1. (*a*) With simple sketch, compare and discuss the differences among freezing of water, solution and food. [0.5]

   (b) Sketch a typical freezing curve for food, and describe the three periods during freezing. [0.5]

2. A meat ball can be assumed as a sphere. If the meat ball has a diameter of 120 mm and is to be cooled under the following conditions:
   Specific heat c = 3800 $Jkg^{-1}K^{-1}$
   Thermal conductivity k = 0.47 $Wm^{-1}K^{-1}$
   Density ρ = 1050 kgm^{-3}
   Initial product temperature T_i = 35°C
   Cooling air temperature T_m = -2°C
   Heat transfer coefficient h = 11.0 $Wm^{-2}K^{-1}$
   Desired final centre temperature T_c = 5°C
   Using the graphical method with Figures 1-3 to calculate the cooling time and the mean temperature for the meat ball.

   General form of the cooling time model is

$$\theta = \frac{-f}{2.303}\ln\left(\frac{Y}{j}\right)$$

   [1.0]

3. *(a)* A 150 kg beef carcass is frozen to -20°C, if the mass fraction of water and protein are 58.21% and 17.48% respectively, and the initial freezing point is -1.7°C, what is the mass of frozen and unfrozen water at -20°C? The mass fraction of ice can be calculated by

$$x_{ice} = \frac{1.105x_{wo}}{1+\frac{0.8765}{\ln(t_f - t - 1)}}$$

   [0.5]

   (b) If the initial temperature of the carcass is 10°C, how much heat must be removed during this freezing process? The enthalpy of unfrozen and frozen foods can be calculated respectively by

$$H = H_f + (t - t_f)(4.19 - 2.30x_s - 0.628x_s^3) \quad \text{(for unfrozen foods)}$$

$$H = (t - t_r)\left[1.55 + 1.26x_s - \frac{(x_{wo} - x_b)L_0 t_f}{t_r t}\right] \quad \text{(for frozen foods)}$$

   where t_r = reference temperature (zero enthalpy) = -40°C; H_f = enthalpy of food at initial freezing temperature, kJ/kg; L_0 = latent heat of fusion of water = 333.6 kJ/kg. (Hint: The equation for frozen foods can be used to calculate H_f). [0.5]

4. Mechanical vapour compression cycle shown in Figure 4 and absorption cycle shown in Figure 5 are two main cycles used in food refrigeration, compare and discuss the differences among these two cycles and describe their operating principles.

[1.0]

