1. Figure 1 shows the schematics of a mechanical vapour compression cycle and absorption cycle, which are two common cycles for food refrigeration, describe their operating principles, and compare and discuss their differences.

2. Blast freezers are the most common freezing system used in the food industry. There are a wide range of blast freezer systems available. List these various types of blast freezers and discuss their operating principles and applications.

3. A meat ball can be assumed to be 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 $k = 0.47$ W m^{-1}K^{-1}
   Density $\rho = 1050$ kg m^{-3}
   Initial product temperature $T_i = 35$°C
   Cooling air temperature $T_m = -2$°C
   Heat transfer coefficient $h = 11.0$ W m^{-2}K^{-1}
   Desired final centre temperature $T_c = 5$°C

   Using the graphical method with Figures 2-4 to calculate the cooling time and the mean temperature for the meat ball.

   General form of the cooling time model is

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

4. The freezing time can be considered as the summation of precooling, phase change and subcooling times. Based on this concept, the following equation was developed to estimate the freezing time:

$$\theta = \frac{D/2}{E_{Freeze}h}\left(\frac{\Delta H_1}{\Delta T_1} + \frac{\Delta H_2}{\Delta T_2}\right)\left(1 + \frac{Bi_s}{4}\right)$$

   Bi_s = Biot number for fully frozen food = hD/k_s; E_{Freeze} = equivalent heat transfer dimensionality; ΔH_1 and ΔT_1 are volumetric enthalpy change and temperature difference for precooling period, and ΔH_2 and ΔT_2 are those for combined freezing-subcooling period:

$$\Delta H_1 = H_i - H_{fm} = C_l(T_i - T_{fm})$$
$$\Delta H_2 = H_{fm} - H_c = [L_f + C_s(T_{fm} - T_c)]$$
$$\Delta T_1 = (T_i + T_{fm})/2 - T_m$$
$$\Delta T_2 = T_{fm} - T_m$$

   T_{fm} is "mean freezing temperature": $T_{fm} = 1.8 + 0.263\, T_c + 0.105\, T_m$

   If a meat product is frozen in air at $T_m = -40$°C from its initial temperature of 35°C to a final temperature of -18°C, calculate the freezing time (the meat product can be assumed to be a sphere with a radius $L = 0.06$ m). Some data are as follows:
   heat transfer coefficient $h = 11.0$ W m^{-2}K^{-1} ; latent heat, $H_s = 209000$ J kg^{-1} ;
   specific heat $c_l = 3800$ J kg^{-1}K^{-1} ; $c_s = 1900$ J kg^{-1}K^{-1} ;
   thermal conductivity $k_l = 0.47$ Wm^{-1}K^{-1} ; $k_s = 1.35$ W m^{-1}K^{-1} ;
   density $\rho_l = 1050$ kgm^{-3} ; $\rho_s = 970$ kg m^{-3} .

