1. Figure 1 shows the schematic of the mechanical vapour compression cycle,
   (1) Explain its operating principle; [0.5]
   (2) If a standard vapour compression cycle operates with a condensing temperature of 35°C and an evaporating temperature of -10°C, draw the standard vapour compression cycle on the pressure-enthalthy diagram in Figure 2. [0.5]

2. Determine the thermal conductivity and density of lean pork shoulder meat which is at a temperature of -40°C. Use both the parallel and perpendicular thermal conductivity models. The composition of the meat is x_{wo} = 0.7263, x_f = 0.0714, x_p = 0.1955, x_a = 0.0102, and other components can be omitted. The initial freezing point of the meat is -2.2°C.

The following equations may be used in the calculation:

$$x_{ice} = (x_{wo} - x_b)\left(1 - {t_f}/{t}\right)$$

$$k_{=} = \Sigma\left(x_i^v k_i\right)$$

$\rho_w = 9.9718\text{x}10^2 + 3.1439\text{x}10^{-3}t - 3.7574\text{x}10^{-3}t^2$

$\rho_{ice} = 9.1689\text{x}10^2 - 1.3071\text{x}10^{-1}t$

$\rho_p = 1.3299\text{x}10^3 - 5.1840\text{x}10^{-1}t$

$\rho_f = 9.2559\text{x}10^2 - 4.1757\text{x}10^{-1}t$

$\rho_c = 1.5991\text{x}10^3 - 3.1046\text{x}10^{-1}t$

$\rho_{fb} = 1.3115\text{x}10^3 - 3.6589\text{x}10^{-1}t$

$\rho_a = 2.4238\text{x}10^3 - 2.8063\text{x}10^{-1}t$

$k_w = 5.7109\text{x}10^{-1} + 1.7625\text{x}10^{-3}t - 6.7036\text{x}10^{-6}t^2$

$k_{ice} = 2.2196 - 6.2489\text{x}10^{-3}t + 1.0154\text{x}10^{-4}t^2$

$k_p = 1.7881\text{x}10^{-1} + 1.1958\text{x}10^{-3}t - 2.7178\text{x}10^{-6}t^2$

$k_f = 1.8071\text{x}10^{-1} - 2.7604\text{x}10^{-3}t - 1.7749\text{x}10^{-7}t^2$

$k_c = 2.0141\text{x}10^{-1} + 1.3874\text{x}10^{-3}t - 4.3312\text{x}10^{-6}t^2$

$k_{fb} = 1.8331\text{x}10^{-1} + 1.2497\text{x}10^{-3}t - 3.1683\text{x}10^{-6}t^2$

$k_a = 3.2962\text{x}10^{-1} + 1.4011\text{x}10^{-3}t - 2.9069\text{x}10^{-6}t^2$

3. An infinite slab beef with thickness of 0.04 m is to be frozen in an air blast freezer. The initial temperature of the beef is 10°C, freezing air temperature is -30°C and surface heat transfer coefficient is 40 W/(m²K). Use Cleland and Earle method to calculate the time required for the thermal centre of the beef to reach a temperature of -15°C.

Some thermal properties of the beef are listed below:

Property	At -40°C	At -10°C	At -1.7°C	At 10°C
ρ, kg/m³	ρ_s = 1018	ρ_s = 1018	ρ_l = 1075	ρ_l = 1075
H, kJ/kg	-	H_s = 83.4	H_l = 274.2	-
c, kJ/kgK	c_s = 2.11	-	-	c_l = 3.52
k, W/mK	k_s = 1.66	-	-	-

The following equations may be used:

$$\theta = \frac{\Delta H_{10}}{(T_f - T_m)E_{Freeze}}\left[\frac{PD}{h} + \frac{RD^2}{k_s}\right]\left[1 - \frac{1.65Ste}{k_s}\ln\left(\frac{T_c - T_m}{T_{ref} - T_m}\right)\right]$$

P = 0.5 [1.026 + 0.5808 Pk + Ste (0.2296 Pk + 0.1050)]

R = 0.125 [1.202 + Ste (3.41 Pk + 0.7336)]

The dimensionless numbers are defined as:

$$Bi = \frac{hD}{k}$$

$$Pk = C_l \frac{T_i - T_f}{\Delta H}$$

$$Ste = C_s \frac{T_f - T_m}{\Delta H}$$

4. Vacuum cooling is an established precooling method to rapidly remove the field heat of leafy vegetables such as lettuce after harvest.
   (1) Explain its cooling principle; [0.5]
   (2) In recent years, some advanced applications of vacuum cooling have been researched, identify these advanced applications and discuss their advantages and disadvantages. [0.5]

