Ref. No. Ex/PE/PC/B/T/223/2024

B.E. POWER ENGINEERING SECOND YEAR SECOND SEMESTER - 2024

SUBJECT: **HEAT TRANSFER**

Time: Three Hours **(Full Marks 100)**

Assume the following properties of air and water unless otherwise specified:

AIR: $\rho = 1.16$ kg m^{-3}, $\nu = 1.8\times10^{-5}$ m^2 s^{-1}, $C_p = 1.014$ kJ kg^{-1} K^{-1}, $Pr = 0.7$

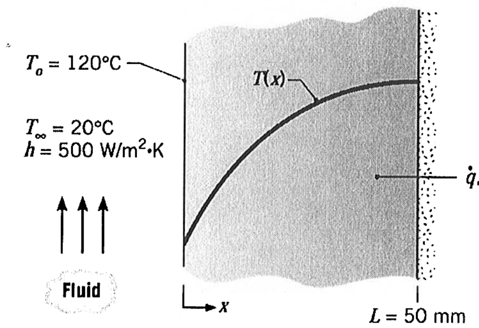
WATER: $\rho = 1000$ kg m^{-3}, $\nu = 1.0\times10^{-6}$ m^2 s^{-1}, $C_p = 4.186$ kJ kg^{-1} K^{-1}, $Pr = 7.0$

Part I (CO1) (25 marks)

1. **Answer ALL** **5×5=25**

a) In a one-dimensional, transient, conduction heat transfer problem with no volumetric heat generation, it is found that the temperature at a point increases with time at a rate of 5 K/s, while the local temperature gradient increases with x at a rate of 200 K/m^2. What is the thermal diffusivity of the medium?

b) One-dimensional, steady-state conduction with uniform internal energy generation occurs in a plane wall with a thickness of 50 mm and a constant thermal conductivity of 5 W/m K. The left edge of the wall is at 120° C as it dissipates the heat by convection to the ambient at 20 °C. The convective heat transfer coefficient is 500 W/m^{2}K. The right edge is insulated. Find the temperature gradients at the left and the right edges of the wall and the value of $\dot{q}$.

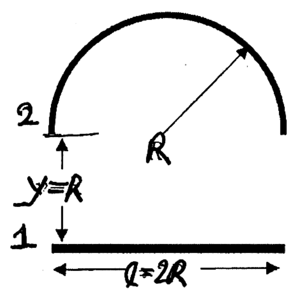


c) A double-pipe (shell and tube) heat exchanger is made up of stainless steel (k = 15.1 W/mK) tube of D_i = 1.5 cm and D_o = 1.9 cm, while the outer shell diameter is 3.2 cm. The convection heat transfer coefficients are h_i= 800 W/m^{2}K for the inner side and h_o= 1200 W/m^{2}K for the outer side of the tube. The fouling factors on the inner and outer sides of the tube walls are $R_{f,i} = 4\times10^{-4}$ m^{2}K/W and $R_{f,o} = 1\times10^{-4}$ m^{2}K/W, respectively. Determine the overall thermal resistance per unit length of the tube.

d) For flow of a liquid metal through an 1 cm diameter circular tube, the velocity and temperature profiles at a particular axial location of the tube may be approximated as $u(r)$= 0.1 m/s and $T(r) = 300 + 100[1-(100r)^2]$ K. Find the wall surface temperature, bulk mean temperature and the Nu.

e) The spectral hemispherical emissivity of an opaque surface at 1000 K is approximated as ε_1= 0.1 (for λ<0. 8 μm), ε_2= 0.9 (for 0.8 < λ< 2 μm), and ε_3= 0.2 (for 2 μm <λ). Determine the total hemispherical emissivity for the surface. Consult the *blackbody radiation fraction table* provided at the end of the question paper.

f) Two infinitely long surfaces 1 and 2, one flat and the other hemispherical, face each other as shown in the figure on the right. Find the view factors F_{11}, F_{12}, F_{21}, and F_{22}.



