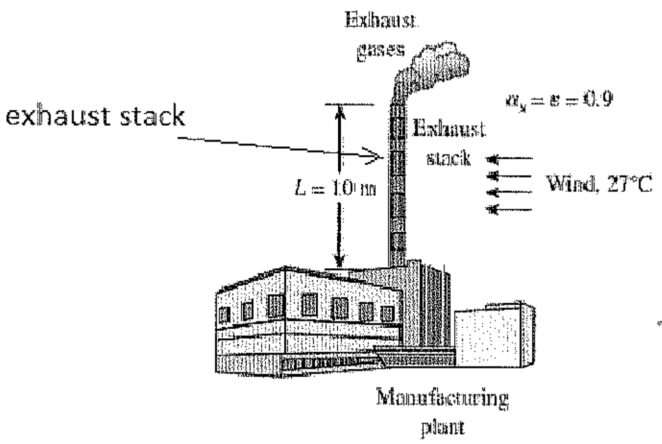
CANKAYA UNIVERSITY
FACULTY OF ENGINEERING AND ARCHITECTURE
MECHANICAL ENGINEERING DEPARTMENT

ME 313 HEAT TRANSFER
FINAL EXAM

FALL 2018

P1) Exhaust gases from a manufacturing plant are being discharged through a 10-m-tall exhaust stack with outer diameter of 1 m. On a particular day, wind at 27 ^{0}C is blowing across the exhaust stack with a velocity of 10 m/s, while the outer surface of the exhaust stack experiences radiation with the surrounding at 27 ^{0}C. Solar radiation is incident on the exhaust stack outer surface at a rate of 1400 W/m^2 , and both the emissivity and solar absorptivity of the outer surface are 0.9. The exhaust stack outer surface temperature is 133 ^{0}C. Estimate the heat loss from the exhaust stack.



$$T_f = \frac{T_s + T_\infty}{2} = 80^\circ C$$

$$k = 0.02953 \text{ W/mK}$$

$$\nu = 2.097 \times 10^{-5} \text{ m}^2/\text{s}$$

$$Pr = 0.7154$$

$$Re_D = \frac{VD}{\nu} = 4.769 \times 10^5$$

$$\overline{Nu_D} = \frac{\bar{h} D}{k} = 0.3 + \frac{0.62\sqrt{Re_D}\, Pr^{1/3}}{\left[1 + (0.4/Pr)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re_D}{282000}\right)^{5/8}\right]^{4/5}$$

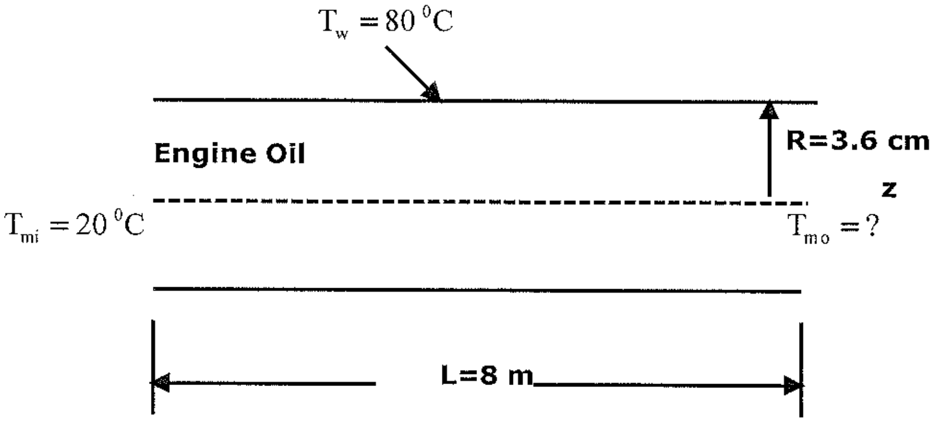
$$\Rightarrow \bar{h} = 19.95 \text{ W/m}^2\text{K}$$

$$A = \pi D L = 31.42 \text{ m}^2$$

$$q = \left[\bar{h}\left[T_s - T_\infty\right] + \epsilon\sigma\left[T_s^4 - T_{sur}^4\right] - \alpha q''\right] \pi D L$$

$$\cong 57600 \text{ W}$$

P2) Engine oil flows through a 3.6 cm diameter 8-m long tube at a mass flow rate of 0.36 kg/s. The oil enters the tube at a temperature of $T_{mi} = 20\,^{\circ}C$.



