Name: BITS ID:

**BITS Pilani, Pilani campus, Second semester 2021-2022**

**Comprehensive Examination**

**ME F220 Heat Transfer**

Total marks: 80, Weightage: 40%, and Date & Time: 07/04/2022 & 8:00 am to 11:00 am.

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**Instructions:** (i) It's an open book examination but Heat transfer textbook by Holman & Bhattacharrya, class slides, and handwritten notes are only permitted. (ii) Assume any missing data and state the assumptions if any.

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## Questions

Q1. A long carbon steel rod of length 40 cm and diameter 40 mm (k = 40 W/mK) is placed in such that one of its ends is 200 $^{o}$C (base temperature) and the ambient temperature is 30 $^{o}$C. Consider convection of the end and assume uniform convective heat transfer coefficient of 10 W/m$^2$K throughout the steel rod. Determine the following: [10 marks]

(a) Heat transfer rate from the fin
(b) Temperature at the mid length of the fin.
(c) Fin efficiency

Q2. Atomization is the process used in making spherical ice balls from water droplets. You are appointed as a technical consultant based your expertise in heat transfer to design the height of the atomization chamber. Find the height of the chamber required to convert the water droplet as per the details given below into complete ice at 0 $^{o}$C. For the simplicity, neglect the density change of water during freezing. (Change in diameter is negligible for 5mm size droplet due to density variation). Make suitable assumption and check the validity of your assumption. Also show the cooling process in a cooling curve clearly mentioning the time for attaining the saturated water, saturated ice and total time.

[15 marks]

| Diameter of water droplet | Initial temperature | Freezing point | Density of water | Latent heat of fusion | Temperature of air in chamber | Velocity of water/ice droplet |
|---|---|---|---|---|---|---|
| 5mm | 30 $^{o}$C | 0 $^{o}$C | 1000 kg/m$^3$. | 310 kJ/kg | -10 $^{o}$C | 2 m/s |

Take properties of air as density= 1.27 kg/m$^3$, k= 0.0246 W/mK, Pr= 0.717, Kinematic viscosity= 1.4x10$^{-5}$ m$^2$/s. Also, take properties of water as density= 1000 kg/m$^3$, k= 0.58 W/mK, $c_p$= 4200 J/kg.K.

Q3. Air is to be heated in a solar concentrating collector tube of inside diameter 5 cm with negligible thickness. The tube receives solar heat flux of 10000 W/m$^2$ on the surface of the tube. If the atmospheric temperature of the air entering the tube is 24 $^{o}$C and need to be heated to 230 $^{o}$C and the maximum temperature of the tube should not exceed 240 $^{o}$C. Assuming fully developed turbulent flow and heat transfer, find the velocity of the air required and the length of the tube required taking the efficiency of solar collector as 60%. [10 marks]

Q4. In a chemical plant, a 3 m diameter spherical tank contains a hot fluid that causes the surface temperature to be 100 $^{o}$C (see Fig. 1). For safety purposes, the tank is enclosed by a 3.15 m -diameter concentric outer spherical cover. The concentric enclosure provides an air gap that serves as an insulation layer. To prevent workplace hazards such as thermal burn on the skin, the outer cover surface temperature should be kept at around 40 ºC. The temperature of ambient air outside the tank is 15 ºC and the outer cover surface of the tank is covered with paint that gives an emissivity of 0.9. Neglecting the radiative heat transfer between the spherical tank and outer cover, determine the total heat transfer across the air gap. Also, estimate the convective heat transfer coefficient at the outer surface. Assume that the properties of air in the enclosure can be evaluated at 77 ºC and 1 atm pressure. [15 marks]

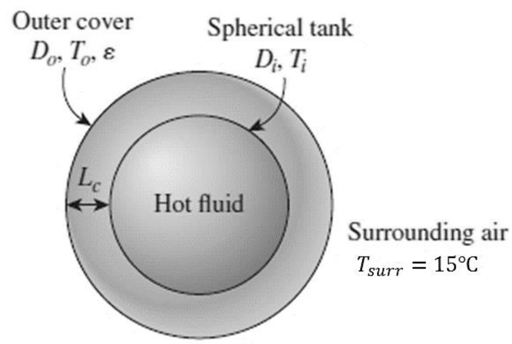


Fig. 1. Schematic diagram for Q4

Q5. Electrical heating of a platinum wire heater is used to boil water in a tank at saturated condition in nucleate boiling regime (see Fig.2). Referring to the relation for the peak boiling heat flux proposed by Sun and Lienhard, calculate the minimum possible diameter of the wire such that the critical heat flux (CHF) should not exceed than that on a thin flat platinum heater. If the radius of the wire is taken as 1 mm, estimate the CHF and corresponding heat transfer coefficient. The properties of water at saturated temperature can be taken as surface tension $\sigma = 0.0589\ N/m,$ density of water and vapor are $\rho_l = 957.9$ kg/m$^3$ and $\rho_v = 0.6$ kg/m$^3$, respectively, Pr = 1.75, $h_{fg} = 2257 kJ/kg$, $\mu_l = 0.282 \times 10^{-3}\ kg/ms$, $c_l = 4.217\ kJ/kg.K$. [15 marks]

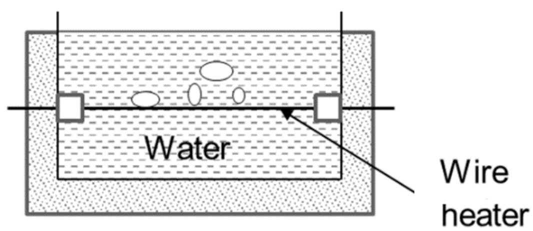


Fig. 2. Schematic diagram for Q5

Q6. Liquid hydrogen used as cryogenic fuel for rocket propulsion at 20 K is kept in a hollow spherical container of 0.5 m diameter and completely fills it. Safety norms do not permit the evaporation rate of liquid beyond 0.01 mg/s. This container is concentrically surrounded by another hollow sphere of 1 m diameter and the annular space between the two is completely evacuated. Surfaces of the spheres facing each other are having surface emissivity of 0.01.

(a) Find the maximum permissible temperature of the outer sphere.
(b) If the third sphere of diameter 0.75 m is inserted concentrically between the two spheres and having surface emissivity of 0.01 on both sides, Find the change in the evaporation rate.

Neglect the temperature difference between the innermost sphere and hydrogen. Neglect the thickness of all spheres. Properties of liquid hydrogen: Density= 71 kg/m$^3$, Boiling point=20 K and latent heat of evaporation= 461 kJ/kg. [15 marks]