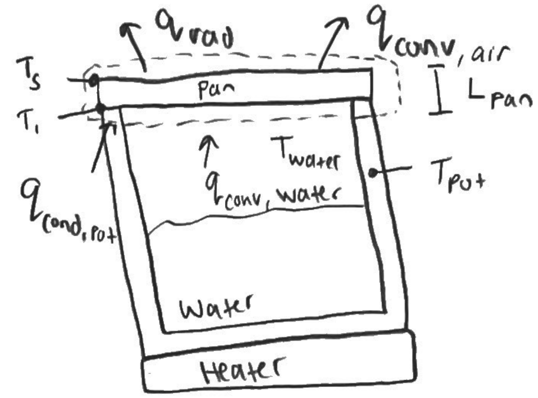
Kiara Koeppen
kkoeppen@purdue.edu
0027178757
Problem 1 Part 1



$$\dot{E}_{in} - \dot{E}_{out} + \cancel{\dot{E}_{gen}}^{0} = \cancel{\dot{E}_{st}}^{0}$$

$$q_{cond,pot} + q_{conv,water} - q_{conv,air} - q_{rad} = 0$$

$$q_{cond,pot} = -k_{pot} \frac{dT}{dx}\Big|_{\text{pot to pan interface}}$$

$$q_{conv,water} = h_{air\,@T_{f,1}} A_{(\text{surface pan exposed to } T_{water})} (T_{water} - T_1)$$

$$q_{conv,air} = h_{air\,@T_{f,2}} A_{(\text{surface, pan})} (T_s - T_\infty)$$

$$q_{rad} = \varepsilon_{pan} \sigma A_{s,pan} (T_s^4 - T_{surr}^4)$$

Assumptions:

- Steady State
- Small pan in large surroundings
- $\dot{E}_{gen} = 0$, no heat generation
- 1D
- $T_{f,1}$ is $T_{f,1} = \frac{T_{water} + T_1}{2}$
- $T_{f,2}$ is $T_{f,2} = \frac{T_\infty + T_s}{2}$
- No sitting water on pans bottom side due to steam, convection from water is the only heat transfer directly to pans surface.

$$-k_{pot} A_{\text{pot contact with bottom pan}} \frac{dT}{dx}\Big|_{\text{pot to pan interface}} + h_{air\,@T_{f,1}} A_{(\text{surface of pan exposed to } T_{water})} (T_{water} - T_1) - h_{air\,@T_{f,2}} A_{\text{pan surface}} (T_s - T_\infty) - \varepsilon_{pan} \sigma A_{\text{pan surface}} (T_s^4 - T_{surr}^4) = 0$$

$$q_{net,out} = q_{rad} + q_{conv,air}$$

$$R = \frac{L_{pan}}{k_{pan} A_{surface,pan}}$$

$$q_{net,in} = q_{net,out}$$

$$q_{net,in} = q_{conv,water} + q_{cond,pot}$$

$$T_1 - T_s = q_{net,in} R_{pan}$$

$$R_{pan} = \frac{L_{pan}}{k_{pan} A_{surface\,pan}}$$

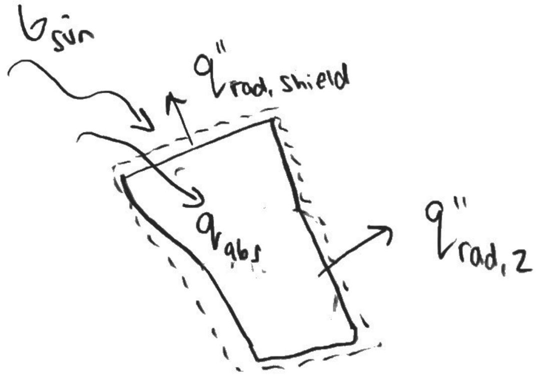
$$T_1 - T_s = (q_{conv,water} + q_{cond,pot}) \left(\frac{L_{pan}}{k_{pan} A_{surface\,pan}} \right)$$

Additional Information Needed:

ε_{pan}, $h_{air\,@T_{f,1}}$, $h_{air\,@T_{f,2}}$, k_{pot}, $A_{surface\,pan}$, Pot wall thickness, L_{pan}

