Problem 1

9.2 Using the values of density for water in Table A.6, calculate the volumetric thermal expansion coefficient at 300 K from its definition, Equation 9.4, and compare your result with the tabulated value.

$T(K)$	$\rho = \frac{1}{v}$	$\beta\left(\frac{1}{K}\times10^{-6}\right)$
295	.998	227.5
300	.997	276.1
305	.995	320.6

$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_p \cong -\frac{1}{\rho_o}\left(\frac{\Delta \rho}{\Delta T}\right)_p$$

$$\beta_{estimate} = -\frac{1}{\rho_o}\left(\frac{\rho_{305}-\rho_{295}}{T_{305}-T_{295}}\right)_p$$

$$\beta_{est.} = -\frac{1}{.997}\left(\frac{.995-.998}{305-295}\right)$$

$$\beta_{est} = 300.9 \times 10^{-6} \; K^{-1}$$

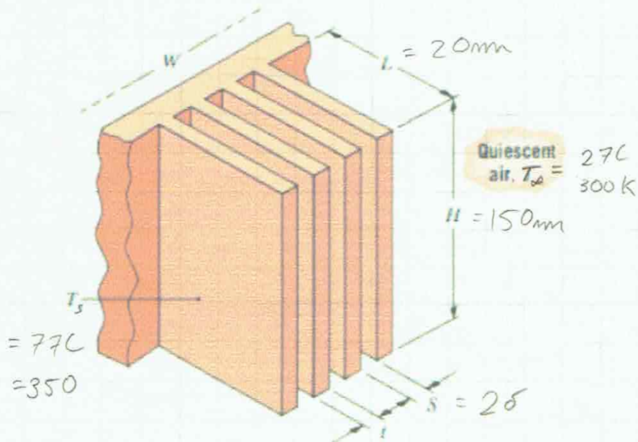
$$\beta_{T=300K} = 276.1 \times 10^{-6} \; K^{-1}$$

$$\frac{300.9-276.1}{276.1} \times 100 = 8.98\%$$

The estimate is 8.98% higher than the real value.

Problem 2 (part a: very similar to our exam 1 question! Note that the fins are isothermal so this is not a true fin problem.) $\rightarrow \Delta T(x) = 0$

9.9 Consider an array of vertical rectangular fins, which is to be used to cool an electronic device mounted in quiescent, atmospheric air at $T_\infty = 27°C$. Each fin has $L = 20$ mm and $H = 150$ mm and operates at an approximately uniform temperature of $T_s = 77°C$.



(a) Viewing each fin surface as a vertical plate in an infinite, quiescent medium, briefly describe why there exists an optimum fin spacing S. Using Figure 9.4, estimate the optimum value of S for the prescribed conditions.

(b) For the optimum value of S and a fin thickness of $t = 1.5$ mm, estimate the rate of heat transfer from the fins for an array of width $W = 355$ mm.

(a) $T_f = (T_s + T_\infty)/2 = (300+350)/2 = 325\ K$

$\rightarrow \nu = 18.41 \times 10^{-6}$

$k = .0282$

$Pr = .7035$

$$\eta = \left(\frac{y}{x}\right)\left(\frac{Gr_x}{4}\right)^{1/4} = \frac{\delta}{H}\left(\frac{1.5\times10^7}{4}\right)^{1/4} =$$

$$Gr_{x=H} = \frac{g\beta(T_s - T_\infty)x^3}{\nu^2} \qquad \beta = 1/325$$

$$= \frac{(9.81)\left(\frac{1}{325}\right)(50)(.15)^3}{(18.41\times10^{-6})^2} = 1.5\times10^7$$

$$Ra_L = Gr_L Pr = (1.5\times10^7)(.7035) = 10.5\times10^6$$

$\rightarrow$ Fig 9.4, when $Pr = .7035$ @ $y \approx \delta$, $\eta \cong 5$

$$\delta = \frac{\eta H}{\left(\frac{1.5\times10^7}{4}\right)^{1/4}} = 17\ mm \qquad \text{eq. } 9.24$$

$$S = 2\delta = (2\times18.7) = 34.1\ mm$$

$$\overline{Nu}_L = 0.59(Ra_L)^{.25} = 59.72$$

(a) If the fins are too far apart, then there won't be enough surface area to heat all the available air flowing inbetween. If the fins are too close, then the boundary layers will "join", and the surfaces won't be able to transfer as much heat.