a) For the configuration given in the problem, show that the average Nusselt number is given by

$$\overline{Nu_L} = \frac{1}{4}\frac{(Re_D\,Pr)}{(L/D)}\ln\left(\frac{T_w - T_{mi}}{T_w - T_{mo}}\right)$$

b) Find the outlet temperature T_{mo} of the air

c) Find the heat transfer

Hint: Estimate the fluid properties at the inlet temperature $20\,^{\circ}C$

$\overline{T} = 20^{\circ}C = 290K$

$\rho = 890\ kg/m^3$ $\quad C_p = 1.868\ KJ/kgK$ $\quad \mu = 100\times10^{-2}\ \frac{Ns}{m^2}$

$k = 0.145\ W/mK$ $\quad Pr = 12900$

a) $$\frac{T_s - T_{mo}}{T_s - T_{mi}} = \exp\left[-\frac{PL}{\dot{m}C_p}\,\overline{h}\right]$$

$$\ln\left[\frac{T_s - T_{mo}}{T_s - T_{mi}}\right] = -\frac{\pi D\,L}{\rho V \frac{D^2\pi}{4} C_p}\,\overline{h}$$

$$= -\frac{4\,(L/D)}{\frac{\mu C_p}{k}\ \frac{\rho V D}{\mu}}\cdot\frac{\overline{h}D}{k}$$

$$\overline{Nu_D} = \frac{Re\,Pr}{4(L/D)} \ln\left[\frac{T_w - T_{mi}}{T_w - T_{mo}}\right]$$

b) $$Re_D = \frac{4\dot{m}}{\pi D \mu} = 12{,}7$$

$$z_{fd,H} = 0.05\, Re_D D = 0.02291 \ll L$$

$$z_{fd,T} = 0.05\, Re_D D\, Pr$$

$$\cong 295\ \text{m} \gg L$$

HFD and thermally developing

$$\overline{Nu_D} = 3{,}66 + \frac{0.0668\,(D/L)\,Re\,Pr}{1 + 0.04\left[\left(\frac{D}{L}\right)Re\,Pr\right]^{2/3}}$$

$$= 5{,}22$$

$$\bar{h} = \frac{k}{D}\overline{Nu} = \left(\frac{0.145}{0.036}\right)(5{,}22) = 21{,}31\ \text{W/m}^2\text{K}$$

$$\frac{T_w - T_{mo}}{T_w - T_{mi}} = \exp\left[-\frac{\pi D L \bar{h}}{\dot{m} c_p}\right]$$

$$T_{mo} = 21.55°\text{C}$$

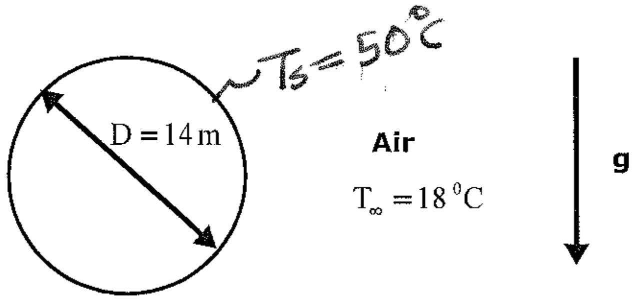
c) $$q = \dot{m} c_p (T_{mo} - T_{mi})$$

$$= 1042\ \text{W}$$

no more iteration is necessary

sin $\overline{T_m} = \frac{(21.55 + 20)}{2} \cong 20{,}77°\text{C}$

3) A hot -air balloon measuring 14 m in diameter is neutrally buoyant in 18 ^{0}C air at an altitude of 1500 m above sea level. The temperature of the fabric, which reflects the average temperature of air inside the balloon , must be 50 ^{0}C for the balloon to maintain its vertical position. Find the rate at which heat must be supplied to air in the balloon by its propane burner system.