Kiara Koeppen
kkoeppen@purdue.edu
0027178757
Problem 1 Part 2

Assumptions: Steady State, No energy generation, $\tau = 0$, spatially uniform, T_s is constant everywhere on probe



$$\dot{E}_{in} - \dot{E}_{out} + \cancel{\dot{E}_{gen}}^{0} = \cancel{\dot{E}_{st}}^{0}$$

$$q_{abs} - q_{rad,shield} - q_{rad,2} = 0$$

$$q_{abs} = \alpha G_{sun} A_{shield} = (1-\rho_s) G_{sun} A_{shield}$$

$$q_{rad,shield} = \varepsilon_c A_{shield} \sigma T_s^4$$

$$q_{rad,2} = \varepsilon_o A_{(surface-shield)} \sigma (T_s^4 - \cancel{T_{space}^4}^{OK}) = \varepsilon_o A_{(surface-shield)} \sigma T_s^4$$

$$\boxed{(1-\rho_s) G_{sun} A_{shield} - \varepsilon_c A_{shield} \sigma T_s^4 - \varepsilon_o A_{(surface-shield)} \sigma T_s^4 = 0}$$

$(A_{surface} - A_{shield})$

Need to know

$$\boxed{\rho_s, \varepsilon_o, \varepsilon_c, A_{shield}, A_{surface}, G_{sun}}$$

Kiara Koeppen
kkoeppen@purdue.edu
0027178757

Problem 2

① thermal conductivity of aluminum = 240 W/mK (Assuming 400 K pure aluminum)
Site: Fundamentals of heat and mass transfer 7th edition — Theodore L Bergman, Adrienne S Lavine, Frank P Incorpera, David P Dewitt

②
$$q_{cond} = \frac{(393.15 - 383.15)}{(0.07 - 0.02)}(240)(7.85E\text{-}5) \qquad A_c = \pi(0.005m)^2 = 7.85E\text{-}5$$

$$\boxed{q_{cond} = 3.768\ W}$$

③
$$3.768 = \frac{(373.15 - T_{14})(240)(7.85E\text{-}5)}{(.14 - .12)}$$

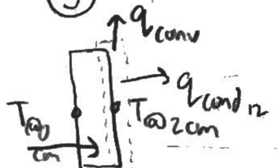
$$\boxed{T_{@14cm} = 369.15K}$$

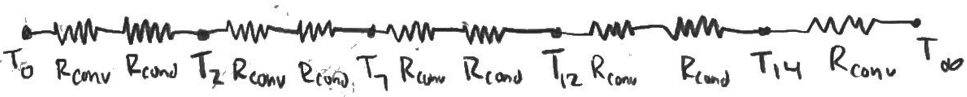
④
$$\dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} = \dot{E}_{st}$$

$\overrightarrow{q_{cond}} \mid \rightarrow q_{conv}$

$$q_{cond} = q_{conv} = 3.768W = hA_c(T_{@14cm} - T_\infty)$$
$$= h(7.85E\text{-}5)(369.15 - 293.15)$$
$$\rightarrow \boxed{h = 631.58\ W/mK}$$

⑤
$$3.768 = \frac{(T_{@0cm} - 393.15)(240)(7.85E\text{-}5)}{(0.02 - 0)} \rightarrow T_{@0cm} = 397.15K$$





$q_{cond,1}$

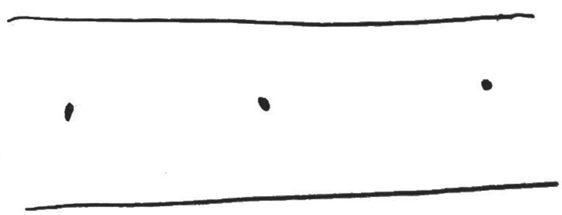
$$\frac{T_0 - T_{14}}{R_{eq}} = q = \frac{397.15 - 369.15}{\frac{.14}{(7.85E5)(240)} + \frac{1}{(631.58)(7.85E\text{-}5)}} = 1.025$$

