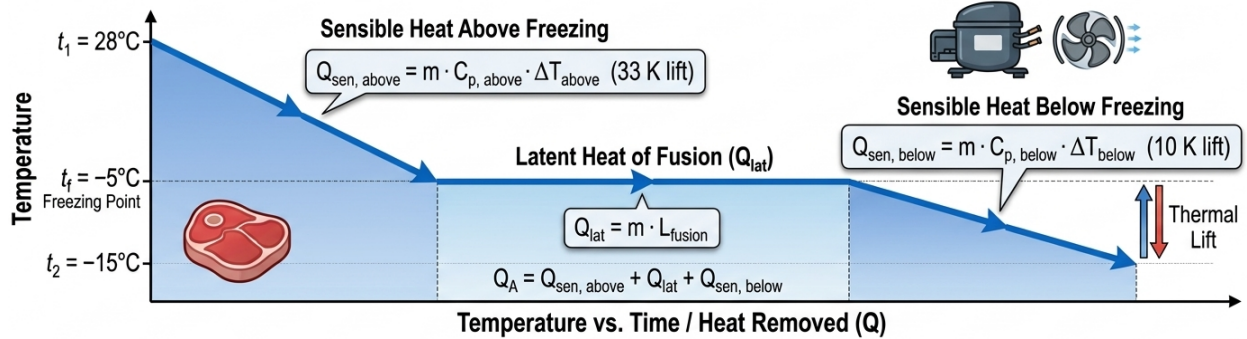


Step 1: Mass Flow Rate Conversion (m)

The product mass is given in short tons (2000 lbs/ton) and must be processed within a time frame of 18 hours. We convert these units into standard SI metric units (kg/s):

$$m = \frac{(15 \text{ tons}) \left(\frac{2000 \text{ lbs}}{1 \text{ ton}} \right) \left(\frac{1 \text{ kg}}{2.2 \text{ lbs}} \right)}{(18 \text{ hrs}) \left(\frac{3600 \text{ s}}{1 \text{ hr}} \right)} = 0.21044 \frac{\text{kg}}{\text{s}}$$



Step 2: Summation of Total Heat Removed Per Kilogram (q_{total})

Following the multi-stage cooling load concept from the material, the total heat extraction spans three distinct regions:

1. **Sensible cooling above freezing (q₁):** From 28 °C to -5°C.

$$q_1 = C_1(t_1 - t_f) = \left(3.0 \frac{\text{kJ}}{\text{kg-K}} \right) [28 - (-5)]^\circ\text{C} = 99 \frac{\text{kJ}}{\text{kg}}$$

2. **Latent heat of fusion phase change (q₂):** Freezing at constant temperature.

$$q_2 = L = 225 \frac{\text{kJ}}{\text{kg}}$$

3. **Sensible cooling below freezing (q₃):** From -5°C down to -15°C.

$$q_3 = C_2(t_f - t_2) = \left(1.8 \frac{\text{kJ}}{\text{kg-K}} \right) [-5 - (-15)]^\circ\text{C} = 18 \frac{\text{kJ}}{\text{kg}}$$

Total heat load per kilogram:

$$q_{total} = 99 + 225 + 18 = 342 \frac{\text{kJ}}{\text{kg}}$$

Step 3: Calculation of Net Refrigeration Capacity (Q_{net})

Now, combine the mass flow rate and total heat load to find the load in kilowatts, then convert to Tons of Refrigeration (TR):

$$Q_{net} = m q_{total} = \left(0.21044 \frac{\text{kg}}{\text{s}} \right) \left(342 \frac{\text{kJ}}{\text{kg}} \right) = 71.97 \text{ kW}$$

Using conversion factor (1 TR = 3.516 kW):

$$Q_{net} = \frac{71.97 \text{ kW}}{3.516 \text{ kW/TR}} = 20.47 \text{ TR}$$

The capacity required is inversely proportional to the processing time (t). If a plant manager requests that this product pull-down run in 9hours instead of 18hours, the machinery size requirements instantly double. Balancing acceptable pull-down windows against equipment capital costs is a core responsibility of refrigeration design engineers.