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: 3 January 2018 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. Heat conducted through unit area and unit thick face per unit time when temperature difference between opposite faces is unity, is called thermal diffusivity.
2. The value of the critical radius of insulation r_0 for a sphere is h/2k.
3. Prandtl number gives an indication of the ratio of momentum diffusivity to the thermal diffusivity.
4. A value of the Nusselt number equal to unity implies that there is no convection.
5. Radiation shields do not deliver or remove heat from the system.
6. Grashof number represents the ratio of the buoyancy force to the square of viscous force acting on the fluid .
7. Mass is transferred by conduction, convection and radiation.
8. In laminar flow maximum heat transfer rate can be expected.
9. For *In-line arrangement*, the maximum velocity occurs at the minimum flow area between the tubes, then the maximum velocity becomes $u_{max} = \left(\frac{S_L}{S_T - D}\right)u$

Q.1.b Write short notes on **(Use neat sketches).**

a. Analogy between Heat and Mass transfer.

b. Different types of fins and its influence on heat transfer.

c. Types of Heat Exchangers.

d. Thermal radiation.

e. Black body radiation

f. Absorptivity, Reflectivity, Transmissivty and Opaque body.

Question (2) [18 Marks]

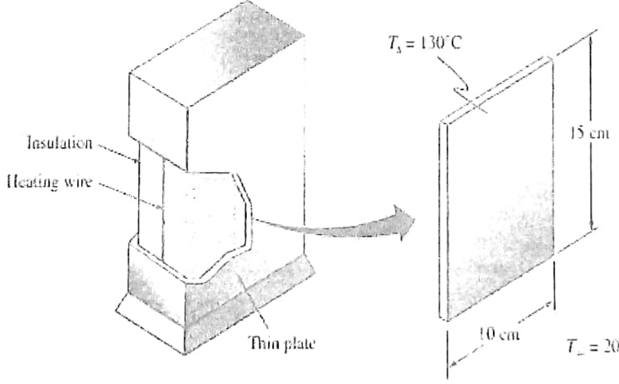
a) Hot water at t_i=120°C flows in a pipe whose inner diameter is 1.6 cm and thickness is 0.2 cm. The pipe is to be covered with fiberglass insulation (k= 0.038 W/m.°C) so that the temperature of the outer surface of the insulation does not exceed 40°C when the ambient temperature is 25°C. If the convective heat transfer coefficients inside and outside the pipe are h_i=70 W/m^2.°C and h_o=20 W/m^2.°C, determine the thickness of fiberglass that needs to be insulated on the pipe.

b) A small medical vertical-plate resistance heater is 15 cm high and 10 cm wide with a surface temperature of 130°C dissipating heat by radiation and convection into a room at 20°C. Determine the electrical power required, also compare the results for a plate 450 cm high. The heat transfer for radiation hr is 8.5 W/m2.K for the specified surface temperatures. The properties of air are:

[υ = 21.1 x 106 m2/s, α =29.65 x 106 m2/s, and k = 0.0291 W/(m.K)].

$$Nu = 0.555(GrPr)^{1/4} \quad GrPr < 10^8$$

$$Nu = 0.021(GrPr)^{1/4} \quad GrPr < 10^{10}$$



Schematic diagram of vertical-plate resistance heater

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 uniform surface heat flux. The flow is hydrodynamically and thermally developed. Calculate the heat transfer coefficient. The properties of water are: [υ = 0.568 x 10-6 m2/s, Pr = 4.32 and k = 0.64 W/(m.°C)].

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

Question (3) [17 Marks]

a) A thin-walled double-pipe counter flow heat exchanger is to be used to cool oil (C_p = *2200 J/kg.K*) from 150°C to 40°C at a rate of 2 kg/s by water (C_p = *4180 J/kg.K*) that enters at 22°C at a rate of 1.5 kg/s .The diameter of the tube is 2.5 cm and its length is 6 m. Determine the overall heat transfer coefficient of this heat exchanger.

b) A thin aluminum sheet with an emissivity of 0.15 on both sides is placed between two very large parallel plates, which are maintained at uniform temperatures of 627 °C and 650 K and have emissivities ε_1= 0.5 and ε_2= 0.8, respectively. Determine the net rate of radiation heat transfer between the two plates per unit surface area of the plates and compare the result with that without the shield. What will happen if another shield is added?

