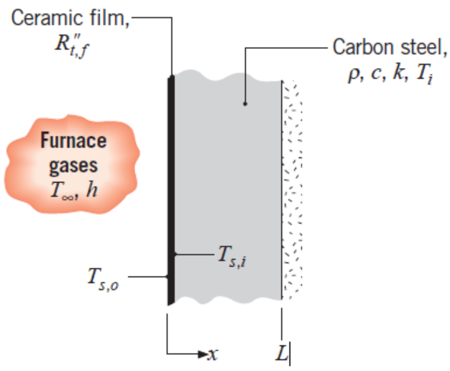
ME 346 S3 TUTORIAL 2

Q1. 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. A thermocouple on the outer surface of the sphere indicates 55 °C 69 s after the sphere is inserted into the airstream. Assume and then justify that the sphere behaves as a spacewise isothermal object and calculate the heat transfer coefficient.

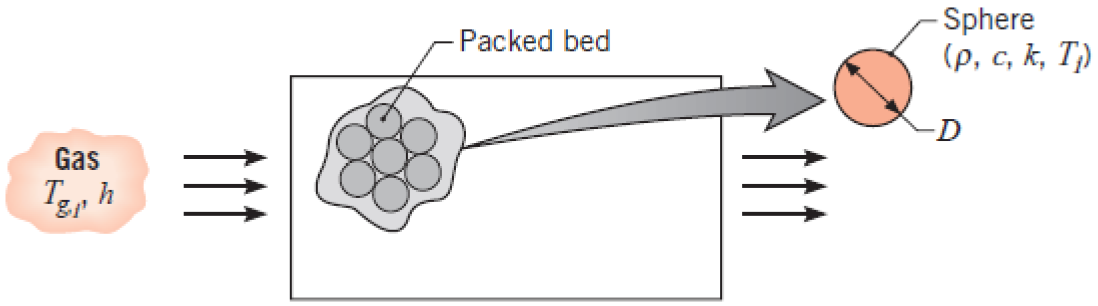
Q2. A plane wall of a furnace is fabricated from plain carbon steel (k = 60 W/mK, ρ = 7850 kg/m^3, c = 430 J/kg K) and is of thickness L = 10mm. To protect it from the corrosive effects of the furnace combustion gases, one surface of the wall is coated with a thin ceramic film that, for a unit surface area, has a thermal resistance of $R''_{t,f}$ = 0.01 m^2 K/W. The opposite surface is well insulated from the surroundings.



At furnace start-up the wall is at an initial temperature of T_i = 300 K, and combustion gases at T_∞ = 1300 K enter the furnace, providing a convection coefficient of h = 25 W/m^2 K at the ceramic film. Assuming the film to have negligible thermal capacitance, how long will it take for the inner surface of the steel to achieve a temperature of $T_{s,i}$ = 1200 K? What is the temperature $T_{s,o}$ of the exposed surface of the ceramic film at this time?

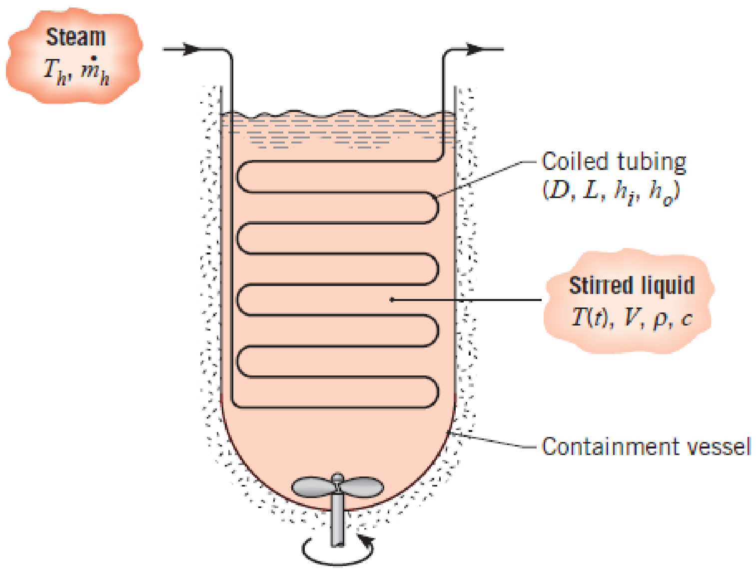
Q3. Thermal energy storage systems commonly involve a packed bed of solid spheres, through which a hot gas flows if the system is being charged, or a cold gas if it is being discharged. In a charging process, heat transfer from the hot gas increases thermal energy stored within the colder spheres; during

discharge, the stored energy decreases as heat is transferred from the warmer spheres to the cooler gas.