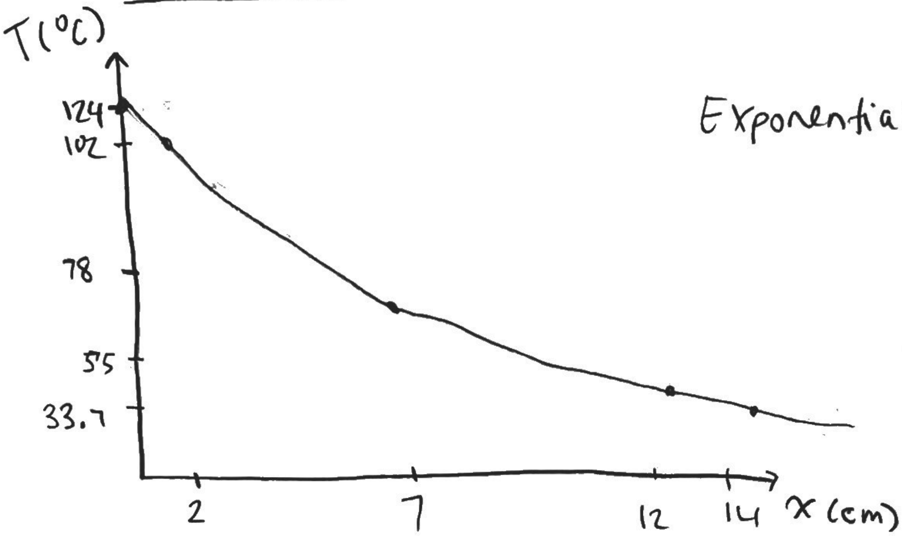
$$\frac{T_0 - T_2}{R_{eq}} = q = \frac{397.15 - T_2}{\frac{0.02}{(7.85E\text{-}5)(240)} + \frac{1}{(631.58)(7.85E\text{-}5)}} = 1.025 \rightarrow T_2 = 375.4\ K = 102.25°C$$

$$\frac{T_2 - T_7}{R_{eq}} = q = \frac{375.4 - T_7}{\frac{.05}{(7.85E\text{-}5)(240)} + \frac{1}{(631.58)(7.85E\text{-}5)}} = 1.025 \rightarrow T_7 = 352K = 78.85°C$$

$$\frac{T_7 - T_{12}}{R_{eq}} = q = \frac{352 - T_{12}}{\frac{.05}{(7.85E\text{-}5)(240)} + \frac{1}{(631.58)(7.85E\text{-}5)}} = 1.025 \rightarrow T_{12} = 328.6 = 55.45$$

$$\frac{T_{12} - T_{14}}{R_{eq}} = q = \frac{328.6 - T_{14}}{\frac{.02}{(7.85E-5)(240)} + \frac{1}{(631.58)(7.85E-5)}} = 1.025 \rightarrow T_{14} = 306.84\ K \approx 33.69°C$$





Exponentially Decreasing

Kiara Koeppen
KKoeppen@purdue.edu
0027178757
Problem 3

$$\frac{640-645}{640-x} = \frac{320-325}{320-323.15} \rightarrow x = 643.15 = k$$

① $\bar{T}_m = 50°C$

W/mK (Heat & Mass Transfer 7th edition, Incropera)

Thermal Conductivity (k) = 643.15 E-3

$$\frac{4.18-4.182}{4.18-x} = \frac{320-325}{320-323.15}$$

$x \approx 4.1813 = c_p$

Dynamic viscosity (μ) = 5.46E-4 $N\cdot s/m^2$
Kinematic viscosity (ν) = 5.52E-7 m^2/s
Density = 988 kg/m^3

Intro to Fluid mechanics Fox and McDonald's 8th edition

Heat capacity (c_p) = 4.1813 kJ/kgK = 4.1813E3 (J/kgK) (heat & Mass transfer 7th edition, Incorpera)

② $$Re_D = 2300 = \frac{u_m D}{\nu} = \frac{4\dot{m}}{\pi D \mu} = \frac{4\dot{m}}{\pi(10E\text{-}3)(5.46E\text{-}4)} \rightarrow \boxed{\dot{m}_c = 0.00986 \ kg/s}$$

③ $\dot{m} = 0.5\dot{m}_c = 0.00493$ kg/s

$$q = \dot{m} c_p (T_{out} - T_{in}) = (.00493)(4.18E3)(278.15 - 368.15) = \boxed{1855.243 \ W \text{ lost}}$$

④ $$Nu_D = \frac{hD}{k_f} = 3.66 = \frac{h(10E\text{-}3)}{(643.15E\text{-}3)} \rightarrow \boxed{h = 235.39 \ \frac{W}{m^2K}}$$

