0.68)^3 (2.255 \times 10^6)}{(2.82 \times 10^{-4}) (0.05) (2)} \right]^{1/4} = 12,117 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (12,117)\pi(0.05)(1.5)(2) = 5710 \text{ W}$$

$$\dot{m} = \frac{5710}{2.255 \times 10^6} = 2.532 \times 10^{-3} \text{ kg/sec} = 9.12 \text{ kg/hr}$$

9-19

$$\rho = 962 \quad \mu = 3.0 \times 10^{-4} \quad k = 0.68 \quad n = 10 \quad d = 0.0254 \text{ m}$$

$$\bar{h} = 0.725 \left[\frac{(962)^2 (9.8) (2.255 \times 10^6) (0.68)^3}{(10)(0.0254)(3.0 \times 10^{-4})(5)} \right]^{1/4} = 8264 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (8264)(100)\pi(0.0254)(2)(0.3048)(5) = 2.01 \times 10^5 \text{ W}$$

$$\dot{m} = \frac{q}{h_{fg}} = 0.0891 \text{ kg/sec} = 320.9 \text{ kg/hr}$$

9-20

$$T_f = 98.5^\circ\text{C} \quad \rho = 960 \quad \mu = 2.82 \times 10^{-4} \quad k = 0.68 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$n = 10 \quad d = 0.0254 \text{ m}$$

$$\bar{h} = 0.725 \left[\frac{(960)^2 (9.8) (2.255 \times 10^6) (0.68)^3}{(10)(0.0254)(2.82 \times 10^{-4})(3)} \right]^{1/4} = 9526 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (9526)(100)\pi(0.0254)(3)(0.3048)(3) = 2.085 \times 10^5 \text{ W}$$

$$\dot{m} = \frac{q}{h_{fg}} = 0.0925 \text{ kg/sec} = 332.9 \text{ kg/hr}$$

9-22

$$h_{fg} = 1135 \text{ kJ/kg} \quad T_f = \frac{90 + 82}{2} = 86^\circ\text{F} = 30^\circ\text{C} \quad \rho = 596$$

$$v = 0.349 \times 10^{-6} \quad k = 0.507 \quad n = 20 \quad d = 0.00635 \text{ m}$$

$$\bar{h} = 0.725 \left[\frac{(596)(9.8)(1.135 \times 10^6)(0.507)^3}{(20)(0.349 \times 10^{-6})(0.00635)(90 - 82)\left(\frac{5}{9}\right)} \right]^{1/4} = 5904 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (5904)(400)\pi(0.00635)(0.3048)(90 - 82)\left(\frac{5}{9}\right) = 63,817 \text{ W}$$

$$\dot{m} = \frac{q}{h_{fg}} = 0.0562 \text{ kg/sec} = 202 \text{ kg/hr}$$

Chapter 9

9-23

$$\dot{m} = 10,000 \text{ kg/hr} = 2.778 \text{ kg/sec}$$

$$h_{fg} = 130.09 \text{ kJ/kg}$$

$$q = \dot{m}h_{fg} = 361,400 \text{ W} \quad T_f = \frac{100 + 90}{2} = 95^\circ\text{F} = 35^\circ\text{C}$$

$$\rho = 1276 \quad \nu = 0.193 \times 10^{-6} \quad k = 0.07 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad n = 25$$

$$d = 0.012$$

$$\bar{h} = 0.725 \left[\frac{(1276)(9.8)(1.3 \times 10^5)(0.07)^3}{(25)(0.0125)(10)\left(\frac{5}{9}\right)(0.193 \times 10^{-6})} \right]^{1/4} = 823.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = hA\Delta T = hn\pi dL\Delta T$$

$$361,400 = (823.4)(625)\pi(0.0125)L(10)\left(\frac{5}{9}\right)$$

$$L = 3.22 \text{ m}$$

9-24

$$d = 0.012 \text{ m} \quad T_f = \frac{32.2 + 26.7}{2} = 29.45^\circ\text{C} \quad \rho = 1295$$

$$k = 0.07 \quad \nu = 0.194 \times 10^{-6} \quad c = 984 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}} \quad h_{fg} = 133.65 \text{ kJ/kg}$$

$$h'_{fg} = 133.65 + (0.68)(0.984)(10)\left(\frac{5}{9}\right) = 137.4 \text{ kJ/kg}$$

$$\bar{h} = 0.555 \left[\frac{(1295)(9.8)(0.137 \times 10^6)(0.07)^3}{(0.194 \times 10^{-6})(0.012)(5.5)} \right]^{1/4} = 1446 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h\pi d\Delta T = (1446)\pi(0.012)(10)\left(\frac{5}{9}\right) = 303 \text{ W/m}$$

9-25

$$\Delta T_x = 107 - 100 = 7^\circ\text{C} \quad \frac{q}{A} = 7.96(7)^4 = 19.11 \text{ kW/m}^2$$

$$q = (19,110)(0.3) = 5734 \text{ W}$$

9-26

$$\begin{array}{c} \text{H}_2\text{O vapor} \\ 213^\circ\text{F} \\ \rho = 14.993 \end{array}$$

Surface tension of H₂O at 212°F = 58.8 dyne/cm

$$\pi r^2(p_v - p_l) = \text{pressure force} \quad 2\pi r\sigma = \text{surface tension force}$$

$$\text{H}_2\text{O at } 212^\circ\text{F} \quad p_l = 14.696 \quad r = \frac{2\sigma}{p_v - p_l} = 0.00226 \text{ in.}$$

9-28

$$\Delta T_x = 119 - 100 = 19^\circ\text{C} \quad c_{sf} = 0.013 \quad \frac{q}{A} = 1.2 \text{ MW/m}^2$$

$$q = (1.2 \times 10^6)(0.3)^2 = 108,000 \text{ W}$$

9-32

$$\text{Re}_f = \frac{4\Gamma}{\mu_f} \quad h_x = \left[\frac{\rho^2 g h_{fg} k^3}{4\mu(T_g - T_w)} \right]^{1/4} \quad \bar{h} = \frac{1}{L} \int_0^L h_x dx$$

$$\bar{h} = \frac{1}{L} \int_0^L \left(\frac{\rho^2 g h_{fg} k^3}{4\mu_f \Delta T} \right) dx \quad \bar{h} = \frac{4}{3} \left(\frac{L^3 \rho^2 g k^3 h_{fg}}{L^4 4\mu_f \Delta T} \right)^{1/4} = \frac{4}{3} (h_x)_{x=L}$$

$$\bar{h} = \Delta T L = q = h_{fg} \Gamma \quad \Gamma = \frac{\bar{h} \Delta T L}{h_{fg}}$$

$$\text{Re}_f = \frac{4\Gamma}{\mu_f} = \frac{4\bar{h} \Delta T L}{\mu_f h_{fg}} \quad \text{Re}^{-1/3} = \left(\frac{\mu_f h_{fg}}{4\bar{h} \Delta T L} \right)^{1/3} = \bar{h} \left(\frac{\mu_f h_{fg}}{4\bar{h} \Delta T L} \right)^{1/3}$$

$$\bar{h}^4 = \left(\frac{4}{3} \right)^4 \left(\frac{\rho_f^2 g h_{fg} k^3}{4L\mu_f \Delta T} \right) \quad \left(\frac{4}{3} \right)^{4/3} \text{Re}_f^{-1/3} = \bar{h} \left(\frac{\mu_f}{\rho_f^2 k_f^3 g} \right)^{1/3}$$

$$1.466 \text{Re}_f^{-1/3} = \bar{h} \left(\frac{\mu_f}{\rho_f^2 k_f^3 g} \right)^{1/3}$$

9-33

$$\Delta T_x = 10^\circ\text{C} \quad \frac{q}{A} = 1.9 \text{ MW/m}^2$$

Chapter 9

9-34

$$T_w = 110^\circ\text{C} \quad T_{b \text{ avg}} = 96^\circ\text{C} \quad \Delta T_x = 10^\circ\text{C} \quad d = 1.25 \text{ cm}$$
$$u_m = 1.2 \text{ m/sec}$$

$$\text{Brass } C_{sf} = 0.006 \text{ for plat } \frac{q}{A} = 2.5 \times 10^4 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} = 7.885 \times 10^4 \text{ W/m}^2$$

$$\left. \frac{q}{A} \right|_{\text{Brass}} = (7.885 \times 10^4) \left(\frac{0.013}{0.006} \right)^3 = 8.02 \times 10^5 \text{ W/m}^2$$

$$\left. \frac{q}{L} \right|_{\text{boiling}} = (8.02 \times 10^5) \pi (0.0125) = 31,494 \text{ W/m}$$

Forced Convection

$$\text{At } 96^\circ\text{C} \quad \rho = 960 \quad \mu = 2.96 \times 10^{-4} \quad k = 0.68 \quad \text{Pr} = 1.83$$

$$\text{Re} = \frac{(960)(1.2)(0.0125)}{2.96 \times 10^{-4}} = 48,650$$

$$h = \frac{0.68}{0.0125} (0.019)(48,650)^{0.8} (1.83)^{0.4} = 7396 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\left. \frac{q}{L} \right|_{\text{conv}} = (7396) \pi (0.0125) (14) = 4066 \text{ W/m}$$

$$\left. \frac{q}{L} \right|_{\text{total}} = 31,494 + 4066 = 35,560 \text{ W/m}$$

9-35

$$q = (2.3)(2.255 \times 10^6) = 5.187 \times 10^6 \text{ J/hr} = 1441 \text{ W}$$

$$\frac{q}{A} = \frac{1441}{\pi(0.15)^2} = 20,382 \text{ W/m}^2 \quad \frac{q}{A} = 5.56(\Delta T_x)^4 \quad \Delta T_x = 7.78^\circ\text{C}$$

$$T_w = 107.8^\circ\text{C}$$

9-36

$$\text{Cu-H}_2\text{O} \quad p = 1 \text{ atm} \quad d = 0.005 \text{ m} \quad T_w - T_{\text{sat}} = 11^\circ\text{C}$$

$$C_{sf} = 0.0128 \approx C_{sf} (\text{plat})$$

From Fig. 9-8 at $\Delta T_x = 11^\circ\text{C}$

$$\frac{q}{A} = 0.11 \text{ MW/m}^2$$

$$\text{For } L = 1.0 \text{ m} \quad A = \pi(0.005) = 0.01571 \text{ m}^2$$

$$q = (0.11 \times 10^6)(0.01571) = 1728 \text{ W/m length}$$

9-37

$$\Delta T_x = 11^\circ\text{C} \quad \frac{q}{A}|_{\text{plat}} = \frac{q}{A}|_{\text{Cu}} = 4000 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} = 126,160 \text{ W/m}^2$$

$$\frac{q}{L} = (126,160)\pi(0.005) = 1982 \text{ W/m}$$

9-38

$$\Delta T_x = 10^\circ\text{C} \quad p = 3 \text{ MN/m}^2 = 435 \text{ psia} \quad d = 0.02 \quad L = 1 \text{ m}$$

$$h = 2.54(10)^3 e^{3/1.551} = 17,576 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (17,576)\pi(0.02)(1)(10) = 11,042 \text{ W}$$

$$h_{fg} \text{ at } 435 \text{ psia} = 771.3 \text{ Btu/lbm} = 1.794 \times 10^6 \text{ J/kg}$$

$$\dot{m} = \frac{11,042}{1.794 \times 10^6} = 6.15 \times 10^{-3} \text{ kg/sec} = 22.16 \text{ kg/hr}$$

9-39

$$\frac{q}{A} = 0.2 \text{ MW/m}^2 = 200 \text{ kW/m}^2 \quad d = 0.003 \quad L = 7.5 \text{ cm}$$

$$p = 1.6 \text{ atm} \quad h = 5.56(\Delta T_x)^3 \quad \frac{q}{A} = h\Delta T_x$$

$$200 \times 10^3 = 5.56(\Delta T_x)^4 (1.6)^{0.4}$$

$$\Delta T_x = 13.14^\circ\text{C} \text{ at } 1.16 \text{ atm} \quad p = 23.52 \text{ psia} \quad T_{\text{sat}} = 236.5^\circ\text{F} = 113.6^\circ\text{C}$$

$$T_w = 113.6 + 13.14 = 126.7^\circ\text{C}$$

9-40

$$d = 2.5 \text{ cm} \quad p = 101 + 34 = 135 \text{ kPa} \quad \Delta T_x = 4^\circ\text{C}$$

$$\text{Assume: horizontal } h = 5.56(4)^3 = 355.8 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{A} = h\Delta T = (355.8)(4) = 1.423 \text{ kW/m}^2$$

above relation does not apply

$$h = 1042(4)^{1/3} = 1654 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \frac{q}{A} = h\Delta T = 6.616 \text{ kW/m}^2$$

$$\dot{m} = 908 \text{ kg/hr} = 0.252 \text{ kg/sec} \quad q = (0.252)(2.255 \times 10^6) = 6616 \text{ A}$$

$$A = 85.96 \text{ m}^2 = \pi dL \quad L = 1095 \text{ m}$$

Chapter 9

9-41

$$\Delta T_x = 15^\circ\text{C} \quad \frac{h}{h_w} = 0.83 \quad \left(\frac{q}{A}\right)_{\text{water}} = 2 \times 10^5 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2}$$

$$\left(\frac{q}{A}\right)_{\text{water}} = 6.308 \times 10^5 \text{ W/m}^2 \quad h_w = \frac{6.308 \times 10^5}{15} = 42,050 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$h_{\text{glycerine}} = (0.83)(42,050) = 34,900 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

9-43

$$\Delta T_x = 30^\circ\text{F} \quad C_{sf} = 0.008 \quad \text{For plat } \frac{q}{A} = 2.5 \times 10^5 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2}$$

$$\left.\frac{q}{A}\right|_{ss} = (2.5 \times 10^5) \left(\frac{0.13}{0.008}\right)^3 = 1.073 \times 10^6 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} = 3.383 \text{ MW/m}^2$$

9-45

$$\Delta T_x = 110 - 100 = 10^\circ\text{C}$$

From Figure $\frac{q}{A} = 0.7 \text{ MW/m}^2$

$$q = \left(\frac{q}{A}\right) \pi d L = (0.7 \times 10^6) \pi (0.001)(0.12) = 264 \text{ W}$$

9-46

$$T_f = \frac{94 + 100}{2} = 97^\circ\text{C} \quad d = 0.04 \text{ m} \quad \rho = 962 \quad k = 0.68$$

$$\mu = 3 \times 10^{-4} \quad h_{fg} = 2.255 \times 10^6 \text{ J/kg}$$

$$\bar{h} = 0.725 \left[\frac{(962)^2 (9.8) (2.255 \times 10^6) (0.68)^3}{(3 \times 10^{-4}) (0.04) (100 - 94)} \right]^{1/4} = 12,533 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = h \pi d \Delta T = (12,533) \pi (0.04) (100 - 94) = 9450 \text{ W/m}$$

9-47

$$\frac{q}{A}|_{\text{total}} = \frac{q}{A}|_{\text{FC}} + \frac{q}{A}|_{\text{boiling}}$$

$$\Delta T_x = 110 - 98 = 12^\circ\text{C} = 21.6^\circ\text{F} \quad \frac{q}{A}|_{\text{plat}} = 4 \times 10^4 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} = 1.26 \times 10^5 \text{ W/m}^2$$

$$\text{At } 100^\circ\text{C} \quad k = 0.68 \quad \text{Pr} = 1.7$$

$$h = \frac{k}{d} (0.019)(40,000)^{0.8} (1.7)^{0.4} = 3070 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{A}|_{\text{brass}} = (1.26 \times 10^5) \left(\frac{c_{\text{plat}}}{c_{\text{brass}}} \right)^3 = 12.8 \times 10^5 \text{ W/m}^2$$

$$h_b = \frac{\frac{q}{A}|_{\text{brass}}}{\Delta T} = \frac{12.8 \times 10^5}{110 - 98} = 10,670 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$h(\text{total}) = 10,670 + 3070 = 13,740 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

9-49

$$h_{fg} = 2.255 \times 10^6 \text{ J/kg} \quad \rho_v = 1.5 \text{ kg/m}^3 \quad p_l = 998 \text{ kg/m}^3$$

$$\sigma = 70 \text{ mN/m}$$

$$\frac{q}{A}|_{\text{max}} = \frac{\pi}{24} (2.255 \times 10^6) (1.5) \left[\frac{(0.07)(9.8)(996)}{(1.5)^2} \right]^{1/4} \left(1 + \frac{1.5}{998} \right)^{1/2} = 1.85 \text{ MW/m}^2$$

9-51

$$h_{fg} = 2.255 \times 10^6 \text{ J/kg} \quad T_w = 813 \text{ K} \quad T_{\text{sat}} = 373 \text{ K}$$

$$(a) \quad T_f = \frac{540 + 100}{2} = 320^\circ\text{C} = 593 \text{ K} \quad \rho_l = 960 \quad \rho_v = 0.365$$

$$k_g = 0.042 \quad \mu_v = 20.6 \times 10^{-6} \quad c_{p_v} = 2000$$

$$\Delta T_x = 440$$

$$h_b = 0.62 \left[\frac{(0.042)^3 (0.365)(960)(9.8)(2.255 \times 10^6 + 2000)(0.4)(4000)}{(0.0125)(20.6 \times 10^{-6})(440)} \right]^{1/4}$$

$$= 171.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$h_r = \frac{(5.669 \times 10^{-8})(0.8)(813^4 - 373^4)}{813 - 373} = 43.04$$

Chapter 9

$$h = (171.5)^{4/3} h^{-1/3} + 43.04 = 204.7 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{A} = h\Delta T_x = (204.7)(440) = 90,068 \text{ W/m}^2$$

9-52

$$T_w = 280^\circ\text{C} \quad T_{\text{sat}} = 100^\circ\text{C} \quad v = 3 \text{ m/sec} \quad d = 0.0004 \text{ m}$$

$$\text{at } 25^\circ\text{C} \text{ flow} = 1 \text{ L/hr} = 1000 \times 10^{-6} \times 996 = 0.996 \text{ kg/hr} = 2.767 \times 10^{-4} \text{ kg/s}$$

$$T_f = \frac{280 + 100}{2} = 190^\circ\text{C} = 463 \text{ K} \quad h_{fg} = 2.255 \times 10^6 \quad \rho_L = 996$$

$$\rho_{vf} = 0.478 \quad c_{pv} = 1980 \quad \sigma = 58.8 \text{ mN/m}$$

$$\lambda = 2.255 \times 10^6 + (1980) \left(\frac{280 - 100}{2} \right) = 2.433 \times 10^6 \text{ J/kg}$$

$$\frac{Q_{\text{max}}}{\text{drop}} = (1.83 \times 10^{-3})(996)(0.0004)^3 (2.433 \times 10^6) \left[\frac{(996)^2 (3)^2 (0.0004)}{(0.478)(0.0588)(1)} \right]^{0.341}$$

$$= 0.0156 \text{ J/drop}$$

$$\frac{\text{mass}}{\text{drop}} = (996) \left(\frac{4}{3} \pi \right) (0.0002)^3 = 3.338 \times 10^{-8} \text{ kg}$$

$$\# \text{ of drops} = \frac{2.767 \times 10^{-4} \text{ kg/sec}}{3.338 \times 10^{-8} \text{ kg/drop}} = 8290 \text{ drops/sec}$$

$$Q_{\text{max}} = (0.0156)(8290) = 129.3 \text{ W}$$

9-53

$$T_f = \frac{100 + 92}{2} = 96^\circ\text{C} \quad d = 0.0125 \quad n = \sqrt{196} = 14$$

$$\rho = 961 \text{ kg/m}^3 \quad \mu = 2.96 \times 10^{-4} \quad k = 0.68 \quad h_{fg} = 2255 \text{ kJ/kg}$$

$$\bar{h} = 0.725 \left[\frac{(961)^2 (9.8) (2255 \times 10^3) (0.68)^3}{(2.96 \times 10^{-4}) (14) (0.0125) (100 - 92)} \right]^{1/4} = 8088 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (8088)(196)\pi(0.0125)(2.0)(100 - 92) = 9.96 \times 10^5 \text{ W} = \dot{m}(2255 \times 10^3)$$

$$\dot{m} = 0.442 \text{ kg/s}$$

9-54

$$T_f = \frac{100 + 91}{2} = 95.5^\circ\text{C} \quad \rho = 961 \text{ kg/m}^3 \quad \mu = 2.97 \times 10^{-4}$$

$$k = 0.68 \quad h_{fg} = 2255 \text{ kJ/kg}$$

$$1800 = \frac{4\bar{h}L(100 - 91)}{2255 \times 10^3 (2.97 \times 10^{-4})}$$

$$\bar{h}_L = 33,487 = 1.13 \left[\frac{(961)^2 (9.8) (2255 \times 10^3) (0.68)^3}{(2.97 \times 10^{-4}) (100 - 91)} \right]^{1/4} L^{3/4}$$

$$L^{3/4} = 4.234 \quad L = 6.85 \text{ m}$$

$$\frac{\dot{m}}{\rho} = \frac{(1800)(2.97 \times 10^{-4})}{4} = 0.134 \text{ kg/s} \cdot \text{m depth}$$