$\boxed{2\delta = S \cong 34.1mm}$

(b) $\boxed{q = 33.68\ W}$

$$\overline{Nu} = \frac{\bar{h}L}{k} \rightarrow \bar{h} = \frac{\overline{Nu}\,k}{H} = 11.23$$

$$q = \bar{h}A(T_s - T_\infty)\cdot N \cdot 2$$

$$N = \frac{W}{S+t} = \frac{355}{34.1+1.5} = 9.97 \text{ Fins}$$

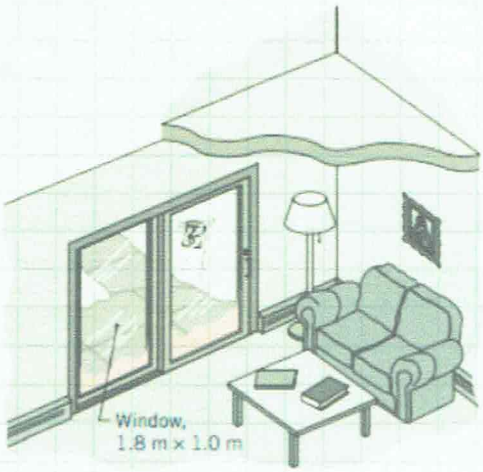
$\downarrow$ 10 Fins

$$q = 2(10)(11.23)(\underbrace{.15 \cdot .02}_{H\cdot L})(350-300)$$

$$q = 33.68$$

Problem 3

9.18 During a winter day, the window of a patio door with a height of 1.8 m and width of 1.0 m shows a frost line near its base. The room wall and air temperatures are 15°C.



(a) Explain why the window would show a frost layer at the base rather than at the top.

(b) Estimate the heat loss through the window due to free convection and radiation. Assume the window has a uniform temperature of 0°C and the emissivity of the glass surface is 0.94. If the room has electric baseboard heating, estimate the corresponding daily cost of the window heat loss for a utility rate of 0.18 $/kW·h.

(a) The Frost occurs near the base b/c, as the window cools the air, it creates a boundary layer that is thinner at the top of the window. A thin boundary layer corresponds to a high heat Flux. Therefore, the low heat Flux on bottom corresponds to a Frosty surface. Also, air is colder on the Floor compared to the ceiling.

@ top

$Ra = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu\alpha}$ $\quad T_f = 7.5°C$

↓ air @ 280K

$\nu = 14.11\times10^{-6}$

$k = .0247$

$\alpha = 1.986\times10^{-5}$

$\sigma = 5.67\times10^{-8}$

$Ra = \frac{(9.81)\left(\frac{1}{280.5}\right)(15)(1.8)^3}{(14.11\times10^{-6})(1.986\times10^{-5})}$

$Ra = 1.0937\times10^{10}$

↓

$\overline{Nu_L} = 0.1\,Ra_L^{1/3} = 222 = \frac{hL}{k}$

↓

$h = 222(.0247)/(1.8) = 3.045$

$q_{conv} = hA\Delta T = 3.045(1.8\times1)(15) = 82.24$

$q_{rad} = \varepsilon\sigma A(T_s^4 - T_{surf}^4) = \overset{A}{(1.8\cdot1)}\overset{\varepsilon}{(0.94)}(5.67\times10^{-8})(288^4 - 273^4)$ $\quad T_s = 288$, $T_{surf} = 273$