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

$$\frac{1}{r}\frac{d}{dr}\left(rk\frac{dt}{dr}\right)+\frac{d}{dz}\left(k\frac{dt}{dz}\right)+q_v=0$$

(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?

Good Luck
Dr. Moustafa El Bouz

Question One (4)

1- False

Thermal Conductivity

2- False $(2K/h)$

3- True

4- True

5- True

6- True

7- False

Mass is transfered by conduction and Convect

8- False

In ~~Laminar~~ Turbulent flow

(9). False

$$u_{max} = \left(\frac{S_T}{S_T - D} \right) u$$

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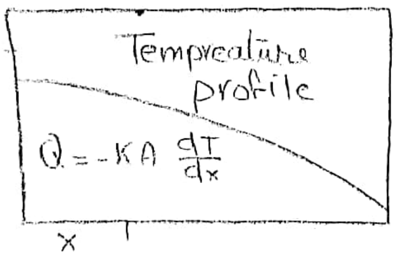
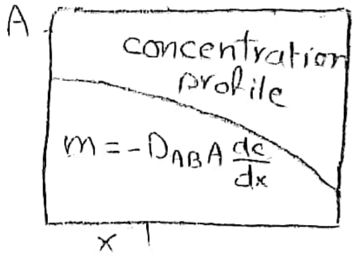
Q.1.b) :

a)

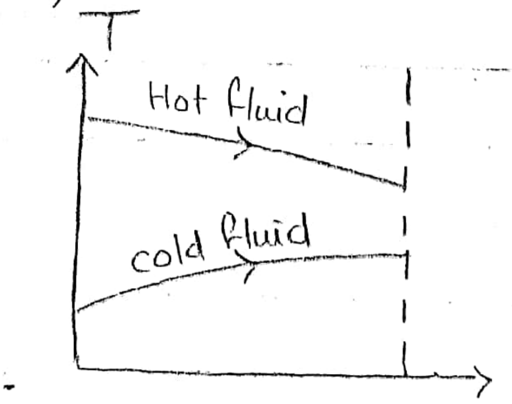
Heat transfer	Mass transfer
$Q_{conduction} = -KA \frac{dT}{dx}$	$\dot{m}_{diff} = -D_{AB} A \frac{dc}{dx}$
$K \rightarrow$ thermal conductivity $A \rightarrow$ Area $Q \rightarrow$ Heat transfer (Fourier's law)	$D_{AB} \rightarrow$ diffiusion coeffecient $A \rightarrow$ Area $\frac{dc}{dx} \rightarrow$ concentration speciese (Fick's Law)
	
$Q_{conv} = hA(T_s - T_\infty)$ $h \rightarrow$ heat transfer coeffeicient $(T_s - T_\infty) \rightarrow$ Tempreature diffrence	$\dot{m}_{con} = h_m A_s (C_o - C_\infty)$ $h_m \rightarrow$ mas transfer coefficient $C_o - C_\infty \rightarrow$ concentration diffrence
 Thermal radiation	 No mass radiation

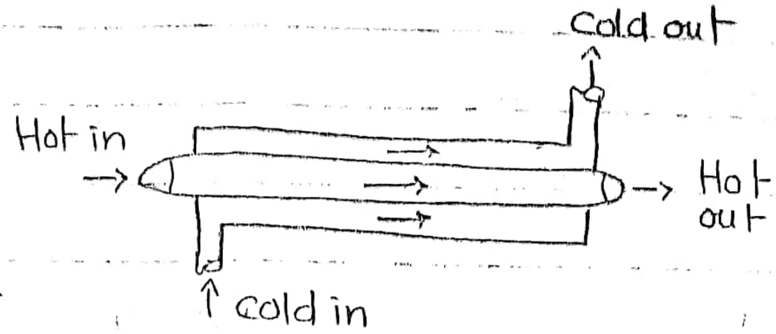
* Mass transfer

The transfer of particles of one material to another one as result of concentration diff and speed diffusivity