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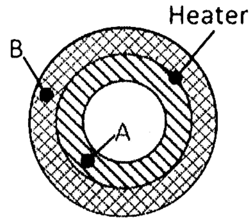
Part II (CO2) (25 marks)

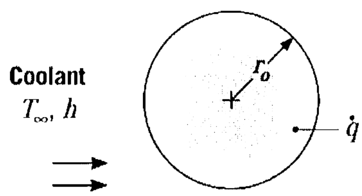
2. A thin electric strip heater is sandwiched between two, tightly fit concentric cylinders A and B, which have thermal conductivities of k_A= 1 W/mK and k_B= 2 W/mK, respectively. The heater steadily dissipates 10000 W/m^2 power. The cylinder-assembly is exposed to room air at 30 °C at the inner and outer faces, with convective heat transfer coefficient of 100 W/m^{2}K. Write the governing differential equation inside the cylinder B and impose the appropriate boundary conditions. Neglecting radiation and contact resistance, deduce the values of inner and outer walls of the cylinder and the heating foil temperature. The inner, heating-plane and the outer cylinder radii are a =10, b =25 and c =50 mm, respectively. Also, draw a qualitative temperature profile in A and B.



10+10+5 = 25

OR

Radioactive wastes are packed in a thin-walled spherical container. The wastes generate thermal energy nonuniformly according to the relation $\dot{q} = \dot{q}_0[1 - (r/r_0)^2]$ where $\dot{q}$ is the local rate of energy generation per unit volume, $\dot{q}_0$ is a constant, and r_0 is the radius of the container. Steady-state conditions are maintained by submerging the container in a liquid that is at T_∞ and provides a uniform convection coefficient h.



(a) Write the governing equation for the conduction heat transfer and impose appropriate boundary conditions

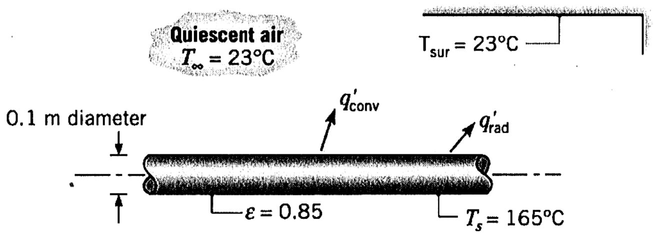
(b) Solve the governing differential equation to determine the temperature distribution $T(r)$ as a function of the r_0, $\dot{q}_0$, T_∞ and h.

(c) If T_{melt} is the melting temperature of the waste, deduce the safe size of the container to avoid melting of the waste within the container in terms of the other parameters.

10+10+5=25

Part III (CO3) (25 Marks)

3. A horizontal, high-pressure steam pipe of 0.1-m outside diameter passes through a large room whose wall and air temperatures are 23°C. The pipe has an outside surface temperature of 165°C and an emissivity of ε=0.85. Estimate the heat loss from the pipe per unit length and the fraction of heat loss that takes place by radiation. The average Nusselt number for horizontal cylinders is expressed as $Nu_D = \{0.6 + 0.378\, Ra^{1/6} / [1+(0.559/Pr)^{9/16}]^{8/27}\}^2$



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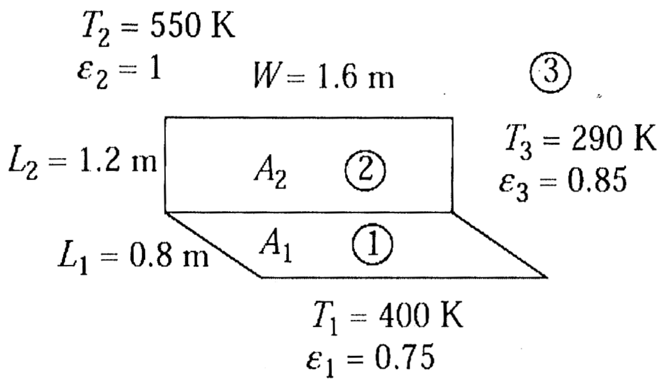
OR