$= 127.12$

$q_{total} = q_{conv} + q_{rad} = 209.4\ W$

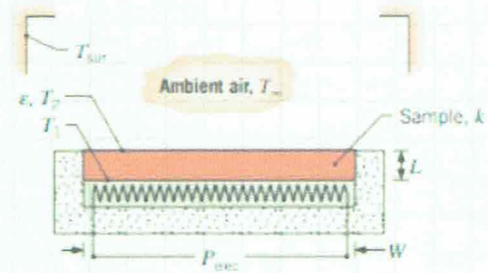
$\frac{\$0.18}{\cancel{kW\cdot h}} \Big| \frac{24\ \cancel{h}}{1\ day} \Big| .2094\ \cancel{kW} = 0.9046$

$\boxed{Cost = \$0.90/day}$

10/10

Problem 4

9.39 The thermal conductivity and surface emissivity of a material may be determined by heating its bottom surface and exposing its top surface to quiescent air and large surroundings of equivalent temperatures, $T_\infty = T_{sur} = 25°C$. The remaining surfaces of the sample/heater are well insulated.



Consider a sample of thickness $L = 25$ mm and a square planform of width $W = 250$ mm. In an experiment performed under steady-state conditions, temperature measurements made at the lower and upper surface of the sample yield values of $T_1 = 150°C$ and $T_2 = 100°C$, respectively, for a power input of $P_{elec} = 70$ W. What are the thermal conductivity and emissivity of the sample?

$$T_f = \frac{T_2 + T_{sur}}{2} = 335.5\ K$$

air

$$\nu = 17.3487 \times 10^{-6}$$
$$k = 27.373 \times 10^{-3}$$
$$\alpha = 24.646 \times 10^{-6}$$
$$Pr = .70497$$
$$\beta = 1/335.5$$

$$L = \frac{A_s}{P} = \frac{W^2}{4W} = \frac{W}{4} = .0625$$

$$Ra_L = \frac{g\beta(T_2 - T_{sur})L^3}{\nu\alpha}$$
$$= \frac{(9.81)(1/335.5)(100-25)(.0625)^3}{(17.3487\times10^{-6})(24.646\times10^{-6})}$$

$$Ra_L = 1.25 \times 10^6$$

$$\overline{Nu}_L = 0.54\,(Ra_L)^{1/4} = 18.06 = \frac{\bar{h}L}{k}$$

$$\frac{(18.06)k}{L} = \bar{h} = 7.911$$

$$q_{cond} = -kA\frac{dT}{dx} = 70W \rightarrow k = \frac{-70}{(.25^2)\left(\frac{100-150}{.025}\right)} = 0.56\ \frac{W}{mK}$$

$$P_{elec} = q_{conv} + q_{rad} = A\left(h(T_2 - T_\infty) + \varepsilon\sigma(T_2^4 - T_{sur}^4)\right)$$

$$70 = W^2\left(7.911(75) + \varepsilon\, 5.67\times10^{-8}(373^4 - 298^4)\right)$$

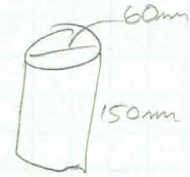
solve on calc

$$\varepsilon = 0.8097$$

$$\boxed{K = 0.56\ \frac{W}{mK} \qquad \varepsilon = 0.81}$$

Problem 5

9.55 Beverage in cans 150 mm long and 60 mm in diameter is initially at 27°C and is to be cooled by placement in a refrigerator compartment at 4°C. In the interest of maximizing the cooling rate, should the cans be laid horizontally or vertically in the compartment? As a first approximation, neglect heat transfer from the ends.