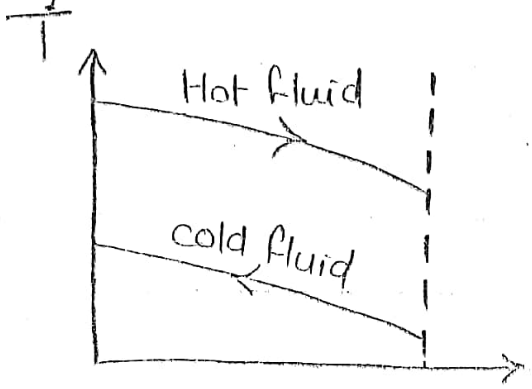
c) Types of Heat Exchangers

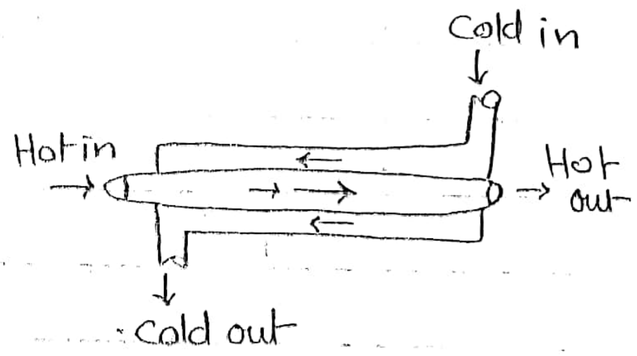
1) Parallel heat flow



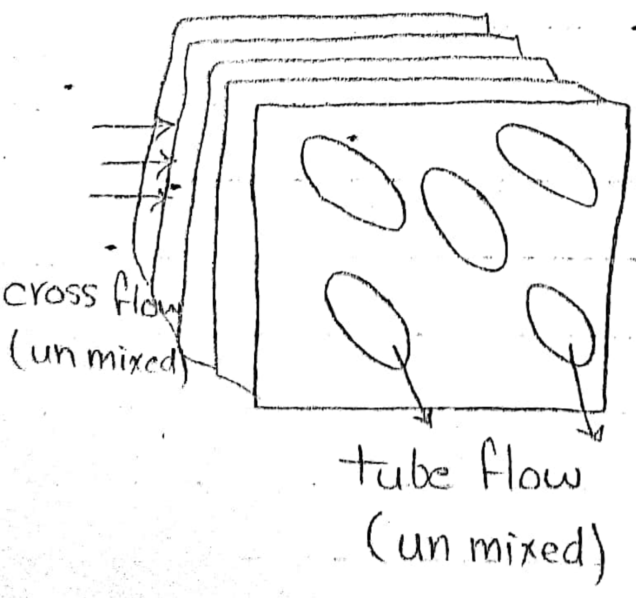


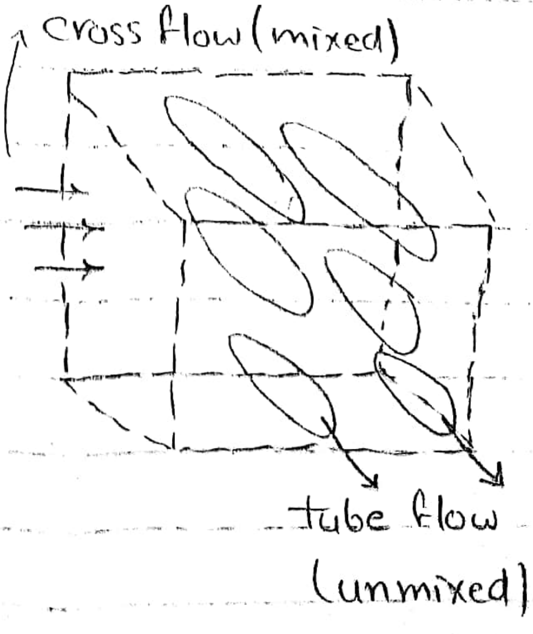
2) Counter heat flow





3) Cross heat flow





d) Thermal radiation

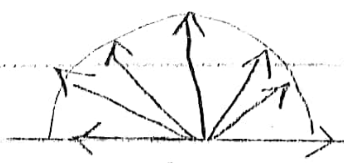
Is defined as the portion of electromagnatic spectrum that extends from 0.1 to 100 μm.