9-55

$$C_{sf} = 0.008 \quad C_{sf} \text{ plat} = 0.013 \quad \Delta T_x = 15^\circ\text{C}$$

$$\frac{q}{A}_{\text{plat}} = 2.7 \times 10^5 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} = 851 \text{ kW/m}^2$$

$$\frac{q}{A}_{ss} = (851) \left(\frac{0.013}{0.008} \right)^3 = 3.65 \text{ MW/m}^2$$

9-56

$$p = 5 \text{ atm} = 0.507 \text{ MPa}$$

$$\frac{q}{A} = 2.253(\Delta T_x)^{3.96} = 2.253(10)^{3.96} = 20,550 \text{ W/m}^2$$

$$h = \frac{q}{A \Delta T} = 2055 \text{ W/m}^2$$

9-57

$$p = 1 \text{ atm} \quad d = 0.3 \text{ m} \quad T_w = 94^\circ\text{C} \quad T_f = 97^\circ\text{C} \quad \mu = 2.8 \times 10^{-4}$$

$$k = 0.68 \quad \rho = 961 \quad h_{fg} = 2.26 \times 10^6 \text{ J/kg}$$

$$\bar{h} = 0.725 \left[\frac{(961)^2 (9.8) (2.26 \times 10^6) (0.68)^3}{(2.8 \times 10^{-4}) (0.3) (100 - 94)} \right]^{1/4} = 7706 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{q}{L} = (7706)\pi(0.3)(100 - 94) = 43,750 \text{ W/m}$$

Chapter 9

9-58

$$T_f = \frac{100 + 93}{2} = 96.5^\circ\text{C} \quad h_{fg} = 2255 \times 10^3 \text{ J/kg} \quad \rho = 961 \text{ kg/m}^3$$

$$\mu = 2.96 \times 10^{-4} \quad k = 0.68$$

$$\bar{h} = 1.13 \left[\frac{(961)^2 (9.8) (2255 \times 10^3) (0.68)^3}{(0.2)(2.96 \times 10^{-4})(100 - 93)} \right]^{1/4} = 12,605 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (12,605)(0.2)^2(100 - 93) = 3530 \text{ W} = \dot{m}(2255 \times 10^3)$$

$$\dot{m} = 0.00156 \text{ kg/s}$$

$$\delta = \left[\frac{(4)(2.96 \times 10^{-4})(0.68)(0.2)(100 - 93)}{(9.8)(2255 \times 10^3)(961)^2} \right]^{1/4} = 8.6 \times 10^{-5} \text{ m}$$

9-59

$$\text{With } h = 5000 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad L_c^{3/2} \left(\frac{h}{kA_m} \right)^{1/2} = 0.654 \quad \eta_f = 0.76$$

$$(\text{No. of fins}) \times (\text{Area of tube + fin}) = (5.9 \times 10^{-4})(50) = 0.0295 \text{ m}^2$$

Average $\Delta T \sim 0.76\Delta T$ (base)

$$T_{\text{water}} = 100^\circ\text{C}$$

T (base)	ΔT (avg)	$\frac{q}{A}$ (Fig 9-8)	q
108	6.1	0.01×10^6	295 W
111	8.4	0.03×10^6	885 W
117	13	0.15×10^6	4425 W

9-60

$$\Delta T_x = 104 - 100 = 4 \quad A = \pi \frac{(0.25)^2}{4} = 0.049 \text{ m}^2$$

$$\frac{q}{A} = 1042(\Delta T_x)^{1/3} = 1042(4)^{1/3} = 1654 \text{ W/m}^2 \quad q = (1654)(0.049) = 81 \text{ W}$$

9-61

$$\Delta T_x = 104 - 100 = 4^\circ\text{C} \quad \frac{q}{A} = 1654 \text{ W/m}^2$$

$$A = \frac{\pi(0.125)^2}{4} + \pi(0.05)(0.125) = 0.0319 \text{ m}^2 \quad q = (1654)(0.0319) = 52.8 \text{ W}$$

9-62

$$\Delta T_x = 17^\circ\text{C} \quad \text{Fig. 9-8} \quad \frac{q}{A}|_{\text{plat}} \approx 0.95 \times 10^6 \text{ W/m}^2$$

$$C_{sf} (\text{plat}) = 0.013$$

$$C_{sf} (\text{teflon}) = 0.0058$$

$$\frac{q}{A} \sim \left(\frac{1}{C_{sf}} \right)^3$$

$$\frac{q}{A} = (0.95 \times 10^6) \left(\frac{0.013}{0.0058} \right)^3 = 1.07 \times 10^7 \text{ W/m}^2$$

$$h = \frac{q}{\Delta T} = \frac{1.07 \times 10^7}{17} = 6.3 \times 10^5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$A = \pi dL = \pi(0.01)(1) = 0.0314 \text{ m}^2$$

$$q = (1.07 \times 10^7)(0.0314) = 3.37 \times 10^5 \text{ W}$$

9-63

$$\text{NO of tubes} = (10)(20) = 200$$

$$d = 12 \text{ mm}$$

$$n = 15$$

$$T_w = 86^\circ\text{C}$$

$$T_g = 100^\circ\text{C}$$

$$T_f = 93^\circ\text{C}$$

$$h_{fg} = 2.26 \times 10^6 \text{ J/kg}$$

$$k_f = 0.678 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$\mu_f = 3.06 \times 10^{-4}$$

$$\rho_f = 963$$

$$\begin{aligned} \bar{h} &= 0.725 \left[\frac{\rho^2 g h_{fg} k^3}{n \mu d (T_g - T_w)} \right]^{1/4} = 0.725 \left[\frac{(963)^2 (9.8) (2.26 \times 10^6) (0.678)^3}{(15) (3.06 \times 10^{-4}) (0.12) (100 - 86)} \right]^{1/4} \\ &= 6920 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \end{aligned}$$

$$A|_{\text{meter}} = 200 \pi (0.012)(1) = 7.54 \text{ m}^2$$

$$q = \bar{h} A (T_g - T_w) = (6920)(7.54)(100 - 86) = 7.31 \times 10^5 \text{ W}$$

Chapter 9

9-64

$$T_w = 85^\circ\text{C} \quad T_g = 100^\circ\text{C} \quad L = 50 \text{ cm} \quad W = 25 \text{ cm} \quad T_f = 92.5^\circ\text{C}$$

$$\rho_f = 964 \quad \mu_f = 3.1 \times 10^{-4} \quad k_f = 0.677 \quad h_{fg} = 2.26 \times 10^6 \text{ J/kg}$$

Assume laminar

$$\bar{h} = 1.13 \left[\frac{\rho^2 g h_{fg} k^3}{L \mu (T_g - T_w)} \right]^{1/4} = 1.13 \left[\frac{(964)^2 (9.8) (2.26 \times 10^6) (0.677)^3}{(0.5) (3.1 \times 10^{-4}) (100 - 85)} \right]^{1/4}$$

$$= 7723 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \bar{h} A \Delta T = (7723)(0.25)(0.5)(100 - 85) = 14,480 \text{ W} = \dot{m} h_{fg}$$

$$\dot{m} = \frac{14,480}{2.26 \times 10^6} = 0.0064 \text{ kg/sec} = 23.1 \text{ kg/hr}$$

$$\text{Re} = \frac{4\dot{m}}{p\mu_f} = \frac{(4)(0.0064)}{(0.25)(3.1 \times 10^{-4})} = 330$$

Laminar assumption OK

$$\delta = \left[\frac{4\mu k L (T_g - T_w)}{g h_{fg} \rho^2} \right]^{1/4} = \left[\frac{(4)(3.1 \times 10^{-4})(0.677)(0.5)(100 - 85)}{(9.8)(2.26 \times 10^6)(964)^2} \right]^{1/4}$$

$$= 1.3 \times 10^{-4} \text{ m} = 0.13 \text{ mm}$$

9-65

$$\dot{m} = 1.3 \text{ kg/s} \quad d = 1.25 \text{ cm} \quad \text{Sp} = 1.9 \text{ cm} \quad T_w = 93^\circ\text{C}$$

$$T_g = 100^\circ\text{C} \quad n = \text{number of rows} \quad T_f = 96.5^\circ\text{C}$$

$$h_{fg} = 2255 \text{ kJ/kg} \quad \rho = 962 \quad \mu = 2.96 \times 10^{-4} \quad k = 0.68$$

$$\bar{h} = 0.725 \left[\frac{(962)^2 (9.8) (2.255 \times 10^6) (0.68)^3}{(2.96 \times 10^{-4}) (0.0125) (7)n} \right]^{1/4} = \frac{16,186}{n^{1/4}}$$

$$q = (1.3)(2.255 \times 10^6) = 2.932 \times 10^6 \text{ W} = \bar{h} A (T_g - T_w)$$

$$x = \text{side of square array} \quad 3x = \text{length} \quad x = n(0.0125) + (n-1)(0.019)$$

$$A = n^2 \pi d (3x) = 0.00371 n^3 - 0.00224 n^2$$

$$2.932 \times 10^6 = \frac{113,302}{n^{1/4}} (0.00371 n^3 - 0.00224 n^2)$$

$$\text{By iteration } n = 25 \quad x = 0.769 \quad 3x = 2.306$$

$$\text{number of tubes} = n^2 = 625$$

9-66

$$\begin{aligned} \dot{m} &= 600 \text{ kg/hr} = 0.1667 \text{ kg/s} & q &= \dot{m}h_{fg} = (0.1667)(2.255 \times 10^6) \\ q &= 3.75 \times 10^5 \text{ W} & T_f &= 98.5^\circ\text{C} & \rho &= 960 & \mu &= 2.82 \times 10^{-4} \\ k &= 0.68 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} & n &= 20 & d &= 0.01 \text{ m} \\ \bar{h} &= 0.725 \left[\frac{(960)^2 (9.8) (2.255 \times 10^6) (0.68)^3}{(20)(0.01)(2.82 \times 10^{-4})(3)} \right]^{1/4} = 10,123 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \\ q &= hn\pi dL(T_g - T_w) \\ 3.75 \times 10^5 &= (10,123)(400)\pi(0.01)L(3) & L &= 0.983 \text{ m} \end{aligned}$$

Chapter 10

10-1

Pipe nearly constant temperature $T_w = 82^\circ\text{C}$ $T_\infty = 30^\circ\text{C}$ $\varepsilon \approx 0.8$

$$h = 1.32 \left(\frac{82 - 30}{0.0564} \right)^{1/4} = 7.27 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q_{\text{conv}} = (7.27)\pi(0.0564)(15)(82 - 30) = 1005 \text{ W}$$

$$q_{\text{rad}} = (5.669 \times 10^{-8})\pi(0.0564)(15)(0.8)(355^4 - 303^4) = 898 \text{ W}$$

$$q_{\text{tot}} = 1903 = (0.6)(4175)\Delta T_w \quad \Delta T_w = 0.76^\circ\text{C}$$

$$T_w (\text{exit}) = 82 - 0.76 = 81.2^\circ\text{C}$$

10-2

$$q = m_w c_w \Delta T_w = (2)(4180)(90 - 60) = 2.508 \times 10^5 \text{ W}$$

$$\Delta T_m = \frac{40 - 50}{\ln\left(\frac{40}{50}\right)} = 44.81^\circ\text{C} \quad q = UA\Delta T_m$$

$$U = \frac{2.508 \times 10^5}{(20)(44.81)} = 279.8 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

By NTU method

$$\varepsilon = \frac{40}{80} = 0.5 \quad \frac{C_{\min}}{C_{\max}} = \frac{30}{40} = 0.75$$

$$C_{\max} = C_w = (2)(4180) = 8360 \quad C_{\min} = C_p = (0.75)(8360) = 6270$$

$$\text{From Fig. 10-13} \quad NTU = 0.9 = \frac{UA}{C_{\min}}$$

$$U = \frac{(0.9)(6270)}{20} = 282 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

10-3

Inside Tube

$$T = 473 \text{ K} \quad d = 0.025 \quad u_m = 6 \text{ m/sec} \quad \mu = 2.58 \times 10^{-5}$$

$$\rho = \frac{2.07 \times 10^5}{(287)(473)} = 1.525 \quad k = 0.0385 \quad c_p = 1030 \quad \text{Pr} = 0.681$$

$$\dot{m} = (1.525)\pi(0.0125)^2(6) = 4.491 \times 10^{-3} \text{ kg/sec}$$

$$\text{Re} = \frac{(1.525)(6)(0.025)}{2.58 \times 10^{-5}} = 8866$$

$$h_i = \frac{0.0385}{0.025} (8866)^{0.8} (0.681)^{0.3} = 45.4 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Conduction resistance negligible.

Outside Tube

$$T_f \approx \frac{200 + 20}{2} = 110^\circ\text{C} = 383 \text{ K} \quad v_f = 25.15 \times 10^{-6} \quad k_f = 0.0324$$

$$\text{Pr}_f = 0.69 \quad d_0 = 0.025 + 0.0016 = 0.0266 \quad \text{Re} = \frac{(12)(0.0266)}{25.15 \times 10^{-6}} = 12,691$$

$$c = 0.193 \quad n = 0.618 \quad \text{from Chap. 6}$$

$$h_o = \frac{(0.0324)(0.193)}{0.0266} (12,691)^{0.618} (0.69)^{1/3} = 71.36 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Base U on A_i

$$U_i = \frac{1}{\frac{1}{45.4} + \frac{0.025}{(0.0266)(71.36)}} = 28.41 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad A_i = \pi(0.025)(3) = 0.236 \text{ m}^2$$

$$C_{\min} = (4.491 \times 10^{-3})(1030) = 4.626 \quad \frac{C_{\min}}{C_{\max}} = 0$$

$$NTU = \frac{(28.41)(0.236)}{4.626} = 1.45 \quad \varepsilon = 0.78$$

$$\Delta T_i = (0.78)(200 - 20) = 140.4^\circ\text{C} \quad T_{\text{exit}} = 200 - 140.4 = 59.6^\circ\text{C}$$

$$\text{If reduce air flow in half, } NTU = (2)(1.45) = 2.90 \quad \varepsilon = 0.95$$

$$\Delta T_i = (0.95)(200 - 20) = 171 \quad T_{\text{exit}} = 200 - 171 = 29^\circ\text{C}$$

10-5Water in tube

$$u_m = 4 \text{ m/s} \quad T_b = 90^\circ\text{C} \quad d = 2.5 \text{ cm} \quad \rho = 965 \quad \mu = 3.15 \times 10^{-4}$$

$$k = 0.676 \quad \text{Pr} = 1.98$$

$$\text{Re}_d = \frac{(965)(4)(0.025)}{3.15 \times 10^{-4}} = 3.06 \times 10^5$$

$$h_i = \frac{0.676}{0.025} (0.023)(3.06 \times 10^5)^{0.8} (1.98)^{0.4} = 20,000 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Oil across tube

$$T = 20^\circ\text{C} \quad u = 7 \text{ m/s} \quad T_f \approx 40^\circ\text{C} \quad d = 0.0266 \text{ m} \quad \rho = 876$$

$$v = 0.00024 \text{ m}^2/\text{s} \quad \text{Pr} = 2870 \quad k = 0.144 \quad \text{Re}_d = \frac{(7)(0.0266)}{0.00024} = 776$$

$$C = 0.683 \quad n = 0.466 \quad \text{Nu} = C \text{Re}^n \text{Pr}^{1/3}$$

$$h_o = \frac{0.144}{0.0266} (0.683)(776)^{0.466} (2870)^{1/3} = 1167 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\underline{R\text{-conduction}} = \frac{\ln\left(\frac{2.66}{2.5}\right)}{2\pi(36)} = 2.74 \times 10^{-4}$$

$$\underline{R\text{-inside}} = \frac{1}{h_i A_i} = \frac{1}{(20,000)\pi(0.025)} = 16.36 \times 10^{-4}$$

$$R_{\text{-outside}} = \frac{1}{h_o A_o} = \frac{1}{(1167)\pi(0.0266)} = 0.0103$$

$$\sum R = 0.0112$$

$$\frac{UA}{\text{m length}} = \frac{1}{0.0112} = 89.2$$

$$\frac{A}{\text{m length}} = \pi(0.0266) = 0.0836$$

$$U_o = \frac{89.2}{0.0836} = 1067 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

10-6

Water at 90°C: $\rho = 965$ $\mu = 3.16 \times 10^{-4}$ $k = 0.676$ $\text{Pr} = 1.96$

$$\text{Re} = \frac{(965)(4)(0.025)}{3.16 \times 10^{-4}} = 3.05 \times 10^5$$

$$h_i = \frac{0.676}{0.025} (0.023)(3.05 \times 10^5)^{0.8} (1.96)^{0.3} = 18,590 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Engine oil at 20°C: $\nu = 0.0009$ $k = 0.145$ $\text{Pr} = 10,400$

$$D_H = 0.0375 - 0.0266 = 0.0109 \text{ m} \quad \text{Re} = \frac{(7)(0.0109)}{0.0009} = 84.78$$

$\text{Re Pr} = (84.78)(10,400) = 8.82 \times 10^5$ h_o is smaller compared to h_i so approximately h_o can be obtained from const. Temp. eq.

$$\text{Re Pr} \frac{d}{l} = \frac{(8.82 \times 10^5)(0.0109)}{6} = 1602.3 \quad \text{at } 90^\circ\text{C} \quad \nu_w = 0.289 \times 10^{-4}$$

$$h_o = \frac{0.145}{0.0109} (1.86)(1602.3)^{1/3} \left(\frac{9}{0.289} \right)^{0.14} = 468.6 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{Based on } A_i: U_i = \frac{1}{\frac{1}{18,590} + \frac{0.025}{(0.0266)(468.6)}} = 485.6 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

10-7

$$d_o = 1.315 \text{ in.} \quad d_i = 0.957 \text{ in.} \quad k = 43 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{For 1 m length: } \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi kL} = 1.176 \times 10^{-3}$$

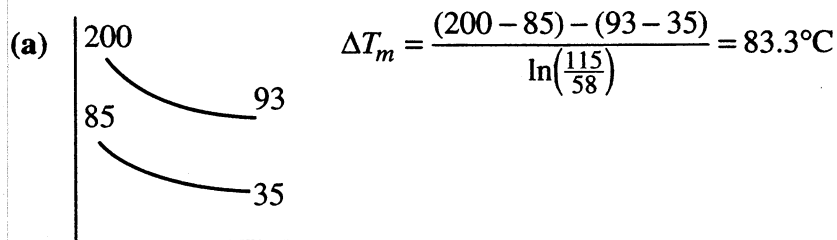
$$\frac{1}{h_o A_o} = \frac{1}{(180)\pi(1.315)(0.0254)} = 0.05294$$

$$\frac{1}{h_i A_i} = \frac{1}{(65)\pi(0.957)(0.0254)} = 0.20146$$

$$UA = \frac{1}{0.05294 + 0.20146 + 1.176 \times 10^{-3}} = 3.9127$$

$$U_i = \frac{3.9127}{\pi(0.957)(0.0254)} = 51.24 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

10-8



$$p = 0.303 \quad R = \frac{200 - 93}{85 - 35} = 2.14 \quad F = 0.92$$

$$q = (2.5)(4175)(85 - 35) = (180)A(0.92)(83.3) = 521.8 \text{ kW}$$

$$A = 37.8 \text{ m}^2$$

(b) $m_g c_g (200 - 93) = (2.5)(4175)(85 - 35) \quad m_g c_g = 4877 = C_{\min}$

$$\frac{C_{\min}}{C_{\max}} = \frac{4877}{10,437} = 0.467 \quad \epsilon = \frac{200 - 93}{200 - 35} = 0.648 \quad \frac{AU}{C_{\min}} = 1.4$$

$$A = \frac{(1.4)(4877)}{180} = 37.9 \text{ m}^2$$

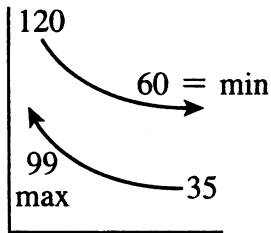
Chapter 10

10-11

$$m_w = 230 \text{ kg/hr} \quad T_{in} = 35^\circ\text{C} \quad A = 1.4 \text{ m}^2 \quad T_{0 \text{ inlet}} = 120^\circ\text{C}$$

$$c_o = 2100 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}$$

$$T_w(\text{exit max}) = 99^\circ\text{C} \quad T_o(\text{exit min}) = 60^\circ\text{C} \quad U = 280 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$



$$q_{\max} = m_w c_w \Delta T_w = \frac{230}{3600} (4180)(99 - 35) = 17,090 \text{ W}$$

$$C_w = \frac{230}{3600} (4180) = 267$$

$$\Delta T(\text{max, oil}) = 120 - 60 = 60 \quad \Delta T(\text{max, water}) = 99 - 35 = 64$$

$$\text{Water is potentially minimum fluid, so that } NTU = \frac{UA}{C_{\min}} = \frac{(280)(1.4)}{267} = 1.47$$

$$\varepsilon = \frac{64}{120 - 35} = 0.753$$

For counterflow, double-pipe this can be accomplished with $\frac{C_{\min}}{C_{\max}} \approx 0.2$

$$C_o = \frac{C_w}{0.2} = 1335 = \dot{m}_o c_o = m_o (2100)$$

$$m_o = 0.636 \text{ kg/s} = 2290 \text{ kg/hr}$$

$$T_{o, \text{exit}} = 120 - \frac{17,090}{1335} = 107.2^\circ\text{C} \text{ which is greater than the allowed value of } 60^\circ\text{C}$$

10-12

$$q = (2500)(2202)(1000)/3600 = 1.53 \text{ MW}$$

$$\Delta T_m = (90-80)/\ln(90/80) = 84.9^\circ\text{C}$$

$$A = (1.53 \times 10^6)/(84.9)(47) = 383 \text{ m}^2$$

10-13

$$C_{\text{air}} = 1.53 \times 10^6 / (40-30) = 153000$$

$$\text{New } C_{\text{air}} = (0.6)(153000) = 91800$$

$$C_{\text{min}}/C_{\text{max}} = 0; \text{ NTU} = (47)(383)/91800 = 0.196$$

$$\varepsilon = 1 - \exp(-0.196) = 0.178$$

$$q = (0.178)(120-30)(91800) = 1.49 \text{ MW}$$

Only 2.6 % drop in condensation rate for 40% drop in air flow rate.

