Mansoura University Faculty of Engineering Program of Biomedical Engineering. Course Title: Heat and Mass Transfer Course Code: MPE 271		Level: 200 Exam Type: Final Date: 11 January 2017 Time: 2 Hours Full Mark: 50

QUESTION NO. One: [15 Marks]

Q.1.a) State true or false. Correct the errors if any, in the following statements:

1. The value of the critical radius of insulation r_0 for a sphere is 2h/k.
2. Prandtl number gives an indication of the ratio of momentum diffusivity to the thermal diffusivity.
3. Nusselt number may be interpreted as the ratio of heat transfer by conduction to that by convection across the fluid layer.
4. In counter flow heat exchangers the outlet temperature of the cold fluid may exceed the outlet temperature of the hot fluid.
5. Nusselt number for turbulent forced convection, inside a circular tube in the hydro dynamically and thermally developed region under the constant wall heat flux boundary condition equals 4.36.
6. Schmidt number gives an indication of the ratio of momentum diffusivity to the mass diffusivity.

Q.1.b) Pick up the most appropriate statement of the multiple-choice answers .

1. ***In the heat flow equation $Q=(kA(t_1-t_2))/x$, the term (x/kA) is known as***

(a) thermal resistance (b) thermal coefficient (c) temperature gradient
(d) thermal conductivity (e) none of the above.

2. ***The heat dissipation from a finite fin with the tip insulated is given by:***

(a) $\sqrt{hPkA}(t_o - t_\infty)$ (b) $\sqrt{hPkA}(t_o - t_\infty)\tanh ml$

(c) $\sqrt{hPkA}(t_o - t_\infty)\dfrac{\tanh ml + (h/mk)}{1+(h/km)\tanh ml}$ (d) $\sqrt{hPkA}(t_o - t_\infty)\dfrac{\tanh ml + (h/k)m}{1+(h/km)\tanh ml}$

3. ***Mass is transferred by***

(a) conduction (b) conduction and radiation (c) conduction and convection
(d) conduction, convection and radiation (e) None of these.

4. ***The total incident radiant energy upon a body which reflects, absorbs and transmits radiant energy is 2200 W/m^2. Of this amount, 450 W/m^2 is reflected and 900 W/m^2 is absorbed by the body, the transmissivity τ will equal***

(a) 0.486 (b) 0.686 (c) 0.386 (d) 0.586.

5. ***The primary driving force for mass transfer is:***
(a) pressure difference (b) velocity difference (c) concentration difference
(d) temperature difference.

6. ***For a flow gas ($Pr = 0.71$, $\mu = 4.63\times10^{-5}$ kg/m.s and $Cp = 1175 J/kg.K$) over a turbine blade of 20 mm length, where the average heat transfer coefficient is 1 $kW/m^2.K$. The Nusselt number equals***
(a) 216 (b) 2.16 (c) 261 (d) 0.261.

7. ***Thermal radiation is defined as the portion of the electromagnetic spectrum that extends from about***
(a) 1 to 100 μm (b) 0.01 to 100 μm (c) 0.1 to 100 μm (d) 0.1 to 1000 μm.

c) A steam pipe of 10 cm inner diameter and 11cm outer diameter is covered with an insulating substance (k_{air} = 1 W/m.K). The steam temperature is 200˚C and ambient temperature is 20˚C. If the convective heat transfer coefficient between insulating surface and air is 8 $W/m^2.K$, find the critical radius of insulation. For this value of r_c, calculate the heat loss per meter of the pipe and the outer surface temperature. Neglect the resistance of the pipe material.

