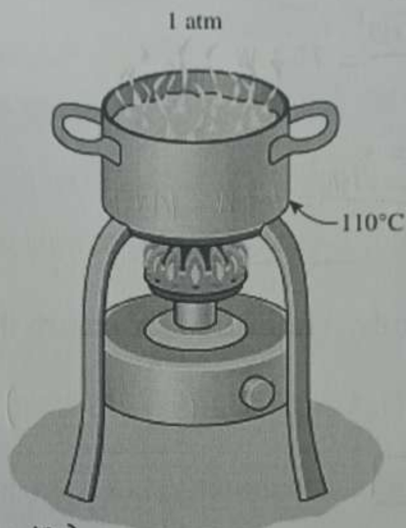
MAE-308 Heat transfer

DDL： 6.2

1. Water is to be boiled at atmospheric pressure in a mechanically polished steel pan placed on top of a heating unit. The inner surface of the bottom of the pan is maintained at 110°C. If the diameter of the bottom of the pan

$d = 30\,cm = 0.3\,m$

is 30 cm, determine (a) the rate of heat transfer to the water and (b) the rate of evaporation.



解:

a) At 1 atm

water $T_{sat} = 100°C$

$\Delta T_{excess} = T_s - T_{sat} = 10°C$

$\Rightarrow$ nucleate boiling

From Table A-9

$\mu_L = 0.282 \times 10^{-3}\ kg/m \cdot s$

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

$\rho_L = 957.9\ kg/m^3$

$\rho_v = 0.5978\ kg/m^3$

$C_{pl} = 4217\ J/kg \cdot K$

$P_r = 1.75$

From Table 10-1

$\sigma = 0.0589\ N/m$

From Table 10-3

$C_{sf} = 0.013,\ n = 1$

$$q_{nucleate} = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{\frac{1}{2}} \left[\frac{C_{pl}(T_s - T_{sat})}{C_{sf}\, h_{fg}\, Pr_l^{n}}\right]^3$$

$$= 140784\ W/m^2$$

$$\Phi = q_{nucleate} \cdot A = q_{nucleate} \cdot \frac{\pi}{4} D^2 = 9951\,W \quad \boxed{ANS}$$

b) $\Phi = \dot{m}\, h_{fg}$

$$\Rightarrow \dot{m} = \frac{\Phi}{h_{fg}} = 4.41 \times 10^{-3}\ kg/s \quad \boxed{ANS}$$

2. Water is boiled at sea level in a coffee maker equipped with a 20-cm-long 0.4-cm-diameter immersion-type electric heating element made of mechanically polished stainless steel. The coffee maker initially contains 1L of water at 14°C. Once boiling starts, it is observed that half of the water in the coffee maker evaporates in 25 min. Determine the power rating of the electric heating element immersed in water and the surface temperature of the heating element. Also determine how long it will take for this heater

Φ

to raise the temperature of 1L of cold water from 14°C to the boiling temperature.

解:

At sea level, pressure = 101 kPa

properties of saturated water at 100°C

from Table A-9

$\rho_L = 957.9\ kg/m^3 \quad \rho_v = 0.6\ kg/m^3$

$Pr_L = 1.75 \quad h_{fg} = 2257000\ J/kg$

$\mu_L = 0.282\times10^{-3}\ kg/m\cdot s \quad C_{PL} = 4217\ J/kg$

from Table 10-1

$\sigma = 0.0589\ N/m$

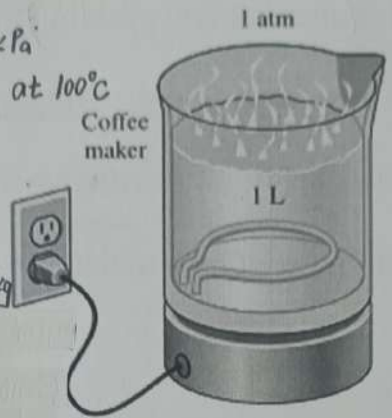
from Table 10-3

$C_{sf} = 0.013,\ n = 1$

$m = \rho_L V = 957.9\times10^{-3} = 0.9579\ kg$

half water evaporation, in 25 mins

$\Phi = \frac{\frac{1}{2} m h_{fg}}{t} = \frac{\frac{1}{2}\times0.9579\times2257\times10^3}{25\times60} = 721\ W$ $\boxed{ANS}$