10-14

$$A = 4.64 \text{ m}^2 \quad U = 280 \quad \dot{m}_a = 0.45 \text{ kg/sec} \quad c_a = 1009$$

$$c_w = 4175 \quad q = (m_c)_w(93 - 20) = (0.45)(1009)(260 - T_e)$$

$$q = (280)(4.64) \frac{(260 - 93) - (T_e - 20)}{\ln\left(\frac{260-93}{T_e-20}\right)} \quad \text{By iteration: } T_e = 45.4^\circ\text{C}$$

$$\dot{m}_w = \frac{(0.45)(1009)(260 - 45.4)}{(4175)(93 - 20)} = 0.32 \text{ kg/sec}$$

10-15

$$C_w = (5)(4180) = 20,900 \quad C_o = (8)(2100) = 16,800 \quad \frac{C_{\min}}{C_{\max}} = 0.8038$$

$$N = \frac{UA}{C_{\min}} = \frac{(120)(100)}{16,800} = 0.714$$

$$\text{From Fig. 10-13} \quad \varepsilon = 0.41 = \frac{\Delta T_o}{\Delta T_{\max} Hx}$$

$$\Delta T_o = (0.41)(100 - 50) = 20.5^\circ\text{C} \quad T_o(\text{exit}) = 100 - 20.5 = 79.5^\circ\text{C}$$

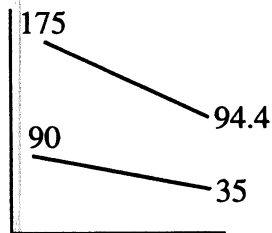
$$q = C_o \Delta T_o = (16,800)(20.5) = 3.44 \times 10^5 \text{ W}$$

10-16-

$$q = (0.7)(4175)(90 - 35) = (0.95)(2100)(175 - T_e) = 160,740 \text{ W}$$

$$T_{e_o} = 94.4^\circ\text{C} \quad \Delta T_m = \frac{85 - 59.4}{\ln\left(\frac{85}{59.4}\right)} = 71.44 \quad A = \frac{160,740}{(425)(71.44)} = 5.294 \text{ m}^2$$

$$\text{Oil is min fluid: } \varepsilon = \frac{175 - 94.4}{175 - 35} = 0.575$$



10-18

$$\text{Glycol} \quad c_p = 2742 \quad q = \frac{4500}{3600} (2742)(140 - 80) = 205,650 \text{ W}$$

$$q = \dot{m}_w (4175)(85 - 35) \quad \dot{m}_w = 0.985 \text{ kg/sec} \quad U = 850 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$C_w = 4112 \quad C_g = \frac{(4500)(2742)}{3600} = 3428 \quad \frac{C_{\min}}{C_{\max}} = 0.834$$

$$\varepsilon = \frac{140 - 80}{140 - 35} = 0.571 \quad \left(\frac{U}{C_{\min}}\right)A = 1.3 \quad A = 5.24 \text{ m}^2$$

Chapter 10

10-19

$$\frac{UA}{C_{\min}} = 2.6 \quad \frac{C_{\min}}{C_{\max}} = 0.417 \quad \varepsilon = 0.82$$

$$\Delta T_g = (0.82)(140 - 35) = 86.1^\circ\text{C} \quad q = (86.1) \left(\frac{3428}{2} \right) = 147,575 \text{ W}$$

reduction of 28.2% in q . $\Delta T_w = \frac{147,575}{4112} = 35.9^\circ\text{C} \quad T_{w_e} = 70.9^\circ\text{C}$

10-20

$$C_{\min} = C_g = 4877 \quad C_{\max} = C_w = (10,437)(0.7) = 7306 \quad \frac{AU}{C_{\min}} = 1.4$$

$$\frac{C_{\min}}{C_{\max}} = \frac{4877}{7306} = 0.667 \quad \varepsilon = 0.62 = \frac{\Delta T_g}{200 - 35} \quad \Delta T_g = 102.3^\circ\text{C}$$

$$q = (4877)(102.3) = 498.9 \text{ kW} \quad 4.5\% \text{ reduction}$$

10-21

$$\Delta T_m = 83.3^\circ\text{C}$$

$$(a) \quad P = 0.303 \quad R = 2.14 \quad F = 0.86 \\ 521.8 \times 10^3 = (180)A(0.86)(83.3) \quad A = 40.5 \text{ m}^2$$

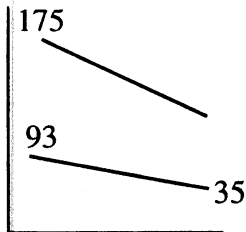
$$(b) \quad \frac{C_{\min}}{C_{\max}} = 0.467 \quad \varepsilon = 0.648 \quad \frac{UA}{C_{\min}} = 1.55 \\ A = \frac{(1.55)(4877)}{180} = 40.6 \text{ m}^2$$

10-22

$$\frac{AU}{C_{\min}} = 1.5 \quad \frac{C_{\min}}{C_{\max}} = 0.934 \quad \varepsilon = 0.53 \quad \Delta T_g = 87.45$$

$$q = (4877)(87.45) = 426.5 \text{ kW} \quad \% \text{ reduction} = \frac{521.8 - 426.5}{521.8} = 18.3\%$$

10-23



$$m_o c_o = \frac{(230)(2100)}{3600} = 134.17$$

$$m_w c_w = \frac{(230)(4175)}{3600} = 266.7$$

$$\Delta T_o = (93 - 35) \left(\frac{266.7}{134.17} \right) = 115.3$$

$$T_{o \text{ out}} = 175 - 115.3 = 59.7^\circ\text{C}$$

$$\Delta T_m = \frac{82 - 24.7}{\ln\left(\frac{82}{24.7}\right)} = 47.75^\circ\text{C}$$

$$q = (266.7)(93 - 35) = 15,469 \text{ W}$$

Ex. 1 $A = \frac{15,469}{(570)(47.75)} = 0.568 \text{ m}^2$

not large enough

Ex. 2 $A = \frac{15,469}{(370)(47.75)} = 0.876 \text{ m}^2$

0.94 m² is large enough

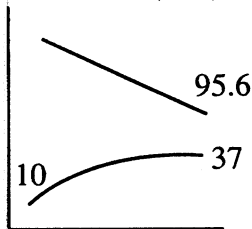
10-24

$$p = 83 \text{ kN/m}^2 = 12 \text{ psia} \quad T_{\text{sat}} = 204^\circ\text{F} = 95.6^\circ\text{C}$$

$$h_{fg} = 976 \text{ Btu/lbm} = 2.27 \times 10^6 \text{ J/kg} \quad q = (2.27 \times 10^6) \left(\frac{0.76}{60} \right) = 28,753 \text{ W}$$

$$\Delta T_m = \frac{85.6 - 38.6}{\ln\left(\frac{85.6}{38.6}\right)} = 59^\circ\text{C}$$

$$A = \frac{q}{U \Delta T_m} = \frac{28,753}{(3400)(59)} = 0.143 \text{ m}^2$$



10-25

$$28,753 = (3400)(0.143)\Delta T_m \quad \Delta T_m = 59^\circ\text{C}$$

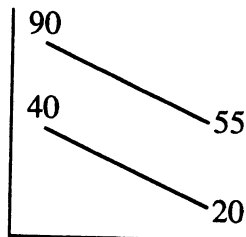
$$\Delta T_m = \frac{(95.6 - 30) - (95.6 - T_{we})}{\ln\left(\frac{65.6}{95.6 - T_{we}}\right)} = 59 \quad \text{By iteration } T_{we} = 42.6^\circ\text{C}$$

$$28,753 = q = \dot{m}_w(4175)(42.6 - 30) \quad \dot{m}_w = 0.5466 \text{ kg/sec}$$

$$\dot{m}_w = \frac{28,753}{(4175)(57 - 10)} = 0.1465 \text{ kg/sec}$$

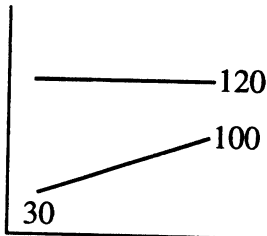
$$\% \text{ increase} = \frac{0.5466 - 0.1465}{0.1465} = 273\%$$

10-26



$$\Delta T_m = \frac{50 - 35}{\ln\left(\frac{50}{35}\right)} = 42.06^\circ\text{C} \quad q = UA\Delta T_m \quad A = \frac{59,000}{(340)(42.06)} = 4.11 \text{ m}^2$$

10-27



$$\Delta T_m = \frac{90 - 20}{\ln\left(\frac{90}{20}\right)} = 46.54^\circ\text{C}$$

$$q = \dot{m}_w c_w \Delta T_w = (2.5)(4180)(100 - 30) = 7.315 \times 10^5 \text{ W}$$

$$A = \frac{q}{U\Delta T_m} = \frac{7.315 \times 10^5}{(2000)(46.54)} = 7.86 \text{ m}^2$$

10-28

$$q = (120 - 95)(1900)(3700)/3600 = 0.488 \text{ MW}$$

$$C_{\text{water}} = 488000/30 = 16300; C_{\text{oil}} = 488000/25 = 19520$$

$$C_{\text{min}}/C_{\text{max}} = 25/30 = 0.833; \epsilon = 30/(120 - 20) = 0.3$$

Fig. 10-15: NTU = 0.45

$$A = (0.45)(16300)/55 = 133 \text{ m}^2$$

10-29

$$\Delta T_{\text{water}} = 10^\circ\text{C}; C_{\text{water}} = (3)(16300) = 48900$$

$$C_{\text{coil}} = C_{\text{min}} = 19520; C_{\text{min}}/C_{\text{max}} = 0.4$$

$$\text{NTU} = (55)(133)/19520 = 0.375$$

Fig. 10-15: $\epsilon \approx 0.3$

$$q = (0.3)(120-40)(19520) = 0.468 \text{ MW}$$

Heat transfer has only dropped by 4.1 percent so no adjustments may be necessary

10-30

$$0.0002 = \frac{1}{U} - \frac{1}{2000} \quad U = 143 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$C_w = C_{\text{min}} = (2.5)(4180) = 10,450$$

$$\text{NTU} = \frac{UA}{C_{\text{min}}} = \frac{(143)(7.86)}{10,450} = 0.1076$$

$$\epsilon = 1 - e^{-0.1076} = 0.1020 = \frac{\Delta T_w}{120 - 30}$$

$$\Delta T_w = 9.18^\circ\text{C}$$

$$T_{w \text{ exit}} = 30 + 9.18 = 39.18^\circ\text{C}$$

10-31

$$C = 1.0 \quad C_{\text{min}} = C_{\text{max}} = (0.5)(1006) = 503 \quad n = 0.903$$

$$N = \frac{(40)(15)}{503} = 1.19$$

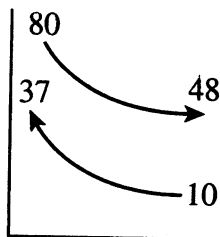
$$\epsilon = 0.50$$

$$\Delta T = (0.50)(400 - 20) = 190^\circ\text{C}$$

$$T_{ce} = 190 + 20 = 210^\circ\text{C}$$

$$T_{he} = 400 - 190 = 210^\circ\text{C}$$

10-32



$$c_a = 1005 \quad \rho_a = \frac{1.013 \times 10^5}{(287)(283)} = 1.247 \text{ kg/m}^3$$

$$\dot{m}_A = (1500)(1.247) = 1871 \text{ kg/min} = 31.19 \text{ kg/sec}$$

Both fluids unmixed

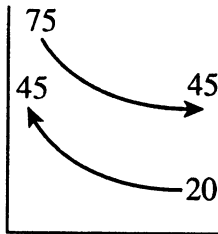
$$\Delta T_m = \frac{43 - 38}{\ln\left(\frac{43}{38}\right)} = 40.45^\circ\text{C} \quad R = \frac{80 - 48}{37 - 10} = 1.18 \quad P = \frac{37 - 10}{80 - 10} = 0.385$$

$$F = 0.96 \quad q = m_a c_a \Delta T_a = (31.19)(1005)(37 - 10) = 8.46 \times 10^5 \text{ W}$$

$$A = \frac{q}{UF\Delta T_m} = \frac{8.46 \times 10^5}{(50)(0.96)(40.45)} = 435.7 \text{ m}^2$$

Chapter 10

10-33



Both fluids unmixed

$$\Delta T_m = \frac{30 - 25}{\ln\left(\frac{30}{25}\right)} = 27.42^\circ\text{C} \quad R = \frac{75 - 45}{45 - 20} = 1.2 \quad P = \frac{45 - 20}{75 - 20} = 0.455$$

$$F = 0.91 \quad A = \frac{q}{UF\Delta T_m} = \frac{35,000}{(50)(0.91)(27.42)} = 28.05 \text{ m}^2$$

10-34

$$c_o = 1920 \quad c_w = 4180 \quad C_o = \frac{(95)(1920)}{60} = 3040 \quad (\text{min})$$

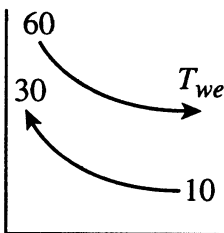
$$C_w = \frac{(55)(4180)}{60} = 3832 \quad \frac{C_{\min}}{C_{\max}} = 0.793 \quad NTU = \frac{(250)(14)}{3040} = 1.151$$

$$\varepsilon = 0.5 = \frac{\Delta T_o}{120 - 30} \quad \Delta T_o = 45^\circ\text{C} \quad T_{oe} = 120 - 45 = 75^\circ\text{C}$$

$$q = C_o \Delta T_o = (3040)(45) = 1.368 \times 10^5 \text{ W}$$

$$\Delta T_w = 45 \left(\frac{3040}{3832} \right) = 35.7^\circ\text{C} \quad T_{we} = 30 + 35.7 = 65.7^\circ\text{C}$$

10-35



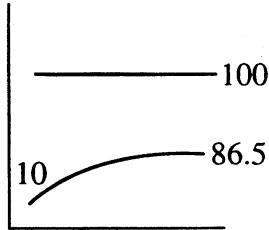
$$C_w = (5)(4180) = 20,900 \quad C_a = 4800$$

$$q = 20,900(60 - T_{we}) = (4800)\dot{m}_a(30 - 10)$$

$$20,900(60 - T_{we}) = UA\Delta T_m = (800)(30) \frac{30 - T_{we} + 10}{\ln\left(\frac{30}{T_{we} - 10}\right)}$$

$$\text{Solve by iteration: } T_{we} = 31^\circ\text{C} \quad \dot{m}_a = \frac{(20,900)(60 - 31)}{(4800)(20)} = 6.31 \text{ kg/sec}$$

10-36



$$U = 150 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad A = 30 \text{ m}^2 \quad \varepsilon = \frac{\Delta T_a}{100 - 10} = 0.85$$

$$\Delta T_a = 76.5^\circ\text{C} \quad T_{a_e} = 76.5 + 10 = 86.5^\circ\text{C} \quad \Delta T_m = \frac{90 - 13.5}{\ln\left(\frac{90}{13.5}\right)} = 40.32^\circ\text{C}$$

$$q = UA\Delta T_m = (150)(30)(40.32) = 1.81 \times 10^5 \text{ W}$$

10-37

$$N = (2)(1.59) = 3.18 \quad n = 0.775 \quad \varepsilon = 0.693 \quad T_{ce} = 283.3^\circ\text{C}$$

$$T_{he} = 136.7^\circ\text{C} \quad \Delta T = (0.693)(400 - 20) = 263.3$$

$$N = \frac{1}{2}(1.59) = 0.795 \quad n = 1.052 \quad \varepsilon = 0.416 \quad \Delta T = 158.2$$

$$T_{ce} = 178.2^\circ\text{C} \quad T_{he} = 241.8^\circ\text{C}$$

10-38

$$C_a = \frac{65}{60}(1006) = 1090 \text{ W}/^\circ\text{C} \quad q = (1090)(45 - 30) = 16,350 \text{ W}$$

$$U = 52 \quad A = 8.0 \quad T_{w_1} = 90^\circ\text{C} \quad \text{Assume air min. fluid}$$

$$\varepsilon = \frac{45 - 30}{90 - 30} = 0.25 \quad N = \frac{(52)(8)}{1090} = 0.382$$

Unable to match on graph so C_w is min. Iterative: $C = \frac{C_w}{C_a}$

C	N	n	ε_c	ΔT_w	$\Delta T_a = C\Delta T_w$	$\Delta T_a - 15$
0.6	0.636	1.104	0.405	24.3	14.6	-0.42
0.48	0.795	1.052	0.48	28.8	13.82	-1.17
0.50	0.764		0.4664	27.98	13.99	-1.008
0.7	0.546	1.143	0.3574	21.44	15.01	+0.01

$$T_{we} = 90 - 21.44 = 68.6^\circ\text{C}$$

Chapter 10

10-39

$$C_{\min} = (5)(4180) = 20,900 \quad n = 4 \quad \varepsilon = \frac{90 - 70}{90 - 50} = 0.5$$
$$\varepsilon = \frac{n\varepsilon_p}{1 + (n-1)\varepsilon_p} \quad \varepsilon_p = \frac{\varepsilon}{n(1-\varepsilon) + \varepsilon} = \frac{0.5}{4(0.5) + 0.5} = 0.20 \quad C = 1.0$$
$$N = -(1+1)^{-1/2} \times \ln \left[\frac{10 - 1 - 1 - (2)^{1/2}}{10 - 1 - 1 + (2)^{1/2}} \right] = 0.253 = \frac{UA}{20,900}$$
$$A = \frac{(20,900)(0.253)}{800} = 6.6 \text{ m}^2 \quad A_{\text{Total}} = (4)(6.6) = 26.4 \text{ m}^2$$

10-41

$$\varepsilon = (120-90)/(120-30) = 0.333$$

Same for parallel and counterflow

10-42

$$C_{\min}/C_{\max} = 10/30 = 0.333$$

$$\varepsilon = 0.333$$

Parallel flow : NTU \approx 0.45

Counterflow: NTU \approx 0.47

10-43

$$C_{\min}/C_{\max} = 0; \quad \varepsilon = 10/(10-30) = 0.11111$$

10-44

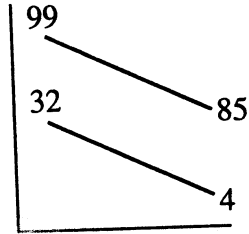
$$\text{NTU} = -\ln(1 - \varepsilon) = 0.1178 \text{ for both cases}$$