Question (2) [15 Marks]

a) A 1 kW medical central heating radiator 1.5 m long and 0.6 m high with a surface temperature of 80°C dissipating heat by radiation and convection into a room at 20°C ***(k_{air} = 0.026 W/m.K and assume black body radiation)***. Determine the Nusselt number for air.

b) A 1m long, 5 cm diameter cylinder placed in an atmosphere of 40˚C is provided with 10 longitudinal straight fins (k = 75 W/m.K) 0.75 mm thick. The fins protrude 2.5cm from the cylinder surface. The heat transfer coefficient from the cylinder and fins to the ambient air is 23.3 $W/m^2.K$. Calculate:

i. The rate of heat transfer if the surface temperature of the cylinder is 150˚C.
ii. Percentage increase in heat dissipation due to fins.
iii. The fin temperature at a distance of 2 cm from the cylinder.

c) Consider the flow of water with a flow rate of 71.4 kg/min through a tube 2 cm in diameter whose wall is maintained at constant temperature. The flow is hydrodynamically and thermally developed. Calculate the heat transfer coefficient. The properties of water are: [$\upsilon = 0.568 \times 10^{-6}$ m^2/s, Pr = 4.32 and k = 0.64 W/(m.˚C)].

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.33} \begin{pmatrix} 0.7 \le \mathrm{Pr} \le 160 \\ \mathrm{Re} \succ 10{,}000 \end{pmatrix}$$ for turbulent flow

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Question (3) [10 Marks]

a) Classify the types of Heat Exchangers? (Use neat sketches).

b) A counter-flow double-pipe heat exchanger is to heat water (C_p = *4180 J/kg.K*) from 20°C to 80°C at a rate of 1.2 kg/s. The heating is to be accomplished by geothermal water(C_p = *4.318 kJ/kg.K*) available at 160°C at a mass flow rate of 2 kg/s. The inner tube is thin-walled and has a diameter of 1.5 cm. If the overall heat transfer coefficient of the heat exchanger is 640 W/m^2.°C, determine the length of the heat exchanger required to achieve the desired heating.

c) Consider a medium in which the heat conduction equation is given in its simplest form as

$$\frac{dt}{d\tau} = \alpha\left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2}\right)$$

(a) Is heat transfer steady or transient?
(b) Is heat transfer one, two, or three dimensional?
(c) Is there heat generation in the medium?
(d) Is the thermal conductivity of the medium constant or variable?

Question (4) [10 Marks]

a) Define the following:
Fick's law of diffusion, Mass flux, Thermal diffusivity, Fin effectiveness, Grashof number, Emissivity, Black body, and Absorptivity.

b) Two very large parallel plates are maintained at uniform temperatures of 377 °C and 400 K, and have emissivities of ε_1= 0.6 and ε_2= 0.9, respectively. A radiation shield with an emissivity of ε_3 on both sides is placed between the plates. Determine the emissivity of the radiation shield if the radiation heat transfer between the plates is to be reduced to 15 % of that without the radiation shield.

Good Luck
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Question One

Q.1.a

1- False $\quad r_c = 2k/h$

2- True

3- False $\quad$ { by convection to that by conduction }

4- True

5- False $\quad$ Laminar flow

6- True

Q.1.b

1- (a) $\quad$ 2- (b)

3- (c) $\quad$ 4- (c)

5- (c) $\quad$ 6- (c)

7- (c)

Q.1.c

$$r_c = \frac{k}{h} = \frac{1}{8} = 0.125\ (m)$$

when $r_c = r_o$ and neglecting the pipe resistance

$$q = \frac{Q}{L} = \frac{(t_s - t_\infty)}{\frac{1}{2\pi k}\ln\left(\frac{r_c}{r_1}\right) + \frac{1}{h 2\pi r_c}}$$

$$= \frac{(200 - 20)}{\frac{1}{2\pi}\ln\left(\frac{0.125}{0.05}\right) + \frac{1}{2\pi * 0.125 * 8}}$$

$$\boxed{q = 621\ (W/m)}$$

To find To

$$q = \frac{(T_o - t_\infty)}{\frac{1}{h\,2\pi r_c}}$$

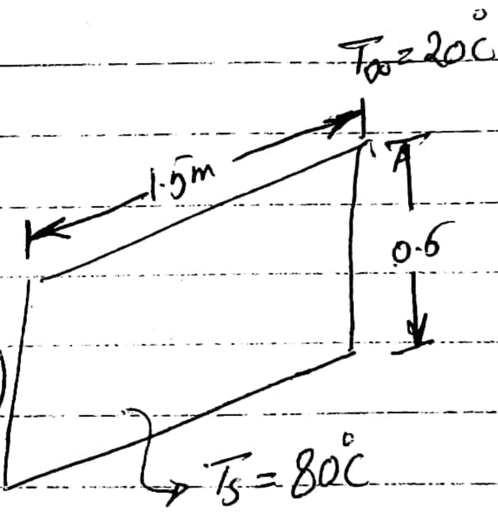
$$t_o = t_\infty + q\left(\frac{1}{h \times 2\pi r_c}\right)$$

