Bachelor of Chemical Engineering Examination, 2018
3rd Year, 1st Semester
Process Heat Transfer

Time: Three Hours

Full Marks: 100

Answer any Five questions
Steam Tables can be used, if necessary

1. **Conduction**

(6+4+10=20)

a. Find out the critical insulation thickness of a hollow sphere of inner radius R_1 and outer radius R_2 *(without insulation)*. Assume the hollow portion is filled in with the same air as ambient, whose heat transfer coefficient would be h.

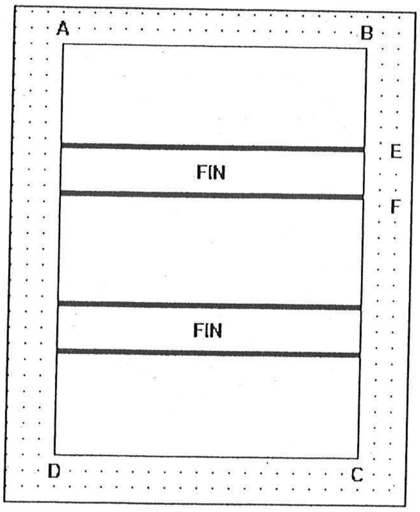
b. Glass spheres of 2 mm radius and at 500 °C are to be cooled by exposing them to an air stream at 25°C. Find the minimum time required for cooling to a temperature of 60°C. Assume the following property values
Density = 2250 kg/m^3
Specific heat = 850 J/kg K
Conductivity = 1.5 W/m K

c. An array of 10 fins of anodized aluminum (k = 180W/m K) is used to cool a transistor operating at a location where the ambient conditions correspond to temperature35 °C and convective heat transfer coefficient 12W/m^2 K. The distance AB is 3 mm, EF is 0.4 mm. The length of the fin is 5 mm and has its base at 60°C. Find the power dissipated by the fin array and fin effectiveness? The surface temperature T, at a distance, x, from the base of the fin is given by:

$$T - T_f = \frac{(T_b - T_f)\cosh m(L-x)}{\sinh mL} \text{ where } m^2 = \frac{hP}{kA_c}$$

Fin Effectiveness (ϵ_{fin}) =

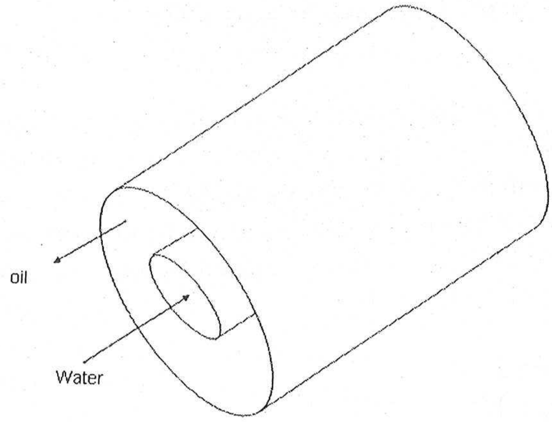
$$\frac{\textit{Fin heat transfer rate}}{\textit{Heat transfer rate that would occur in the absence of the fin}} = \frac{Q_f}{hA_c(T_b - T_f)}$$



2. **Forced and Natural Convection**

(8+12=20)

a. A concentric pipe heat exchanger is used to cool lubricating oil for a large diesel engine. The inner pipe of radius 30mm and has water flowing at a rate of 0.3 kg/s. The oil is flowing in the outer pipe, which has a radius of 50mm, at a rate of 0.15kg/s. Assuming fully developed flow in both inner and outer pipes, calculate the heat transfer coefficient for the water and oil sides respectively. Use oil properties at 80°C and water properties at 35°C.



For oil at 80°C:

c_p=2131 J/kg K; μ = 3.25x10^{-2} Kg/m s; k = 0.138 W/m K

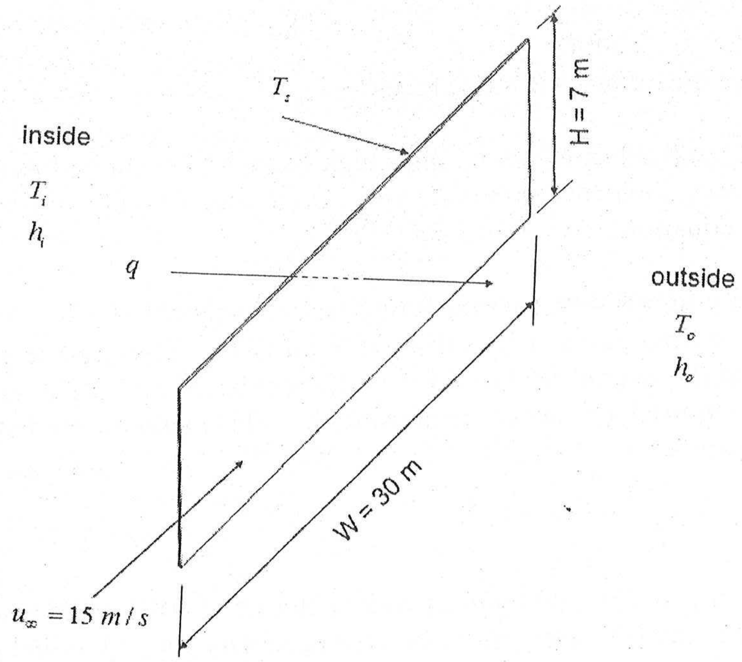
For water at 35°C:

c_p=4178 J/kg K; μ = 725x10^{-6} Kg/m s; k = 0.625 W/m K

b. The side of a building of height $H = 7\ m$ and length $W = 30\ m$ is made entirely of glass. Estimate the heat loss through this glass (ignore the thermal resistance of the glass) when the temperature of the air inside the building is 20°C, the outside air temperature is -15°C and a wind of 15 m/s blows parallel to the side of the building. Select the appropriate correlations from those listed below of *local* Nusselt numbers to estimate the *average* heat transfer coefficients.

For air take: ρ = 1.2 kg / m^3, μ = 1.8 x 10^{-5} kg / m s, Cp = 1 kJ / kg K and Pr = 0.7.

- Free convection in air, laminar ($Gr_x < 10^9$): $Nu_x = 0.3\ Gr_x^{1/4}$
- Free convection in air, turbulent ($Gr_x > 10^9$): $Nu_x = 0.09\ Gr_x^{1/3}$
- Forced convection, laminar ($Re_x < 10^5$): $Nu_x = 0.33\ Re_x^{0.5}\ Pr^{1/3}$
- Forced convection, turbulent ($Re_x > 10^5$): $Nu_x = 0.029\ Re_x^{0.8}\ Pr^{1/3}$



3. **Natural Convection**

(12+6+2=20)

a. In case of natural convection, h could depend on a characteristic length L, a temperature difference ΔT, the conductivity k, the viscosity μ, the specific heat capacity c_p , the density ρ and the volumetric thermal expansion coefficient β of the fluid. *β is usually grouped with g and ΔT as one term ($\beta g \Delta T$) as this group is proportional to the buoyancy force*. Use principles of dimensional analysis to work out a set of non-dimensional groups affecting natural convection.

b. A hot oven is maintained at 180°C having vertical door 50 cm high is exposed to the atmospheric air at 20°C. Calculate the average heat transfer coefficient at the surface of the door. If the oven door is subjected to an upward flow of air (that is forced convection). What would be the minimum free stream velocity for which natural convection may be neglected? Various air properties at the average temperature [(180+20)/2 = 100°C] are, k = 0.032 W/m °C; Pr = 0.7; Kinematic viscosity = 24 x 10^{-6} m^2/s; At T_b = 20°C, β = 1/293K .

4. **Heat Exchanger**

(2+3+5+10=20)

a. In a shell and tube heat exchanger, state the role of baffles.
b. Find out the shell side equivalent diameter (d_e) for a triangular pitch in case of a shell and tube heat exchanger, in terms of tube pitch P_t and the outside diameter of the tube d_o.
c. In a 1-1 shell and tube heat exchanger, a fluid flowing through the tubes in turbulent flow, is being heated by means of steam condensing on the shell side. It is proposed to increase the tube side coefficient by one of the following methods:

- Replace the existing tubes by the same number of tubes with half the original diameter but twice the length.
- Increase the number of tube passes to 2.