10-45

$$m_h = 2.6 \text{ kg/s} \quad m_c = 1.3 \text{ kg/s} \quad \Delta T_h = \frac{1}{2} \Delta T_c = \frac{1}{2} (32 - 4) = 14$$

$$\Delta T_m = \frac{67 - 81}{\ln\left(\frac{67}{81}\right)} = 73.78 \quad q = (1.3)(4175)(32 - 4) = (830)A(73.78)$$

$$A = 2.48 \text{ m}^2 \quad \varepsilon = \frac{32 - 4}{99 - 4} = 29.5\%$$



10-46

$$\varepsilon_c = \frac{T_{c2} - T_{c1}}{T_{h1} - T_{c1}}$$

$$dq = U dA (T_h - T_c) = \dot{m}_c c_c dT_c$$

$$\frac{dT_c}{T_h - T_c} = \frac{U dA}{\dot{m}_c c_c}$$

$$-\ln(T_h - T_c) \Big|_1^2 = \frac{UA}{\dot{m}_c c_c} \Big|_0^A \quad \frac{T_h - T_{c2}}{T_h - T_{c1}} = e^{-\frac{UA}{\dot{m}_c c_c}}$$

$$1 - \frac{T_{c2} - T_{c1}}{T_h - T_{c1}} = e^{-\frac{UA}{\dot{m}_c c_c}}$$

$$\varepsilon = \frac{T_{c2} - T_{c1}}{T_h - T_{c1}} = 1 - e^{-\frac{UA}{\dot{m}_c c_c}}$$

10-47

$$\Delta T_w = 75 - 30 = 45^\circ\text{C}$$

$$\Delta T_o = 48 - 25 = 23^\circ\text{C}$$

Water is minimum fluid.

$$\varepsilon = \frac{\Delta T_w}{\Delta T_{\max}} = \frac{45}{75 - 25} = 0.9$$

10-49

$$0.004 = \frac{1}{U} - \frac{1}{340} \quad U = 144 \quad A = (2.45) \left(\frac{340}{144} \right) = 5.78 \text{ m}^2$$

with original area, oil is min fluid $c = 1900$

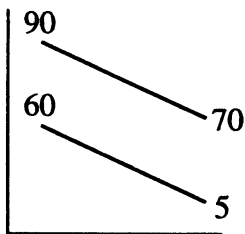
$$C_o = \frac{29,000}{90 - 55} = 828.6 \quad C_w = \frac{29,000}{50 - 25} = 1160 \quad \frac{C_{\min}}{C_{\max}} = 0.714$$

$$NTU = \frac{(144)(2.45)}{828.6} = 0.426 \quad \epsilon = 0.29 = \frac{\Delta T_o}{90 - 25}$$

$$\Delta T_o = 18.85^\circ\text{C} \quad q = (828.6)(18.85) = 15,619 \text{ W}$$

reduced by 46%

10-50



$$q = 60 \text{ kW} \quad U = 1100 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\text{Cold fluid is minimum fluid} \quad \epsilon = \frac{60 - 5}{90 - 5} = 0.647 \quad \frac{C_{\min}}{C_{\max}} = \frac{20}{55} = 0.364$$

$$NTU = 1.5 \quad C_{\min} = \frac{60,000}{60 - 5} = 1091 \quad A = \frac{(1091)(1.5)}{1100} = 1.49 \text{ m}^2$$

10-51

$$NTU = 1.9 \quad \frac{C_{\min}}{C_{\max}} = (2)(0.364) = 0.728 \quad \epsilon = 0.69 = \frac{\Delta T_{\min}}{80 - 5}$$

$$\Delta T_{\min} = 51.75^\circ\text{C} \quad q = (51.75)(1091) = 56,460 \text{ W} \quad \text{only reduced by 6\%}$$

10-52

$$29,000 = C_a(25 - 15) = C_w(70 - 40) \quad C_w = 966.7$$

$$\frac{C_w}{C_a} = \frac{C_{\min}}{C_{\max}} = \frac{10}{30} = 0.333 \quad \epsilon = \frac{30}{70 - 15} = 0.545 \quad \frac{UA}{C_{\min}} = 1.0$$

$$A = \frac{(1.0)(966.7)}{45} = 21.5 \text{ m}^2$$

Chapter 10

10-53

$$C_w = \frac{9667}{3} = 322.2 \quad \frac{C_{\min}}{C_{\max}} = \frac{0.333}{3} = 0.111$$

$$NTU = \frac{UA}{C_{\min}} = \frac{(45)(21.5)}{322.2} = 3.0 \quad \varepsilon = 0.92 = \frac{\Delta T_w}{70 - 15}$$

$$\Delta T_w = 50.6^\circ\text{C} \quad q = C_w \Delta T_w = 16,303 \text{ W}$$

10-54

For parallel flow assume $\dot{m}_c = \dot{m}_h$

$$q = \dot{m}_h c_{p_h} (T_{h_1} - T_{h_2}) = \dot{m}_c c_{p_c} (T_{c_1} - T_{c_2}) \quad c_{p_h} = c_{p_c} \quad \dot{m}_h = \dot{m}_c$$

$$\frac{T_{h_2} - T_{c_2}}{T_{h_1} - T_{c_1}} = \exp UA \left(\frac{1}{\dot{m}_h c_{p_h}} + \frac{1}{\dot{m}_h c_{p_h}} \right) = \exp \left[-\frac{UA}{\dot{m}_c c_{p_c}} \left(1 + \frac{\dot{m}_c c_{p_c}}{\dot{m}_h c_{p_h}} \right) \right]$$

$$\frac{T_{h_2} - T_{c_2}}{T_{h_1} - T_{c_1}} = \exp \left(-2 \frac{UA}{\dot{m}_c c_{p_c}} \right) \quad \text{consider cold fluid: } \varepsilon = \frac{T_{c_2} - T_{c_1}}{T_{h_1} - T_{c_1}}$$

$$\frac{T_{h_2} - T_{c_2}}{T_{h_1} - T_{c_1}} = \frac{T_{h_1} - 2T_{c_2} + T_{c_1}}{T_{h_1} - T_{c_1}} \quad T_{h_2} = T_{h_1} + (T_{c_1} - T_{c_2})$$

$$\frac{(T_{h_1} - T_{c_1}) + (T_{c_1} - T_{c_2}) + (T_{c_1} - T_{c_2})}{T_{h_1} - T_{c_1}} = 1 - 2\varepsilon \quad \varepsilon = \frac{1 - e^{-2UA}}{2}$$

For counter flow: $\dot{m}_h c_{p_h} dT_h = \dot{m}_c c_{p_c} dT_c = dq \quad dq = U dA (T_h - T_c)$
 $q = UA(T_h - T_c)$

$$\varepsilon = \frac{q_{\text{act}}}{q_{\text{max}}} = \frac{UA(T_h - T_c)}{\dot{m}_c (T_{h_1} - T_{h_2})} = NTU \left(\frac{T_{h_1} - T_{c_1}}{T_{h_1} - T_{c_2}} \right) = NTU \left(1 + \frac{T_{c_2} - T_{c_1}}{T_{h_1} - T_{c_2}} \right) = NTU(1 - \varepsilon)$$

$$= \frac{NTU}{1 + NTU}$$

10-55

$$C_w(90 - 55) = C_o(50 - 25) \quad \frac{C_w}{C_o} = \frac{25}{35} \quad C_w = C_{\min} \quad \varepsilon = \frac{90 - 55}{90 - 25} = 53.8\%$$

10-56

$$C_g = (3428)(0.6) = 2056.8 \quad \frac{C_{\min}}{C_{\max}} = \frac{2057}{4112} = 0.500$$

$$\frac{UA}{C_{\min}} = \frac{(850)(5.24)}{2057} = 2.17 \quad \varepsilon = 0.77$$

$$q = (2057)(0.77)(140 - T_{w_i}) = (4112)(85 - T_{w_i}) \quad T_{w_i} = 50.54^\circ\text{C}$$

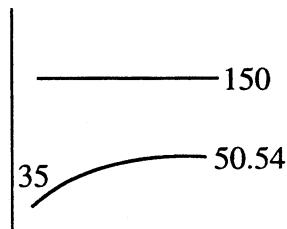
Preheater heats water from 35°C to 50.54°C

$$q = (4112)(50.54 - 35) = 63,900 \text{ W}$$

$$\Delta T_m = \frac{115 - 99.5}{\ln\left(\frac{115}{99.5}\right)} = 107^\circ\text{C} \quad A = \frac{63,900}{(2000)(107)} = 0.299 \text{ m}^2$$

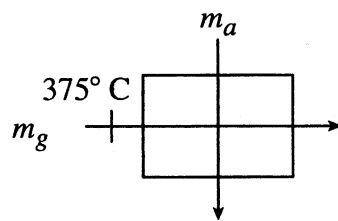
$$\text{At } T = 150^\circ\text{C} = 302^\circ\text{F} \quad h_{fg} = 910 \text{ Btu/lbm}$$

$$h_{fg} = 2.117 \times 10^6 \text{ J/kg} \quad m_s = \frac{63,900}{2.117 \times 10^6} = 0.03 \text{ kg/sec}$$



10-58

$$m_a = 5.0 \text{ kg/sec} \quad A = 110 \text{ m}^2 \quad U = 50 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad m_g = 5 \text{ kg/s}$$



(a) Both unmixed $\frac{C_{\min}}{C_{\max}} = 1.0 \quad NTU = \frac{(110)(50)}{(5)(1005)} = 1.095$

$\varepsilon = 0.49 \quad \Delta T = (0.49)(375 - 27) = 170.5$

$T_{a_2} = 170.5 + 27 = 197.5^\circ\text{C} \quad T_{g_2} = 375 - 170.5 = 204.5^\circ\text{C}$

$q = (5025)(170.5) = 8.57 \times 10^5 \text{ W}$

(b) $\varepsilon = 0.48 \quad$ one fluid mixed about same results

Chapter 10

10-59

$$m_w = 30 \text{ kg/s} \quad C_w = (30)(4174) = 125,220 \quad T_{w_1} = 20^\circ\text{C}$$

$$T_{w_2} = 40^\circ\text{C} \quad T_{o_i} = 200^\circ\text{C} \quad U = 275$$

$$q = (125,220)(40 - 24) = 2.504 \times 10^6 \text{ W} \quad N = \frac{1}{c-1} \ln\left(\frac{\epsilon-1}{c\epsilon-1}\right)$$

T_{be}	ΔT_o	C_o	C	ϵ	NTU
190	10	250,440	0.5	0.1111	0.1212
180	20	125,220	1.0	0.1111	0.125
140	60	41,740	0.333	0.333	0.432
80	120	20,870	0.167	0.667	1.177

10-60

$$m_w = 50 \text{ kg/s} \quad T_{w_1} = 60^\circ\text{C} \quad T_{w_2} = 90^\circ\text{C} \quad U = 4500$$

$$T_s = 200^\circ\text{C} \quad C_w = (50)(4174) = 208,700 \quad C = 0$$

$$\epsilon = \frac{30}{200 - 60} = 0.2143 \quad N = -\ln(1 - 0.2143) = 0.2412$$

$$A = \frac{(0.2412)(208,700)}{4500} = 11.18 \text{ m}^2 \quad \epsilon = \frac{T_{w_2} - 60}{T_s - 60} = 0.2143$$

$$T_{w_2} = 0.2143T_s + 47.1$$

10-61

$$(a) \quad q = (5.0)(4180)(80 - 30) = 1.045 \times 10^6 \quad \epsilon = \frac{80 - 30}{100 - 30} = 0.7143$$

$$N = -\ln(1 - \epsilon) = 1.253 \quad A = \frac{(1.253)(5)(4180)}{900} = 29.09 \text{ m}^2$$

$$(b) \quad N = \frac{(900)(29.09)}{(1.3)(4180)} = 4.818 \quad \epsilon = 1 - e^{-N} = 0.992$$

$$\Delta T_w = (0.992)(100 - 30) = 69.4^\circ\text{C} \quad T_{we} = 69.4 + 30 = 99.4^\circ\text{C}$$

10-62

$$C_w = (0.48)(4180) = 2006 \quad C_a = (1.0)(1005) = 1005$$

$$C = \frac{1005}{2006} = 0.5 \quad NTU = \frac{(50)(20)}{1005} = 1.0 \quad \epsilon = 0.55$$

$$\Delta T_a = (0.55)(80 - 10) = 38.5^\circ\text{C} \quad T_{a \text{ exit}} = 10 + 38.5 = 48.5^\circ\text{C}$$

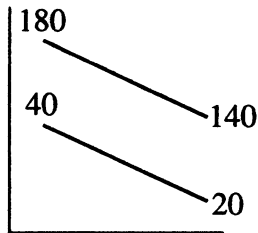
$$\Delta T_w = (0.5)(38.5) = 19.25^\circ\text{C} \quad T_{w \text{ exit}} = 80 - 19.25 = 60.75^\circ\text{C}$$

10-63

$$\Delta T_m = \frac{60 - 40}{\ln\left(\frac{60}{40}\right)} = 49.33^\circ\text{C} \quad q = 600,000 = UA\Delta T_m = (300)A(49.33)$$

$$A = 40.55 \text{ m}^2 \quad \varepsilon = \frac{160 - 90}{160 - 50} = \frac{70}{110} = 0.636$$

10-64



$$U = 130 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad C_o = 2100 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}} \quad \dot{m}_w = 3.0 \text{ kg/sec}$$

$$C_w = (3)(4180) = 12,540 \quad q = C_w \Delta T_w = C_o \Delta T_o = 2.508 \times 10^5 \text{ W}$$

$$C_o = (12,540) \left(\frac{40 - 20}{180 - 140} \right) = 6270 \quad \frac{C_{\min}}{C_{\max}} = 0.5 \quad \varepsilon = \frac{180 - 140}{180 - 120} = 0.25$$

$$NTU = 0.35 \quad A = \frac{(0.35)(6270)}{130} = 16.88 \text{ m}^2$$

if water flow cut in half $C_w = 6270$

$$q = (2.508 \times 10^5)(0.5) = 1.254 \times 10^5 \text{ W}$$

Oil flow will be reduced so it will still be min. fluid.

$$q = c_o(180 - T_{o2}) = (130)(16.88) \frac{(180 - 40) - (T_{o2} - 20)}{\ln\left(\frac{140}{T_{o2} - 20}\right)}$$

$$\text{Solve by iteration: } T_{o2} = 36^\circ\text{C} \quad C_o(180 - 36) = 1.254 \times 10^5 \quad C_o = 870.8$$

Flow is reduced by 86%.

Chapter 10

10-65

$$\dot{m}_a = 0.8 \text{ kg/sec} \quad T_{a_1} = 30^\circ\text{C} \quad T_{a_2} = 7^\circ\text{C} \quad T_{w_1} = 3^\circ\text{C}$$

$$U = 55 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \dot{m}_w = 0.75 \text{ kg/sec} \quad C_a = (0.8)(1005) = 804$$

$$C_w = (0.75)(4180) = 3135 \quad \varepsilon = \frac{30-7}{30-3} = 0.85 \quad \frac{C_{\min}}{C_{\max}} = \frac{804}{3135} = 0.256$$

$$NTU = 2.4 \quad A = \frac{(2.4)(804)}{55} = 35.08 \text{ m}^2$$

$$\text{Water cut in half:} \quad \frac{C_{\min}}{C_{\max}} = (2)(0.256) = 0.512 \quad NTU = 2.4$$

$$\varepsilon = 0.76 = \frac{\Delta T_a}{30-3} \quad \Delta T_a = 20.52^\circ\text{C}$$

$$\% \text{ reduction} = \left(1 - \frac{20.52}{23}\right) \times 100 = 10.8\%$$

10-66

$$\varepsilon = \frac{30-7}{30-1.7} = 0.813 \quad NTU = -\ln(1-\varepsilon) = 1.675$$

$$A = \frac{(1.675)(804)}{125} = 10.77 \text{ m}^2 \quad \text{Reduce air flow by } \frac{1}{3}$$

$$NTU = \frac{1.675}{\frac{2}{3}} = 2.512 \quad \varepsilon = 1 - e^{-N} = 0.919 = \frac{\Delta T_a}{30-1.7} \quad \Delta T_a = 26^\circ\text{C}$$

$$\text{Initial} \quad q = (804)(30-7) = 18,492 \text{ W}$$

$$\text{Reduced} \quad q = (804)\left(\frac{2}{3}\right)(26) = 13,936 \text{ W}$$

Reduced by 24%

10-67

$$m_o = 4000 \text{ kg/hr} = 1.111 \text{ kg/sec}$$

$$C_o = 2000 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}$$

$$C_o = C_{\min} = (2000)(1.111) = 2222$$

$$\varepsilon = \frac{\Delta T_o}{\Delta T_{\max}} = \frac{80 - 40}{100 - 40} = 0.667$$

$$N = -\ln(1 - \varepsilon) = 1.099 = \frac{UA}{C_{\min}}$$

$$A = \frac{(1.099)(2222)}{1200} = 2.034 \text{ m}^2$$

When oil flow cut in half:

$$NTU = (2)(1.099) = 2.198$$

$$\varepsilon = 1 - e^{-N} = 0.889 = \frac{\Delta T_o}{100 - 40}$$

$$\Delta T_o = 53.34^\circ\text{C} \quad q = C_o \Delta T_o = \frac{2222}{2} (53.34) = 59,260 \text{ W} = \dot{m}_s h_{fg}$$

$$\dot{m}_s = \frac{59,260}{2.255 \times 10^6} = 0.0262 \text{ kg/sec}$$

10-68

$$\varepsilon = 0.75 = \frac{\Delta T_w}{100 - 50}$$

$$\Delta T_w = 37.5^\circ\text{C}$$

$$N = -\ln(1 - \varepsilon) = 1.386$$

$$A = \frac{(1.386)(5)(4180)}{1200} = 24.14 \text{ m}^2$$

10-69

Reduce water flow in half $NTU = \frac{1.386}{0.5} = 2.772$

$$\varepsilon = 1 - e^{-N} = 0.937 = \frac{\Delta T_w}{100 - 50} \quad \Delta T_w = 46.9^\circ\text{C}$$

$$T_{w_e} = 46.9 + 50 = 96.9^\circ\text{C} \quad q = C_w \Delta T_w = (5)(0.5)(4180)(46.9) = 4.901 \times 10^5 \text{ W}$$

10-70

$$\Delta T_w = 80 - 52 = 28^\circ\text{C}$$

$$\Delta T_a = 40 - 7 = 33^\circ\text{C}$$

Air is minimum fluid: $\varepsilon = \frac{33}{80 - 7} = 0.452$

10-71

$$q = m_w C_w (28) = \dot{m}_a C_a (33)$$

$$\dot{m}_w = 150 \text{ kg/min} = 2.5 \text{ kg/sec}$$

$$q = (2.5)(4180)(28) = 2.926 \times 10^5 \text{ W} \quad \frac{C_a}{C_w} = \frac{28}{33} = 0.848$$

$$NTU = 0.8 = \frac{UA}{C_a}$$

$$A = \frac{(0.8)(2.5)(4180)(0.848)}{50} = 142 \text{ m}^2$$

Chapter 10

10-72

$$\dot{m}_g = 10 \text{ kg/sec} \quad \dot{m}_w = 15 \text{ kg/sec} \quad C_g = 2420 \quad C_w = 4180 \frac{\text{kJ}}{\text{kg} \cdot ^\circ\text{C}}$$

$$C_g = 24,200 \quad C_w = 62,700 \quad \frac{C_{\min}}{C_{\max}} = 0.386$$

$$\text{Glycol is minimum fluid} \quad \varepsilon = \frac{40 - 20}{70 - 20} = 0.4 \quad NTU = 0.6 = \frac{UA}{C_{\min}}$$

$$A = \frac{(0.6)(24,200)}{40} = 363 \text{ m}^2$$

10-73

$$C_w = (10)(4180) = 41,800 \quad U = 35 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \frac{C_{\min}}{C_{\max}} = \frac{24,200}{41,800} = 0.579$$

$$NTU = \frac{(35)(363)}{24,200} = 0.525 \quad \varepsilon = 0.38 = \frac{\Delta T_g}{70 - 20} \quad \Delta T_g = 19^\circ\text{C}$$

$$T_g = 20 + 19 = 39^\circ\text{C}$$

10-74

$$C_w = (4)(4180) = 16,720 = C_{\min} = C_{\max} \quad U = 800 \quad n = 3$$

$$\varepsilon = \frac{60 - 20}{80 - 20} = 0.66667 \quad \frac{C_{\min}}{C_{\max}} = 1.0$$

$$\text{From next to last entry of Table 10-3 for } C = 1 \quad \varepsilon = \frac{n\varepsilon_p}{1 - (n-1)\varepsilon_p}$$

$$\text{Solving for } \varepsilon_p, \quad \varepsilon_p = \frac{\varepsilon}{n - (n-1)\varepsilon} = 0.4$$

$$\text{From Fig. 10-17, at } C = 1 \quad \varepsilon = 0.4 \quad N_p = 0.8 = \frac{UA}{C_w}$$

$$A_p = \frac{(0.8)(16,720)}{800} = 16.72 \text{ m}^2 \quad A_{\text{total}} = (3)(16.72) = 50.16 \text{ m}^2$$

