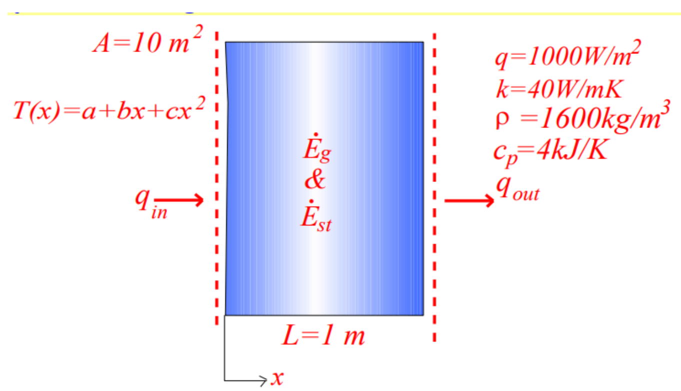
ME 346 – Heat Transfer: Tutorial 1

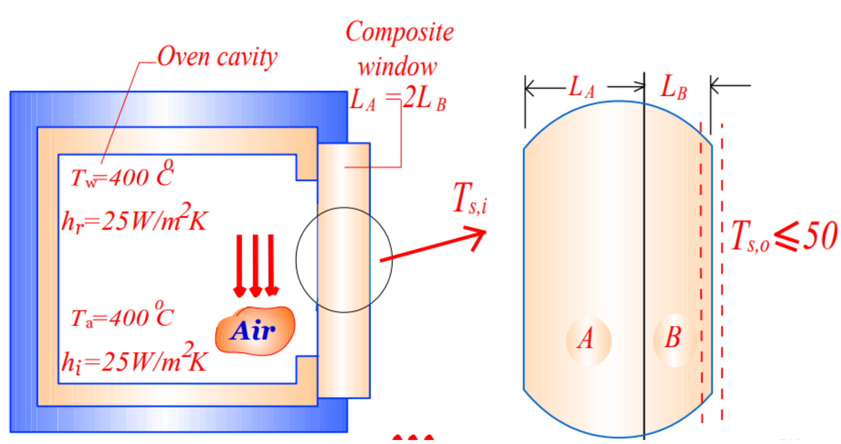
Q1: The temperature distribution across a wall of 1 m thick at a certain instant of time is given as $T(x) = a+bx+cx^2$ where T is in degrees Celsuis and x is in meters, while a = 800 °C, b = -350 °C/m, and c = -60 °C/m^2 . A uniform heat generation, = 1000 W/m^3 , is present in the wall of area 10 m^2 having the properties ϱ = 1600 kg/m^3 , k = 40 W/m.K, and Cp = 4 kJ/kg.K.

- Determine the rate of heat transfer entering the wall (x = 0) and leaving the wall (x = 1m)
- Determine the rate of change of energy storage in the wall
- Determine the time rate of temperature change at x = 0.25 and 0.5 m

(**Conservation of Energy**)



Q2: A leading manufacturer of household appliances is proposing a self-cleaning oven design that involves use of a composite window separating the oven cavity from the room air. The composite is to consist of two high temperature plastics (A and B) of thicknesses $L_A = 2L_B$ and thermal conductivities $k_A = 0.15\ W\ m.K$ and $k_B = 0.08\ W\ m.K$. During the self-cleaning process, the oven wall and air temperatures, $Tw = Ta = 400$ ℃, while the room air temperature is 25 ℃. The inside convection and radiation heat transfer coefficients h_i and h_r , as well as the outside convection coefficient ho , are each approximately 25 W/m^2 .K. What is the minimum window thickness, $L = L_A + L_B$, needed to ensure a temperature that is 50 ℃ or less at the outer surface of the window? This temperature must not be exceeded for safety reasons



Q3: Derive Heat Diffusion equation in cylindrical coordinates:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(k.r\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial}{\partial \phi}\left(k.r\frac{\partial T}{\partial \phi}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+q_V=\rho c_p\frac{\partial T}{\partial t}$$

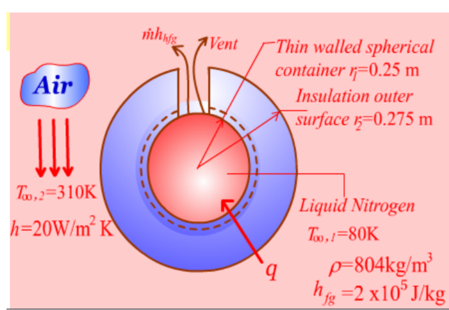
where
k is the materials conductivity [$W.m^{-1}.K^{-1}$]
q_V is the rate at which energy is generated per unit volume of the medium [$W.m^{-3}$]
ρ is the density [$kg.m^3$]
c_p is the specific heat capacity [$J.kg^{-1}.K^{-1}$]