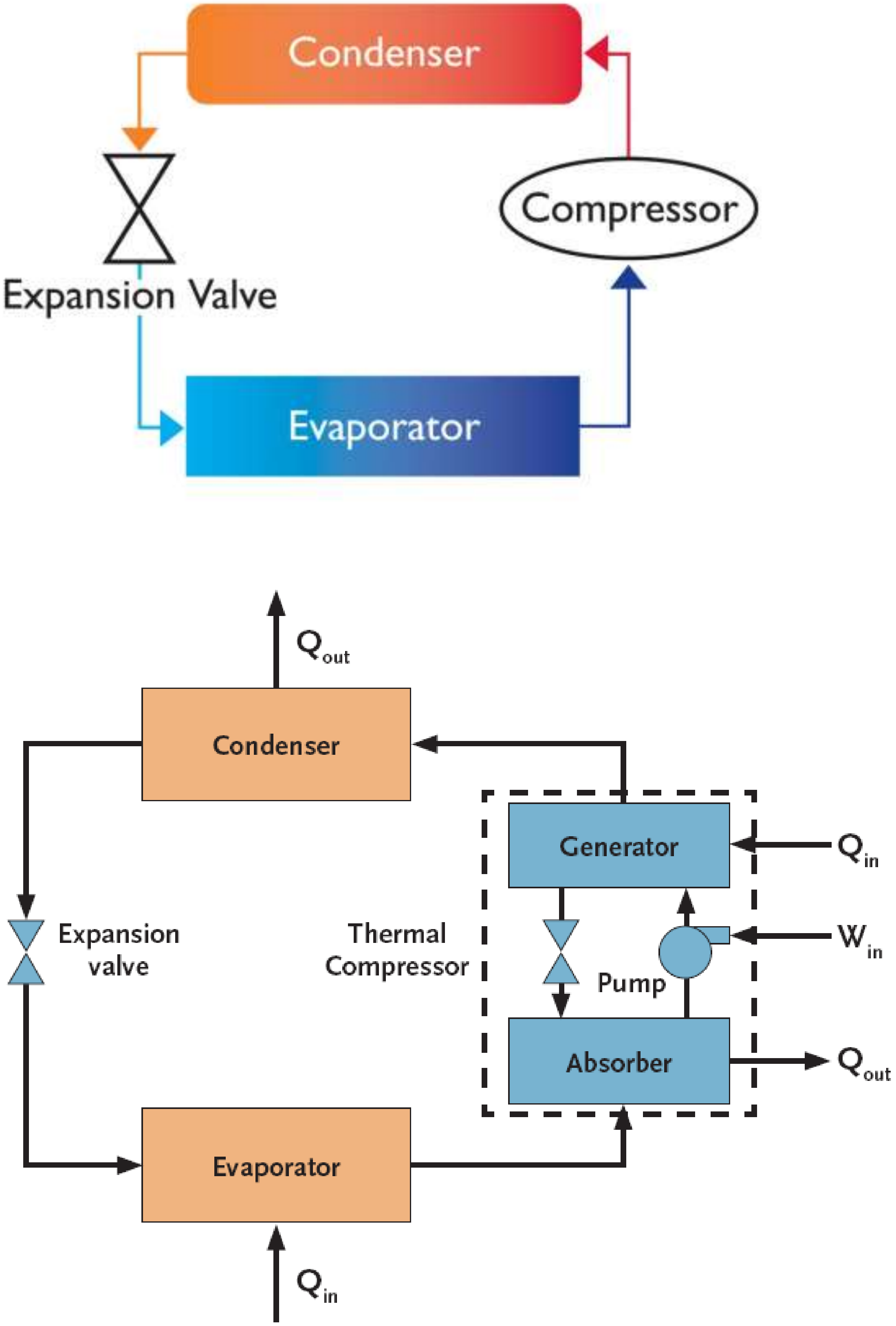

Figure 1. The schematics of mechanical vapour compression cycle and absorption cycle.

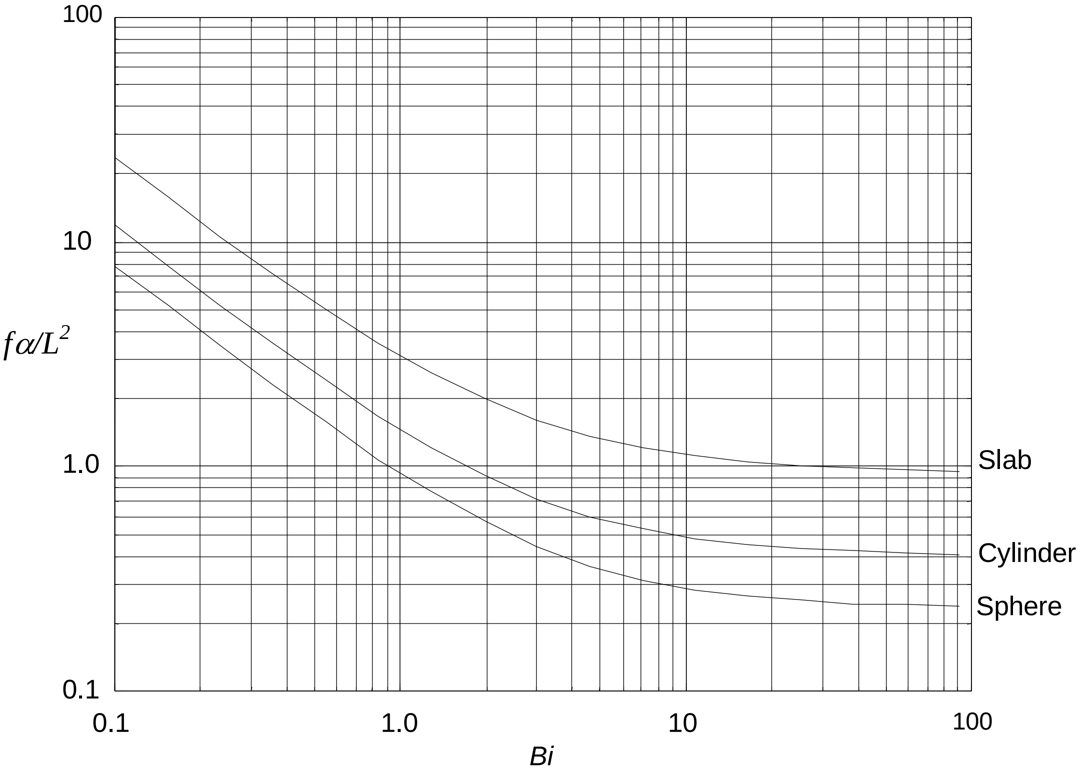

Figure 2. Plot of $f\alpha/L^2$ against Biot number.