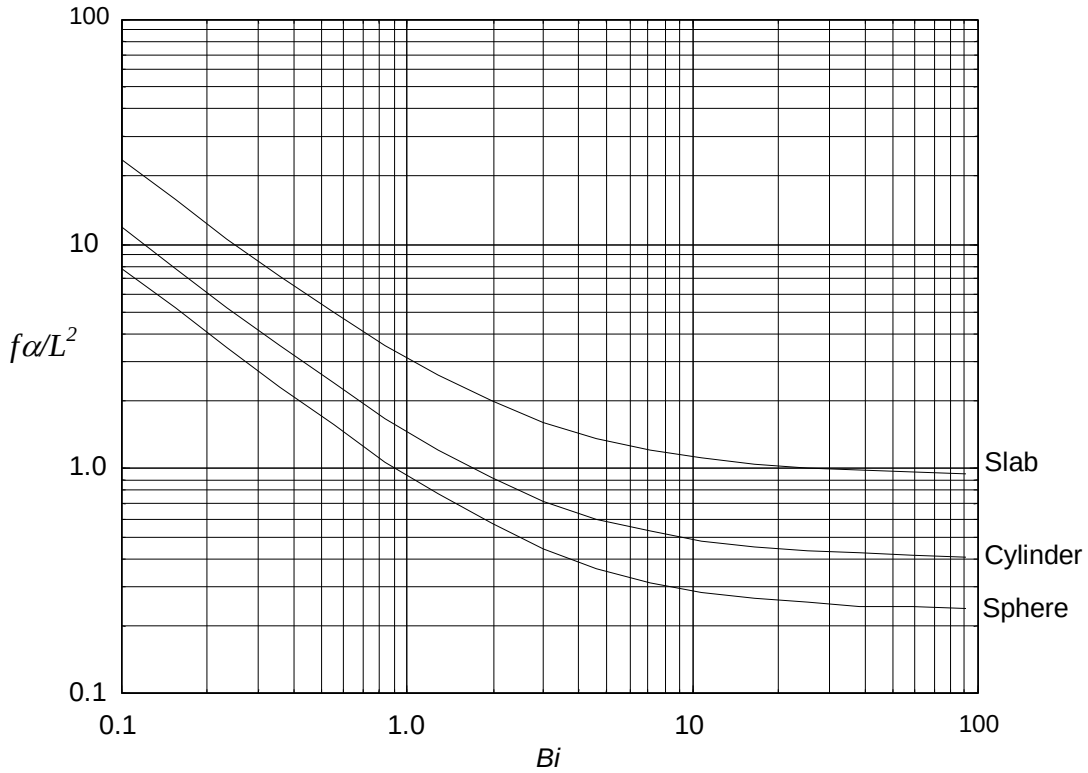

Figure 1. Plot of $f\alpha/L^2$ against Biot number.

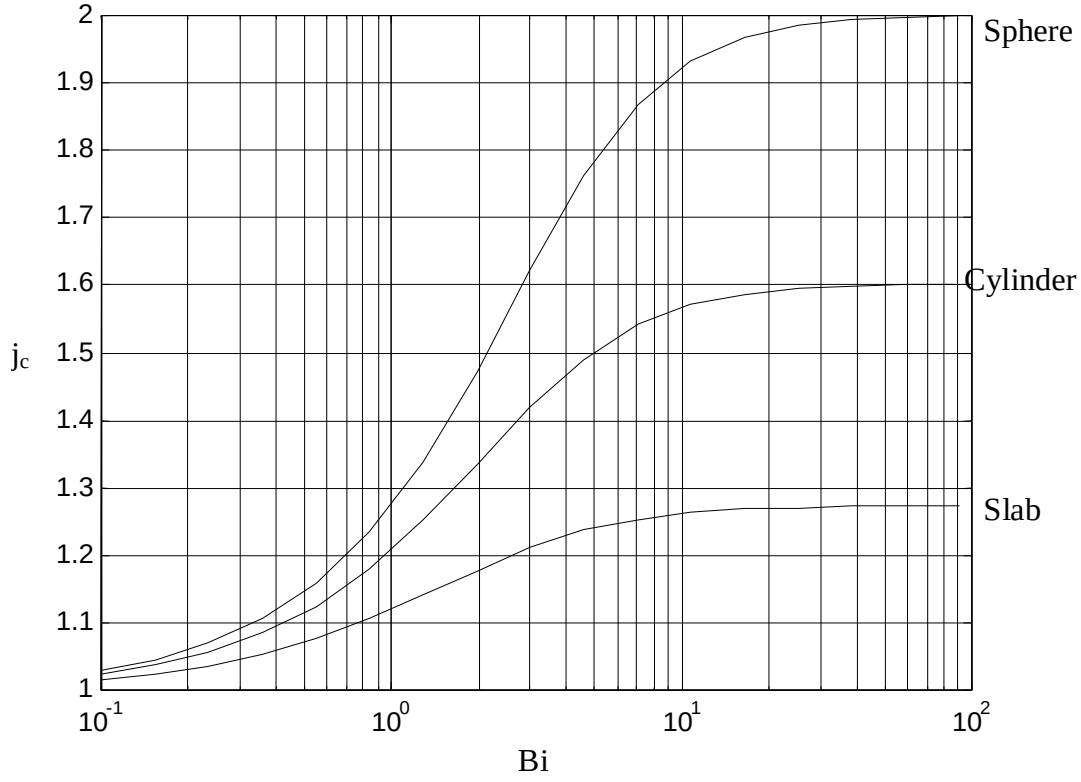

Figure 2. Plot of j_c against Biot number.