$$\boxed{t_o = 118.72\ (^\circ C)}$$

Question Two

(a)

$$Q = Q_C + Q_R$$



$$1 * 10^3 = h\,A(t_s - t_\infty) + \varepsilon\sigma A(T_s^4 - T_\infty^4)$$

$$= h(1.5 * 0.6)(80 - 60) + 5.67 * 10^{-8}(1.5 * 0.6)(353^4 - 293^4)$$

$$h = 10.816\ (W/m^2\text{-}K)$$

$$Nu = \frac{hL}{K}$$

$$= \frac{10.816 * 0.6}{0.026}$$

$$\boxed{Nu = 249.6}$$

(b) $Q_{fin} = \sqrt{PhKA}\,(t_o - t_\infty)\tanh(ml)$

$P = 2b = 2\ m$ (neglecting thickness δ)

$A = b * \delta$

$A = 75 * 10^{-5}\ m^2$

$$m = \sqrt{\frac{hP}{KA}}$$

$$ml = \sqrt{\frac{23.3 * 2}{75 * 75 * 10^{-5}}}\left(\frac{2.5}{10^2}\right)$$

$ml = 0.719$

$$Q_{fins} = \eta_{fins}\sqrt{hPKA}\,(t_o - t_\infty)\tanh(ml)$$

$$\boxed{Q_{fins} = 1069(W)}$$

$$Q_{cyl} = h\,(A_{cyl} - A_{fins})\,(t_s - t_\infty)$$

$$= 23.3\left[(\pi * 0.05 * 1) - (10 * 75 * 10^{-5})\right](150 - 40)$$

$Q_{cyl} = 383.16\ (W)$

$Q_{tot} = Q_{fins} + Q_{cyl} = 1452.16\ (W)$

$Q_{\text{(بدون زعانف) without fins}} = h A_{cy} (t_s - t_\infty)$

$= 402.6\ W$

% increase in heat dissipation due to fins

$$= \frac{Q_{with\ fins} - Q_{without\ fins}}{Q_{without\ fins}} * 100$$

% increase $\simeq$ 261%

$$\frac{t - t_\infty}{t_o - t_\infty} = \frac{\cosh m(l-x)}{\cosh(ml)} \qquad x = 2*10^{-2}\,m$$

$$\frac{t - 40}{150 - 40} = \frac{\cosh m(0.5*10^{-2})}{\cosh(ml)}$$

$$\boxed{t_x = 127.5\,^\circ C}$$

$\boxed{C}$

$$\dot{m} = \rho A u_m$$

$$\frac{71.4}{60} = 10^3 * \frac{\pi}{4}(0.02)^2 * u_m$$

$$\boxed{u_m = 3.79\ m/s}$$

$$Re = \frac{u_m D}{\nu} = \frac{3.79 * 0.02}{0.568*10^{-6}} = 133376.35 > 10^4$$

