

**24AG301- APPLIED THERMODYNAMICS AND THERMAL
SYSTEMS IN AGRICULTURAL ENGINEERING**

**UNIT 3 REFRIGERATION SYSTEMS IN AGRICULTURAL
STORAGE**

HANDLED BY

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$$\begin{aligned}
 \text{Heat rejected to the condenser} &= \dot{m}(h_2 - h_3) \\
 &= 0.18 (209.41 - 74.59) \\
 &= 24.27 \text{ kW} \quad \text{Ans. (e)} \\
 h_4 &= h_f + x_4 h_{fg} = 26.87 + x_4 \times 156.31 = 74.59 \\
 \therefore x_4 &= \frac{47.72}{156.31} = 0.305
 \end{aligned}$$

$$\therefore \text{Flash gas percentage} = 30.5\% \quad \text{Ans. (f)}$$

$$\begin{aligned}
 \text{COP} &= \frac{h_1 - h_4}{h_2 - h_1} = \frac{183.19 - 74.59}{209.41 - 183.19} \\
 &= \frac{108.60}{26.22} = 4.14 \quad \text{Ans. (g)}
 \end{aligned}$$

$$\begin{aligned}
 \text{Power required to drive the compressor} \\
 &= \dot{m}(h_2 - h_1) = 0.18 \times 26.22 = 4.72 \text{ kW} \quad \text{Ans. (h)}
 \end{aligned}$$

$$\text{COP (Reversible)} = \frac{T_2}{T_1 - T_2} = \frac{263}{50} = 5.26$$

$$\therefore \frac{\text{COP (Vap. Comp. cycle)}}{\text{COP (Carnot cycle)}} = \frac{4.14}{5.26} = 0.787 \quad \text{Ans.}$$

Example A Refrigerant-12 vapour compression plant producing 10 tonnes of refrigeration operates with condensing and evaporating temperatures of 35°C and -10°C respectively. A suction line heat exchanger is used to subcool the saturated liquid leaving the condenser. Saturated vapour leaving the evaporator is superheated in the suction line heat exchanger to the extent that a discharge temperature of 60°C is obtained after isentropic compression.

Determine (a) the subcooling achieved in the heat exchanger, (b) the refrigerant flow rate in kg/s, (c) the cylinder dimensions of the two-cylinder compressor, if the speed is 900 rpm, stroke-to-bore ratio is 1.1, and the volumetric efficiency is 80%, (d) the COP of the plant, and (e) the power required to drive the compressor in kW.

Solution From the p - h chart of R-12, the property values at the states, as shown in Fig. Ex.

$$\begin{aligned}
 h_3 &= 882, h_2 = 1034 \\
 h_6 &= 998, h_1 = 1008 \text{ kJ/kg} \\
 v_1 &= 0.084 \text{ m}^3/\text{kg}
 \end{aligned}$$

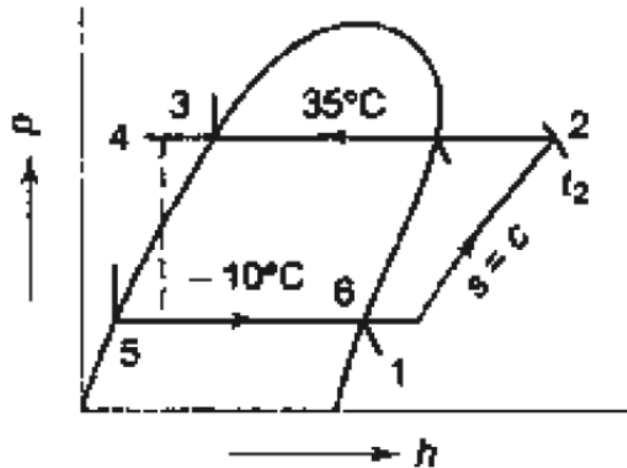
$$h_3 - h_4 = h_1 - h_6$$

$$882 - h_4 = 1008 - 998 = 10$$

$$\therefore h_4 = 872 \text{ kJ/kg}$$

$$\therefore t_4 = 25^\circ\text{C}$$

So 10°C subcooling is achieved in the heat exchanger. Refrigeration effect
 $= h_6 - h_5 = 998 - 872 = 126 \text{ kJ/kg}$ Ans. (a)



$$\therefore \text{Refrigerant flow rate} = \frac{10 \times 14000}{126} = 1110 \text{ kg/h} \quad \text{Ans. (b)}$$

$$= 0.31 \text{ kg/s}$$

$$\text{Volume flow rate} = w \cdot v_1 = 1110 \times 0.084 = 93 \text{ m}^3/\text{h}$$

$$\text{Compressor displacement} = \frac{93}{0.8} = 116 \text{ m}^3/\text{h} = 1.94 \text{ m}^3/\text{min}$$