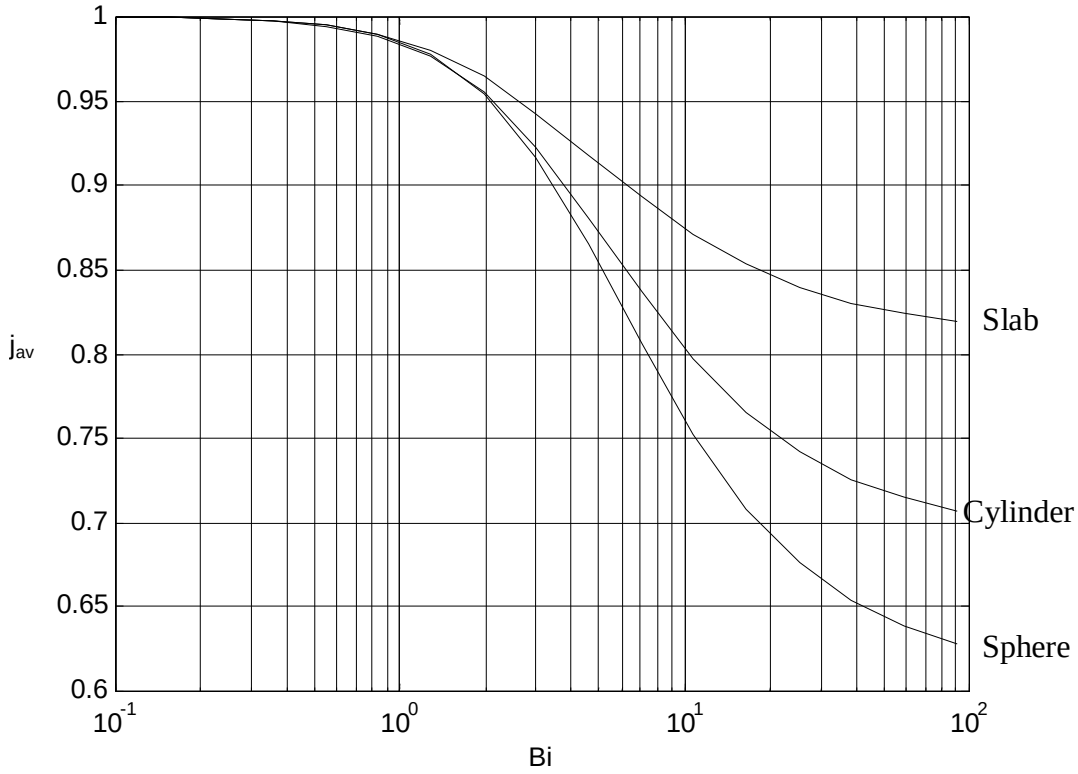

Figure 3. Plot of j_{av} against Biot number.