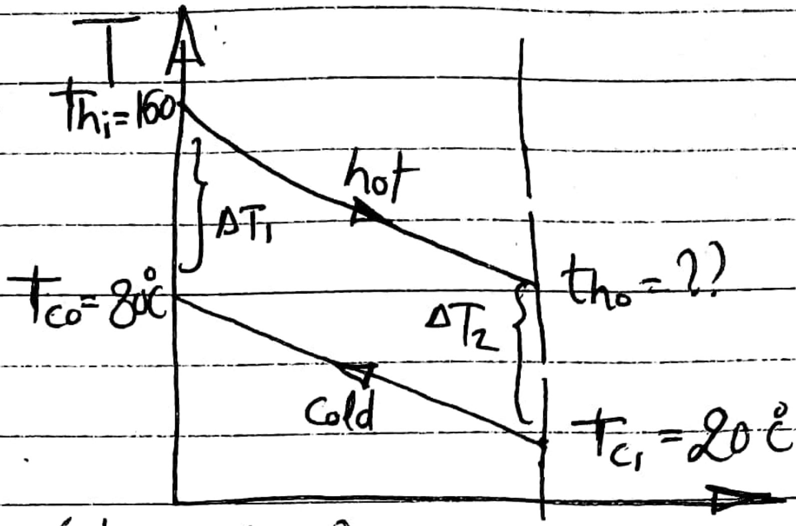
$$Nu = 0.023\, Re^{0.8}\, Pr^{0.33}$$

$$Nu = 469.35$$

$$h = \frac{Nu\,k}{D} \implies \boxed{h = 15.019\ KW/m^2\,^\circ C}$$

Question (3)

(b)



$$Q_c = \dot{m}_c \, Cp_c \, (t_{co} - t_{ci})$$

$$= 1.2 * 4180 \, (80 - 20) = 300.96 \, [KW]$$

$$Q_c = Q_h$$

$$Q_h = \dot{m}_h \, Cp_h \, (t_{hi} - t_{ho})$$

$$300.96 = 2 * 4.318 \, (160 - t_{ho})$$

$$t_{ho} = 125.15 \, ^\circ C$$

$$\Delta T_m = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} = \frac{(125.15 - 20) - (160 - 80)}{\ln\left(\frac{125.15 - 20}{160 - 80}\right)}$$

$$= 92 \, ^\circ C$$

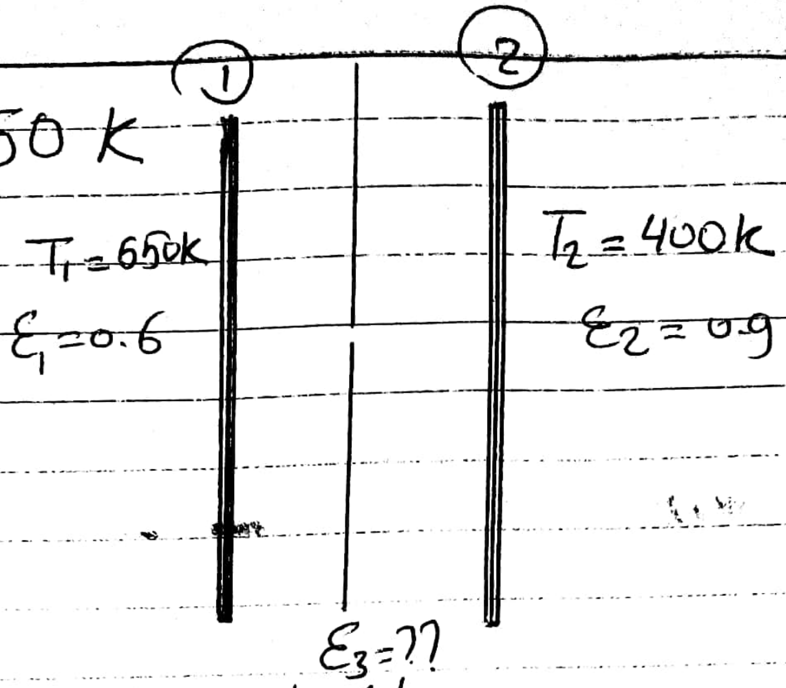
$$Q = U A_s \Delta T_m$$

$$A_s = 5.11 \, (m^2)$$

$$A_s = \pi d L \Longrightarrow \boxed{L = 108.5 \, (m)}$$

$T_1 = 377 + 273 = 650\ K$

Req: ε_3



(*) Without Radiation Shield

$$q_1 = \frac{Q}{A} = \frac{\sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$= \frac{5.67 \times 10^{-8} (650^4 - 400^4)}{\frac{1}{0.6} + \frac{1}{0.9} - 1}$$

$$q_1 = 4876.75\ (W/m^2)$$

(*) With Radiation shield

$$q_2 = 0.15\ q_1 = 731.5\ (W/m^2)$$

$$q_2 = \frac{\sigma (T_1^4 - T_2^4)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right) + \left(\frac{1}{\varepsilon_{3,1}} + \frac{1}{\varepsilon_{3,2}} - 1\right)}$$

$$\boxed{\varepsilon_3 = 0.18}$$

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