This is equal to $\frac{\pi}{4} D^2 L N n$

where D = diameter

L = stroke

N = rpm

n = number of cylinders of the compressor.

$$\frac{\pi}{4} D^2 \times 1.1D \times 900 \times 2 = 1.94 \text{ m}^3/\text{min}$$

$$D^3 = 1250 \text{ cm}^3$$

$$\dot{W}_c = \dot{m}_2 (h_2 - h_1) + \dot{m}_1 (h_4 - h_3)$$

$$= 0.0954 \times 169 + 0.124 \times 184.6 = 16.19 + 22.89$$

$$= 39.08 \text{ kW}$$

$$\text{COP} = \frac{30 \times 3.89}{39.08} = 2.986$$

Single stage

$$h_1 = 1404.6 \quad h_2 = 1805.1$$

$$h_3 = 371.7 = h_4$$

$$\dot{m} = \frac{30 \times 3.89}{1404.6 - 371.7} = \frac{116.7}{1032.9}$$

$$= 0.113 \text{ kg/s}$$

$$\dot{W}_c = \dot{m}(h_2 - h_1) = 0.113 \times 400.5$$

$$= 45.26 \text{ kW}$$

$$\therefore \text{COP} = \frac{116.7}{45.26} = 2.578$$

Increase in work of compression (for single stage)

$$= \frac{45.26 - 39.08}{39.08} \times 100 = 15.81\%$$

Increase in COP for 2-stage compression

$$= \frac{2.986 - 2.578}{2.578} \times 100 = 15.82\%$$

Thermodynamic Properties of Refrigerants

The performance and selection of refrigerants in a refrigeration or air conditioning system are primarily determined by their **thermodynamic properties**. These properties dictate how effectively a fluid can absorb and reject heat through phase changes (evaporation and condensation) within the operating temperature and pressure ranges of the system.

Key thermodynamic properties for refrigerants include:

- **Boiling Point and Freezing Point:** A refrigerant should have a **low boiling point** at atmospheric pressure to facilitate evaporation at low temperatures (in the evaporator) and a **very low freezing point** to ensure it doesn't freeze at the coldest operating temperatures.
- **Latent Heat of Vaporization (hfg):** This must be **high**. Latent heat is the amount of energy absorbed per unit mass during evaporation. A high value means a small amount of refrigerant mass flow can transfer a large amount of heat, which increases the refrigerating effect and efficiency.
- **Critical Temperature and Pressure:** The **critical temperature** should be **high**—significantly above the highest condensing temperature. If the condensing temperature is above the critical temperature, condensation (a phase change) cannot occur, and the system efficiency drops drastically. The **critical pressure** should also be manageable within system design limits.

- **Evaporator and Condenser Pressures:** For efficiency and practical design, the operating pressures in both the evaporator (low-pressure side) and condenser (high-pressure side) should be **positive** (above atmospheric pressure) to prevent air and moisture from leaking *into* the system and to aid in leak detection. A low-pressure ratio (condenser pressure divided by evaporator pressure) is also desirable for higher volumetric efficiency and lower power consumption.
- **Specific Heat (Liquid and Vapor):**
 - **Low specific heat** of the **liquid** is desirable as it minimizes the wasted refrigeration effect due to pre-cooling (subcooling) losses before the expansion valve.
 - **High specific heat** of the **vapor** is desirable to reduce the amount of superheating that occurs during the compression process, which can increase efficiency.
- **Specific Volume (v):** The **specific volume of the vapor** at the compressor suction should be **low**. A lower specific volume reduces the size required for the compressor for a given refrigerating capacity.
- **Isentropic Index of Compression:** A **small value** is preferable, as it minimizes the temperature rise of the refrigerant