Assuming that the fluid flow rate remains high enough to ensure a Reynolds number of over 10,000 in all cases, indicate the method you would select. Justify your selection in brief. Use Dittus-Boelter equation: $Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$.

d. Hot gases enter a finned tube counter-flow heat exchanger at 300°C and leave at 100°C. It is used to heat water at a flow rate of 1 kg/s from 35°C to 125°C. The specific heat of exhaust hot gas is 1000 J/kg.K and the overall heat transfer coefficient based on the gas side is Uh = 100 W/m^2.K. Determine the required gas surface area using the NTU method. Use Effectiveness – NTU (N) relationship, given by, $\varepsilon = \{1 - e^{[-N(1-C)]}\} / \{1 - Ce^{[-N(1-C)]}\}; C = C_{min}/C_{max}$.

5. **Heat Exchanger**

(5+7+8=20)

a. A heat exchanger heats 50,000 kg/hr of water entering at 30°C while cooling 30,000 kg/hr of water from 100°C to 80°C. Determine the area necessary for (i) Parallel flow arrangement; (ii) Counter flow arrangement. Overall heat transfer coefficient may be assumed as 1,600 W/m^{2}K. C_p (water)=4.184 kJ/kgK)

b. Water enters a parallel flow double-pipe heat exchanger at 15°C, flowing at the rate of 1200 kg/hr. It is heated by oil (C_p=2000 J/kg.K), flowing at the rate of 500 kg/hr from an inlet temperature of 90°C. For an area of 1 m^2 and an overall heat transfer coefficient of 1,200 W/m^2.K, determine the total heat transfer and the outlet temperatures of water and oil. For parallel flow, relation between effectiveness (e) and NTU (N) is given by, $\varepsilon = \{1 - e^{[-N(1+C)]}\} / (1 + C)$; $C = C_{min}/C_{max}$.

c. In a counter-current heat exchanger, an oil stream is cooled from 450 K to 410 K by water inlet and outlet temperatures of 300 K and 350 K respectively. The exchanger consists of a number of tubes of 1 m length each. It is now desired to cool the oil to 390 K (instead of 410 K) while maintaining the flow rate of oil, flow rate of water, inlet temperature of oil and water, and the number of tubes at the same values as before. Calculate the length of each tube required for this purpose. Assume that the physical properties remain unchanged.

6. **Boiling and Condensation**

(2+1+3+2+3+4+5=20)

a. Which type of boiling occurs in steam boilers employing natural convection? Explain.

b. In case of a '*Sub-cooled Boiling*, the temperature of liquid is below the saturation temperature and boiling takes place only in the vicinity of heated surface. Explain.

c. Explain '*Leidenfrost Point*' with respect to a 'heat flux versus excess temperature' diagram.

d. Why does the heat flux increase with excess temperature beyond the Leiden-frost point? Is it due to a) predominance of radiation effect, b) occurrence of sub-cooled boiling, c) larger vapor space or d) promotion of nucleate-boiling. Explain.

e. Explain '*Peak Heat Flux*'.

f. A plate condenser of dimensions l * b has been designed to be kept with side l in the vertical position. However due to oversight during erection and installation, it was fixed with side b vertical.

i. How would this affect the heat transfer? Assume laminar conditions and same thermos-physical properties and take b = l/2.

ii. How should the condenser be installed: with shorter side horizontal/longer side horizontal/longer side vertical/shorter side vertical. Explain.

g. Steam at atmospheric pressure condenses on a 0.25 m2 vertical plate. The plate temperature is 96°C. Find the heat transfer coefficient and the mass of steam condensed per hour. The length of the plate is 50 cm. At 97°C, $\rho_c = 960$ kg/m^3; $k = 0.68$ W/m.K; $\mu_c = 2.82 \times 10^{-4}$ kg/m.s; $h_{fg} = 2255$ kJ/kg.

$$h_m = 0.943\left(\frac{g\rho_l(\rho_l - \rho_v)h_{fg}k_l^3}{\mu_l(T_v - T_w)L}\right)^{1/4}$$

7. **Radiation**

(5x4=20)

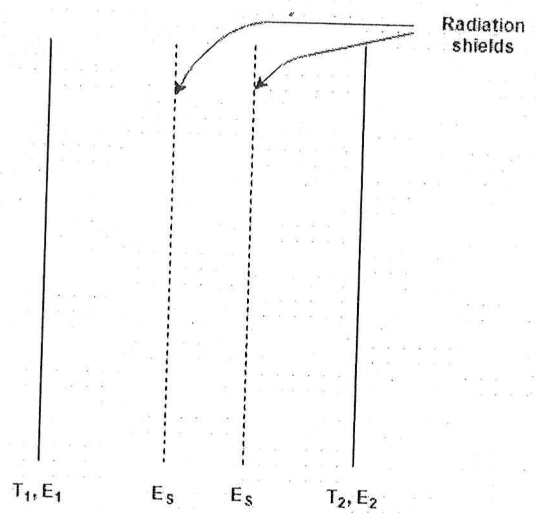
a. Write short notes on Radiation Shields. Starting with the following equation,