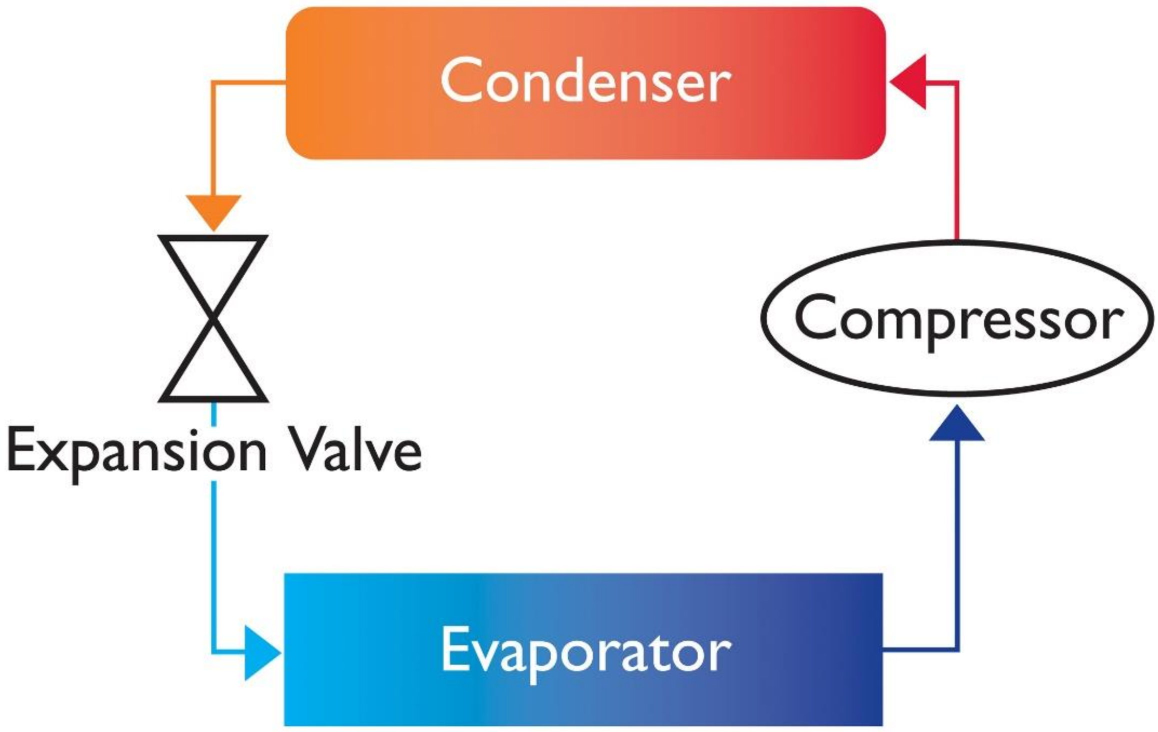

Figure 1. Mechanical vapour compression cycle.

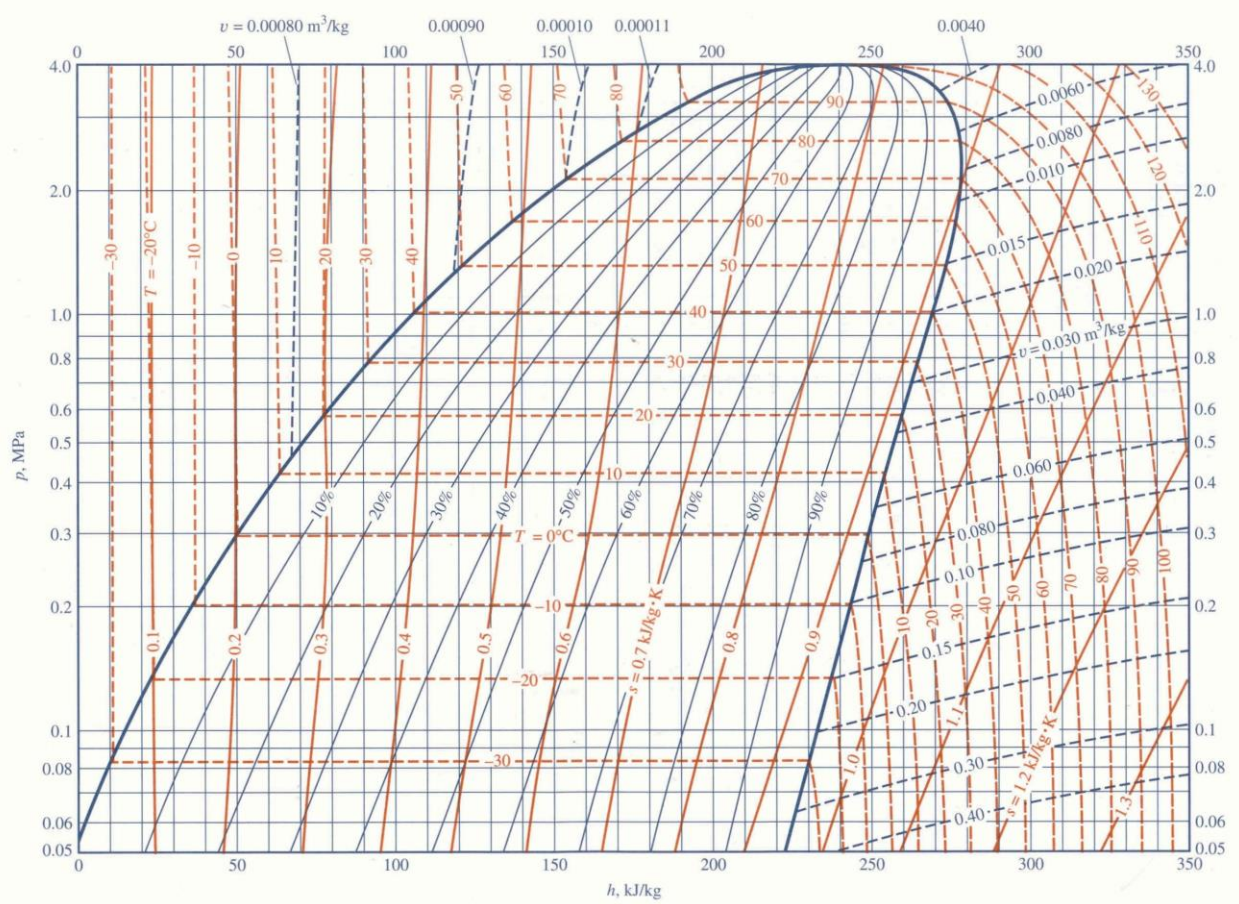

Figure 2. Pressure-enthalphy diagram for refrigerant 134a.