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AMSE502 Phase Transformations

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1. To harden fully a sheet of low-alloy steel during a quench (to 0°C) from an initial temperature, T_o, the sheet must be cooled at 200 K s^{-1} in the vicinity of 925 °C.

   a) Write the power series solution to this problem. Let *h* be the thickness of the sheet and α the thermal diffusivity.
   b) Sketch the temperature at the sheet's center as a function of time, as estimated by the first term approximation of T(x,t). Under what conditions is the approximation valid to within 5%.
   c) Develop an expression for the cooling rate at the center of the steel sheet and determine when a one-term approximation is valid to within 5%.
   d) Calculate the cooling rate at the sheet's center when its temperature is 600 °C.
   e) Estimate the maximum sheet thickness that can be hardened fully in this quenching medium. α = 0.15 cm^{2}s^{-1}. Comment on how your result depends upon the steel's initial temperature. Do not conclude that there is no dependence simply because T_o does not appear in your final expression. The latter was derived on the basis of simplifying assumptions made earlier. Examine these assumptions in order to explain the relationship between cooling rate and T_o.

2. An iron plate measuring 4 m × 1 m × 1 cm has an initial nitrogen content of 100 ppm. The plate is laid flat on the floor of a furnace heated to a temperature of 1000 K. The nitrogen potential in the atmosphere of the furnace is fixed at 5 ppm. The diffusivity of atomic nitrogen in iron is constant at a value of 4 × 10^{-7} cm^2 s^{-1}.

   (a) Write the differential equation along with the applicable initial and boundary conditions for the denitriding of such a plate. Assume that the reaction to form molecular nitrogen is fast, i.e., not rate controlling. Neglect nitrogen losses from the bottom and edges of the plate.
   (b) Write an expression for $\rho(x,t)$ valid at all times.
   (c) Calculate how long it will take for the average nitrogen concentration in the plate to drop to 50% of the initial value.
   (d) If you assume that the diffusivity of nitrogen increases with nitrogen concentration, how does your answer to part (c) change? Longer or shorter time required? Justify your answer.

3. Consider injection of an alloying element B in a metallic matrix A. The initial composition of B in A is 0.01. Injection is carried out by maintaining the surface composition of B to be 0.05. The diffusion coefficient of B in A is 4.529×10^{-7} exp[-147723(J)/RT] (m^2/s). The injection temperature is between 1173K and 1473K. Injection distance is defined to be the distance from the surface of a point where the composition of B is half of the target value (0.03). Using the diffusion simulation code (FDM.for), perform the followings:

   (a) How does the injection distance depend on injection time?
   (b) How does the injection distance depend on temperature?
   (c) How can you determine the activation energy for the reaction, and what is it?