e) Black body radiation

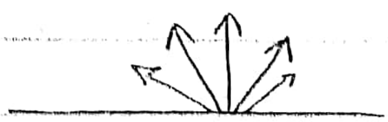
Black body is defined as perfect emitter and absorber of radiation

- A Black body absorbs all the incident radiation regardless of its wavelength or direction.
- A Black body emitis all the radiant energy Uniformally in all direction normal to the direction on the emission.

Emissivety = 1



Uniform.
Black body



Non_uniform
Real body.

P- Absorpitivity $= \alpha = \dfrac{\text{Absorbed radiation}}{\text{incidant radiation}} = \dfrac{G_{abs}}{G}$

$$0 \leqslant \alpha \leqslant 1$$

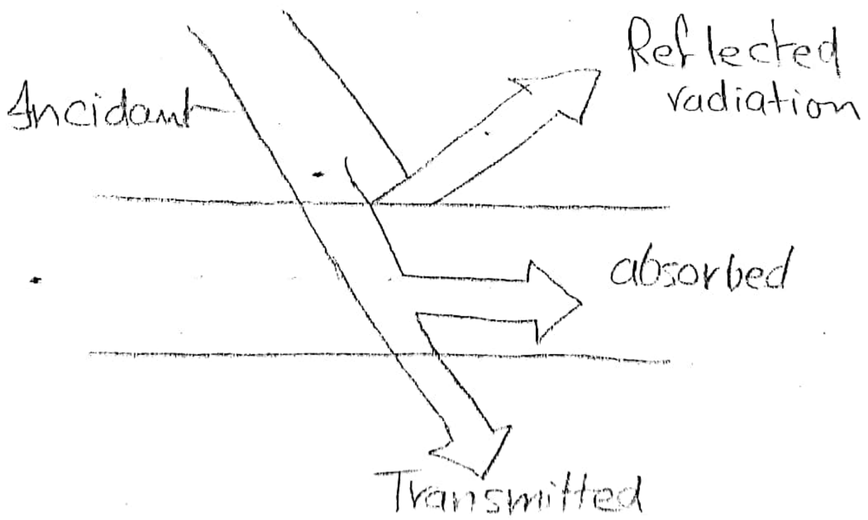
Reflectivity $= \rho = \dfrac{\text{Reflected radiation}}{\text{incidant radiation}} = \dfrac{G_{Ref}}{G}$

$$0 \leqslant \rho \leqslant 1$$

- Transimissivty $\tau = \dfrac{\text{Transmitted radiation}}{\text{incidant radiation}} = \dfrac{G_{Tran}}{G}$

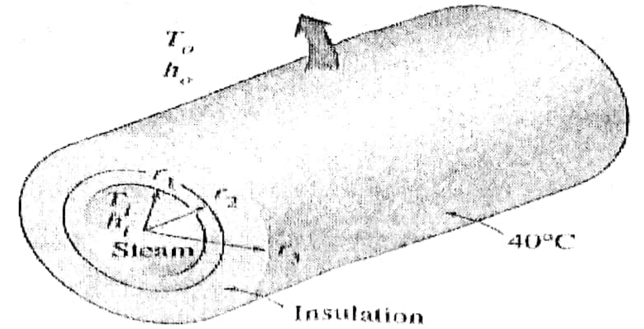
$$0 \leqslant \tau \leqslant 1$$

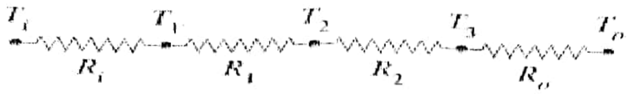
$$\alpha + \rho + \tau = 1$$



Opaque body:
The body which has $\tau = 0$

Question 2 (a)





