SOLUTIONS

MIE 354 - Heat Transfer
Professor Rothstein
FINAL **Exam**
May 18, 2004

You will have 2 hours to complete the following problems. Please write carefully and clearly and make sure that you justify any assumption that you make. The exam is open book and open notes. Don't forget print your name at the top of this page. Good luck.

1. Some Quick Questions (20 Points)

a) Is the heat transfer coefficient larger for a laminar or a turbulent flow?

turbulent (1)

b) Under what conditions can the lumped capacity model be used to predict transient response of a solid?

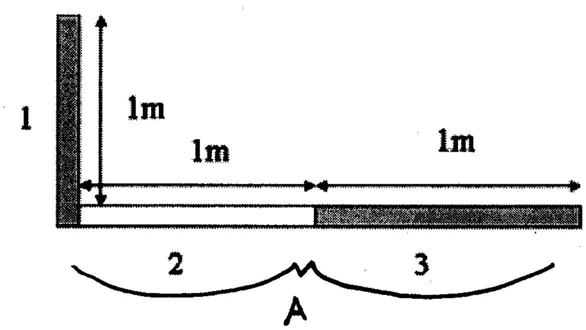
$Bi < 1/6$ (1) (1)

c) What is the Reynolds-Colburn analogy? (1) explain

(1) $$\frac{C_f}{2} = \frac{Nu}{Re\,Pr} Pr^{2/3} = \frac{Nu}{Re\,Pr^{1/3}}$$

d) If the temperature gradient in the fluid near a surface is increased, will the heat transfer coefficient be increased or decreased? increased (1)

e) What is the view factor from surface 1 to 3 below? The surfaces can be considered infinitely deep into the paper and are each 1m long.



(1)
$$F_{1A} = F_{12} + F_{13}$$

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

(1)
$$F_{1A} = \frac{1 + (2/1) - [1 + (2/1)^2]^{1/2}}{2}$$

$$F_{1A} = 0.38 \quad (1)$$

$$F_{12} = \frac{1 + 1 - [1 + 1^2]^{1/2}}{2}$$

$$F_{12} = 0.29$$

$$\boxed{F_{13} = 0.09} \quad (1)$$

2) a)

$$T_{\infty,out} \quad \frac{1}{h_o A} \quad T_{w,out} \quad \frac{t_w}{k_w A} \quad T_{w,in} \quad \frac{1}{h_i A} \quad T_{\infty,in}$$

$$A = L \cdot W = 0.5 m^2 \qquad R_w = \frac{t}{k_w A} = 7.14 \times 10^{-3}\ K/W$$

b) To determine $\overline{Nu}_{out}$ we first must determine if it is laminar or turbulent by calculating the Reynolds #.

$$Re_{out} = \frac{UL}{\nu} = 6.31 \times 10^6 > 5 \times 10^5 \quad \underline{\text{turbulent}}$$

we need to consider the laminar boundary layer as well so

$$\overline{Nu}_{L,out} = (0.037\, Re_L^{4/5} - 871)\, Pr^{1/3} = 661$$

$$\overline{h}_{L,out} = \frac{\overline{Nu}_{L,out}\, k}{L} = 29.1\ W/m^2 K$$

$$R_{out} = \frac{1}{hA} = 6.87 \times 10^{-2}\ K/W$$

c) The minimum heat transfer coefficient on the inside of the windshield corresponds to the condition where

$$T_{w,in} = T_{dp} = 5°C$$

To solve for the heat transfer coefficient we recognize that because the resistors above are in series, each has the same heat transfer rate flowing through it. So

$$q = \frac{(T_{w,in} - T_{\infty,out})}{R_{out} + R_w} = \frac{(T_{\infty,in} - T_{w,in})}{R_i}$$

$$R_i = \frac{1}{h_i A} = \frac{(T_{\infty,in} - T_{w,in})}{(T_{w,in} - T_{\infty,out})} (R_{out} + R_w)$$

$$R_i = 1.06 \times 10^{-[illegible]}\ K/W$$

$$h_i = \frac{1}{R_i A} = 18.8 \ W/m^2K \quad ①$$

d) If the flow is assumed fully turbulent then

$$\overline{Nu_L} = 0.037 \ Re^{4/5} Pr^{1/3} = 428 \quad ①$$

①

$$Re = \left(\frac{\overline{Nu_L}}{0.037 \ Pr^{1/3}} \right)^{5/4} = 1.39 \times 10^5 \quad ①$$