$T_i = 27C = 300$

$T_\infty = 4C = 277K$

air @ 288.5

$\nu = 14.8665 \times 10^{-6}$

$k = 25.38 \times 10^{-3}$

$\alpha = 20.982 \times 10^{-6}$

$Pr = .710$

$$Ra = \frac{g\beta(T_s - T_\infty)L^3}{\nu\alpha}$$

horiz.
Cylinder

$$Ra_D = \frac{(9.81)(1/288.5)(23)(.06^3)}{(14.8665\times10^{-6})(20.982\times10^{-6})}$$

$= 5.41 \times 10^5$

$\overline{Nu}_D = C\,Ra_D^{\,n}$ where (table 9.1) $C = 0.48$, $n = 0.25$

$= .48\,Ra_D^{1/4}$

$= 13.02 = \frac{\bar{h}D}{k}$

$$\frac{13.02(25.38\times10^{-3})}{.06} = 5.51\ \frac{W}{m^2K}$$

$q = \bar{h}A(T_s - T_\infty) = 5.51(\pi \cdot .06 \cdot .15)(23)$

$q_{horiz.} = 3.583\ W$

tall
cylinder

$$Ra_L = \frac{(9.81)(1/288.5)(23)(.15^3)}{(14.8665\times10^{-6})(20.982\times10^{-6})}$$

$= 8.46 \times 10^6$

$\overline{Nu}_L = 0.59\,Ra_L^{1/4} = 31.82 = \frac{\bar{h}L}{k}$

$$\frac{(31.82)\,25.38\times10^{-3}}{.15} = \bar{h} = 5.38\ \frac{W}{m^2K}$$

$q = \bar{h}A(T_s - T_\infty) = 5.38(\pi \cdot .06 \cdot .15)(23)$

$q_{tall} = 3.499\ W$

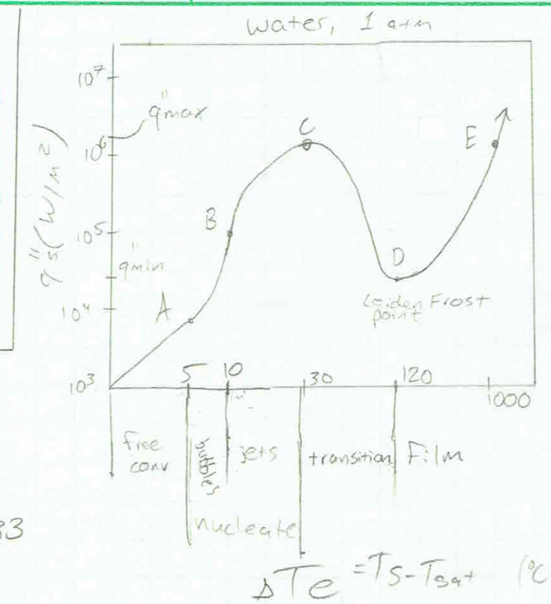
$q_{horiz} = 3.583_W > 3.499_W = q_{tall}$

The can should be layed horizontally

Problem 6

10.4 Estimate the heat transfer coefficient, h, associated with Points A, B, C, D, and E in Figure 10.4. Which point is associated with the largest value of h? Which point corresponds to the smallest value of h? Determine the thickness of the vapor blanket at the Leidenfrost point, neglecting radiation heat transfer through the blanket. Assume the solid is a flat surface.

~Suppose $10^7 \le Ra_L \le 10^{11}$, all Pr



eq 9.31

Free conv: $\bar{h} = 0.15\, Ra_L^{1/3} \dfrac{k}{L}$

Nucleate: $h = q''_s/\Delta T_e \rightarrow 2000 \lesssim h \lesssim 33333$

Transition: h decreases w/ increasing Te

Film: $h = q''_s/\Delta T_e$

A: $h \cong \dfrac{9\times10^3}{5} = 1800$

B: $h \cong \dfrac{10^5}{10} = 10{,}000$

C: $h \cong \dfrac{1.5\times10^6}{30} = 50{,}000$ $\boxed{\text{Point C has the largest h-value}}$

D: $h \cong \dfrac{3\times10^4}{120} = 250$ $\boxed{\text{Point D has the smallest h-value}}$

