Name Key

Class Time (**circle one**): **morning afternoon**

MECH-420 Heat Transfer-Final Exam

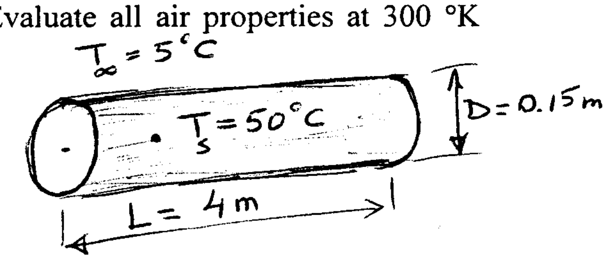
Thursday, June 17, 2004
1:00-3:00 p.m.
International Room

A. Pourmovahed

1.	Write your name at the top of this page. **Circle your class time.**
2.	This is an **open-book, open-notes** exam.
3.	You have **120 minutes** for this exam.
4.	**All work leading to the answer must be shown.**

Problem 1 (35 Points)

An insulated steam pipe is routed horizontally through an unheated room. The pipe is 4 m long; the outside diameter of the insulation is 0.15 m. The outside temperature of the insulation is 50 °C. The room temperature is 5 °C. How much heat is lost from the insulation by convection per unit time (in Watts)? Evaluate all air properties at 300 °K (except for the coefficient of thermal expansion, β).



Natural Convection, Horiz. Cyl.

Air at 300°K:

$\rho = 1.177\ kg/m^3$, $c_p = 1.006\ \frac{kJ}{kg \cdot °K}$

$\nu = 15.68 \times 10^{-6}\ m^2/s$

$\alpha = 0.2216 \times 10^{-4}$ " , $P_r = 0.708$, $K_f = 0.02624\ \frac{W}{m \cdot °K}$

$$\beta = \frac{1}{T_\infty} = \frac{1}{5+273} = 0.0036\ /°K$$

$$Ra_D = \frac{g\beta(T_s - T_\infty)D^3}{\nu\alpha} = \frac{9.81 * 0.0036\,(50-5)\,(0.15)^3}{(15.68\times10^{-6})(0.2216\times10^{-4})}$$

$Ra = 1.54 \times 10^7$

$$\overline{Nu}_D = \frac{\bar{h} D}{K_f} = \left\{0.6 + \frac{0.387\, Ra_D^{1/6}}{\left[1+\left(\frac{0.559}{P_r}\right)^{9/16}\right]^{8/27}}\right\}^2 = \frac{\bar{h}\,(0.15)}{0.02624}$$

$\bar{h} = 5.62\ \frac{W}{m^2 \cdot °K}$, $q = h(\pi D L)(T_s - T_\infty)$

$q = 5.62(\pi)(0.15)(4)(50-5) = 477\ W$

Problem 2 (40 Points)

A bank of diesel engines is used for electric power generation. It is proposed to use all or part of the exhaust gases for heating air, which can then be used for space heating to reduce costs. The mass flow rate of exhaust gases available from the engines is 90 kg/hour. The exhaust gas temperature is 600 °K. Air is available at 20 °C at a mass flow rate of 100 kg/hour and is not of much use unless it can be heated to at least 80 °C. A counter-flow, double-pipe heat exchanger with a $U_0 = 14.1\ W/(m^2 \cdot {}^\circ K)$ is available. **Using the NTU method, determine the required length of this heat exchanger in meters.**

The outside diameter of the inner pipe is 0.07938 m.

Evaluate air properties at 323 °K for which:

$c_p = 1007\ J/(kg.{}^\circ K)$

Treat diesel engine exhaust gases as CO_2 at an average temperature of 500 °K for which:

$c_p = 1013\ J/(kg.{}^\circ K)$

Hot fluid: exhaust gases, $T_{h,i} = 600°K$

$c_{p,h} = 1013\ J/Kg \cdot °K$

$\dot{m}_h = 90\ Kg/hr.$

Cold fluid: air $T_{c,i} = 20°C$, $T_{c,o} = 80°C$

$c_{p,c} = 1007 \frac{J}{Kg \cdot °K}$, $\dot{m}_c = 100\ Kg/hr.$

$$C_{min} = (\dot{m}\, c_p)_h = 90 \frac{Kg}{3600\ s}\ 1013 \frac{J}{Kg \cdot °K} = 25.325 \frac{W}{°K}$$

$$C_{max} = (\dot{m}\, c_p)_c\quad 100 \frac{1}{3600} (1007) = 27.972\ "$$

$$q = C_c (T_{c,o} - T_{c,i}) = 27.972 (80-20) = 1678\ W$$

$$q = \epsilon\, C_{min} (T_{h,i} - T_{c,i}) \Rightarrow \epsilon = \frac{1678}{25.325 (600-293)} = 0.216$$

$$C_r \equiv \frac{C_{min}}{C_{max}} = \frac{25.325}{27.972} = 0.905$$

$$NTU = \frac{1}{C_r - 1} \ln \left(\frac{\epsilon - 1}{\epsilon C_r - 1} \right) = \frac{1}{0.905-1} \ln \left(\frac{0.216-1}{.216 \times .905 - 1} \right) = 0.272$$

$$NTU \equiv \frac{U_o A_o}{C_{min}} = \frac{U_o (\pi D_o L)}{C_{min}} \Rightarrow L = \frac{NTU \cdot C_{min}}{\pi D_o U_o}$$

$$L = \frac{0.272 \times 25.325}{\pi (0.07938)(14.1)} = 1.96\ m$$

Problem 3 (25 Points)
Two very large parallel plates with emissivity of 0.7 exchange heat by radiation. One plate is at 800 °K, the other at 500 °K. Find the net **radiative** heat flux between these plates (W/m^2) when **two radiation shields** also with emissivities of 0.7 are placed between these plates.

$$\epsilon_1 = \epsilon_2 = 0.7 = \epsilon$$

$$(q_{12})_N = \frac{1}{N+1} (q_{12})_0$$

N = number of shields = 2

$$(q_{12})_2 = \frac{1}{3} (q_{12})_0 = \frac{1}{3} \frac{A\sigma (T_1^4 - T_2^4)}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}$$

$$(q''_{12})_2 \equiv \frac{(q_{12})_2}{A} = \frac{1}{3} \frac{\sigma (T_1^4 - T_2^4)}{\frac{2}{\epsilon} - 1}$$

$$= \frac{1}{3} \frac{5.67 \times 10^{-8} [800^4 - 500^4]}{\frac{2}{0.7} - 1}$$

$$= 3532 \frac{W}{m^2}$$