10-75

Water is minimum fluid

$$q = 800 \times 10^6 = C_w(30 - 25) \quad C_w = 1.6 \times 10^8 \quad U = 2000 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\varepsilon = \frac{\Delta T_w}{\Delta T_{\max}} = \frac{30 - 25}{100 - 25} = 0.06667 \quad N = -\ln(1 - \varepsilon) = 0.069 = \frac{UA}{C_{\min}}$$

$$A = \frac{(0.069)(1.6 \times 10^8)}{2000} = 5519 \text{ m}^2$$

10-76

$$\begin{aligned} \text{Water flow in half} \quad C_w &= 0.8 \times 10^8 & NTU &= 0.138 \\ \varepsilon = 1 - e^{-N} &= 0.1289 = \frac{\Delta T_w}{100 - 25} & \Delta T_w &= 9.67^\circ\text{C} \\ q = C_w \Delta T_w &= 7.73 \times 10^8 \text{ W} = \dot{m}_s h_{fg} & h_{fg} &= 2.255 \times 10^6 \text{ J/kg} \\ \dot{m}_s &= \frac{7.73 \times 10^8}{2.25 \times 10^6} = 343 \text{ kg/sec} = 1.235 \times 10^6 \text{ kg/hr} \end{aligned}$$

10-77

$$\begin{aligned} T_{g1} &= 25^\circ\text{C} & T_{g2} &= 65^\circ\text{C} & C_g &= 2474 & \dot{m}_g &= 1.2 \text{ kg/s} & T_{w1} &= 95^\circ\text{C} \\ T_{w2} &= 55^\circ\text{C} & U &= 600 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} & \Delta T_g &= \Delta T_w \\ C_g &= (1.2)(2474) = 2969 = C_w & \frac{C_{\min}}{C_{\max}} &= 1.0 & \varepsilon &= \frac{40}{95 - 25} = 0.571 \\ NTU &= 1.4 = \frac{UA}{C_{\min}} & A &= \frac{(1.4)(2969)}{600} = 6.93 \text{ m}^2 \end{aligned}$$

10-78

$$\begin{aligned} \rho &= 1.1774 \text{ kg/m}^3 & c_p &= 1005 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}} & \text{Pr} &= 0.708 \\ \mu &= 1.846 \times 10^{-5} & \sigma &= 0.697 = \frac{A_c}{A} & D_h &= 0.0118 \text{ ft} = 0.0036 \text{ m} \\ \text{Frontal area} &= (0.3)(0.6) = 0.18 \text{ m}^2 & A_c &= (0.697)(0.18) = 0.1254 \text{ m}^2 \\ G &= \frac{\rho u_\infty A}{A_c} = \frac{(1.1774)(10)}{0.67} = 17.57 \frac{\text{kg}}{\text{m}^2 \cdot \text{s}} \\ \text{Re} \frac{D_h G}{\mu} &= \frac{(0.0036)(12.57)}{1.846 \times 10^{-5}} = 3426 & \text{St Pr}^{2/3} &= 0.004 = \frac{h}{G c_p} \text{Pr}^{2/3} \\ h &= (0.004)(17.57)(1005)(0.708)^{-2/3} = 88.09 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \end{aligned}$$

This coefficient is controlling

$$\text{Volume} = (0.3)^2(0.6) = 0.054 \text{ m}^3$$

$$\text{Heat Transfer Area} = (0.054)\alpha = (0.054) \left(229 \frac{\text{ft}^2}{\text{ft}^3} \times 3.28 \frac{\text{ft}}{\text{m}} \right) = 40.56 \text{ m}^2$$

$$q = hA \left(100 - \frac{27}{2} - \frac{T_2}{2} \right) = \dot{m} c_p (T_2 - 27)$$

$$(88.9)(40.56) \left(100 - \frac{27}{2} - \frac{T_2}{2} \right) = (1.1774)(10)(0.18)(1005)(T_2 - 27)$$

$$T_2 = 93.93^\circ\text{C}$$

Chapter 10

$$q = 1.43 \times 10^5 \text{ W} = \dot{m}_s h_{fg} \quad h_{fg} = 2.255 \times 10^6 \text{ J/kg}$$

$$\dot{m}_s = \frac{q}{h_{fg}} = 0.63 \text{ kg/s}$$

10-81

$$c_g = 2382 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}$$

$$q = m_w c_w \Delta T_w = m_g c_g \Delta T_g = (0.6)(4180)(80 - 60) = (0.8)(2382)\Delta T_g = 50,160 \text{ W}$$

$$= UA \Delta T_w$$

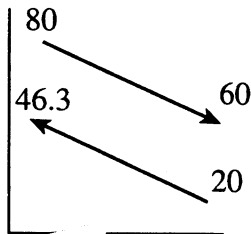
$$\Delta T_g = 26.3^\circ\text{C}$$

$$\varepsilon = \frac{26.3}{80 - 20} = 0.439$$

Assume counterflow

$$\Delta T_m = \frac{33.7 - 40}{\ln \frac{33.7}{40}} = 36.76^\circ\text{C}$$

$$A = \frac{50,160}{(1000)(36.76)} = 1.36 \text{ m}^2$$



10-82

$$q = m_w c_w \Delta T_w = m_o c_o \Delta T_o = (0.6)(4180)(50 - 20) = (1.2)(2100)(100 - T_{oe})$$

$$= 75,240 \text{ W}$$

$$\Delta T_o = 29.86 \quad T_{oe} = 70.14^\circ\text{C}$$

Water is min. fluid and mixed

Oil is max fluid and unmixed.

$$\varepsilon = \frac{30}{100 - 20} = 0.375 \quad \frac{C_{\min}}{C_{\max}} = \frac{29.86}{30} = 0.995$$

$$N = \frac{-1}{0.995} \ln[1 + 0.995 \ln(1 - 0.375)] = 0.634 = \frac{UA}{C_{\min}}$$

$$A = \frac{(0.634)(0.6)(4180)}{250} = 0.636 \text{ m}^2$$

10-83

Water is min fluid and unmixed

Oil is max fluid and mixed

$$N = -\ln \left\{ 1 + \frac{1}{0.995} \ln[1 - 0.995(0.375)] \right\} = 0.469 \quad A = 0.470 \text{ m}^2$$

10-84

$$q = m_w c_w \Delta T_w = m_o c_o \Delta T_o = (2)(4180)(70 - 10) = (3)(2100)(120 - T_{oe})$$

$$= 501,600 \text{ N}$$

$$\Delta T_o = 79.62 \quad T_{oe} = 40.38^\circ\text{C}$$

Oil is min fluid.

$$C = \frac{60}{79.62} = 0.7536 \quad \varepsilon = \frac{79.62}{120 - 10} = 0.7238 \quad n = 3$$

$$\varepsilon_p = \frac{\left(\frac{1-\varepsilon C}{1-\varepsilon}\right)^{1/n} - 1}{\left(\frac{1-\varepsilon C}{1-\varepsilon}\right)^{1/n} - C} \quad (\text{See Prob. 10-83})$$

$$= \frac{\left(\frac{1-(0.7278)(0.7536)}{1-0.7238}\right)^{1/3} - 1}{\left(\frac{1-(0.7278)(0.7536)}{1-0.7238}\right)^{1/3} - 0.7536} = \frac{1.1806 - 1}{1.1806 - 0.7536} = 0.423$$

$$\text{From Fig. 10-16, } N(1 \text{ shell pass}) = 0.75 \quad N(\text{total}) = (3)(0.75) = 2.25$$

$$2.25 = \frac{UA}{(3)(2100)} \quad A = \frac{(2.25)(3)(2100)}{300} = 47.25 \text{ m}^2$$

10-85

$$C_w = (1)(4180) = 4180 \quad C_o = (3)(2100) = 6300 \quad \frac{C_{\min}}{C_{\max}} = \frac{4180}{6300} = 0.663$$

$$NTU = \frac{(300)(47.25)}{4180} = 3.391$$

$$N(1 \text{ shell}) = 1.13 \quad \varepsilon_p = 0.54 \quad \text{From Fig. 10-16}$$

From Table 10-3

$$\varepsilon = \frac{\left[\frac{1-(0.54)(0.663)}{1-0.54}\right]^3 - 1}{\left[\frac{1-(0.54)(0.663)}{1-0.54}\right]^3 - 0.663} = 0.836 = \frac{\Delta T_w}{120 - 10}$$

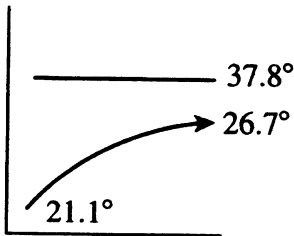
$$\Delta T_w = 91.97^\circ\text{C} \quad T_{we} = 10 + 91.97 = 101.97^\circ\text{C}$$

$$\text{From energy balance: } \Delta T_o = 61.02^\circ\text{C} \quad T_{oe} = 120 - 61.02 = 58.98^\circ\text{C}$$

$$q = 3.844 \times 10^5 \text{ W}$$

Chapter 10

10-86



$$U = 700 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \dot{m}_F = 0.23 \text{ kg/s} \quad h_{fg} = 120 \text{ kJ/kg}$$

$$q = \dot{m}_F h_{fg} = (0.23)(120) = 27,600 \text{ W} = \dot{m}_w c_w (26.7 - 21.1)$$

$$\dot{m}_w c_w = C_w = 4929 \quad \Delta T_m = \frac{11.1 - 16.7}{\ln\left(\frac{11.1}{16.7}\right)} = 13.71^\circ\text{C} \quad F = 1.0$$

$$q = UAF\Delta T_m \quad A = \frac{27,600}{(700)(13.71)} = 2.88 \text{ m}^2 \quad \varepsilon = \frac{5.6}{16.7} = 0.335$$

10-87

$$C_w = \left(\frac{1}{2}\right)(4929) = 2464 \quad N = \frac{UA}{C_w} = \frac{(700)(2.88)}{2464} = 0.818$$

$$\varepsilon = 1 - e^{-N} = 0.559 = \frac{\Delta T_w}{37.8 - 21.1} \quad \Delta T_w = (0.559)(16.7) = 9.33^\circ\text{C}$$

$$q = C_w \Delta T_w = (9.33)(2464) = 22,991 \text{ W}$$

$$\% \text{ Reduction} = \frac{27,600 - 22,991}{27,600} \times 100 = 17\%$$

10-88

$$m_h c_h = m_c c_c = (3)(4180) = 12,540 \quad C = 1.0 \quad n = 4$$

$$\varepsilon = \frac{20}{80 - 10} = 0.2857$$

Using Eq. in Table 10-3 for $C = 1$

$$\varepsilon[1 + (n-1)\varepsilon_p] = n\varepsilon_p \quad \varepsilon_p = \frac{\varepsilon}{n - \varepsilon(n-1)} = \frac{0.2857}{4 - (3)(0.2857)} = 0.0909$$

From Table 10-4

$$N = \frac{1}{\sqrt{2}} \ln\left(\frac{22 - 1 - 1 - \sqrt{2}}{22 - 1 - 1 + \sqrt{2}}\right) = 0.1002 = \frac{UA}{C_{\min}} = \frac{1000A}{(3)(4180)}$$

$$A = 1.256 \text{ m}^2 \quad A_{\text{total}} = (4)(1.256) = 5.024 \text{ m}^2$$

10-89

$$\text{New } C_{\min} = (1.5)(4180) = 6270 \quad C = 0.5$$

$$\text{One shell pass} \quad N = (2)(0.1002) = 0.2004$$

$$\text{From Table 10-3} \quad \epsilon_p = 2 \left[1 + 0.5 + (1.118) \frac{1 + e^{-0.224}}{1 - e^{-0.224}} \right]^{-1} = 0.173$$

Also from Table 10-3

$$\epsilon = \frac{\left(\frac{1-0.0865}{1-0.173} \right)^4 - 1}{\left(\frac{1-0.0865}{1-0.173} \right)^4 - C} = 0.4943 = \frac{\Delta T_w}{80 - 10} \quad \Delta T_w = 34.6^\circ\text{C}$$

$$q = (1.5)(4180)(34.6) = 2.156 \times 10^5 \text{ W}$$

$$\text{For Prob. 10-80} \quad q = (3)(4180)(20) = 2.508 \times 10^5 \text{ W}$$

14% reduction in heat transfer

10-90

$$C = 0.5 \text{ and } 1.0$$

$$\text{Take } N \text{ (1 shell)} = 1.0$$

$$\text{Fig. 10-16} \quad \epsilon_p = 0.525 \quad \text{at } C = 0.5$$

$$\epsilon_p = 0.45 \quad \text{at } C = 1.0$$

$$\text{Fig. 10-17} \quad N = 2 \quad \epsilon_p = 0.76 \quad \text{at } C = 0.5$$

$$\epsilon_p = 0.62 \quad \text{at } C = 1.0$$

$$\text{at } C = 0.5 \quad \epsilon = \frac{\left(\frac{1-0.2625}{1-0.525} \right)^2 - 1}{\left(\frac{1-0.2625}{1-0.525} \right)^2 - 0.5} = 0.738$$

$$\text{at } C = 1.0 \quad \epsilon = \frac{(2)(0.45)}{1 + (2-1)(0.45)} = 0.621$$

Good agreement, considering accuracy of reading figures.

10-91

Solve third from last equation of Table 10-3 for ϵ_p .

Chapter 10

10-92

$$C_o = (7.0)(2100) = 14,700 \quad T_{wi} = 20^\circ\text{C}$$

$$C_{\text{mixed}} = C_w = (3.5)(4180) = 14,630 \quad T_{oi} = 100^\circ\text{C}$$

$$\varepsilon = 0.6 = \frac{\Delta T_w}{100 - 20} \quad \Delta T_w = 48^\circ\text{C}$$

$$q = (14,630)(48) = (14,700)\Delta T_o \quad \Delta T_o = 47.8^\circ\text{C} \quad T_{we} = 68^\circ\text{C}$$

$$T_{oe} = 52.3^\circ\text{C} \quad \frac{C_{\text{mixed}}}{C_{\text{unmixed}}} = \frac{14,630}{14,700} = 0.995 \quad N = 2.5 = \frac{UA}{14,630}$$

$$UA = 36,575$$

10-93

$$C_w = (1.0)(4180) = 4180 \quad NTU = \frac{(2500)(0.8)}{4180} = 0.4785$$

$$\varepsilon = 1 - e^{-0.4785} = 0.38 = \frac{\Delta T_w}{100 - 20} \quad \Delta T_w = 30.4^\circ\text{C}$$

$$T_{we} = 20 + 30.4 = 50.4^\circ\text{C}$$

10-94

$$C_w = (1.5)(4180) = 6270 \quad C_g = (3.0)(2474) = 7422$$

$$q = (6270)(50 - 20) = 7422\Delta T_g = 1.881 \times 10^5 \text{ W} \quad \Delta T_g = 25.34^\circ\text{C}$$

$$\varepsilon = \frac{\Delta T_w}{80 - 20} = \frac{30}{60} = 0.5 \quad C = \frac{6270}{7422} = 0.845 \quad n = 4$$

From Prob. 10-77

$$\varepsilon_p = \frac{\left[\frac{1 - 0.5(0.845)}{1 - 0.5} \right]^{1/4} - 1}{\left[\frac{1 - 0.5(0.845)}{1 - 0.5} \right]^{1/4} - 0.845} = 0.1914$$

From Table 10-4 $(1 + C^2)^{1/2} = 1.3092$

$$N_p = \frac{-1}{1.3092} \ln \left(\frac{\frac{2}{0.1914} - 1 - 0.845 - 1.3092}{\frac{2}{0.1914} - 1 - 0.845 + 1.3092} \right) = 0.234$$

$$N_{\text{total}} = (4)(0.234) = 0.937 = \frac{900A}{6270} \quad A = 6.53 \text{ m}^2$$

10-95

$$C_g = \frac{7422}{2} = 3711 = C_{\min}$$

$$N_p = \frac{(900)(6.53)}{(371)(4)} = 0.3959$$

$$C = \frac{3711}{6270} = 0.592$$

$$(1 + C^2)^{1/2} = 1.162$$

$$N(1 + C^2)^{1/2} = 0.46$$

From Table 10-3

$$\epsilon_p = 2 \left[1 + 0.592 + (1.162) \frac{1 + e^{-0.46}}{1 - e^{-0.46}} \right]^{-1} = 0.297$$

From Table 10-4

$$\epsilon = \frac{\left[\frac{1 - 0.297(0.592)}{1 - 0.297} \right]^4 - 1}{\left[\frac{1 - 0.297(0.592)}{1 - 0.297} \right]^4 - 0.592} = 0.685 = \frac{\Delta T_g}{80 - 20}$$

$$\Delta T_g = 41.13^\circ\text{C} \quad \Delta T_w = \frac{(41.13)(3711)}{6270} = 24.34^\circ\text{C}$$

$$T_{we} = 20 + 24.34 = 44.34^\circ\text{C}$$

10-96

$$U = 57 \quad C_w = (0.5)(4174) = 2087 \quad C_a = (2)(1005) = 2010$$

$$\frac{C_{\min}}{C_{\max}} = \frac{2010}{2087} = 0.963 \quad NTU = \frac{(57)(52)}{2010} = 1.474$$

$$\epsilon = 0.55 = \frac{\Delta T_a}{130 - 75} \quad \Delta T_a = 30.25^\circ\text{F} = 16.81^\circ\text{C}$$

$$\Delta T_w = (16.81) \left(\frac{2010}{2087} \right) = 16.19^\circ\text{C} \quad T_{w \text{ exit}} = 100.9^\circ\text{F} = 38.26^\circ\text{C}$$

$$q = C_a \Delta T_a = (2010)(16.81) = 33,788 \text{ W}$$

10-97

$$C_a = (1005)(0.2) = 201 \quad C_w = (4180)(0.2) = 836 \quad \frac{C_{\min}}{C_{\max}} = \frac{201}{836} = 0.24$$

$$NTU = \frac{UA}{C_{\min}} = \frac{(40)(5)}{201} = 1.0 \quad \epsilon = 0.59 = \frac{\Delta T_a}{90 - 20} \quad \Delta T_a = 41.3^\circ\text{C}$$

$$q = C_a \Delta T_a = (201)(41.3) = 8301 \text{ W} \quad \epsilon = 1 - \exp \left[\frac{\exp(-0.24) - 1}{0.24} \right] = 0.59$$

10-98

Using equation from Problem 10-83

$$n = 3$$

$$C = \frac{2}{3} \quad \epsilon = \frac{60 - 30}{110 - 30} = 0.375$$

$$\epsilon_p = 0.158$$

Chapter 10

10-99

$$q = (3)(4180)(20) = C_o(30) \quad C_o = C_{\min} = 8360$$

$$\text{Table 10-4} \quad (1 + c^2)^{1/2} = 1.202$$

$$N_p = -\frac{1}{1.202} \times \ln \left(\frac{\frac{2}{0.158} - 1 - 0.667 - 1.202}{\frac{2}{0.158} - 1 - 0.667 + 1.202} \right) = 0.183$$

$$N(\text{total}) = (3)(0.183) = 0.548 = \frac{230A}{8360} \quad A(\text{total}) = 19.92$$

Reduce water to 2 kg/s

$$C_w = (2)(4180) = 8360 = C_o \quad C = 1.0 \quad (1 + C^2)^{1/2} = 1.414$$

$$\varepsilon_p = 2 \left[1 + 1 + (1.414) \frac{1 + \exp(-0.183 \times 1.414)}{1 - \exp(-0.183 \times 1.414)} \right]^{-1} = 0.154 \quad (\text{From Table 10-3})$$

Next to last Equation of Table 10-3 for $C = 1$

$$\varepsilon = \frac{n\varepsilon_p}{1 + (n-1)\varepsilon_p} = \frac{(3)(0.154)}{1 + (2)(0.154)} = 0.353 = \frac{\Delta T_w}{110 - 30} \quad \Delta T_w = 28.2^\circ\text{C} = \Delta T_o$$

$$T_{we} = 110 - 28.2 = 81.8^\circ\text{C} \quad T_{oe} = 30 + 28.2 = 58.2^\circ\text{C}$$

$$q = (8360)(28.2) = 2.36 \times 10^5 \text{ W}$$

10-100

$$h_i = 3000 \quad h_o = 190 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad d_o = 25 \text{ mm} \quad r_o - r_i = 0.8 \text{ mm}$$