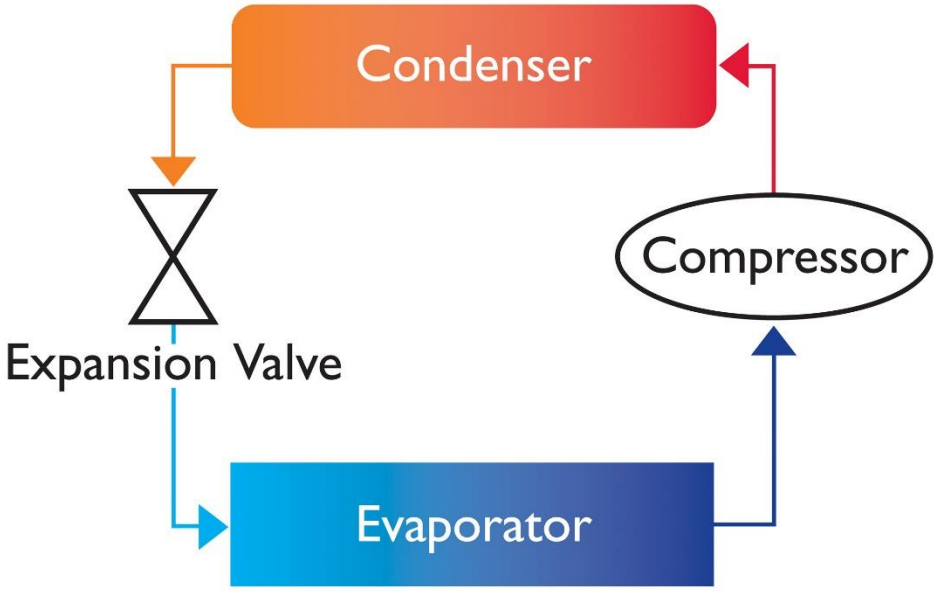

Figure 4. Mechanical vapour compression cycle.

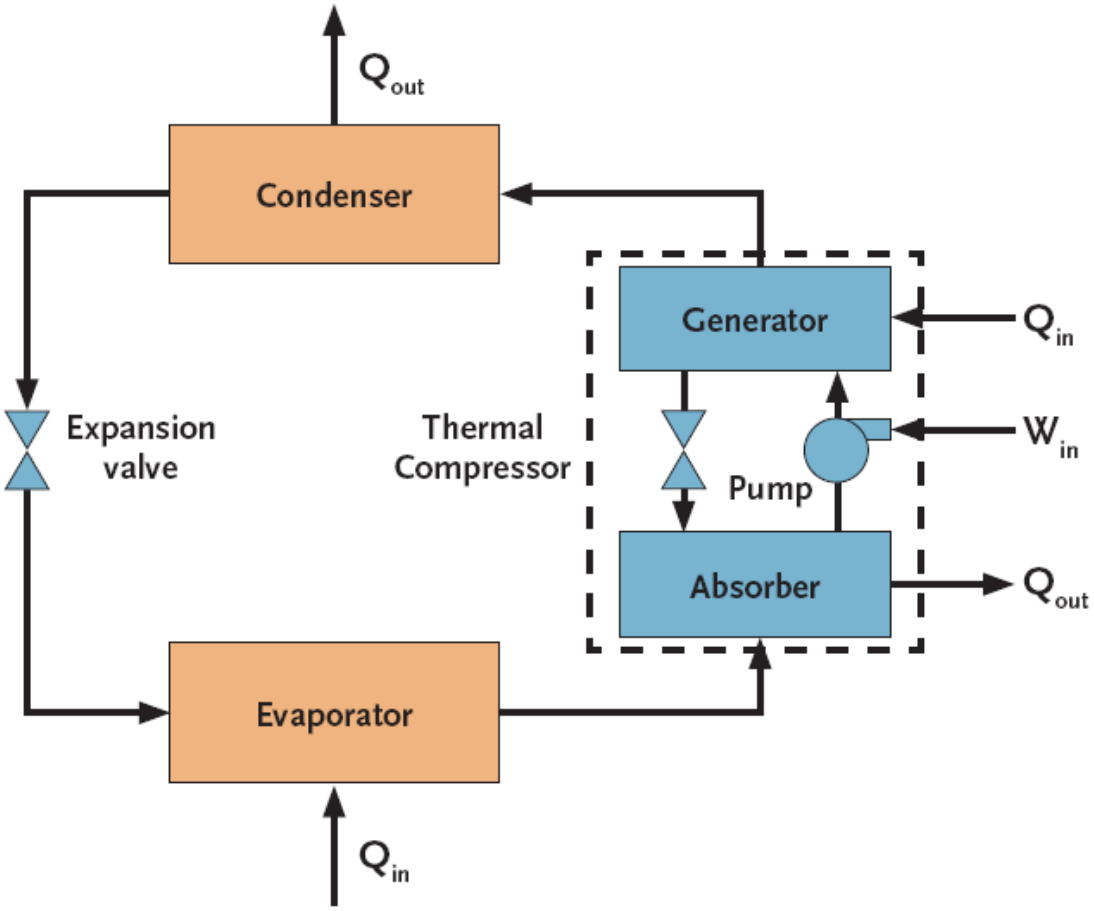

Figure 5. Absorption refrigeration cycle.