The density of air at 1500 m is $\rho = 1.059\ \mathrm{kg/m^3}$ .The remaining air properties do not change with altitude.

$$T_f = \frac{T_s + T_\infty}{2} = 34°C = 307K$$

$$\mu = 187.9 \times 10^{-7}\ N.s/m^2 \qquad k = 0.0268\ W/m\,K$$

$$\beta = \frac{1}{T_f} = 3.257 \times 10^{-3}\ 1/K, \quad \rho = 1.059\ kg/m^3$$

$$\nu = \mu/\rho = 1.774 \times 10^{-5}\ m^2/s$$

$$\alpha = \frac{k}{\rho c_p} = 2.513 \times 10^{-5}\ m^2/s$$

$$Pr = \frac{\nu}{\alpha} = 0.706$$

$$Ra_D = \frac{g\beta (T_s - T_\infty) D^3}{\nu \alpha} = 6.293 \times 10^{12}$$

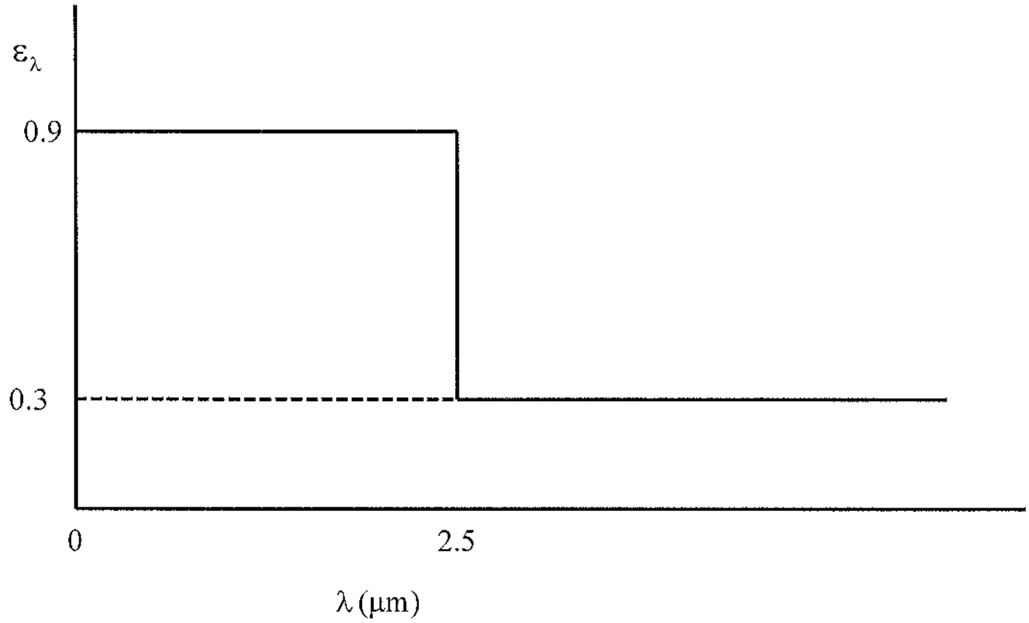
$$\overline{Nu}_D = \frac{\bar{h} D}{k} = 2 + \frac{0.589\, Ra_D^{1/4}}{\left[1 + \left(\frac{0.469}{Pr}\right)^{9/16}\right]^{4/9}}$$

$$= 721$$

$$\bar{h} = \frac{k}{D} \overline{Nu}_D = 1.38\ W/m^2K$$

$$q = \bar{h}\, \pi D^2 (T_W - T_\infty) = 27.2\ kW$$

4) A surface has a spectral, hemispherical emissivity that approximated by the distribution shown in the diagram below, and the temperature of the surface is 1927 °C . Find the total hemispherical emissivity and the total emissive power (radiative heat flux) of the surface.



$0 < \lambda < 2.5$ $\quad \epsilon_1 = 0.9$

$\lambda > 2.5$ $\quad \epsilon_2 = 0.3$

$$\epsilon = \frac{\epsilon_1 \int_0^{2.5} E_{\lambda b} d\lambda}{\sigma T^4} + \epsilon_2 \int_{2.5}^{\infty} \frac{E_{\lambda b} d\lambda}{\sigma T^4}$$