E: $h \cong \dfrac{1.5\times10^6}{1000} = 1500$

@ LeidenFrost, $q''_s \cong 3\times10^4$

$\Delta T_e \cong 120°C$

vapor k @ T = 430K, k = 0.0304

$\Delta T_e = T_s - T_{sat} = T_s - 100$

$120 + 100 = T_s = 220°C = 493K$

$T_s = 493$, $T_{sat} = 373$ } $T_{vapor} \approx 433$

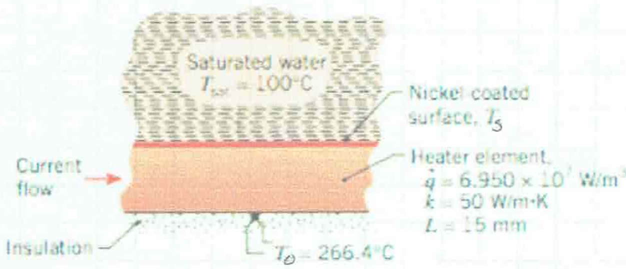
$q''_{cond} \cong 3\times10^4 = -k \dfrac{dT}{dx}$

$dx = \delta = \dfrac{-k\, dT}{3\times10^4} = \dfrac{(+.0304)(+120)}{3\times10^4} = +1.216\times10^{-4}\, m$ (dT = Te)

$\boxed{dx = 0.122 \text{ mm}}$

Problem 7

10.13 A nickel-coated heater element with a thickness of 15 mm and a thermal conductivity of 50 W/m·K is exposed to saturated water at atmospheric pressure. A thermocouple is attached to the back surface, which is well insulated. Measurements at a particular operating condition yield an electrical power dissipation in the heater element of 6.950×10^7 W/m³ and a temperature of $T_o = 266.4°C$.



(a) From the foregoing data, calculate the surface temperature, T_s, and the heat flux at the exposed surface.

(b) Using the surface heat flux determined in part (a), estimate the surface temperature by applying an appropriate boiling correlation.

water @ 100°C

$\nu = 1.044 \times 10^{-3}$

$k_f = 680 \times 10^{-3}$

$c_p = 4.217 \times 10^3$

$P_r = 1.76$

$\beta = 750.1 \times 10^{-6}$

$\alpha = \frac{\nu}{Pr} = \frac{1.044 \times 10^{-3}}{1.76}$

$\alpha = 5.932 \times 10^{-4}$

$\mu = 279 \times 10^{-6}$

$h_{fg} = 2257 \times 10^3$

$\sigma = 58.9 \times 10^{-3}$

$$T(0) = 266.4°C = \frac{\dot{q} L^2}{2 k_{heater}} + T_s$$

$$@ L = .015, \quad T_s = 266.4 - \frac{(6.95 \times 10^7)(.015^2)}{2(50)}$$

$$T_s = 110.025°C$$

$$\underset{\frac{W}{m^2}}{q''} = \underset{\frac{W}{m^3}}{\dot{q} L} = (6.95 \times 10^7)(.015) = 1{,}042{,}500$$

$$\cancel{Ra_L = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu\alpha}}$$

$$\cancel{= (9.81)(750.1 \times 10^{-6})(}$$

(a) $\boxed{T_s = 110 °C}$

$\boxed{q'' = 1{,}042{,}500 \ \frac{W}{m^2}}$

(b) $\boxed{T_s = 109.1 °C}$

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water-nickel → $C_{s,f} = .006$, $n = 1$; $\rho_l = 1/(1.044 \times 10^{-3})$, $\rho_v = 1/1.679$

suppose nucleate boiling

$$q_s'' = 1042500 = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2} \left(\frac{c_{p,l} \Delta T_e}{C_{s,f} h_{fg} Pr_l^n}\right)^3$$

$$1042500 = (279 \times 10^{-6})(2257 \times 10^3)\left[9.81(957.9 - .595)\right]^{1/2} \cdot \left(\frac{4.217 \times 10^3 \, \Delta T_e}{.006(2257 \times 10^3) 1.76}\right)^3$$

$$1042500 = 2.51 \times 10^5 \left(\frac{\Delta T_e}{5.652}\right)^3$$

$$\Delta T_e = 9.08 = T_s - T_{sat}$$

$$T_s = 109.1$$