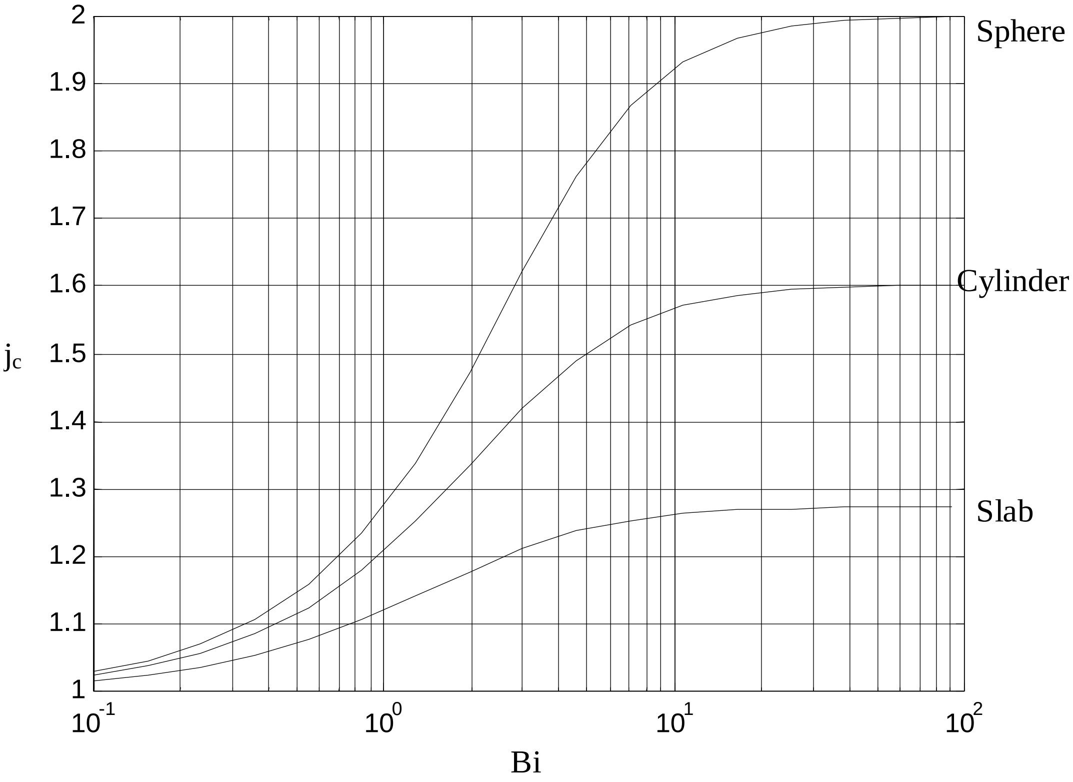

Figure 3. Plot of j_c against Biot number.

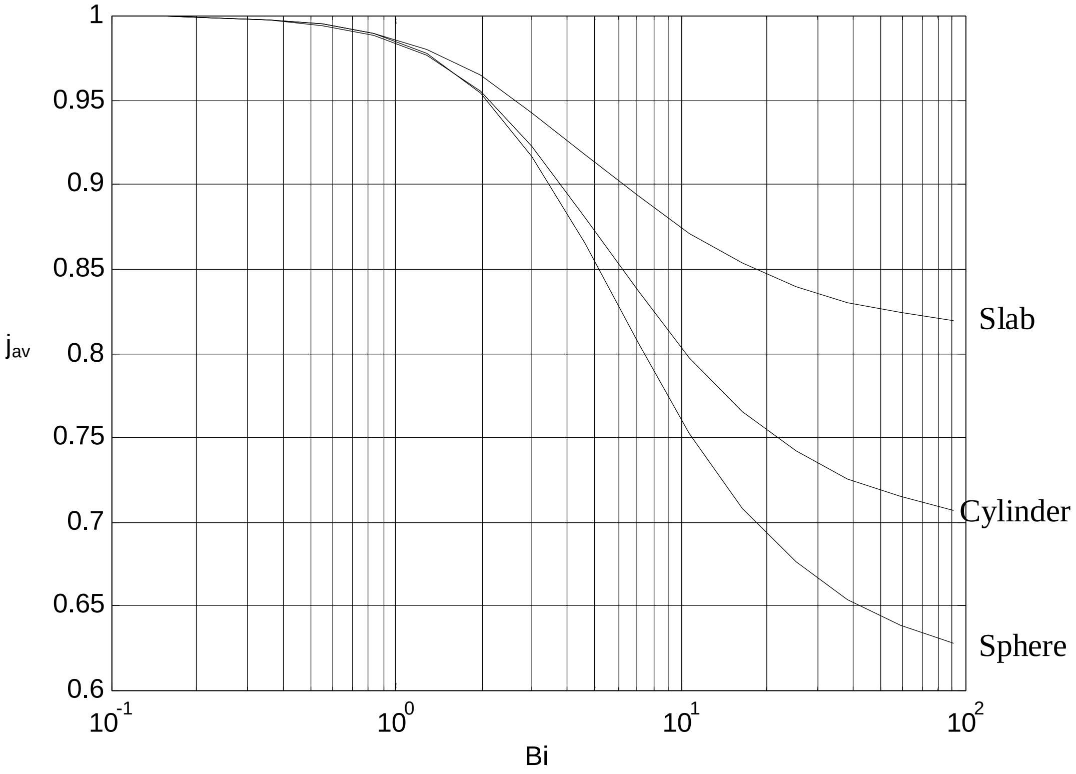

Figure 4. Plot of j_{av} against Biot number.