

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

$$\begin{aligned}q &= -kA \frac{dT}{dx} & \frac{dx}{\pi r^2} &= -k \frac{dT}{q} \\ r &= ax + b; \quad x = 0; \quad r = 0.0375 \\ x &= 0.3, \quad r = 0.0625 \\ r &= 0.0833x + 0.0375 \\ \int \frac{dx}{\pi(0.0833x + 0.0375)^2} &= -\frac{(204)(93 - 540)}{q} \\ \frac{-1}{\pi(0.0833)} \left(\frac{1}{0.0833x + 0.0375} \right) \Big|_{x=0}^{x=0.3} &= -\frac{(204)(-447)}{q} \\ q &= 2238 \text{ W}\end{aligned}$$

1-4

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

1-5

$$\begin{aligned}A &= \pi r^2 & q &= -k4\pi r^2 \frac{dT}{dr} & q &= \frac{-4\pi k(T_0 - T_i)}{\frac{1}{r_i} - \frac{1}{r_0}} \\ q &= \frac{-4\pi(2 \times 10^{-4})(21 + 196)}{\frac{1}{0.26} - \frac{1}{0.285}} = 1.617 \text{ W} \\ \text{mass evaporated} &= \frac{1.617}{199,000} = 0.813 \times 10^{-5} \text{ kg/s} \\ &= 0.702 \text{ kg/day}\end{aligned}$$

Chapter 1**1-7**

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

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

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

1-11

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

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

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

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

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

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

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

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

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

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

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**

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

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

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

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

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

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

$$\begin{aligned} q_{\text{rad}} &= \sigma \epsilon A_1 (T_1^4 - T_2^4) \\ &= (5.669 \times 10^{-8})(0.7)\pi(0.05)(1)(473^4 - 283^4) \\ &= 272 \frac{\text{W}}{\text{m}} \text{ length} \end{aligned}$$

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

Most heat transfer is by convection.

1-30

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

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

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

$$\begin{aligned} q_{\text{conv}} &= (4.5)(0.3)^2(50 - 20) \quad (2 \text{ sides}) \\ &= 24.3 \text{ W} \end{aligned}$$

$$\begin{aligned} q_{\text{rad}} &= \sigma \epsilon A_1 (T_1^4 - T_2^4) = (5.669 \times 10^{-8})(0.8)(0.3^2)(323^4 - 293^4) \quad (2 \text{ sides}) \\ &= 28.7 \text{ W} \end{aligned}$$

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

Convection and radiation are about the same magnitude.

1-31

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

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

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

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

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

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

Solution by iteration:

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

Chapter 1**1-32**

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

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

$$\begin{array}{cc} T_{w_2} & f(T_{w_2}) \end{array}$$

$$320 \quad 158.41$$

$$350 \quad 907.22$$

$$310 \quad -77.03$$

$$313.3 \quad 0.058$$

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

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.