Q4: Derive Heat Diffusion equation in spherical coordinates:

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(k.r^2\frac{\partial T}{\partial r}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial}{\partial \phi}\left(k\frac{\partial T}{\partial \phi}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial \theta}\left(k.\sin\theta\frac{\partial T}{\partial \theta}\right)+q_V=\rho c_p\frac{\partial T}{\partial t}$$

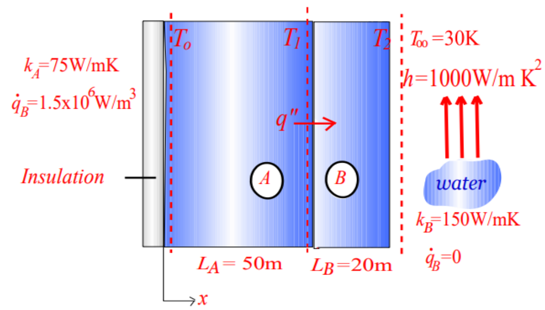
Q5: A steel tube (k = 46 W/m-K) has an inside diameter of 3 cm and a wall thickness of 2mm. A fluid flows inside the tube producing a convection heat transfer coefficient of 1500 W/m2-K on the inside surface while on the outside surface a second fluid flows producing a heat transfer coefficient of 200 W/m2-K on the outer surface of the tube. The inside fluid is at 223 °C while the outside fluid is at 57 °C. Calculate the overall heat transfer coefficient based on the tube inside area and also based on the tube outside area. Also, calculate the heat loss per unit length of the tube. **(1D, Steady state conduction with no internal generation in cylinder)**

Q6: A spherical thin walled metallic container is used to store liquid nitrogen at 80 K. The container has a diameter of 0.5 m and is covered with an evacuated, reflective insulation composed of silica powder. The insulation is 25 mm thick, and its outer surface is exposed to ambient air at 310 K. The convection coefficient is known to be 20 W/m2 K. The latent heat of vaporization and the density of the liquid nitrogen are $2x10^5$ J/kg and 804 kg/m3 , respectively. Thermal conductivity of evacuated silica powder (300 K) is 0.0017 W/mK. What is the rate of heat transfer to the liquid nitrogen? What is the rate of liquid boil-off? **(1D, Steady state conduction with no internal generation in sphere)**



Q7: A 3 mm diameter and 6 m long electric wire is tightly wrapped with a 2 mm thick plastic cover whose thermal conductivity is k = 0.15 W/m.°C. Electrical measurements indicate that a current of 10 A passes through the wire and there is a voltage drop of 8 V along the wire. If the insulated wire is exposed to a medium at 27 °C with a heat transfer coefficient of h=12 W/m2°C, determine the temperature at the interface of the wire and the plastic cover in steady operation. Also determine whether doubling the thickness of the plastic cover will increase or decrease this interface temperature. (**Critical Radius of Insulation**)

Q8: A plane wall is a composite of two materials, A and B. The wall of material A has uniform heat generation $\dot{q} = 1.5\times10^6\ W/m^3$ $k_A = 75\ W\ m.K$ and thickness $L_A = 50\ mm$. The wall material B has no generation with $k_B = 150\ W\ m.K$ and thickness $L_B = 20\ mm$. The inner surface of material A is well insulated, while the outer surface of material B is cooled by water stream $T_\infty = 30$ ℃ and $h = 1000\ W/m2\ .\ K$. Sketch the temperature distribution that exists in the composite under steady state conditions. Determine the temperature T_o of the insulated surface and the temperature T_2 of the cooled surface. (**Rectangle Composite Stack with 1D Heat Generation**)



Q9:

3. An experimental boiling device consists of a semiconductor slab of thickness L_1 and thermal conductivity k_1, perfectly insulated on its backside, which is covered with a second slab of a thermally conducting, electrically insulating ceramic of thickness L_2 and conductivity k_2, pressed upon which is a third material slab of thickness L_3 and conductivity k_3 (See Figure). Heat is generated at a uniform rate q''' (W/m3) in slab by passing electrical current through the slab. The h eat is conducted through the other two slabs and dissipated by boiling saturated liquid (at T_{sat}) on the exposed surface of the metallic wall. The boiling heat flux is known to follow the relation

$q'' = C\,(T_{wall} - T_{sat})^3$ where C is a known empirical constant and T_{wall} is the temperature of the boiling surface.

(a) Derive an expression for T_{wall} in terms of q''', C, T_{sat} and the thicknesses and thermal conductivities of the slabs

(b) Derive an expression for the highest temperature in the boiling device

Hints:

i) Thermal resistance per unit area for a plane wall of thickness L and conductivity is L/k

ii) The steady, one-dimensional heat diffusion equation for a medium of conductivity k is