Two rectangular surfaces are mounted perpendicular to each other with a common edge which is 1.6 m long. The horizontal surface is 0.8 m wide and the vertical surface is 1.2 m high. The horizontal surface has an emissivity of ε_1=0.75 and is maintained at 400 K. The vertical surface is a blackbody and is maintained at 550 K. The back sides of the two surfaces are insulated. The surrounding is at 290 K, and can be considered to have an emissivity of ε_3=0.85. Determine the net rate of radiation heat transfers between the two surfaces, and between the horizontal surface and the surroundings. Use the view factor chart provided at the end of the question paper.



Part IV (CO4) (25 Marks)

4. A 20 m-long, thin-walled double pipe heat exchanger is used to heat a liquid chemical (Cp_{ch}=1800 J/kgK, k_{ch}= 1 W/mK) with hot water (Cp_w= 4180 J/kgK, k_w = 0.6 W/mK). The inner and outer tube diameters are 10 and 15 cm, respectively. The chemical enters through the outer tube at 5° C at a rate of 3 kg/s, while the water enters the inner tube at 95°C at a rate of 2 kg/s. The Nussle numbers at the inner and outer sides are Nu_i=400 and Nu_o=120, respectively. Determine the outlet temperatures of the chemical and water and the heat exchanger efficiency if the heat exchanger has counterflow arrangement. Use the charts/ expressions provided at the end of the question paper.

OR

One end of a long copper rod (k=386 W/mK) of 3 cm diameter is maintained at a constant temperature by placing it in a furnace, while the rest of the rod is exposed to the environment at 25 °C. In steady state the temperature at two different locations 25 cm apart along the length of the rod is found to be 200 °C and 100 °C, respectively. Determine the fin effectiveness.

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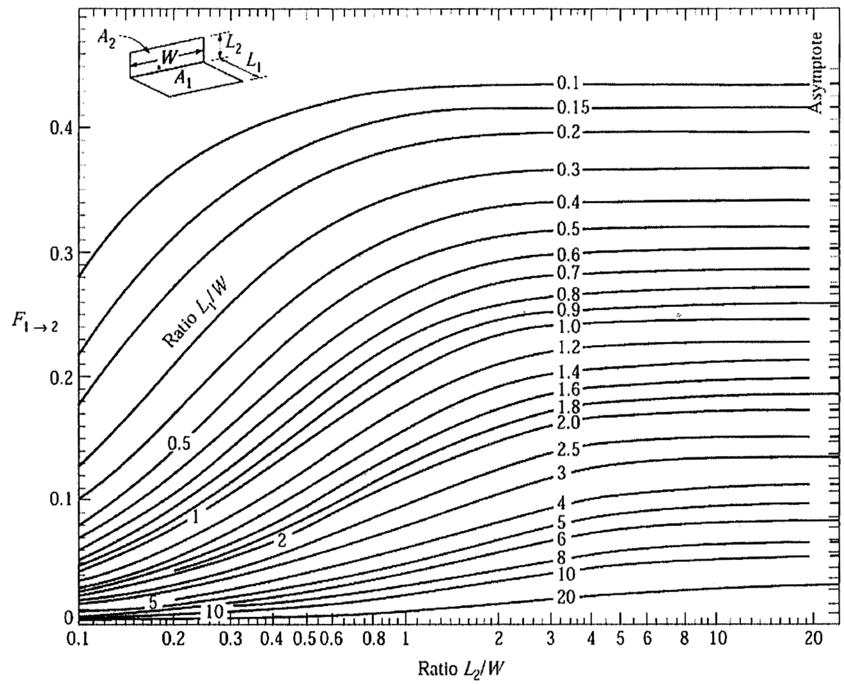
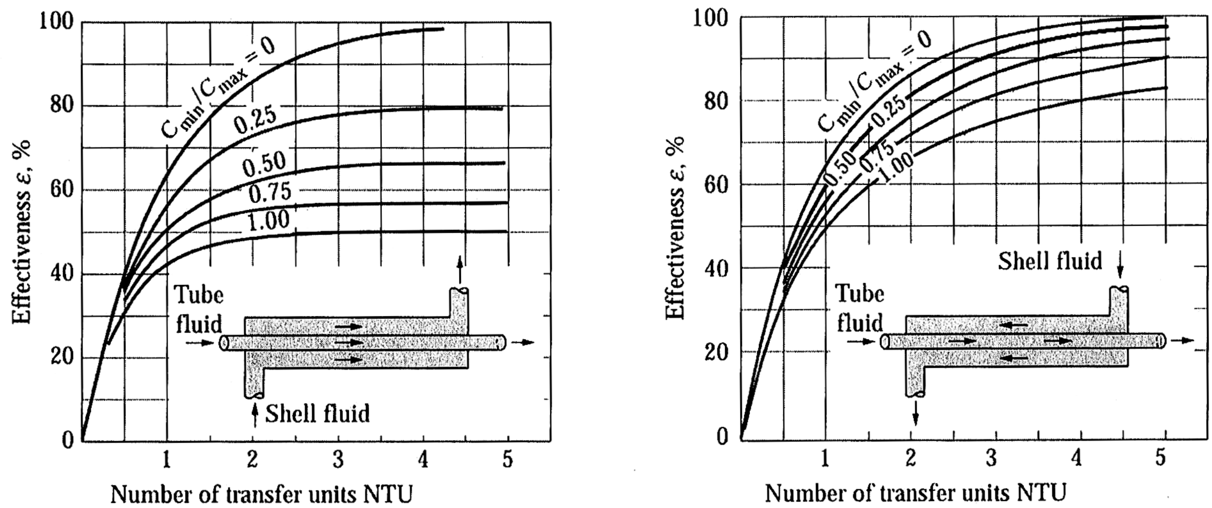
ADDITIONAL INFORMATION