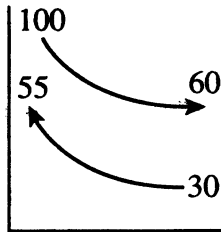
$$\text{copper } k = 386 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$$

$$r_o = 12.5 \text{ mm} \quad r_i = 11.7 \text{ mm} \quad d_i = 23.4 \text{ mm}$$

$$U_i = \frac{1}{\frac{1}{h_i} + \frac{A_i \ln(r_o/r_i)}{2\pi k L} + \frac{1}{h_o} \frac{A_i}{A_o}} = \frac{1}{\frac{1}{3000} + \frac{\pi(0.0234) \ln(12.5/11.7)}{2\pi(386)} + \frac{11.7}{(12.5)(190)}}$$

$$= 190 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

10-102



$$\Delta T_h = 40^\circ\text{C} \quad \Delta T_c = 25^\circ\text{C}$$

Hot fluid is minimum fluid

$$\varepsilon = \frac{\Delta T(\text{min fluid})}{\Delta T(\text{max Hx})} = \frac{40}{100 - 30} = 0.571$$

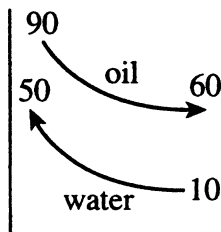
10-103

2 shell passes, 4 tube passes; oil in tubes, 90°C to 60°C ;

water in shell, 10°C to 50°C $U = 53 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$ $c_o = 2000 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}$

$$q = 500 \text{ kW} \quad \Delta T_h = 30 \quad \Delta T_c = 40 \quad \text{Water is min fluid}$$

$$\varepsilon = \frac{50 - 10}{90 - 10} = 0.5$$



$$\frac{C_{\min}}{C_{\max}} = \frac{30}{40} = 0.75$$

$$NTU = 0.9 = \frac{UA}{C_{\min}}$$

$$q = C_o(30) = C_w(40) \quad C_o = 16,667 \quad C_w = 12,500 = C_{\min}$$

$$A = \frac{(0.9)(12,500)}{53} = 212 \text{ m}^2 \quad (\varepsilon - NTU \text{ method})$$

$$\dot{m}_w = \frac{12,500}{4180} = 2.99 \text{ kg/s} \quad LMTD = \Delta T_m = \frac{40 - 50}{\ln\left(\frac{40}{50}\right)} = 44.8^\circ\text{C}$$

$$T_1 = 90 \quad T_2 = 60 \quad t_1 = 10 \quad t_2 = 50 \quad R = \frac{30}{40} = 0.75$$

$$P = \frac{40}{80} = 0.5 \quad F = 0.98 \quad q = UAF\Delta T_m$$

$$A = \frac{500,000}{(53)(0.98)(44.8)} = 215 \text{ m}^2 \quad (\text{LMTD method})$$

Chapter 10

10-104

$$q = 250,000 \text{ W} \quad C_o = 16,667 \quad A = 212 \text{ m}^2$$

$$U = 53 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

C_w	$\frac{C_w}{C_o}$	NTU	ϵ	ΔT_w	q
5000	0.3	2.25	0.82	65.6	328,000
2000	0.12	5.62	0.97	77.6	155,200
3000	0.18	3.75	0.94	75.2	225,600

$$C_w \sim 3500$$

$$\% \text{ Reduction} = \frac{12,500 - 3500}{12,500} \times 100 = 72\%$$

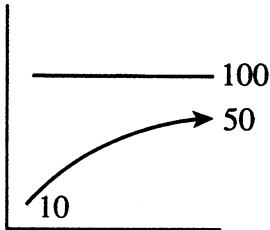
10-105

Finned tube, steam at 100°C

$$q = 44 \text{ kW}$$

Air heated from 10°C to 50°C

$$U = 25 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$



$$\epsilon = \frac{50 - 10}{100 - 10} = 0.444$$

$$\frac{C_{\min}}{C_{\max}} = 0$$

$$N = -\ln(1 - \epsilon) = -\ln(1 - 0.444) = 0.588 \quad C_{\min} = \frac{44,000}{50 - 10} = 1100$$

$$NTU = \frac{UA}{C_{\min}} \quad A = \frac{(0.588)(1100)}{25} = 25.87 \text{ m}^2$$

10-106

$$U \sim \dot{m}^{0.8} \sim C^{0.8} \quad \frac{C_{\min}}{C_{\max}} = 0 \quad \varepsilon = 1 - e^{-N}$$

$$q = \left(\frac{2}{3}\right)(44,000) = 29,350 \text{ W}$$

$C_{\min} (C_{\text{air}})$	U	NTU	ε	ΔT_{air}	q
1000	23.16	0.599	0.451	40.57	40,570
600	15.39	0.664	0.485	43.66	26,194
700	17.41	0.644	0.474	42.71	29,899

$$C_{\text{air}} = 690 \text{ for } q = 29,350 \text{ W} \quad \% \text{ Reduction} = \frac{1100 - 690}{1100} \times 100 = 37\%$$

10-107

Steam in shell at 38°C Water 20°C to 27°C 1 shell, 2 tube passes

$$q = 700 \text{ MW} \quad \text{Assume } U = 2500 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\varepsilon = \frac{27 - 20}{38 - 20} = 0.38889 \quad N = -\ln(1 - \varepsilon) = 0.492 \quad q = C_w \Delta T_w$$

$$C_w = \frac{700 \times 10^6}{27 - 20} = 1 \times 10^8 \quad m_w = \frac{1 \times 10^8}{4180} = 23,920 \text{ kg/sec}$$

$$NTU = 0.492 = \frac{UA}{C_{\min}} \quad A = \frac{(0.492)(1 \times 10^8)}{2500} = 19,680 \text{ m}^2$$

10-108

$$q = 7 \times 10^8 = C_w(34 - 20) \quad C_w = 5 \times 10^7$$

$$\varepsilon = \frac{34 - 20}{38 - 20} = 0.7778 \quad N = -\ln(1 - \varepsilon) = 1.5 = \frac{UA}{C_{\min}}$$

$$A = \frac{(1.5)(5 \times 10^7)}{2500} = 30,080 \text{ m}^2$$

Chapter 10

10-109

$$A = 19,680 \text{ m}^2 \quad \varepsilon = \frac{34 - 20}{38 - 20} = 0.7778$$

$$N = -\ln(1 - 0.7778) = 1.5 = \frac{UA}{C_{\min}} \quad C_{\min} = \frac{(2500)(19,680)}{1.5} = 3.28 \times 10^7$$

$$q = C_w \Delta T_w = (3.28 \times 10^7)(34 - 20) = 459 \text{ MW}$$

$$\% \text{ Reduction} = \frac{700 - 459}{700} \times 100 = 34.4\%$$

10-111

$$d_o = 1.315 \quad d_i = 1.049 \text{ in.} \quad k = 43 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}} \quad \bar{T}_b = \frac{80 + 60}{2} = 70^\circ\text{C}$$

$$\rho = 858 \quad c_p = 2090 \quad \nu = 0.6 \times 10^{-4} \quad k = 0.139$$

$$\text{Pr} = 770 \quad \text{Re} = \frac{(5)(1.049)(0.0254)}{0.6 \times 10^{-4}} = 2220$$

$$\text{Free convection} \quad T_f = \frac{70 + 20}{2} = 45^\circ\text{C} \quad \frac{g\beta\rho^2 c_p}{\mu k} = 4.2 \times 10^{10}$$

$$k = 0.64 \quad \text{Gr Pr} = (4.2 \times 10^{10})(1.315)^3(0.0254)^3(70 - 20) = 7.82 \times 10^7$$

$$h_o = \frac{0.64}{(1.315)(0.0254)} (0.53)(7.82 \times 10^7)^{1/4} = 953 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = \dot{m} c_p \Delta T_b = (858)(5) \frac{\pi(1.049)^2}{4} (0.0254)^2 (2090)(80 - 60) = 99,970 \text{ W}$$

Assume inside barely turbulent:

$$h_i = \frac{0.139}{(1.049)(0.0254)} (0.023)(2220)^{0.8}(770)^{0.3} = 419 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Neglect conduction resistance

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}} = 291 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = U \pi d L \Delta T$$

$$d = \frac{1.049 + 1.315}{2} = 1.18 \text{ in.}$$

$$L = \frac{99,970}{(291)\pi(1.18)(0.0254)(70 - 20)} = 72.8 \text{ m}$$

10-113

At 40 mph $q = 60,000$ Btu/hr $U = 35 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$ $\Delta T = 10^\circ\text{F}$

$$U = kv^{0.7} = 0.0066v^{0.7} \quad \dot{m}_{\text{air}} = k_2v = 0.118v$$

At 40 mph = 211,200 ft/hr

$$G_a = \frac{\Delta T_a}{T_f - T_{a1}} = 0.182 \quad \frac{C_{\min}}{C_{\max}} = 0 \quad NTU = 0.20 \quad A = \frac{NTU}{\frac{C_{\min}}{U}} = 34.3 \text{ ft}^2$$

At 30 mph = 158,000 ft/hr

$$U = 28.5 \quad \dot{m} = 18,700 \quad C_{\min} = 4490 \quad NTU_{\max} = 0.218$$

$$\varepsilon = 0.185 = \frac{T_{e_a} - 95}{55} \quad T_{e_a} = 105.2^\circ\text{F}$$

$$q = \dot{m}_a c_{p_a} \Delta T_a = 58,000 \text{ Btu/hr} \quad 3.3\% \text{ reduction}$$

At 20 mph = 105,600 ft/hr

$$U = 21.6 \quad \dot{m}_a = 12,450 \quad C_{\min} = 2290 \quad NTU_{\max} = 0.248$$

$$\varepsilon = 0.20 = \frac{T_{e_a} - 95}{55} \quad T_{e_a} = 106^\circ\text{F}$$

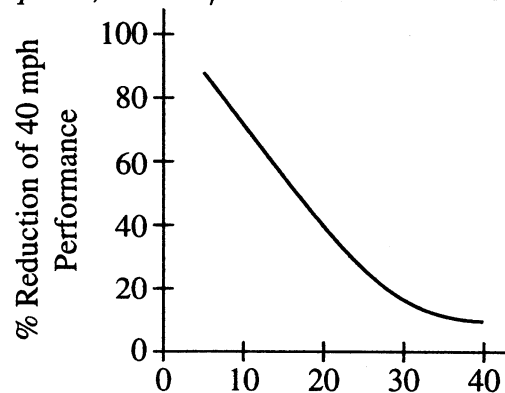
$$q = 32,900 \text{ Btu/hr} \quad 45.2\% \text{ reduction}$$

At 10 mph = 52,800 ft/hr

$$U = 13.3 \quad \dot{m}_a = 6230 \quad C_{\min} = 1495$$

$$NTU_{\max} = 0.305 \quad \varepsilon = 0.26 \quad T_{e_a} = 109.3^\circ\text{F}$$

$$q = 21,400 \text{ Btu/hr} \quad 64.4\% \text{ Reduction}$$



10-114

$$p = 345 \text{ kN/m}^2 = 50 \text{ psia} \quad T_{\text{sat}} = 281^\circ\text{F} = 138^\circ\text{C}$$

$$\Delta T_m = \frac{53 - 39}{\ln\left(\frac{53}{39}\right)} = 45.64 \quad q = (7.5)(4175)(99 - 85) = 438,375 \text{ W}$$

$$q = (2800)A(45.64) \quad A = 3.43 \text{ m}^2 = (30)\pi(0.025)(2L) \quad L = 0.728 \text{ m}$$

Chapter 10

10-115

$$R_f = 0.0005 = \frac{1}{U_{\text{dirty}}} - \frac{1}{U_{\text{clean}}} \quad U_{\text{dirty}} = 1167 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$q = (1167)(3.43)(45.64) = 182,636 \text{ W} \quad \Delta T_w = \frac{182,636}{(7.5)(4175)} = 5.83^\circ\text{C}$$

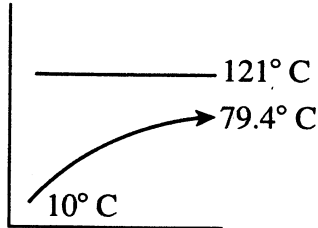
$$T_{w_e} = 99 - 5.83 = 93.2^\circ\text{C}$$

10-116

$$h \text{ (steam)} \sim 9000 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$U = \frac{1}{\frac{1}{h_o} + \frac{1}{h_i}} = \frac{1}{\frac{1}{9000} + \frac{1}{1420}} = 1226 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$C_w = C_{\text{min}} = (0.76)(4180) = 3176$$



$$\varepsilon = \frac{69.4}{111} = 0.625 \quad N = -\ln(1 - \varepsilon) = 0.981 = \frac{UA}{C_w}$$

$$A = \frac{(0.981)(3176)}{1226} = 2.54 \text{ m}^2$$

Water flow reduced by 60% to $C_w = (0.4)(3176) = 1270$

$$N = \frac{UA}{C_w} = \frac{(1226)(2.54)}{1270} = 2.45 \quad \varepsilon = 1 - e^{-N} = 0.914 = \frac{\Delta T_w}{111}$$

$$\Delta T_w = 101.4^\circ\text{C} \quad T_{w \text{ exit}} = 10 + 101.4 = 111.4^\circ\text{C}$$

10-117

$$0.0002 + 0.0004 = \frac{1}{U} - \frac{1}{150} \quad U = 137.6 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$\frac{A_{\text{dirty}}}{30} = \frac{150}{137.6} \quad A_{\text{dirty}} = 32.7 \text{ m}^2 \quad 9\% \text{ increase}$$

10-118

Sat steam: $p_s = 100$ psia $T_s = 328^\circ\text{F}$ $h = 1000 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$

$h_{fg} = 888.8$ Btu/lbm neglect wall resistance.

CO_2 : $\dot{m}_c = 3600$ lbm/hr $p_c = 15$ psia $T_{c_2} = 70^\circ\text{F}$ $T_{c_1} = 200^\circ\text{F}$

$c_{p_c} = 0.208 \frac{\text{Btu}}{\text{lbm} \cdot ^\circ\text{F}}$ $\rho_c = 0.1106$ lbm/ft³ at 90°F $\frac{S_o}{d} = \frac{S_u}{d} = \frac{3}{2}$

$C = 0.25$ $n = 0.62$ $\text{Nu} = \frac{hd}{k} = C \left(\frac{u_{\max} d}{\nu} \right)^n$ $T_f = 231^\circ\text{F}$

$u_\infty = \frac{\dot{m}c}{\rho A}$ $\rho = 0.0874$ $u_{\max} = u_\infty \left(\frac{S_n}{S_n - d} \right)$ $k = 0.0134$

$\text{Re}_d = \frac{\rho u_m d}{\mu}$ $h_c = \frac{k}{d} C(\text{Re})^n$ $q_c = UAF(\Delta T_m)$ $F = 1$

Assume $L = 3.25'' = 0.271$ ft $UA = \frac{1}{\frac{1}{h_i A_i} + \frac{1}{h_o A_o}}$ $A = 0.1775$ ft²

$\Delta T_m = \frac{(T_{h_2} - T_{h_1}) - (T_{c_1} - T_{c_2})}{\ln \left(\frac{T_{h_2} - T_{c_1}}{T_{h_1} - T_{c_2}} \right)}$ $u_\infty = 199,000$ ft/hr

$u_{\max} = 597,000$ ft/hr $\text{Re}_d = 24,200$ $h = 83.5$

$UA(\Delta T_m) = \dot{m}c_p(T_2 - T_1)_{\text{CO}_2}$ $UA = \frac{4.98}{t}$ $L = 107.5$

$\frac{107.5}{400} = 0.268 = 3.22$ in. $\approx 3.25''$ this assumption was o.k.

10-121

$m_o(2100)(138 - 93) = (2.5)(4175)(65 - 25)$

$m_o = 4.417$ kg/sec $U = 450$ $A_1 = A_2$ Assume oil is min fluid

$\epsilon_1 = \frac{138 - T_1}{138 - 25}$ $\epsilon_2 = \frac{138 - T_2}{138 - 50}$ $C_{\max} = (2.5)(4175) = 10,438$

$C_{\max_2} = (1.88)(4175) = 7849$ $\frac{\text{NTU}_1}{\text{NTU}_2} = \frac{C_{\min_1}}{C_{\min_2}} = \frac{m_{o2}}{m_{o1}} = \frac{4.417}{m_{o1}} - 1$

$(10,438)(50 - 25) = C_{\min_1}(138 - T_1) = 260,950$

$(7849)(65 - 50) = C_{\min_2}(138 - T_2) = 117,735$

By iteration: $m_{o1} = 3.638$ $T_1 = 103.8^\circ\text{C}$ $\epsilon_1 = 0.3023$

$C_1 = 0.732$ $N_1 = 0.4099$

$A_1 = A_2 = \frac{(0.4099)(3.638)(2100)}{450} = 6.96$ m²

Chapter 10

10-122

Water is min fluid $F = 1$ $A_1 = 1.535 \text{ m}^2$ $A_2 = 0.863 \text{ m}^2$

$$(\Delta T_m)_1 = \frac{(138 - 25) - (138 - 50)}{\ln\left(\frac{113}{88}\right)} = 99.98^\circ\text{C}$$

$$(\Delta T_m)_2 = \frac{(138 - 50) - (138 - 65)}{\ln\left(\frac{88}{73}\right)} = 80.27^\circ\text{C}$$

$$q_1 = (2.5)(4175)(50 - 25) = 1700A_1(99.98) = 260.9 \text{ kW}$$

$$q_2 = (1.88)(4175)(65 - 50) = 1700A_2(80.27) = 117.7 \text{ kW}$$

$$m_{s1} = \frac{q_1}{h_{fg}} = 0.116 \text{ kg/sec}$$

$$m_{s2} = \frac{q_2}{h_{fg}} = 0.052 \text{ kg/sec}$$

10-126

Both unmixed $h_a = 174$ $h_s = 5000$ $U = 168$ $c = 0$

$$\text{Volume} = (0.5)(0.4) = 0.2 \text{ m}^3 = 7.063 \text{ ft}^3 \quad \text{Area} = (7.063)(229) = 1617 \text{ ft}^2$$

$$A = 150.3 \text{ m}^2 \quad C_{\min} = (1.1774)(0.5)(15)(1006) = 8883 \text{ W/}^\circ\text{C}$$

$$N = \frac{(168)(150.3)}{8883} = 2.843 \quad \epsilon = 1 - e^{-2.843} = 0.942$$

$$\Delta T_a = (0.942)(373 - 300) = 68.7^\circ\text{C} \quad T_{a2} = 368.7 \text{ K} = 95.7^\circ\text{C}$$

$$q = (8883)(68.7) = 6.1 \times 10^5 \text{ W}$$

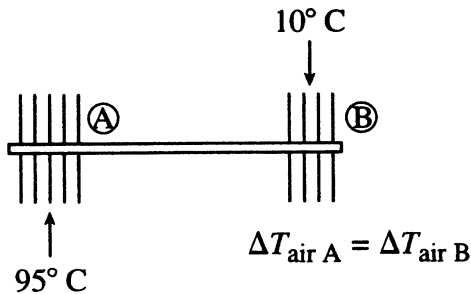
10-134

If the pair of heat exchangers had a very large mass flow of water circulating negligible temperature drop would occur in the water and there would be maximum transfer of heat from the outside to inside air. In addition, if the area of the exchangers is very large the limiting case will be experienced where the temperature of the air discharged to outside will be equal to the outside air temperature entering the system. These conditions represent the limiting case for operation of the system, and all other cases will involve somewhat degraded performance. Selection of an eventual design would have to balance system costs against energy savings achieved.