$$\dot{Q}_{12} = \frac{E_{b1}-E_{b2}}{\frac{1-\epsilon_1}{\epsilon_1 A_1}+\frac{1}{A_1F_{12}}+\frac{1-\epsilon_2}{\epsilon_2 A_2}}$$

show that when n-shields are arranged between the two surfaces then,

$$\left(\frac{\dot{Q}}{A}\right)_{net_{with\ shield}} = \frac{1}{n+1}\left(\frac{\dot{Q}}{A}\right)_{without\ shield}$$

b. Two large parallel planes with emissivity 0.4 are maintained at different temperatures and exchange heat only by radiation. What percentage change in net radiative heat transfer would occur if two equally large radiation shields with surface emissivity 0.04 are introduced in parallel to the plates?



Hint: Without shields: $Q_{12} = (F_g)_{12} A_1 \sigma_b (T_1^4 - T_2^4)$.

c. A surface has a monochromatic emissivity of 0.2 for all the wavelengths less than or equal to 0.3 μm and 0.85 for all the wavelengths greater than or equal to 3 μm. Find the total emissivity of the surface for a surface temperature of 1100K. Determine also the solar absorptivity of the surface.

d. A pipe having 30 cm diameter is carrying saturated steam at 8 bar of absolute pressure. The pipe runs through a room. The wall of the room is at 300K. A portion around 2 m of the pipe insulation is damaged and exposed to the room atmosphere. Calculate the net rate of heat loss from the pipe by radiation. Temperature of the steam at the prevailing pressure (From steam table) = 450K. (σ=5.67 X 10-8 $W/m^2/K^4$)

8. **Evaporator**

(2+3+2+3+10=20)

a. What are the *limitations* of a *Forward Feed* arrangement in evaporators.
b. Enlist three specific cases where *forced-circulation* type of evaporators should be used.
c. Give two advantages and two disadvantages of Long-Tube Vertical evaporators.
d. A lower operating pressure in an evaporator reduces the boiling point, increases the temperature driving force and hence reduces the heat transfer area. Is there any factor that indirectly tends to increase the requirement of heat transfer area as the operating pressure decreases.
e. A single-effect, vertical short-tube evaporator is used to concentrate a syrup from 10% to 45% solids at the rate of 2400 kg of feed per hour. The feed enters at 30°C and a reduced pressure of 0.2713 bar is maintained in the vapour space. At this pressure, the liquor boils at 340 K. Saturated steam at 388K is supplied to the steam chest. No sub-cooling of the condensate occurs. Calculate the steam requirement and the number of tubes (0.0254 m, 16 BWG) if the height of the calandria is 1.5 m. The following data are given: specific heat of liquor =3.4 kJ/kg°C; latent heat of steam at 0.2713 bar=2342 kJ/kg; boiling point of water at this pressure=340K. The overall heat transfer coefficient=8996 $kJ/h.m^2.°C$.

9. **Evaporator**

(5+3+5+7=20)

a. Give a schematic diagram of a Mixed Feed evaporator. Enlist one each of its *advantage* and *limitation.*
b. Suggest a specific type of an evaporator to be used for concentrating fruit juices. Show the schematic drawing.
c. Enumerate the steps while designing Multiple Effect Evaporators.
d. For a forced circulation evaporator concentrating sulfite liquor under certain special conditions, an apparent overall heat transfer coefficient is found to be 4170.7 $W\ m^{-2}\ K^{-1}$. How long will it take to concentrate 9071.8 kg of a feed liquor containing 5% solute by weight to a final concentration of 15% if the steam temperature is 110.4°C and the temperature corresponding to the pressure in the vapor space is 99.27°C. The heating surface is 9.3 m^2. *Assumptions:* (i) Steady state operation; (ii) No elevation in boiling point due to solute concentration; (iii) No elevation in boiling point due to hydrostatic head; (iv) No sub-cooling of condensate; (v) Feed is at the temperature of 99.27°C. λ_S = 532 $Cal.gm^{-1}$ for the temperature 110.4°C; λ_V = 539.4 $Cal.gm^{-1}$ for the temperature 99.27°C.