$$A_1 = 2\pi r_1 L = 2\pi(0.008 \text{ m})(1 \text{ m}) = 0.0503 \text{ m}^2$$

$$A_3 = 2\pi r_3 L = 2\pi r_3 (1 \text{ m}) = 6.28 r_3 \text{ m}^2$$

Then the individual thermal resistances are determined to be

$$R_i = R_{\text{conv},1} = \frac{1}{h_i A_1} = \frac{1}{(70 \text{ W/m}^2 \cdot {}^\circ\text{C})(0.0503 \text{ m}^2)} = 0.284^\circ\text{C/W}$$

$$R_1 = R_{\text{pipe}} = \frac{\ln(r_2/r_1)}{2\pi k_1 L} = \frac{\ln(0.01/0.008)}{2\pi(15 \text{ W/m} \cdot {}^\circ\text{C})(1 \text{ m})} = 0.0024^\circ\text{C/W}$$

$$R_2 = R_{\text{insulation}} = \frac{\ln(r_3/r_2)}{2\pi k_2 L} = \frac{\ln(r_3/0.01)}{2\pi(0.038 \text{ W/m} \cdot {}^\circ\text{C})(1 \text{ m})}$$

$$= 4.188 \ln(r_3/0.01)^\circ\text{C/W}$$

$$R_o = R_{\text{conv},2} = \frac{1}{h_o A_3} = \frac{1}{(20 \text{ W/m}^2 \cdot {}^\circ\text{C})(6.28 r_3 \text{ m}^2)} = \frac{1}{125.6 r_3}\,^\circ\text{C/W}$$

Noting that all resistances are in series, the total resistance is determined to be

$$R_{\text{total}} = R_i + R_1 + R_2 + R_0$$

$$= [0.284 + 0.0024 + 4.188 \ln(r_3/0.01) + 1/125.6 r_3]^\circ\text{C/W}$$

Then the steady rate of heat loss from the steam becomes

$$\dot{Q} = \frac{T_i - T_o}{R_{\text{total}}} = \frac{(120 - 125)^\circ\text{C}}{[0.284 + 0.0024 + 4.188 \ln(r_3/0.01) + 1/125.6 r_3]^\circ\text{C/W}}$$

Noting that the outer surface temperature of insulation is specified to be 40°C, the rate of heat loss can also be expressed as

$$\dot{Q} = \frac{T_3 - T_o}{R_o} = \frac{(40 - 25)^\circ\text{C}}{(1/125.6 r_3)^\circ\text{C/W}} = 1884 r_3$$

Setting the two relations above equal to each other and solving for r_3 gives $r_3 = 0.0170$ m. Then the minimum thickness of fiberglass insulation required is

$$t = r_3 - r_2 = 0.0170 - 0.0100 = 0.0070 \text{ m} = 0.70 \text{ cm}$$

Question 2(b)

The film temperature is 75°C, and the corresponding value of Gr_L is found to be $65L^3(T_s - T_\infty)$, where L is in centimeters and T is in K, from the last column in Table 28, Appendix 2 by interpolation. For the specified conditions, we get

