Q1) Liquid oxygen is stored in a thin-walled, spherical container 0.6 m in diameter, which is enclosed within a second thin-walled, spherical container 1 m in diameter. The opaque, diffuse, gray container surfaces have an emissivity of 0.08 and are separated by an evacuated space. If the outer surface is at 285 K and the inner surface is at 90 K, what is the mass rate of oxygen lost due to evaporation? (The latent heat of vaporization of oxygen is 2.13 = 105 J/kg.)

$2.13\times10^{5}\ J/kg$

$$\dot{m} = \frac{-\sigma\left(\pi D_i^2\right)\left(T_i^4 - T_o^4\right)}{h_{fg}\left[\frac{1}{\varepsilon_i} + \frac{1-\varepsilon_o}{\varepsilon_o}\left(\frac{r_i}{r_o}\right)^2\right]}$$

$$\dot{m} = \frac{-5.67\times10^{-8}\cdot(\pi)(0.6)^2(90^4 - 285^4)}{2.13\times10^{5}\left[\frac{1}{0.08} + \frac{1-0.08}{0.08}\left(\frac{0.3}{0.5}\right)^2\right]}$$

$$\dot{m} = 1{,}18\cdot10^{-4}\ kg/s$$

Q2) In a cross-flow heat exchanger, engine oil is cooled by using ethylene glycol as coolant. The inlet and exit temperatures of the oil are 137°C and 47°C respectively, whereas ethylene glycol enters the heat exchanger at a temperature of 17°C. The flow rate of oil is 3 kg/s while the flow rate of ethylene glycol is given as 10 kg/s. The configuration of the heat exchanger ensures that the oil flows through individual tubes while ethylene glycol flows in between these tubes, being mixed in the process. If the effective area of the heat exchanger is known to be 17 m2, calculate the overall heat transfer coefficient, U.

$$NTU = \frac{U.A}{C_{min}}$$

$$C_{min} = 1184 \times 3 = 6552 \ W/K$$

$$C_{max} = 2438 \times 10 = 24380 \ W/K$$

$$\varepsilon = \frac{q}{q_{max}} = \frac{C_{min}(T_{h,i} - T_{h,o})}{C_{min}(T_{h,i} - T_{c,i})} = \frac{90}{120} = 0.75$$

$C_{min} \rightarrow$ unmixed , $C_{max} \rightarrow$ mixed

$$\frac{C_{min}}{C_{max}} = 3.72$$

NTU is 2.2 from table

$$U = \frac{NTU . C_{min}}{A} = 847.8 \ W/k$$

Q3) A cylindrical rod experiences uniform volumetric heat generation at a rate of 2000 W/m3. The cylinder has a diameter of 120 cm and a thermal conductivity of 70 W/m.K. The cylinder is surrounded by a fluid in all directions, and the resulting heat transfer coefficient is known to be 30 W/m2K. The fluid is at a bulk temperature of 10°C. Calculate the temperature of the cylinder at **(a)** its center and **(b)** its surface.

$$T(r) = \frac{\dot{q} \cdot r_o^2}{4k}\left(1 - \frac{r^2}{r_o^2}\right) + T_s \quad (3.53)$$

$$\dot{q} = \dot{q}_{conv} = h.A\,(T_s - T_\infty)$$

$$q' = E_{gen} = \dot{q}\,V = (2000).\left(\frac{\pi D^2}{4}\right)$$

$$q' = 2262 \text{ w/m}$$

$$q' = h.A\,(T_s - T_\infty) \Rightarrow 2262 = (30)(\pi.2.2)(T_s - 10)$$

$$T_s = 30°C$$

$$T(r) = \frac{\dot{q} \cdot r_o^2}{4k}\left(1 - \frac{r^2}{r_o^2}\right) + T_s = \frac{(2000)(1.2)^2}{4.(70)}(1-0) + 30$$

$$T(0) = 32.57°C$$

Q4) Atmospheric air at 27°C and a velocity of 0.8 m/s flows over a 20-W incandescent light bulb whose surface temperature is at 127°C. The bulb may be approximated as a sphere whose diameter is 55 mm. Calculate the rate of convective heat loss from the bulb to the air.

$$\overline{Nu}_D = 2 + (0.4Re_D^{1/2} + 0.06Re_D^{2/3})Pr^{0.4}\left(\frac{\mu}{\mu_s}\right)^{1/4} \quad (7.56)$$

$$\begin{bmatrix} 0.71 \lesssim Pr \lesssim 380 \\ 3.5 \lesssim Re_D \lesssim 7.6 \times 10^4 \\ 1.0 \lesssim (\mu/\mu_s) \lesssim 3.2 \end{bmatrix}$$

$$q = h.A(T_s - T_\infty) = 10{,}78 . \pi(0{,}055)^2 . (127-27)$$

$$=$$

$$Re = \frac{V.D}{\nu} = \frac{(0.8)\times(0{,}055)}{15{,}85.10^{-6}} = 2763$$

$$\overline{Nu}_D = 28.55$$

$$\bar{h} = \frac{Nu_D . k}{D} = \frac{(28.55).(0{,}0263)}{0{,}055} = 10{,}78 \ W/m^2.K$$

Q5) The heat transfer coefficient for air flowing over a sphere is to be determined by observing the temperature–time history of a sphere fabricated from pure copper. The sphere, which is 12.7 mm in diameter, is at 66°C before it is inserted into an airstream having a temperature of 27°C. 69 s after the sphere is inserted in the airstream, a thermocouple on the outer surface of the sphere gives a reading of 55°C. Assuming that the lumped capacitance method can be used for this problem, calculate the heat transfer coefficient. Using the value that you find, justify your assumption.

$$R_t = \frac{1}{h.A}$$

$$\frac{T(t)}{T} = \exp\left(-\frac{t}{R_t C_t}\right)$$

$$C_t = \rho V c_p$$

$$\frac{T(t) - T_\infty}{T - T_\infty} = \exp\left(\frac{-69}{R_t C_t}\right)$$

$$R_t . C_t = 298 s$$

$$h = \frac{\rho V c_p}{A . R_t C_t} = 35.3 \ W/m^2.k$$

$$Bi = \frac{h L_c}{k} = \frac{35.3 . \frac{0.0127}{6}}{398} = 1.88 \times 10^{-4} < 0.1$$