$$= \epsilon_1 F_{0-2.5} + \epsilon_2 (1 - F_{0-2.5})$$

$\lambda_1 T = (2.5 \mu m)(2200 K) = 5500 \mu m K$

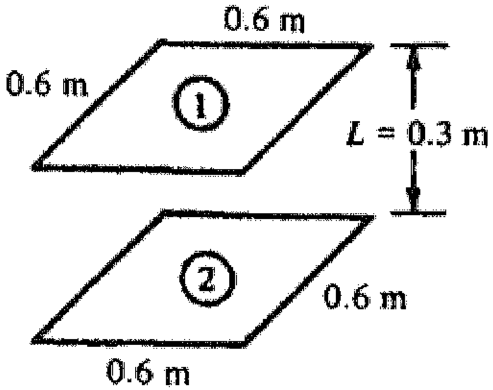
$F_{0-\lambda_1} \simeq 0.69703$

$\epsilon = 0.9 \times 0.69703 + 0.3 (1 - 0.69703) = 0.714$

$E = \epsilon \sigma T^4 = 0.714)(5.67 \times 10^{-8})(2200)^4$

$= 9.48 \times 10^5 \ W/m^2$

P5) Two aligned, parallel square plates 0.6 m by 0.6 m are separated by $L = 0.3$ m, as illustrated in the accompanying figure. Plate 1 is maintained at $T_1 = 1000$ K and has an emissivity $\varepsilon_1 = 0.7$. Plate 2 is maintained at $T_2 = 500$ K and has an emissivity $\varepsilon_2 = 0.5$. The plates are exposed through the opening between them into an ambient which can be regarded as a black medium at $T_\infty = 300$ K. Sketch the radiation network for the two surfaces and the ambient. Calculate the heat transfer between the plate and the heat loss to the ambient.



$X = 0.6\,m \quad Y = 0.6\,m$

$L = 0.3\,m$

$\frac{X}{L} = 2, \quad \frac{Y}{L} = 2 \quad F_{12} \cong 0.42, \quad F_{21} \cong 0.42$

$\cancel{F_{11}} + F_{12} + F_{13} = 1$ ($F_{11} = 0$)

$F_{13} = 1 - F_{12} = 0.58$

$F_{21} + \cancel{F_{22}} + F_{23} = 1$ ($F_{22} = 0$)

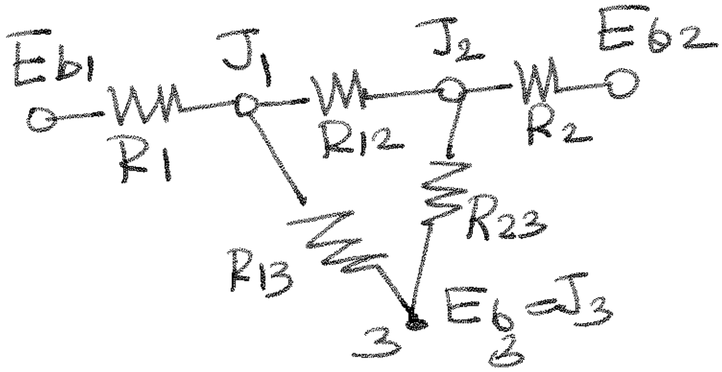
$F_{23} = 1 - F_{21} = 0.58$

$R_1 = \frac{1-\varepsilon_1}{\varepsilon_1 A_1} = 1.19$

$R_2 = \frac{1-\varepsilon_2}{\varepsilon_2 A_2} = 2.78$

$R_{12} = \frac{1}{A_1 F_{12}} = 6.61$

$R_{23} = \frac{1}{A_2 F_{23}} = 4.79$



$E_{b_1} = \sigma T_1^4 = 5.67 \times 10^4\ W/m^2$

$E_{b_2} = \sigma T_2^4 = 0.3544 \times 10^4\ W/m^2$

$E_{b_3} = \sigma T_3^4 = 0.04593\ W/m^2$

Node-1

$$\frac{E_{b1}-J_1}{R_1}+\frac{J_2-J_1}{R_{12}}+\frac{E_{b3}-J_1}{R_{13}}=0$$

Node 2

$$\frac{E_{b2}-J_2}{R_2}+\frac{J_1-J_2}{R_{12}}+\frac{E_{b3}-J_2}{R_{13}}=0$$

$J_1 = 40\,956 \ \omega/m^2$

$J_2 = 10\,804 \ \omega/m^2$

so

$$q_1=\frac{E_{b1}-J_1}{\frac{1-\epsilon_1}{\epsilon_1 A_1}}=13\,231 \ W$$

$$q_2=\frac{E_{b2}-J_2}{\frac{1-\epsilon_2}{\epsilon_2 A_2}}=-2504 \ W$$

$$q_3=\frac{E_{b3}-J_1}{R_{13}}+\frac{E_{b3}-J_2}{R_{23}}=-10551 \ W$$