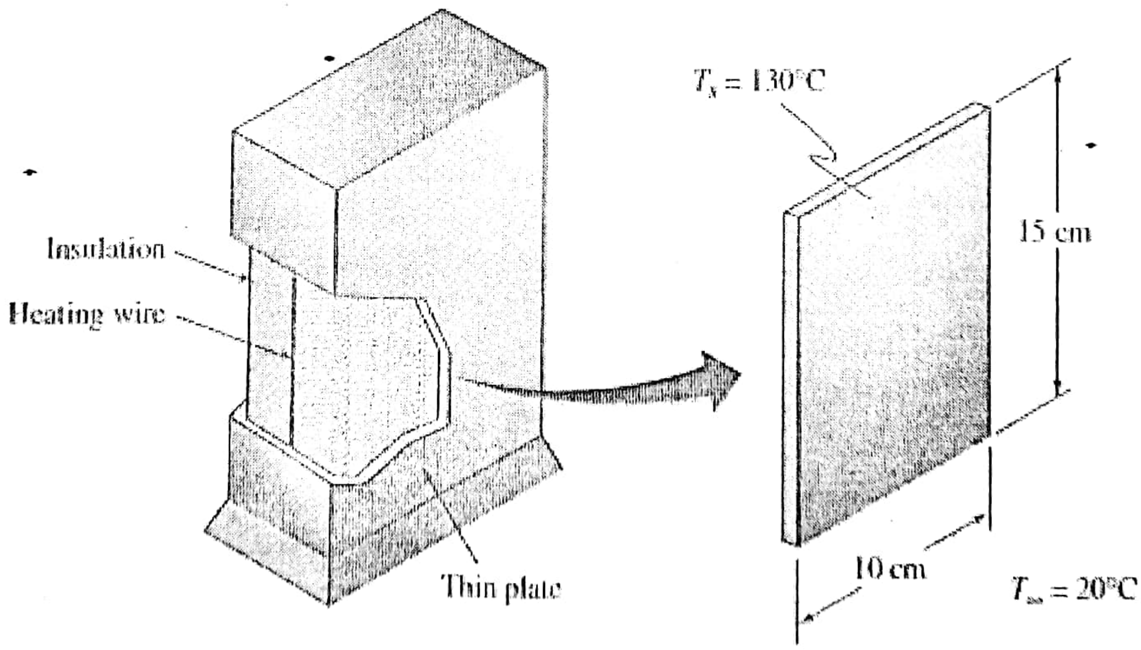
$$Gr_L = (65\ \text{cm}^{-3}\ \text{K}^{-1})(15\ \text{cm})^3(110\ \text{K}) = 2.41 \times 10^7$$

for the smaller plate. Since the Grashof number is less than 10^9, the flow is laminar. For air at 75°C, the Prandtl number is 0.71, and GrPr is therefore 1.17×10^7. From Fig. 5.5, the average Nusselt number is 35.7 at GrPr $= 1.17 \times 10^7$, and therefore

$$\bar{h}_c = 35.7\frac{k}{L} = (35.7)\frac{(2.9 \times 10^{-2}\ \text{W/m K})}{(0.15\ \text{m})} = 6.90\ \text{W/m}^2\text{K}$$

Combining the effects of convection and radiation as shown in Chapter 1, the total dissipation rate from both sides of the plate is therefore

$$q = A(\bar{h}_c + \bar{h}_r)(T_s - T_\infty)$$
$$= [(2)(0.15)(0.10)\ \text{m}^2][(6.9 + 8.5)\ \text{W/m}^2\text{K}](110\ \text{K}) = 50.8\ \text{W}$$



For the large plate, the Rayleigh number is $(450/15)^3$ times larger or $Ra = 4.62 \times 10^{11}$, indicating that the flow is turbulent. From Fig. 5.5, the average Nusselt number is 973 and $\bar{h}_c = 6.3\ \text{W/m}^2\text{K}$. The total heat dissipation rate from both sides of the plate is therefore

$$q = [(2)(4.5)(0.10)\ \text{m}^2][(6.3 + 8.5)\ \text{W/m}^2\text{K}](110\ \text{K}) = 1465\ \text{W}$$

c) $\dot{m} = \frac{71.4}{60} = 1.19 \ \frac{Kg}{sec}$

$D = 0.02$

$Re = \frac{U_\infty D}{\nu}$

$Re = \frac{3.78 * 0.02}{0.568 * 10^{-6}}$

$\therefore Re = 133.09 * 10^{3}$

$\therefore \dot{m} = \rho U A$

$1.19 = 1000 * U * \frac{\pi}{4}(0.02)^2$

$U_\infty = 3.78$

$\therefore Re > 2300 \quad \therefore$ turbulent flow

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

$Nu = 468.547$

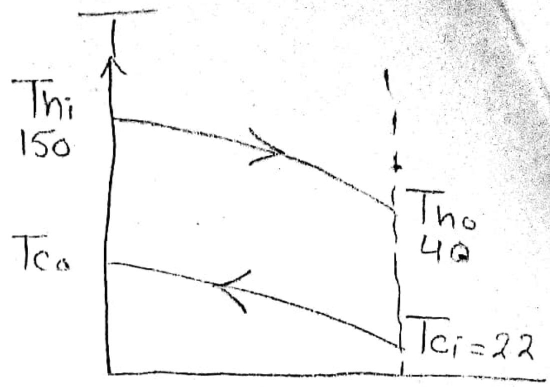
$\therefore Nu = \frac{h.D}{K} \quad \therefore 468.547 = \frac{h.0.02}{0.64}$