Consider a packed bed of 75-mm-diameter aluminum spheres (ρ = 2700 kg/m3, c = 950 J/kg K, k = 240 W/m K) and a charging process for which gas enters the storage unit at a temperature of Tg,i = 300°C. If the initial temperature of the spheres is Ti = 25°C and the convection coefficient is h =75 W/m2 K, how long does it take a sphere near the inlet of the system to accumulate 90% of the maximum possible thermal energy? What is the corresponding temperature at the center of the sphere? Is there any advantage to using copper instead of aluminum?

Q4. Batch processes are often used in chemical and pharmaceutical operations to achieve a desired chemical composition for the final product and typically involve a transient heating operation to take the product from room temperature to the desired process temperature. Consider a situation for which a chemical of density ρ = l200 kg/m3 and specific heat c =2200 J/kg K occupies a volume of V = 2.25m^3 in an insulated vessel. The chemical is to be heated from room temperature, Ti = 300 K, to a process temperature of T = 450 K by passing saturated steam at Th = 500 K through a coiled, thin-walled, 20-mm-diameter tube in the vessel. Steam condensation within the tube maintains an interior convection coefficient of hi = 10,000 W/m^2 K, while the highly agitated liquid in the stirred vessel maintains an outside convection coefficient of ho = 2000 W/m^2 K.



If the chemical is to be heated from 300 to 450 K in 60 min, what is the required length L of the submerged tubing?

Q5. A two-dimensional rectangular plate is subjected to prescribed boundary conditions. Solve for the temperature distribution and calculate the temperature at the midpoint (1, 0.5) by considering the first five nonzero terms of the infinite series that must be evaluated. Assess the error resulting from using only the first three terms of the infinite series. Plot the temperature distributions $T(x, 0.5)$ and $T(1.0, y)$.

Q6. For two dimension heat conduction in a plate, as shown in figure 3, find the temperature distribution T (x,y) by solving the boundary value problem. Use the steady state heat conduction equation.

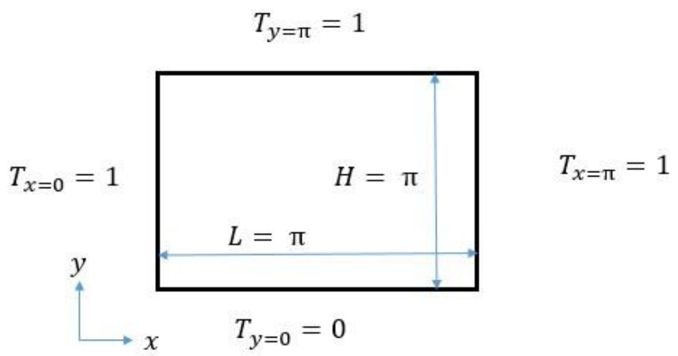


Figure 3

Q7. Obtain the temperature distribution T (x,y) for the square plate subjected to two-dimensional steady-state heat conduction. Referring to figure 2, the left side wall is subjected to T = T_0, and both the right and bottom sides are insulated such that $\frac{\partial T}{\partial x}(x=L) = \frac{\partial T}{\partial y}(y=0) = 0$. The top side is cooled by convection, which can be expressed as $-k\frac{\partial T}{\partial y}(y=th/2) = h(T_{y=th/2} - T_\infty)$.

Use the steady state heat conduction equation as: $\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0$.

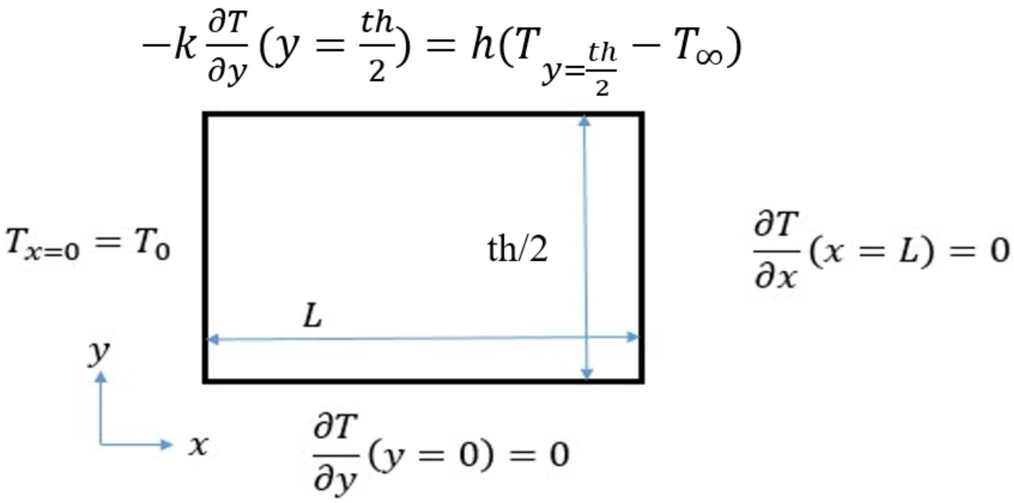


Figure 2