10-136

$$T_{\text{dryer}} = 95^\circ\text{C} = 368 \text{ K} \quad T_{\text{air inlet}} = 10^\circ\text{C}$$

$$\dot{m}_a = \frac{p\dot{V}}{RT} = \frac{(1.0132 \times 10^5)(34)}{(60)(287)(368)} = 0.544 \text{ kg/sec} \quad U \sim 30 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$



$$\text{Choose } \Delta T_{\text{air}} = 50^\circ\text{C}$$

$$q = \dot{m}c_p\Delta T = (0.544)(1005)(50) = 27,340 \text{ W}$$

Since heat pipe temp remains constant, air is min fluid

$$\varepsilon_A = \varepsilon_B = \frac{40}{95 - T_p} = \frac{40}{T_p - 10} \quad T_p = \frac{105}{2} = 52.5^\circ\text{C}$$

$$\varepsilon = \frac{40}{42.5} = 0.94 = 1 - e^{-N} \quad N = 2.833 = \frac{UA}{C_{\text{min}}}$$

$$A = \frac{(2.833)(0.544)(1005)}{30} = 51.6 \text{ m}^2$$

$$\text{Cost savings with electricity} = (0.085)(27.34) = \$2.32/\text{hr}$$

$$\text{Cost savings with gas} = (27,340)(3600) \left(\frac{\$9.00}{10^9 \text{ J}} \right) = \$0.886/\text{hr}$$

If operated 12 hr/day, 365 days/yr

$$\text{savings (elec)} = (2.32)(12)(365) = \$10,161/\text{yr}$$

$$\text{savings (gas)} = (0.886)(12)(365) = \$3881/\text{yr}$$

10-143

Installation of the pipes in the ground can be either in a vertical or horizontal configuration, which will influence the conduction shape factor between the pipe and soil. (Chapter 3) Actual installation conditions depend strongly on the locale. Both cases might be examined. For the calculations the thermal resistance due to the water side heat transfer coefficient can probably be neglected in comparison to the resistance of the pipe and conduction resistance to the soil.

Chapter 11

11-1

$$\dot{m} = -D \frac{dc}{dx} \quad D = \frac{-\dot{m}}{dc/dx} \quad \dot{m} \approx \bar{v} \sim T^{1/2} \quad \frac{dc}{dx} \sim p \sim \frac{1}{T}$$

$$\therefore D \sim \frac{T^{1/2}}{1/T} \sim T^{3/2}$$

11-2

$$v(\text{C}_6\text{H}_6) = 6(14.8 + 3.7) - 15 = 96 \quad v_{\text{air}} = 29.9$$

$$T = 25^\circ\text{C} = 298 \text{ K} \quad M(\text{C}_6\text{H}_6) = 78 \quad M(\text{air}) = 28.9$$

$$D = \frac{(435.7)(298)^{3/2}}{(1.0132 \times 10^5)[(96)^{1/3} + (29.9)^{1/3}]^2} \left(\frac{1}{78} + \frac{1}{289} \right)^{1/2} = 0.082 \text{ cm}^2/\text{sec}$$

11-3

$$T_\infty = 25^\circ\text{C} \quad u_\infty = 1.5 \text{ m/sec} \quad L = 30 \text{ cm}$$

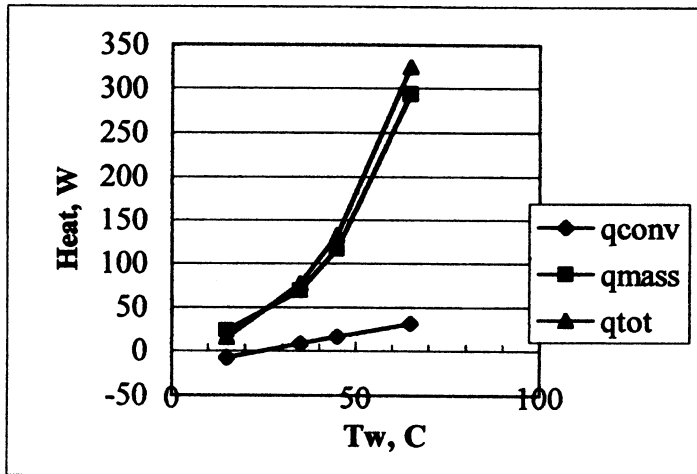
$^\circ\text{F}$	T_w $^\circ\text{C}$	h_{fg} $\times 10^{-6}$	C_w	T_f $^\circ\text{K}$	v $\times 10^{-6}$	k	c_p	Pr	ρ_f
59	15	2.47	0.0128	293	14.81	0.026	1005	0.69	1.2
95	35	2.42	0.039	303	15.98	0.0265	1005	0.69	1.17
113	45	2.40	0.065	308	16.49	0.027	1005	0.69	1.15
149	65	2.34	0.164	318	17.51	0.0275	1005	0.69	1.11

$$\bar{h} = \frac{k}{L} (0.664) \text{Re}_L^{1/2} \text{Pr}^{1/3} \quad h_D = \frac{\bar{h}}{\rho_f c_p} \left(\frac{\text{Pr}}{\delta_c} \right)^{2/3}$$

$$\left(\frac{\text{Pr}}{\delta_c} \right)^{2/3} = \left(\frac{0.69}{0.6} \right)^{2/3} = 1.098$$

$$\text{Pr}^{1/3} = 0.884$$

T_w	q_{conv}	q_{mass}	q_{tot}
15	-7.983	22.99	15.01
35	7.83	68.97	76.8
45	15.71	116.39	132.1
65	31.07	293.23	324.3



$$q = hA(T_w - T_\infty) + h_D A(C_w - C_\infty)h_{fg} = q_{conv} + q_{mass}$$

11-4

$$h_{fg} = 3.77 \times 10^5 \text{ J/kg} \quad T_w = 26^\circ\text{C} = 299 \text{ K} \quad p = 13.3 \text{ kN/m}^2$$

$$T_\infty - T_w = \frac{h_D}{h}(C_w - C_\infty)h_{fg} \quad C_w = \frac{(13,300)(78)}{(8316)(299)} = 0.417$$

$$S_c = 1.76 \quad \text{Pr} = 0.7 \quad \text{Assume } T_f \approx 70^\circ\text{C} = 343 \text{ K}$$

$$\rho_f = \frac{1.0132 \times 10^5}{(287)(343)} = 1.029 \quad \rho_f = \frac{1.0132 \times 10^5}{(287)(343)} = 1.029$$

$$\frac{h_D}{h} = \frac{1}{(1.029)(1009)} \left(\frac{0.7}{1.76} \right)^{2/3} = 5.209 \times 10^{-4}$$

$$T_\infty - T_w = (5.209 \times 10^{-4})(0.417)(3.77 \times 10^5) = 81.89^\circ\text{C} \quad T_\infty = 107.89^\circ\text{C}$$

Repeat with ρ_f at $T_f = \frac{108 + 26}{2} = 67^\circ\text{C} = 340 \text{ K}$. Close enough.

11-5

$$h_{fg} = 2.45 \times 10^6 \text{ J/kg} \quad u_m = 3 \text{ m/sec} \quad \rho = \frac{1.0132 \times 10^5}{(287)(298)} = 1.185$$

$$\mu = 1.98 \times 10^{-5} \quad k = 0.026 \quad \text{Pr} = 0.7 \quad \text{Sc} = 0.6$$

Chapter 11

$$D = 0.256 \text{ cm}^2/\text{sec} = 2.56 \times 10^{-5} \text{ m}^2/\text{sec} \quad \text{Re} = \frac{(1.185)(0.05)(3)}{1.98 \times 10^{-5}} = 8977$$

$$h_D = \frac{2.56 \times 10^{-5}}{0.05} (0.023)(8977)^{0.83} (0.6)^{0.44} = 0.018$$

At 25°C $C_w = 0.0229$

$$\dot{m}_w = (0.018)\pi(0.05)(3) \left(0.0229 - \frac{C_{w \text{ exit}}}{2} \right) = (\text{air volume flow}) C_{w \text{ exit}}$$

$$\text{air volume flow} = \frac{\pi d^2}{4} u_m = \frac{\pi(0.05)^2}{4} (3) = 5.89 \times 10^{-3} \text{ m}^3/\text{sec}$$

Solving for $C_{w \text{ exit}}$: $C_{w \text{ exit}} = 0.0192 \text{ kg/m}^3$

11-6

$$p_{w_1} = 0.4593 \text{ psia} \quad T = 25^\circ\text{C} = 298 \text{ K} \quad p_{w_2} = \frac{0.4593}{2} = 0.2297 \text{ psia}$$

$$D = 0.256 \text{ cm}^2/\text{sec} = 2.56 \times 10^{-5} \text{ m}^2/\text{sec}$$

$$p_{a_1} = 14.696 - 0.4593 = 14.237 \text{ psia} = 9.8155 \times 10^4 \text{ N/m}^2$$

$$p_{a_2} = 14.696 - 0.2297 = 14.466 \text{ psia} = 9.9736 \times 10^4 \text{ N/m}^2$$

$$m_w = \frac{(2.56 \times 10^{-5})(1.0132 \times 10^5)\pi(0.1)^2(18)}{(8316)(298)(0.075)} \ln\left(\frac{9.9736}{9.8155}\right)$$

$$= 1.26 \times 10^{-7} \text{ kg/sec} = 0.454 \text{ g/hr}$$

11-7

$$D = 0.088 \text{ cm}^2/\text{sec} = 8.8 \times 10^{-6} \text{ m}^2/\text{sec}$$

$$p_{a_1} = 101.32 - 13.3 = 88.02 \text{ kN/m}^2 \quad p_{a_2} = 101.32 - 0 = 101.32 \text{ kN/m}^2$$

$$m_B = \frac{(8.8 \times 10^{-6})(1.0132 \times 10^5)(78)\pi(0.00625)^2}{(8316)(299)(0.15)} \ln\left(\frac{101.32}{88.02}\right)$$

$$= 3.22 \times 10^{-9} \text{ kg/sec} = 0.0116 \text{ g/hr}$$

11-8

$$T_f = \frac{25 + 0}{2} = 12.5^\circ\text{C} = 285.5 \text{ K} \quad \rho = 1.34 \quad \mu = 1.64 \times 10^{-5}$$

$$k = 0.0235 \quad \text{Pr} = 0.71 \quad c_p = 1009 \quad \text{Re} = \frac{(1.34)(1.5)(0.3)}{1.64 \times 10^{-5}} = 36,768$$

$$h = \frac{0.0235}{0.3} (0.664)(36,768)^{1/2} (0.71)^{1/3} = 8.9 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \quad \text{Sc} = 0.6$$

$$h_D = \frac{8.9}{(1.34)(1009)} \left(\frac{0.71}{0.6} \right)^{2/3} = 7.36 \times 10^{-3} \quad \text{at } 0^\circ\text{C} \quad C_w = 4.845 \times 10^{-3}$$

$$m_w = (7.36 \times 10^{-3})(0.3)^2(4.845 \times 10^{-3} - 0) = 3.21 \times 10^{-6} \text{ kg/sec} = 0.0116 \text{ kg/hr}$$

11-9

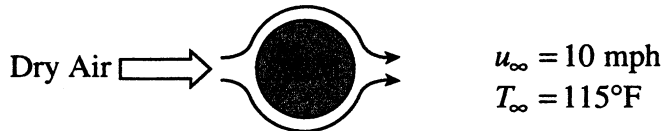
$$T_w = 32^\circ\text{C} = 305 \text{ K} = 89.6^\circ\text{F} \quad C_w = 0.0342 \quad h_{fg} = 2.42 \times 10^6 \text{ J/kg}$$

$$\text{Sc} = 0.6 \quad \text{Pr} = 0.7 \quad \text{Assume } T_f \approx 350 \text{ K} \quad \rho_f = 0.998$$

$$c_p = 1009 \quad T_\infty - T_w = \frac{(0.0342 - 0)(2.42 \times 10^6)}{(0.998)(1009)} \left(\frac{0.7}{0.6} \right)^{2/3} = 91^\circ\text{C}$$

$$T_\infty = 32 + 91 = 123^\circ\text{C} \quad T_f = \frac{123 + 32}{2} = 77.5^\circ\text{C} = 350.5 \text{ K}$$

11-10



$$T_\infty = 115^\circ\text{F} \quad \mu_\infty = 10 \text{ mph} = 52,800 \text{ ft/hr} \quad L = 1 \text{ ft}$$

$$q_{\text{sun}} = 350(A_{\text{new}})\epsilon_1 \quad \epsilon_1 = 1.0$$

Neglect internal heat generation

$$q_{\text{rad}}|_{\text{sun}} + q_{\text{conv}}|_{\text{air}} = q_{\text{rad}}|_{\text{arm}} + q_{\text{evap}}|_{\text{arm}} \quad q_{\text{rad}}|_{\text{sun}} = 350dL = 116.5 \text{ Btu/hr}$$

$$q_{\text{conv}} = hA(T_\infty - T_w) \quad q_{\text{rad}}|_{\text{arm}} = \epsilon\sigma AT_w^4 \quad q_{\text{evap}} = h_D A(C_w - C_\infty)h_{fg}$$

$$C_\infty = 0 \quad 350 \frac{A}{\pi} + hA(T_\infty - T_w) - \epsilon\sigma AT_w^4 - h_D AC_w h_{fg} = 0$$

$$h = \frac{k_f}{d} C \left(\frac{\rho u_\infty d}{\mu} \right)^n \quad \text{assume } T_w = 58^\circ\text{F}$$

$$\therefore T_f = 86.5^\circ\text{F}$$

$$\rho = 0.0728 \quad d = 0.333 \text{ ft} \quad \mu = 0.045 \quad k = 0.0154$$

$$\text{Re}_d = \frac{(0.0708)(52,800)(0.333)}{0.046} = 28,300 \quad c = 0.174 \quad m = 0.618$$

$$h = 4.53 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}} \quad \frac{h}{h_0} = \rho c_p \left(\frac{\text{Sc}}{\text{Pr}} \right)^{2/3} \quad \therefore h_D = 289$$

$$c_p = 0.24 \quad \frac{\text{Sc}}{\text{Pr}} = 0.85$$

$$\frac{350}{\pi} + 4.53(T_\infty - T_w) - \epsilon\sigma T_w^4 - 289C_w h_{fg} = 0$$

$$111 + 256 - 123 - 237 = -3 \approx 0$$

close enough

Chapter 11

$$T_w = 58^\circ\text{F}$$

The above calculation of the radiation from the arm is not strictly correct because the effective radiation temperature of the surroundings is not given. Certain view factors would also need to be known. When the calculation is repeated neglecting the radiation from the arm the result is:

$$T_w = 67^\circ\text{F}$$

11-11

$$h(T_\infty - T_w) = h_D C_w h_{fg} + \sigma(T_w^4 - T_s^4) \quad T_\infty = 43^\circ\text{C} \quad T_s = 10^\circ\text{C}$$

$$L = 30 \text{ cm} \quad u_\infty = 12 \text{ m/sec} \quad \text{Pr} = 0.71 \quad \text{Sc} = 0.6$$

$$\text{Assume } T_f \approx 300 \text{ K} \quad \rho_f = 1.177 \quad \mu_f = 1.983 \times 10^{-5}$$

$$k_f = 0.02624 \quad c_p = 1006 \quad h_{fg} = 2.42 \times 10^6$$

$$\text{Re} = \frac{(1.177)(12)(0.3)}{1.983 \times 10^{-5}} = 2.14 \times 10^5$$

$$\bar{h} = \frac{(0.02624)(0.664)}{0.3} (2.14 \times 10^5)^{1/2} (0.71)^{1/3} = 23.95 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$h_D = \frac{23.95}{(1.177)(1.006)} \left(\frac{0.71}{0.6} \right)^{2/3} = 0.0226 \quad \text{By iteration } T_w = 14.1^\circ\text{C}$$

11-12

$$\begin{aligned} m_w &= h_D C_w A = \frac{[h(T_\infty - T_w) - \sigma(T_w^4 - T_s^4)]A}{h_{fg}} \\ &= \frac{(0.091)[(23.95)(43 - 14.1) - (5.669 \times 10^{-8})(287.1^4 - 283^4)]}{2.42 \times 10^6} \\ &= 2.49 \times 10^{-5} \text{ kg/sec} = 0.09 \text{ kg/hr} \end{aligned}$$

11-13

$$T_\infty = 115^\circ\text{F} \quad u_\infty = 10 \text{ mph} = 52,800 \text{ ft/hr}$$

$$\dot{q}_{\text{gen}} V + q_{\text{rad}}|_{\text{sun}} + q_{\text{conv}}|_{\text{air}} = q_{\text{rad}}|_{\text{arm}} + q_{\text{evap}}|_{\text{arm}}$$

$$\dot{q}V = \frac{(180)\pi d^2 L}{4} = 15.7 \text{ Btu/hr}$$

$$\frac{A15.7}{A} + 350 \frac{A}{\pi} + hA(T_\infty - T_w) - \epsilon\sigma AT_w^4 - h_D A C_w h_{fg} = 0$$

$$h = \frac{k_f}{d} C \left(\frac{\rho u_\infty d}{\mu} \right)^n \quad \frac{h}{h_D} = \rho c_p \left(\frac{\text{Sc}}{\text{Pr}} \right)^{2/3}$$

Assume value of T_w , evaluate properties at film temperature. Solve for h , h_0 , and Re_d .

$$C = 0.174 \quad \frac{Sc}{Pr} = 0.85 \quad n = 0.618 \quad h_{fg} = 1057 \text{ Btu/lbm}$$

$$C_w = 0.000976 \text{ lbm/ft}^3$$

By trial and error: $T_w = 51.785^\circ\text{F}$

11-16

$$T_\infty = 65^\circ\text{C} \quad L = 0.3 \text{ m} \quad u_\infty = 6 \text{ m/sec} \quad T_w = 38^\circ\text{C} = 311 \text{ K}$$

$$T_f = \frac{38 + 65}{2} = 51.5^\circ\text{C} = 324.5 \text{ K} \quad \rho_f = 1.088 \quad \mu_f = 2.03 \times 10^{-5}$$

$$c_p = 1008 \quad k_f = 0.0281 \quad Sc = 0.6 \quad Pr = 0.7$$

$$Re = \frac{(1088)(6)(0.3)}{2.03 \times 10^{-5}} = 96,472$$

$$\bar{h} = \frac{0.0281}{0.3} (0.664)(96,472)^{1/2} (0.7)^{1/3} = 17.5 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

$$h_D = \frac{17.15}{(1.088)(1008)} \left(\frac{0.7}{0.6} \right)^{2/3} = 0.0173$$

$$hA(T_\infty - T_w) + \sigma A(T_\infty^4 - T_w^4) + m_w i_w (25^\circ\text{C}) = h_D C_w h_{fg}$$

i_w is neg. compared to h_{fg} . m_w is determined by energy balance:

$$h_{fg} = 2.41 \times 10^6 \text{ at } 38^\circ\text{C}$$

$$m_w = \frac{(0.09)[(17.15)(65 - 38) + (5.669 \times 10^{-8})(338^4 - 311^4)]}{2.41 \times 10^6}$$

$$= 2.51 \times 10^{-5} \text{ kg/sec} = 0.09 \text{ kg/hr}$$

11-20

$$T_{\infty} = 35^{\circ}\text{C} = 95^{\circ}\text{F}, u = 250 \text{ m/min} = 224 \text{ mi/day}$$

$$\begin{aligned} \text{Evap rate} &= 350 \text{ g/m}^2\text{-hr} = 32.52 \text{ g/ft}^2\text{-hr} = 780 \text{ g/ft}^2\text{-day} \\ &= 1.719 \text{ lbm/ft}^2\text{-day} \end{aligned}$$

$$A = \pi(4)^2/4 = 12.57 \text{ ft}^2$$

$$1 \text{ inch depth} = (12.57)(1/12)(62.4) = 65.35 \text{ lbm}$$

$$\text{Evap rate (in day)} = (1.719)(12.57)/65.35 = 0.331$$

Eq. (11-36):

$$0.331 = [0.37 + (0.0041)(224)](p_s - p_w)^{0.88}$$

$$\text{At } 95^{\circ}\text{F} \quad p_s = 1.662 \text{ in. Hg}$$

$$\text{Solving; } p_w = 1.662 - 0.2135 = 1.448 \text{ in Hg}$$

$$\text{Relative humidity} = 1.448/1.662 = 87 \%$$

11-21

$$\begin{aligned} \bar{u} &= 2.2 \text{ m/s} = 118 \text{ mi/day} & T_{\infty} &= 20^{\circ}\text{C} & \text{RH} &= 40\% \\ \text{at } 20^{\circ}\text{C} & & p_s &= 2.34 \text{ kPa} = 0.0691 \text{ in Hg} \end{aligned}$$

$$p_w = (0.4)(0.0691) = 0.0276 \text{ in Hg}$$

$$\begin{aligned} E_{lp} &= [0.37 + (0.0041)(118)](0.0691 - 0.0276)^{0.88} \\ &= 0.052 \text{ in./day} = 0.1313 \text{ cm/day} = 0.0055 \text{ cm/hr} \end{aligned}$$

$$A = \pi(2)^2 = 12.57 \text{ ft}^2 = 1.1675 \text{ m}^2$$

$$\frac{E_{lp}}{A} = \frac{0.0055}{1.1675} = 0.00471 \frac{\text{cm}}{\text{m}^2 \cdot \text{hr}} = 47.1 \frac{\text{g}}{\text{m}^2 \cdot \text{hr}}$$

$$\text{For } \bar{u} = 0 \quad \frac{E_{lp}}{A} = 20.4 \frac{\text{g}}{\text{m}^2 \cdot \text{hr}}$$