How Thermodynamic Properties of Refrigerants affect refrigerator selection

Property	What It Means / Typical Values	How It Affects Refrigerator Selection / Design
Normal Boiling Point / Evaporation Temperature	The temperature at which the refrigerant boils (evaporates) at a given low pressure; low boiling point = cold evaporation.	Determines how low the refrigerator/freezer temps can go. If you want a freezer section, you need refrigerants that boil at sufficiently low temps. Also affects suction pressure; if evaporation pressure is too low (far below atmospheric), risk of air / moisture ingress, sealing, etc.
Critical Temperature	The temperature above which a refrigerant cannot be liquefied no matter how much pressure is applied.	The critical temperature should be well above the condenser (ambient) temperature to allow good condensation. If too close, condensation will be difficult, efficiency drops, more power required.
Saturation Pressures (Evaporator & Condenser Pressures)	The pressures corresponding to the evaporation and condensation at set temperatures.	These determine the pressure levels in suction (low side) and discharge (high side). Very high pressures → need stronger, more expensive, safer components; very low suction pressures → risk of leaks/ingress of air, and larger volume flow for a given capacity, so larger compressor, piping.
Volumetric Refrigeration Capacity / Vapor Density	How much cooling per unit volume of refrigerant vapor, which depends on density and latent heat.	If vapor density is low, more volume has to be moved by compressor for the same cooling load → bigger, more expensive compressor, larger pipes. High volumetric capacity means smaller/more compact design.
Latent Heat of Vaporization	The energy absorbed when the refrigerant evaporates (phase change), per unit mass.	Higher latent heat means more cooling per kg of refrigerant, which can reduce refrigerant charge required; better efficiency; possibly lower running costs.

Property	What It Means / Typical Values	How It Affects Refrigerator Selection / Design
Specific Heat / Heat Capacities (in vapor & liquid)	How much heat per unit mass/temperature change in superheated vapor or subcooled liquid portions.	If latent heat is low, more mass flow needed → more compressor work Affects compressor discharge temperatures, superheat/subcooling behavior, energy losses. For example, a refrigerant with high specific heat in vapor may lead to larger superheating requirement, higher compression work.
Thermophysical Properties such as viscosity, thermal conductivity, surface tension, etc.	These tell how easily refrigerant flows (liquid/vapor), how well it transfers heat, etc.	High viscosity → more friction, greater pressure drops, larger pump/compressor work. Low thermal conductivity → less efficient heat exchangers, needing larger surface areas. All these affect the size, cost, and maybe reliability of components.
Freezing / Solidification Point	Temperature at which refrigerant (or some portion) may freeze / solidify.	Must be well below the lowest operating temperature inside/outside the system so that refrigerant does not solidify in lines, expansion device, etc. Otherwise risk blockages or damage.

Environmental impact and refrigerant selection for rural storage

- Global Warming Potential (GWP):**
Refrigerants escape into the atmosphere through leaks, servicing, disposal. HFCs in particular can have very high GWP (hundreds to thousands of times that of CO₂). The more leaks or the larger the charge (amount used), the worse the climate impact.
- Ozone Depletion Potential (ODP):**
Older refrigerants (CFCs, HCFCs) damage the ozone layer. Many have been phased out under international agreements (Montreal Protocol, etc.). Modern refrigerants generally have ODP = 0.
- Lifecycle Emissions:**
Emissions come not just from leaks, but from manufacturing, energy usage (indirect emissions via electricity), end-of-life disposal (if refrigerants are not properly recovered) etc. Poor maintenance or inappropriate disposal worsens total emissions.
- Toxicity & Safety, Chemical Pollution:**
Some natural refrigerants are flammable or somewhat toxic (e.g. ammonia). If used improperly they can pose risk. Also, refrigerants must not produce harmful byproducts or residuals that contaminate environment.
- Energy Efficiency:**
A refrigerant that enables high efficiency reduces electricity consumed, resulting in lower indirect emissions (often more significant in rural areas where grid emissions can be high or energy supply is limited).

Specific Challenges in Rural Storage Context

Rural storage (cold rooms, cold storage for farm produce, vaccine storage, etc.) has special constraints & considerations:

- **Limited access to skilled technicians:** Maintenance, leak repair, proper installation may be harder. So refrigerants or systems that are forgiving or low-maintenance are better.
- **Reliability / robustness needed:** Power may be intermittent; systems might be simple; easy to repair is important.
- **Cost sensitivity:** Both upfront cost and operating cost matter. More eco-friendly refrigerants may cost more or need more safety features or expensive components.
- **Regulatory & supply constraints:** Certain refrigerants or replacement parts may be unavailable or expensive in remote areas. Also rules governing disposal and safety matter.
- **Safety risks are more critical:** Because of fewer people around, delayed response to leaks or accidents could be worse.