Notre Dame University Faculty of Engineering Mechanical Engineering Dep.

TEST– MEN310 (Heat Transfer)

January 23, 2001

1. A radiation shield is placed between two parallel plates. The radiation properties and the surface conditions for each plate are as follow:

   - Plate 1: T_1=1000K, ε_1=0.8
   - Plate 2: T_2=500K, ε_2=0.5

   Determine the emissivity of the shield in order to reduce the radiation heat transfer between the plates to one tenth of that without the shield. Find the net radiative heat transfer rate per unit area between plates 1 and 2 and calculate the equilibrium temperature of the shield.

2. Consider the flow of oil (assume engine oil) at 20°C inlet temperature in a 30-cm-diameter pipeline at an average velocity of 2 m/s. A 200-m-long section of the pipeline passes through icy waters of a lake at 0°C. The pipe wall is characterized by a negligible resistance to heat transfer.

   a) Assuming the pipe wall temperature equal to 0°C, determine the temperature of the oil when the pipe leaves the lake and the heat lost to the icy waters.

   b) Instead of the 0°C wall temperature assumption, one can argue that a 20°C wall temperature is a better assumption. Determine the heat lost by the pipeline during its passage in the lake.

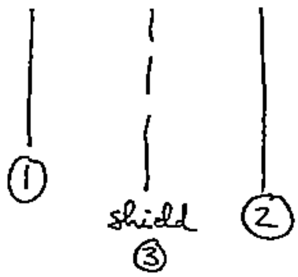
   c) In your opinion, which assumption (a or b) is better to correctly represent the real heat transfer behavior of the pipeline in the icy waters. Explain.

Points: 1 (40%) and 2 (60% or 25%+25%+10%).

Jan. 23, 2001

1) $T_1 = 1000K$; $\epsilon_1 = 0.8$

$T_2 = 500K$; $\epsilon_2 = 0.5$



$\epsilon_3 = ?$ $\quad q_{shield} = \frac{1}{10} q_{without}$

using eq. 8-42 $\longrightarrow \frac{q}{A}_{without} = \dfrac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = 23620.833 \, W/m^2$

$\longrightarrow \frac{q}{A}_{shield} = 2362.0833 \, W/m^2$

Using figure 8.31 $\longrightarrow \frac{q}{A}\Big)_{shield} = \dfrac{Eb_1 - Eb_2}{\Sigma R} = \dfrac{\sigma(T_1^4 - T_2^4)}{\Sigma R}$

$\longrightarrow \Sigma R = 22.5$

$$\longrightarrow \Sigma R = \frac{1-\varepsilon_1}{\varepsilon_1} + \frac{1}{\underbrace{F_{13}}_{=1}} + 2\left(\frac{1-\varepsilon_3}{\varepsilon_3}\right) + \frac{1}{\underbrace{F_{32}}_{=1}} + \frac{1-\varepsilon_2}{\varepsilon_2}$$

$\longrightarrow \varepsilon_3 = \frac{8}{85} \longrightarrow \boxed{\varepsilon_3 = 0.0941}$

- net radiative heat transfer is already calculated $\longrightarrow$

$$\frac{q}{A} = 2362.0833 \, W/m^2.$$

- $T_3 = ?$

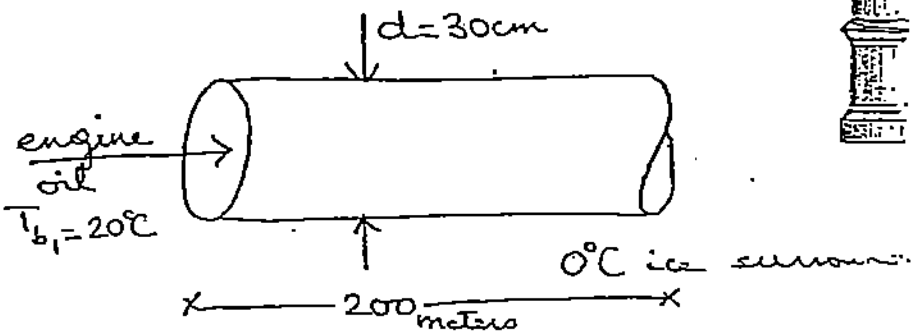
Referring to fig 8-32, p.437 $\longrightarrow \dfrac{q}{A} = \dfrac{Eb_1 - Eb_3}{\left(\frac{1-\varepsilon_1}{\varepsilon_1} + \frac{1}{F_{13}} + \frac{1-\varepsilon_3}{\varepsilon_3}\right)} \longrightarrow Eb_3 =$ 30997.