⑤ $$q = hA_s\Delta T_{lm} \rightarrow \Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \rightarrow$$

$\Delta T_1 = T_s - T_{m,i} = 0-95$
$\Delta T_1 = -95$
$\Delta T_2 = T_s - T_{m,o} = 0-5$
$\Delta T_2 = -5$

$$\Delta T_{lm} = -30.566°C$$

$$\dot{m} c_p (T_{out} - T_{in}) + h\pi D L \Delta T_{lm} = 0$$

$$L = -\frac{\dot{m} c_p (T_{out} - T_{in})}{h\pi D \Delta T_{lm}}$$

$$L = \frac{(.00493 \ kg/s)(4.1813E3 \ J/kgK)}{(235.39 \ \frac{W}{m^2K})(\pi)(10E\text{-}3m)} \frac{(5°C - 95°C)}{-30.566°C} = \boxed{8.2078m}$$

⑥ $$q'' = h(T_s - T_m(x))$$

$$q'' = (235.39)(273.15 - 323.15) = \boxed{-11769.5 \ W/m^2}$$

Kiara Koeppen
KKoeppen@purdue.edu
0027178757

Assumptions: SS,

Problem 4

Source: Fundamentals of Heat + Mass Transfer 7th edition Incoropera

① $T_f = \dfrac{T_s + T_\infty}{2} = \dfrac{32+22}{2} = 27°C = 300K$

$\rho = 1.1614\ kg/m^3$, $C_p = 1.007\ \frac{KJ}{kg K}$, $\mu = 184.6E-7\ \frac{N \cdot s}{m^2}$, $\nu = 15.89E-6\ \frac{m^2}{s}$, $k = 26.3E-3\ \frac{W}{mK}$, $\alpha = 22.5E-6\ m^2/s$

② $Ra_L = \dfrac{g\beta(T_s - T_\infty)L^3}{\nu\alpha} = \dfrac{(9.81)\left(\frac{1}{300}\right)(305.15-295.15)(.5)^3}{(15.89E-6)(22.5E-6)} = 11432766 9.4$

$\overline{Nu}_L = 0.59 Ra_L^{1/4} = 61.0084 = \dfrac{\bar{h}L}{k} \rightarrow \bar{h} = 3.209\ W/m^2K$

$q_{conv} = hA(T_s - T_\infty) = (3.209)(.5 \times .5)(305.15-295.15) = 8.0226W$

$q_{conv,total} = 2q_{conv} = \boxed{16.0452W}$

③ $q_{rad} = \varepsilon A\sigma(T_s^4 - T_{surr}^4) = (1)(.5 \times .5)(5.67E-8)(305.15^4 - 295.15^4)$

$q_{rad} = 15.336W$

$q_{rad,total} = 2q_{rad} = \boxed{30.672W}$

```
T_start = 25 + 273.15
T_end=50 + 273.15
T_surr=22 + 273.15
L=0.5
T_inf=22 + 273.15
nu=15.89*10**(-6)
k=26.3*10**(-3)
alpha=22.5*10**(-6)
T_s=np.arange(T_start, T_end, 1)
l=np.arange(0, (T_end-T_start)/1, 1, dtype=int)
q_conv=np.zeros(len(T_s), dtype=float)
q_rad=np.zeros(len(T_s), dtype=float)
q_total=np.zeros(len(T_s), dtype=float)
for i in l:
  T_film=((T_s[i]+T_inf)/2)
  Ra=((9.81)*(1/T_film)*(T_s[i]-T_inf)*(L**3))/((nu)*(alpha))
  Nu=(0.59)*(Ra**0.25)
  h_bar=Nu*k/L
  q_conv[i]=h_bar*L*L*2*(T_s[i]-T_inf)
  q_rad[i]=(5.67*10**(-8))*L*L*2*((T_s[i]**4-T_surr**4))
  q_total[i]=q_conv[i]+q_rad[i]
plt.plot(T_s, q_conv, label="q_convection")
plt.plot(T_s, q_rad, label="q_radiation")
plt.plot(T_s, q_total, label="q_total")
plt.legend()
plt.title('Heat Loss')
plt.xlabel('Temperature (K)')
plt.ylabel('Heat Loss (W)')
```

```
Text(0, 0.5, 'Heat Loss (W)')
```