View Factor Chart



ε-NTU plots for concentric tube heat exchangers

$$\varepsilon_{PARALLEL} = \frac{1-exp\left[-NTU\left(1+C_r\right)\right]}{1+C_r}; \qquad \varepsilon_{COUNTER} = \frac{1-exp\left[-NTU\left(1-C_r\right)\right]}{1-C_r\,exp\left[-NTU\left(1-C_r\right)\right]} \quad \left(for\ C_r < 1\right)$$

$$= \frac{NTU}{1+NTU} \qquad \left(for\ C_r = 1\right)$$

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Blackbody Radiation Function

λT (μm · K)	$F_{(0 \to \lambda)}$
200	0.000000
400	0.000000
600	0.000000
800	0.000016
1,000	0.000321
1,200	0.002134
1,400	0.007790
1,600	0.019718
1,800	0.039341
2,000	0.066728
2,200	0.100888
2,400	0.140256
2,600	0.183120
2,800	0.227897
2,898	0.250108
3,000	0.273232
3,200	0.318102
3,400	0.361735
3,600	0.403607
3,800	0.443382
4,000	0.480877
4,200	0.516014
4,400	0.548796
4,600	0.579280
4,800	0.607559
5,000	0.633747
5,200	0.658970
5,400	0.680360
5,600	0.701046
5,800	0.720158
6,000	0.737818
6,200	0.754140
6,400	0.769234
6,600	0.783199
6,800	0.796129
7,000	0.808109
7,200	0.819217
7,400	0.829527
7,600	0.839102
7,800	0.848005
8,000	0.856288
8,500	0.874608
9,000	0.890029
9,500	0.903085
10,000	0.914199
10,500	0.923710
11,000	0.931890
11,500	0.939959
12,000	0.945098
13,000	0.955139
14,000	0.962898
15,000	0.969981
16,000	0.973814
18,000	0.980860
20,000	0.985602
25,000	0.992215
30,000	0.995340
40,000	0.997967
50,000	0.998953
75,000	0.999713
100,000	0.999905