$\longrightarrow \boxed{T_3 = 859. \, K}$

TEL.: 950415 - TELEX: 20049 AQUALI LE - B.P. 80106 - BEYROUTH - LIBAN

Jan. 23, 2001

2)



$u_\infty = 2\,m/sec$

a) $T_w = 0°C$

$\Rightarrow$ forced convection is encountered :

oil: ~~$T_f = \frac{20+0}{2} = 10°C$~~ Using equation 6-10 ;

assume $T_{b\,avg} = 20°C \longrightarrow \rho = 888.23\ Kg/m^3$

$\nu = 0.0009\ m^2/sec$

$P_r = 10400$

$k = 0.145$

$\rightarrow R_{e_d} = \frac{u_\infty d}{\nu} = \frac{2 \times 0.3}{0.0009} = 666.667 < 2300 \rightarrow$ laminar

$R_{e_d} P_r \frac{d}{L} > 10$

$\rightarrow$ eq. 6.10 valid.

$$Nu_d = 1.86 \left(Re_d P_r\right)^{1/3} \cdot \left(\frac{d}{L}\right)^{1/3} \cdot \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

where $\mu = \rho \nu$

$\mu_w = \rho \nu\ (@\ 0°C)$

$= 899.12 \times 0.004$

$= 3.8482336\ Kg$

$\rightarrow Nu_d = 32.58179767 = \frac{hd}{k}$

$\longrightarrow \boxed{h = 15.74786\ W/m^2\,°C}$

$q = hA\left(\frac{T_{b_1}+T_{b_2}}{2} - T_w\right) = \dot{m}\, c_p \left(T_{b_1} - T_{b_2}\right)$ where $\dot{m} = \rho u_\infty \frac{\pi d^2}{4}$

1.88×1

Jan. 23, 2001

$\rightarrow \boxed{T_{b_2} = 19.75°C.}$; $q = hA\left(\frac{T_{b_1}+T_{b_2}}{2} - T_w\right) = 58996.98333$ Watts

(a second iteration could be better, but it will not improve more). (or Use Mixed-Convection phenomena ; $\Rightarrow Re = 231.66$
$\rightarrow Gr\,Pr\,d/L = 120216.1956$ $\rightarrow \bar{h} = 20.402\ W/m^2°C$)

b) $T_w = 20°C$ $\rightarrow$ no heat transfer due to forced convection

$\rightarrow$ free convection is encountered.

$$T_f = \frac{20+0}{2} = 10°C \rightarrow$$

$c_p = 4.195 \cdot 10^3\ J/Kg°C$

$\rho = 999.2\ Kg/m^3$

$\mu = 1.31\ Kg/m\cdot sec \times 10^{-3}$

$k = 0.585\ W/m°C$

$Pr = 9.4$

$\frac{g\beta\rho^2 c_p}{\mu k} = 6.34 \times 10^9 /m^3°C$

$Gr\,Pr = 6.34 \times 10^9 \times (20-0) \times 0.3^3 = 34.236 \times 10^8$

Using eq. (7.25) $\rightarrow C = 0.13$, $m = 1/4$.

$\overline{Nu}_f = 0.13\,(Gr\,Pr)^m = 31.4459 = \frac{hd}{k}$

$\rightarrow h = 61.3195\ W/m^2°C$.

$\rightarrow q = hA\,(T_w - T_\infty) = h\,\pi d L\,(T_w - T_\infty)$

$\boxed{q = 231169.0689 \text{ Watts}}$

~~c) Since $h_a < h_b$~~
~~$\rightarrow \frac{1}{h_a} > \frac{1}{h_b}$~~
~~$\rightarrow R_a > R_b$~~
~~$\rightarrow$ for b $\rightarrow \frac{1}{R_b} \gg \rightarrow \Delta T$.~~
~~$\rightarrow$ T should close to c~~
~~$\rightarrow$ a is a better assu~~