$\therefore h = 14.99 * 10^{3} \ W/m^2.C$

Q 3) $Cp_h = 2200$
$\dot{m}_h = 2$

a) $Cp_c = 4180$
$\dot{m}_c = 1.5$

$D = 0.025$, $L = 6$



$$Q_h = m_h Cp_h (T_{hi} - T_{ho})$$

$$Q = 2 * 2200 (150 - 40) = 484000$$

$$Q_c = m_c Cp_c (T_{co} - T_{ci})$$

$$484000 = 1.5 * 4180 (T_{co} - 22)$$

$$T_{co} = 99.19 \ ^\circ C$$

$$\Delta T_m = \frac{\Delta t_1 - \Delta t_2}{\ln\left(\frac{\Delta t_1}{\Delta t_2}\right)}$$

$\Delta t_1 = T_{hi} - T_{co} = 50.81$
$\Delta t_2 = T_{ho} - T_{ci} = 18$

$$\Delta T_m = 32.002$$

$$Q = U A \Delta T_m$$

$$484000 = U \pi * 0.025 * 6 * 32.002$$

$$U = 32094.24 \ W/m^2 \cdot s$$

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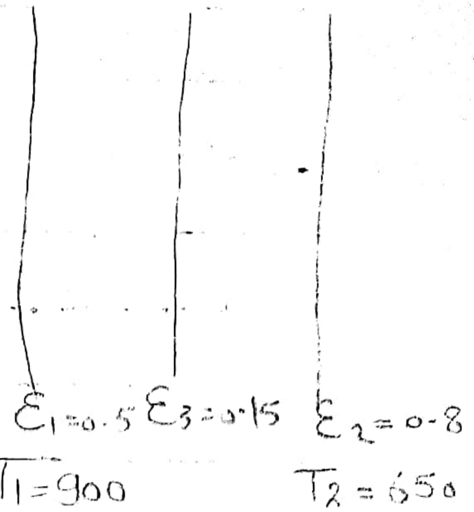
b)

$$q_{\substack{with \\ Sheilds}} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1\right) + \left(\frac{1}{\varepsilon_3} + \frac{1}{\varepsilon_2} - 1\right)}$$



$$q_{with} = \frac{5.67 \times 10^{-8}\left(900^4 - 650^4\right)}{\left(\frac{1}{0.5} + \frac{1}{0.15} - 1\right) + \left(\frac{1}{0.15} + \frac{1}{0.8} - 1\right)}$$

$$q_{with} = 1856.8845 \text{ W}$$

$$q_{without} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)}$$

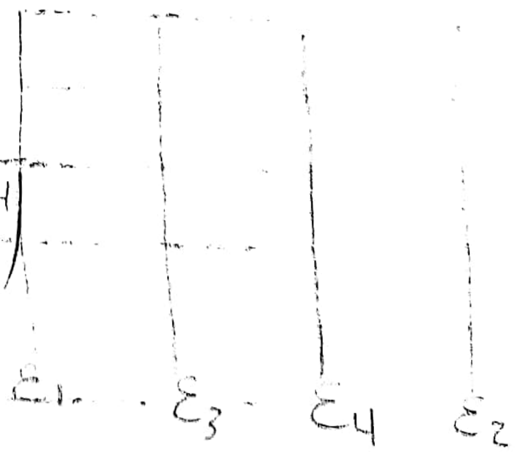
$$q_{without} = 12035.36 \text{ W}$$

$$\Delta q = \frac{q_{without} - q_{with}}{q_{without}} = \frac{12035.36 - 1856.8845}{12035.36}$$

$$\Delta q = 0.8457 \quad \therefore \% q = 84.57\%$$

If another shield added

$$q_{with} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1\right) + \left(\frac{1}{\varepsilon_3} + \frac{1}{\varepsilon_4} - 1\right) + \left(\frac{1}{\varepsilon_4} + \frac{1}{\varepsilon_2} - 1\right)}$$



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