Assume nucleate boiling

$$q_{nucleate} = \mu_l h_{fg} \cdot \left[\frac{g(\rho_L-\rho_v)}{\sigma}\right]^{\frac{1}{2}} \left[\frac{C_{pL}(T_s - T_{sat})}{C_{sf}\cdot h_{fg}\cdot Pr_L^n}\right]^3$$

$$= \frac{\Phi}{\pi D\cdot L}$$

$\Rightarrow T_s = 113°C$ $\boxed{ANS}$

$\Delta T = (113-100) = 13°C \in (5, 30)$ check

water from 14°C to boiling T = 100°C

$T_{arg} = \frac{14+100}{2} = 57°C$

From Table A-9

$\rho_L = 985.2 + \frac{57-55}{60-55}\times(983.3-985.2) = 984.4\ kg/m^3$

$C_{PL} = 4184\ J/kg\cdot K$

$\Phi \cdot t = \rho_L V\cdot C_{PL}(T_2 - T_1)$

$\Rightarrow t = \frac{\rho_L V\cdot C_{PL}(T_2-T_1)}{\Phi} = 491\ s$ $\boxed{ANS}$

3. Mechanically polished, 5-cm-diameter, stainless steel ball bearings are heated to 125°C uniformly. The ball bearings are then submerged in water at 1 atm to be cooled. Determine the rate of heat that is removed from a ball bearing at the instant it is submerged in the water.

解: At 1 atm,

for water, $T_{sat} = 100°C$

$\Delta T_{excess} = 125 - 100 = 25°C$

consider it as nucleate boiling

From Table A-9

$\mu_L = 0.282\times10^{-3}\ kg/m\cdot s$

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

$\rho_L = 957.9\ kg/m^3,\ \rho_v = 0.5978\ kg/m^3$

$C_{PL} = 4217\ J/kg\cdot K,\ Pr_L = 1.75$

Table 10-1, $\sigma = 0.0589\ N\cdot m$; Table 10-3, $C_{sf} = 0.013,\ n = 1$

$$q_{nucleate} = \mu_l h_{fg}\left[\frac{g(\rho_L-\rho_v)}{\sigma}\right]^{\frac{1}{2}}\left[\frac{C_{pL}(T_s-T_{sat})}{C_{sf} h_{fg} Pr_L^n}\right]^3$$

$$= 2199753\ W/m^2$$

$\Phi = q_{nucleate}\cdot 4\pi r^2 = 17277\ W = 17.277\ kW$ $\boxed{ANS}$

4. A small surface of area $A_1 = 3\ cm^2$ emits radiation as a blackbody, and part of the radiation emitted by A_1 strikes another small surface of area $A_2 = 8\ cm^2$ oriented as shown in the figure. If the rate at which radiation emitted by A_1 that strikes A_2 is measured to be 274×10^{-6} W, determine the

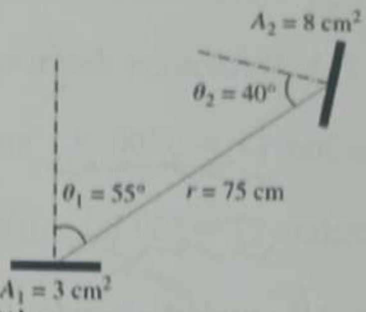
(intensity of the radiation) emitted by A_1, and the (temperature) of A_1.

解: $F_{1-2} = \frac{1}{A_1}\int_{A_2}\int_{A_1}\frac{\cos\theta_1\cos\theta_2}{\pi r^2}dA_1 dA_2$

$= \frac{1}{A_1}\frac{\cos\theta_1\cos\theta_2}{\pi r^2}A_1 A_2$

$= \frac{\cos\theta_1\cos\theta_2}{\pi r^2}A_2$

$= 1.989\times10^{-4}$



$\Phi_1 = A_1 E_{b_1} F_{1-2}$

$= A_1\sigma T_1^4 F_{1-2} = 274\times10^{-6}\ W$

$\Rightarrow T_1 = 533.5\ k$ $\boxed{ANS}$

$E_{b_1} = 4592\ W/m^2$

$I_1 = \frac{E_{b1}}{\pi} = 1462\ W/m^2$ $\boxed{ANS}$

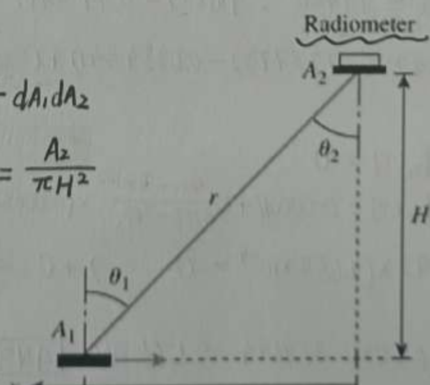
5. A radiometer can be used to determine the position of an approaching hot object by measuring the amount of (irradiation) it detects. Consider a radiometer placed at a distance H = 0.5 m from the x-axis is used to measure the position of an approaching small (blackbody) object. If the radiometer is measuring (80%) of the irradiation corresponding to the position of the (object directly) under the radiometer (x = 0), determine the position of the object L.