$$U = \frac{Re \, \nu}{L} = 3.1 \ m/s \quad ①$$

However, if we take into account the laminar region of the boundary layer

Extra

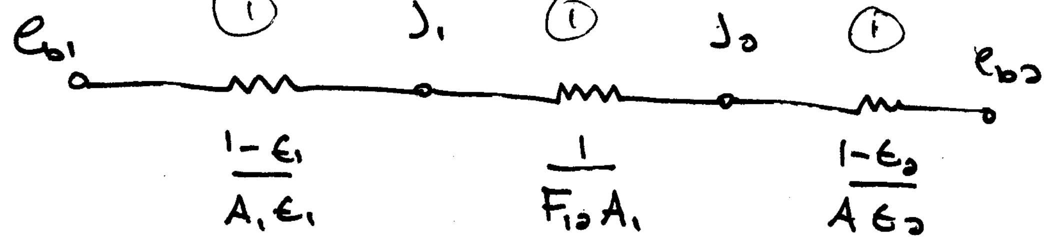
$$\overline{Nu_L} = (0.037 \ Re^{4/5} - 871) Pr^{1/3} \quad ①$$

$$Re = \left(\frac{\overline{Nu_L}}{Pr^{1/3}} + 871 \right)^{5/4} = 5.05 \times 10^6 \quad ①$$

$$U = 11.11 \ m/s \quad ①$$

$$\% \text{ difference/error} = \frac{11.11 - 3.1}{11.11} = \underline{\underline{72\%}} \quad ①$$

3) a)



b) $$q' = \frac{(e_{b2} - e_{b1})}{\Sigma R'} = \frac{\sigma(T_2^4 - T_1^4)}{\Sigma R'}$$

$$\Sigma R' = \frac{1-\epsilon_1}{2\pi R_1\epsilon_1} + \frac{1}{2\pi F_{12}R_1} + \frac{1-\epsilon_2}{2\pi R_2\epsilon_2} \quad ; \quad F_{12} = 1$$

$$\Sigma R' = R'_{TOT} = 343\,mK/W + 10.6\,mK/W + 121\,mK/W$$

$$R_{TOT} = 475\,mK/W$$

$$q' = 0.84\ W/m$$

c) if $\epsilon_1 = \epsilon_2 = 1$ then

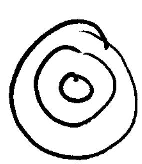
$$R'_{TOT} = \frac{1}{F_{12}(2\pi R_1)} = 10.6\ mK/W$$

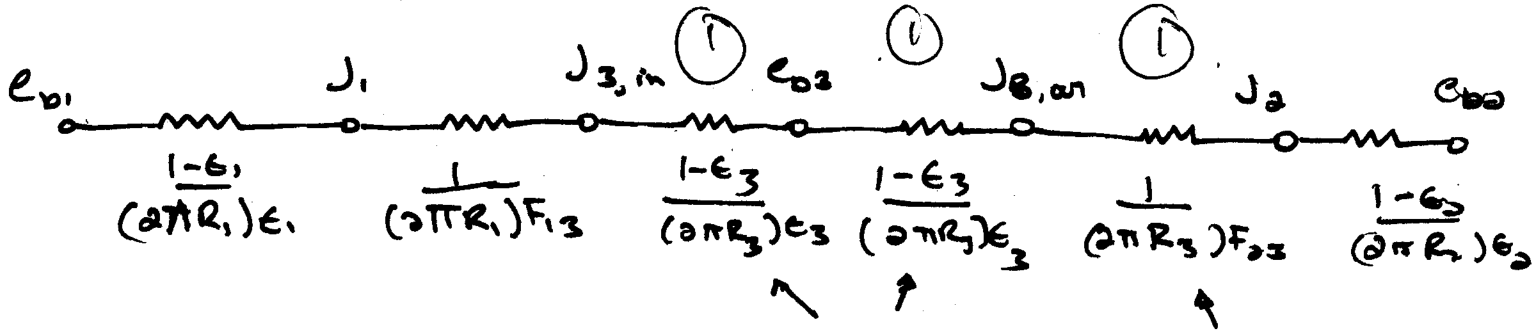
$$q' = 37.5\ W/m$$

if $\epsilon_1 = \epsilon_2 = 0$ then $R'_{TOT} = \infty$ and

$$q' = 0\ W/m$$

d) Now lets add an additional radiation shield having $\epsilon_3 = 0.03$





$$\sum R' = R'_{TOT} = \underbrace{475\ mK/W}_{part\ (b)} + 2\left(257\ mK/W\right) + 7.96\ mK/W$$

$$R'_{TOT} = 997\ mK/W \quad 1$$

$$q' = \frac{\sigma(T_2^4 - T_1^4)}{R_{TOT}'} = 0.399\ W/m \quad 1$$