Chapter 11

11-22

$$E_{lp} = 0.3 \frac{\text{g}}{\text{s} \cdot \text{m}^2} = 1080 \frac{\text{g}}{\text{h} \cdot \text{m}^2} = (1080)(1.1675) = 1261 \text{ g/h} = 1.02 \text{ in./day}$$

for standard pan, 4 ft diameter

$$\bar{u} = 4.5 \text{ m/s} = 241.6 \text{ mi/day} \quad E_{lp} = (0.37 + 0.0041\bar{u})(p_s - p_w)^{0.88}$$

$$1.02 = [0.37 + (0.0041)(241.6)](p_s - p_w)^{0.88}$$

$$p_s - p_w = 0.721 \text{ in Hg} = (1 - \text{RH})p_s$$

$$\text{at } 40^\circ\text{C} \quad p_s = 7.39 \text{ kPa} = 2.18 \text{ in Hg}$$

$$0.721 = (1 - \text{RH})(2.18)$$

$$\text{RH} = 67\%$$

11-23

$$\text{Pasadena} \quad \text{RH} = 30\% \quad T_\infty = 80^\circ\text{F}$$

Assume breeze at 3 mi/hr = 72 mi/day = \bar{u}

$$p_s = 0.5073 \text{ psia} = 1.033 \text{ in Hg}$$

$$p_w = (0.3)(0.5073) = 0.152 \text{ psia} = 0.31 \text{ in Hg}$$

Floating Pan

$$E_{lp} = 0.8(0.37 + 0.0041\bar{u})(p_s - p_w)^{0.88}$$

$$= (0.8)[0.37 + (0.0041)(72)](1.033 - 0.31)^{0.88} = 0.4 \text{ in./day}$$

(b) Phoenix $\text{RH} = 5\%$ $T_\infty = 110^\circ\text{F}$

$$p_s = 1.276 \text{ psia} = 2.6 \text{ in Hg} \quad p_w = 0.05p_s = 0.13 \text{ in Hg}$$

$$E_{lp} = (0.8)[0.37 + 0.0041(72)](2.6 - 0.13)^{0.88} = 1.18 \text{ in./day}$$

11-24

$$1 \text{ mm/day} = \frac{\text{in./day}}{25.4} \quad 1 \text{ m/s} = 53.69 \text{ mi/day}$$

$$1 \text{ Pa} = 2.953 \times 10^{-4} \text{ in Hg}$$

$$E(\text{mm/day}) = (0.00736 + 0.00427\bar{u})(p_s - p_w)^{0.88}$$

$$p_s \text{ and } p_w \text{ in Pa} \quad \bar{u} \text{ in m/s}$$

Chapter 12

12-1

Air @ 300K $k = 0.0262$

Vertical plate $GrPr = 10^4$; $Nu = hL/k = 54.2(\Delta TL^3)^{1/4}$

Fig 12-8 $GrPr = 10^4$ $Nu = 6$

$$GrPr = 10^9 \quad Nu = 100$$

$$GrPr = 10^{12} \quad Nu = 1000$$

$$6 = 54.2 (\Delta TL_1)^{1/4}$$

$$100 = 54.2 (\Delta TL_2^3)^{1/4} = 50(\Delta TL_2^3)^{1/3}$$

$$1000 = 50(\Delta TL_3^3)^{1/3}$$

For $\Delta T = 10^\circ\text{C}$: $L_1 = 0.015\text{m}$, $L_2 = 0.64\text{ m}$, $L_3 = 641\text{ m}$

For $\Delta T = 20^\circ\text{C}$: $L_1 = 0.012\text{ m}$, $L_2 = 0.51\text{ m}$, $L_3 = 510\text{ m}$

12-2 Open ended problem

12-3

$$d = 15\text{ mm} \quad T_s = 800\text{ K}, \quad T_a = 300\text{K} \quad A_1 = A_2 = \pi d/2 = 0.0236\text{ m}^2$$

$$A_d = d = 0.015 \quad \varepsilon = 0.7$$

$$0.7\sigma(0.0236)(800^4 - T_2^4) = 0.02136 h(T_2 - 300) + \sigma(T_2^4 - T_1^4) \quad ?103$$

$$\sigma(T_2^4 - T_1^4) \quad ?103 = 0.0236 h_1 - 300)$$

In example 12-10 for $d = 15\text{ mm}$ $Re_d = 6194$, and $h = 37.9\text{ W/m}^2\text{-}^\circ\text{C}$

Substituting in above equations, $T_1 = 354\text{ K}$, $T_2 = 567\text{ K}$ and $q = 287\text{ W/m}$

12-4

Water, $H = 50 \text{ mm}$, $W = 25 \text{ mm}$ $T_f = 300 \text{ K}$

Table A-9: $\text{GrPr} = (0.05)^3(20)(1.91 \times 10^{10}) = 4.78 \times 10^7$

$$\text{Pr} = 5.85 \quad k = 0.614$$

Fig. 12-8 $\text{Nu} = 60$

$$h = (60)(0.614)/0.05 = 737$$

$$q = (737)(0.05)(0.025)(20) = 18.4 \text{ W}$$

Fig. 12-12(a) $\delta = 2.5 \text{ mm}$

Fig. 12-14 $u_{\text{max}} = 110 \text{ mm/s}$

12-5

Air Fig. 12-11 $\text{GrPr} = 3.5 \times 10^5$

Fig. 12-8 $\text{Nu} = 14$

$$h = (14)(0.02624)/0.05 = 7.35$$

$$q = 97.35(0.05)(0.025)(20) = 0.184 \text{ w}$$

99.9% TOO LOW

12-6

$L = 5 \text{ m}$ $p = 1 \text{ atm}$, $u = 300 \text{ mi/h} = 134 \text{ m/s}$, $T_f = 300 \text{ K}$

$$\nu = 15.2 \times 10^{-6} \quad k = 0.02624, \text{Pr} = 0.7$$

$$\text{Re} = (134)(5)/15.2 \times 10^{-6} = 4.27 \times 10^7$$

Fig. 12-3, $\text{Nu} = 50000$

$$h = (50000)(0.02624)/5 = 262.4$$

$$q = (2)(5)(262)(20) = 52800 \text{ W/ m length}$$

12-7

$$\lambda_1 T = 2900 \mu\text{-K}$$

$$\lambda_2 T = 11600 \mu\text{-K}$$

Fig. 12-9, Fraction = $0.97 - 0.26 = 0.68$

12-8

Vertical heater surface makes no sense!

12-9

$$\text{Re} = 10000, T = 300 \text{ K}, k = 0.02624, \text{Pr} = 0.7$$

Take $d = 1 \text{ cm} = 10 \text{ mm}$

$$h = (k/d)(0.023)\text{Re}^{0.8} \text{Pr}^{0.4} = 82.9$$

At $\text{Re} = 100$, and taking $d/L = 1/20$, $\text{Gz} = (100)(0.7)/20 = 3.5$

Fig. 12-5, $\text{Nu} = 3$

$$h = (3)(0.02624)/0.01 = 7.87$$

12-10

$$k = 0.69, \rho = 1600, c = 800$$

$$h = 1.42((400-300)/0.1)^{1/4} = 8$$

$$\text{Volume} = (0.05)(0.1)(0.2) = 0.001 \text{ m}^3$$

$$\text{Area} = (2)[(0.05)(0.1) + (0.1)(0.2) + (0.05)(0.2)] = 0.07 \text{ m}^2$$

$$h(V/A)/k = (8)(0.001/0.07)/0.69 = 0.127$$

If assume lumped capacity, $T_0 = 350$, $T_i = 400$, $T_\infty = 300$

$$\theta_0/\theta_i = 0.5$$

Fig. 4-13, $BiFo = 0.7 = (8)(0.07/0.001)\tau/(1600)(800)$

And $\tau = 1600$ sec

12-11

$T_f = 325$ K $\nu = 13 \times 10^{-6}$, $k = 0.024$, $Pr = 0.7$, $u_\infty = 50$, $L = 1.0$

$$Re_L = (50)(1)/13 \times 10^{-6} = 3.85 \times 10^6$$

Fig. 12-3, $Nu = (0.7)^{1/3}(7000) = 6215$

$$h = (6215)(0.024)/1 = 149$$

$$q = (149)(1)(350-300) = 7458 \text{ W/m depth}$$

12-12

$$Re_d = (50)(0.3)/13 \times 10^{-6} = 1.15 \times 10^6$$

Fig. 12-6, $Nu_d = (1300)(0.7)^{1/3} = 1154$

$$h = (1154)(0.024)/0.3 = 92.3$$

$$q/L = (92.3)(\pi)(0.3)(350-300) = 4352 \text{ W/m}$$

12-13

$$Re_d = (50)(0.002)/15.7 \times 10^{-6} = 6400; k = 0.02624$$

Fig. 12-7; $(Nu - 2)/Pr_\infty^{0.4}(\mu_\infty/\mu_w)^{1/4} = 55$

$$\mu_\infty/\mu_w = 2.08/1.85 = 1.12$$

$$Nu_{d,\infty} = (55)(1.12)^{1/4}(0.7)^{0.4} + 2 = 51.1$$

$$h = (51.1)(0.02624)/0.002 = 670$$

12-14 Open ended

12-15

$$T_f = 325 \text{ K}, \nu = 18 \times 10^{-6}, k = 0.024, \text{Pr} = 0.7$$

$$\text{GrPr} = (9.8)(1/325)(50)(0.025 \times 10^{-3})^3 (0.7) / (18 \times 10^{-6})^2 = 5 \times 10^{-5}$$

$$\text{Fig. 12-9: Nu} = 0.38$$

$$h = (0.38)(0.024) / 0.000025 = 365$$

$$q = (365)\pi(0.000025)(50) = 1.43 \text{ W}$$

12-16

$$T_f = 325 \text{ K}$$

$$\text{GrPr} = (9.8)(1/325)(0.009)(0.002)^3 (0.7) / (18 \times 10^{-6})^2 = 17.3$$

$$\text{Fig. 12-10 Nu} = 2.9$$

$$h = (2.9)(0.024) / 0.002 = 3.48$$

12-17

$$\text{GrPr} = (9.8)((1/325)(50)(0.07)^3 (0.7) / (18 \times 10^{-6})^2 = 1.1 \times 10^6$$

$$\text{Fig. 12-11; } \delta = (18)(20/50)^{1/4} = 14.3 \text{ mm}$$

$$\text{Fig. 12-13; } u_{\max} = 130 \text{ mm/s}$$

12-18

$$\text{Fig. 12-12(a) } \delta = 2.7 \text{ mm}$$

$$\text{Fig. 12-14(a) } u_{\max} = 17 \text{ mm/s}$$

12-19

Liquid water $k = 0.61$

$$Gr_{\delta}Pr = (1.91 \times 10^{10})(20)(0.01)^3 = 3.8 \times 10^5$$

Fig. 12-15; $k_{\text{eff}}/k = 6.2$

$$q/A = (6.2)(0.61)(20)/(0.01) = 7560 \text{ W/m}^2$$

12-20

$$Gr_{\delta}Pr = (9.8)(1/300)(20)(0.01)^3(.7)/(15.7 \times 10^{-6})^2 = 1865$$

Fig 12-17; $k_{\text{eff}}/k = 1.3$

$$q/A = (1.3)(0.026)(20)/0.01 = 67.6 \text{ W/m}^2$$

12-21

$p_1 = 1 \text{ atm}$, air at 300 K $\delta = 10 \text{ cm}$, $\Delta T = 20^\circ\text{C}$, $p_2 = 0.000001 \text{ atm}$

Fig. 12-18(a) $q/A]_{1 \text{ atm}} \approx 4.5 \text{ W/m}^2$

Fig. 12-18(b) $q/A]_{0.000001 \text{ atm}} \approx 1.4$

Percent reduction = 69%

12-22

$$\lambda T = (20)(300) = 6000 \mu\text{-K}$$

Fig. 12-19 Fraction below 20 $\mu = 0.735$

12-23

$d = 4 \text{ cm}$ $T_1 = 475 \text{ K}$ $T_2 = 300\text{K}$, $\epsilon_1 = 0.5$, $\epsilon_2 = 0.7$

$$A_1 = 4\pi(0.02)^2 = 0.005$$

$$A_2 = (6)(0.06)^2 = 0.022$$

Fig. 12-20; $(1/\epsilon_2 - 1)(A_1/A_2) = 0.0974$;

$$q/A_1(E_{b1} - E_{b2}) = 0.48$$

$$E_{b1} = 2886$$

$$E_{b2} = 459$$

$$q = (0.48)(0.005)(2886 - 459) = 5.8 \text{ W}$$

12-24

$$\epsilon = 0.7, T = 273 + 200 = 473 \text{ K}, d = 0.1 \text{ m}$$

$$\text{Table 7-2, } h_{\text{conv}} = 1.32((473-300)/0.1)^{1/4} = 8.51$$

$$\text{Fig. 12-21; } h_{\text{rad}} = (0.7)(14) = 9.8$$

$$q = (8.51 + 9.8)(\pi)(0.1)(473 - 300) = 995 \text{ W/m length}$$

12-25

$$p = 0.1 \text{ MPa}, \Delta T_x = 10^\circ\text{C}$$

$$\text{Fig. 12-23 ; } h \approx 0.0023$$

$$\text{Fig. 12-25; } h \approx 0.0045$$

Not too bad considering equations upon which charts are based.

Also compare Figures 9-8 and 12-24 for $\Delta T_x = 10^\circ\text{C}$ and $p = 2.6 \text{ Mpa}$

$$\text{Fig. 9-8; } h \approx 0.07$$

$$\text{Fig. 12-24 } h \approx 0.09 \text{ agreement is rather good}$$

Chapter 12

12-1

Air @ 300K $k = 0.0262$

Vertical plate $GrPr = 10^4$; $Nu = hL/k = 54.2(\Delta TL^3)^{1/4}$

Fig 12-8 $GrPr = 10^4$ $Nu = 6$

$$GrPr = 10^9 \quad Nu = 100$$

$$GrPr = 10^{12} \quad Nu = 1000$$

$$6 = 54.2 (\Delta TL_1)^{1/4}$$

$$100 = 54.2 (\Delta TL_2^3)^{1/4} = 50(\Delta TL_2^3)^{1/3}$$

$$1000 = 50(\Delta TL_3^3)^{1/3}$$

For $\Delta T = 10^\circ\text{C}$: $L_1 = 0.015\text{m}$, $L_2 = 0.64\text{ m}$, $L_3 = 641\text{ m}$

For $\Delta T = 20^\circ\text{C}$: $L_1 = 0.012\text{ m}$, $L_2 = 0.51\text{ m}$, $L_3 = 510\text{ m}$

12-2 Open ended problem

12-3

$$d = 15\text{ mm} \quad T_s = 800\text{ K}, \quad T_a = 300\text{K} \quad A_1 = A_2 = \pi d/2 = 0.0236\text{ m}^2\text{m}$$

$$A_d = d = 0.015 \quad \varepsilon = 0.7$$

$$0.7\sigma(0.0236)(800^4 - T_2^4) = 0.02136 h(T_2 - 300) + \sigma(T_2^4 - T_1^4) \cdot 103$$

$$\sigma(T_2^4 - T_1^4) \cdot 103 = 0.0236 h (T_2 - 300)$$

In example 12-10 for $d = 15\text{ mm}$ $Re_d = 6194$, and $h = 37.9\text{ W/m}^2\text{-}^\circ\text{C}$

Substituting in above equations, $T_1 = 354\text{ K}$, $T_2 = 567\text{ K}$ and $q = 287\text{ W/m}$

12-4

Water, $H = 50 \text{ mm}$, $W = 25 \text{ mm}$ $T_f = 300 \text{ K}$

Table A-9: $\text{GrPr} = (0.05)^3(20)(1.91 \times 10^{10}) = 4.78 \times 10^7$

$$\text{Pr} = 5.85 \quad k = 0.614$$

Fig. 12-8 $\text{Nu} = 60$

$$h = (60)(0.614)/0.05 = 737$$

$$q = (737)(0.05)(0.025)(20) = 18.4 \text{ W}$$

Fig. 12-12(a) $\delta = 2.5 \text{ mm}$

Fig. 12-14 $u_{\text{max}} = 110 \text{ mm/s}$

12-5

Air Fig. 12-11 $\text{GrPr} = 3.5 \times 10^5$

Fig. 12-8 $\text{Nu} = 14$

$$h = (14)(0.02624)/0.05 = 7.35$$

$$q = 97.35(0.05)(0.025)(20) = 0.184 \text{ w}$$

99.9% TOO LOW

12-6

$L = 5 \text{ m}$ $p = 1 \text{ atm}$, $u = 300 \text{ mi/h} = 134 \text{ m/s}$, $T_f = 300 \text{ K}$

$$\nu = 15.2 \times 10^{-6} \quad k = 0.02624, \text{Pr} = 0.7$$

$$\text{Re} = (134)(5)/15.2 \times 10^{-6} = 4.27 \times 10^7$$

Fig. 12-3, $\text{Nu} = 50000$

$$h = (50000)(0.02624)/5 = 262.4$$

$$q = (2)(5)(262)(20) = 52800 \text{ W/ m length}$$

12-7

$$\lambda_1 T = 2900 \mu\text{-K}$$

$$\lambda_2 T = 11600 \mu\text{-K}$$

Fig. 12-9, Fraction = $0.97 - 0.26 = 0.68$

12-8

Vertical heater surface makes no sense!

12-9

$$\text{Re} = 10000, T = 300 \text{ K}, k = 0.02624, \text{Pr} = 0.7$$

$$\text{Take } d = 1 \text{ cm} = 10 \text{ mm}$$

$$h = (k/d)(0.023)\text{Re}^{0.8} \text{Pr}^{0.4} = 82.9$$

$$\text{At } \text{Re} = 100, \text{ and taking } d/L = 1/20, \text{Gz} = (100)(0.7)/20 = 3.5$$

Fig. 12-5, $\text{Nu} = 3$

$$h = (3)(0.02624)/0.01 = 7.87$$

12-10

$$k = 0.69, \rho = 1600, c = 800$$

$$h = 1.42((400-300)/0.1)^{1/4} = 8$$

$$\text{Volume} = (0.05)(0.1)(0.2) = 0.001 \text{ m}^3$$

$$\text{Area} = (2)[(0.05)(0.1) + (0.1)(0.2) + (0.05)(0.2)] = 0.07 \text{ m}^2$$

$$h(V/A)/k = (8)(0.001/0.07)/0.69 = 0.127$$

If assume lumped capacity, $T_0 = 350, T_i = 400, T_\infty = 300$

$$\theta_0/\theta_i = 0.5$$

Fig. 4-13, $BiFo = 0.7 = (8)(0.07/0.001)\tau/(1600)(800)$

And $\tau = 1600$ sec

12-11

$T_f = 325$ K $\nu = 13 \times 10^{-6}$, $k = 0.024$, $Pr = 0.7$, $u_\infty = 50$, $L = 1.0$

$$Re_L = (50)(1)/13 \times 10^{-6} = 3.85 \times 10^6$$

Fig. 12-3, $Nu = (0.7)^{1/3}(7000) = 6215$

$$h = (6215)(0.024)/1 = 149$$

$$q = (149)(1)(350-300) = 7458 \text{ W/m depth}$$

12-12

$$Re_d = (50)(0.3)/13 \times 10^{-6} = 1.15 \times 10^6$$

Fig. 12-6, $Nu_d = (1300)(0.7)^{1/3} = 1154$

$$h = (1154)(0.024)/0.3 = 92.3$$

$$q/L = (92.3)(\pi)(0.3)(350-300) = 4352 \text{ W/m}$$

12-13

$$Re_d = (50)(0.002)/15.7 \times 10^{-6} = 6400; k = 0.02624$$

Fig. 12-7; $(Nu - 2)/Pr_\infty^{0.4}(\mu_\infty/\mu_w)^{1/4} = 55$

$$\mu_\infty/\mu_w = 2.08/1.85 = 1.12$$

$$Nu_{d,\infty} = (55)(1.12)^{1/4}(0.7)^{0.4} + 2 = 51.1$$

$$h = (51.1)(0.02624)/0.002 = 670$$

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Percent reduction = 69%

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