解: object directly under the radiometer

$\theta_1 = \theta_2 = 0$

$F_{1-2} = \frac{1}{A_1}\int_{A_2}\int_{A_1}\frac{\cos\theta_1\cos\theta_2}{\pi H^2}dA_1 dA_2$

$= \frac{1}{A_1}\frac{1}{\pi H^2}\cdot 1\cdot A_1\cdot A_2 = \frac{A_2}{\pi H^2}$



$\Phi_1 = A_1 E_{b_1} F_{1-2}$

object distance $x = L$

$\cos\theta_1 = \frac{H}{r}$, $\cos\theta_2 = \frac{H}{r}$

$F_{1-2}' = \frac{1}{A_1}\int_{A_2}\int_{A_1}\frac{\cos\theta_1\cos\theta_2}{\pi r^2}dA_1 dA_2$

$= \frac{1}{A_1}\frac{1}{\pi r^2}\cdot\frac{H^2}{r^2}\cdot A_1 A_2 = \frac{H^2}{\pi r^4}A_2$

$\Phi_1' = A_1 E_{b_1} F_{1-2}' = 80\%\ A_1 E_{b_1} F_{1-2}$

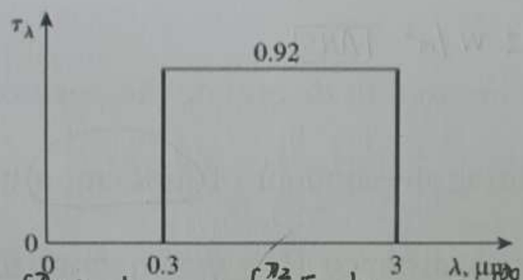
$\Rightarrow \frac{H^2}{\pi r^4}A_2 = 0.8\times\frac{A_2}{\pi H^2}$

$\Rightarrow r = (\frac{1}{0.8}H^4)^{\frac{1}{4}} = 0.5287\ m$

$L = \sqrt{r^2 - H^2} = 0.1718\ m$ $\boxed{ANS}$

6. The variation of the spectral transmissivity of a 0.6-cm-thick glass window is as given in Fig. Determine the average transmissivity of this window for solar radiation (T ≈ 5800 K) and radiation coming from surfaces at room temperature (T ≈ 300 K). Also, determine the amount of solar radiation transmitted through the window for incident solar radiation of 650 W/m2.

G



解:

$$\tau(T) = \frac{\tau_1 \int_0^{\lambda_1} E_{b\lambda} d\lambda}{E_b(T)} + \frac{\tau_2 \int_{\lambda_1}^{\lambda_2} E_{b\lambda} d\lambda}{E_b(T)} + \frac{\tau_3 \int_{\lambda_2}^{\infty} E_{b\lambda} d\lambda}{E_b(T)}$$

$$= \tau_1 f_{0-\lambda_1}(T) + \tau_2 f_{\lambda_1-\lambda_2}(T) + \tau_3 f_{\lambda_2-\infty}(T)$$

$$= \tau_1 f_{\lambda_1}(T) + \tau_2 [f_{\lambda_2}(T) - f_{\lambda_1}(T)] + \tau_3 [1 - f_{\lambda_2}(T)]$$

At $T = 5800K$,

$\lambda_1 T = 0.3 \times 5800 = 1740$, $f_{\lambda_1}(T) = 0.019718 + \frac{1740-1600}{1800-1600} \times (0.039341 - 0.019718) = 0.0334541$

$\lambda_2 T = 3 \times 5800 = 17400$, $f_{\lambda_2}(T) = 0.973814 + \frac{17400-16000}{18000-16000} \times (0.980860 - 0.973814) = 0.9787732$

$\tau(T) = 0 + 0.92 \times (0.9787732 - 0.0334541) + 0 = 0.869694$ $\boxed{ANS}$

At $T = 300K$

$\lambda_1 T = 90$, $f_{\lambda_1}(T) = 0$

$\lambda_2 T = 900$, $f_{\lambda_2}(T) = 0.000016 + \frac{900-800}{1000-800} \times (0.000321 - 0.000016) = 1.685 \times 10^{-4}$

$\tau(T) = 0 + 0.92 \times (1.685 \times 10^{-4} - 0) + 0 = 1.5502 \times 10^{-4}$ $\boxed{ANS}$

$G_{tr} = G \cdot \tau = 650 \times 0.869694 = 565\ W$ $\boxed{ANS}$