

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

**UNIT 3 REFRIGERATION SYSTEMS IN AGRICULTURAL
STORAGE**

HANDLED BY

MS SWETHA S



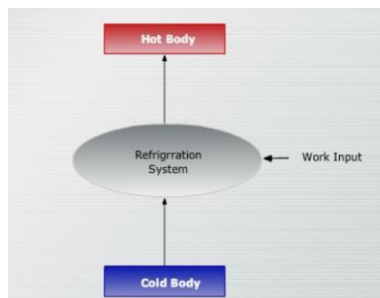
UNIT III

Refrigeration is the science of producing and maintaining temperatures below that of the surrounding atmosphere. This means the removing of heat from a substance to be cooled. Heat always passes downhill, from a warm body to a cooler one, until both bodies are at the same temperature. Maintaining perishables at their required temperatures is done by refrigeration.

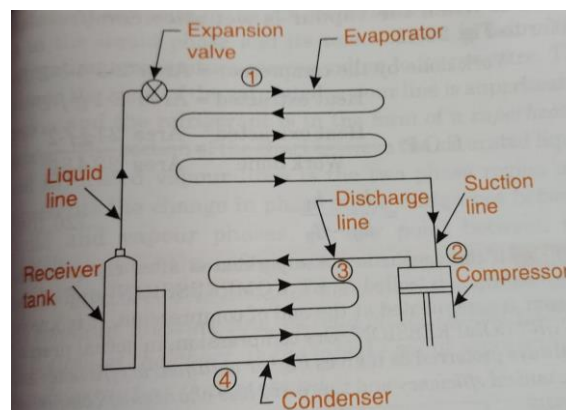
Important refrigeration applications:

- 1. Ice making
- 2. Transportation of foods above and below freezing
- 3. Industrial air-conditioning
- 4. Comfort air-conditioning
- 5. Chemical and related industries
- 6. Medical and surgical aids
- Processing food products and beverages
- 8. Oil refining and synthetic rubber manufacturing
- 9. Manufacturing and treatment of metals
- 10. Freezing food products

The principle of refrigeration is based on second law of thermodynamics. It states that heat does not flow from a low temperature body to a high temperature body without the help of an external work.



PARTS OF VAPOUR COMPRESSION SYSTEM



- The vapour at low temperature and pressure (state '2') enters the "compressor" where it is compressed isentropically and subsequently its temperature and pressure increase considerably (state '3').

- This vapour after leaving the compressor enters the "condenser" where it is condensed into high pressure liquid (state '4') and is collected in a "receiver tank"
- From receiver tank it passes through the "expansion valve", here it is throttled down to a lower pressure and has a low temperature (state '1'). After finding its way through expansion "valve" it finally passes on to "evaporator" where it extracts heat from the surroundings or circulated fluid being refrigerated and vapourises to low pressure vapour.

Functions of parts

1. Compressor. The function of a compressor is to remove the vapour from the evaporator, and to raise its temperature and pressure to a point such that it (vapour) can be condensed with available condensing media.
2. Discharge line (or hot gas line). A hot gas or discharge line delivers the high-pressure, high-temperature vapour from the discharge of the compressor to the condenser,
3. 3. Condenser. The function of a condenser is to provide a heat transfer surface through which heat passes from the hot refrigerant vapour to the condensing medium. The purpose of the condensation is to provide a means by which the vapour rejects the heat absorbed at the evaporator as well as the heat of compression
4. Receiver tank. A receiver tank is used to provide storage for a condensed liquid so that a constant supply of liquid is available to the evaporator as required.
5. Liquid line. A liquid line carries the liquidrefrigerant from the receiver tank to the refrigerant flow control.
6. Expansion valve (refrigerant flow control).

Its function is to meter the proper amount of refrigerant to the evaporator and to reduce the pressure of liquid entering the evaporator so that liquid will vapourize in the evaporator at the desired low temperature and take out sufficient amount of heat.

7. Evaporator.

An evaporator provides a heat transfer surface through which heat can pass from the refrigerated space into the vapourizing refrigerant.

8. Suction line.

Suction line. The suction line conveys the low pressure vapour from the evaporator to the suction inlet of the compressor.

- The performance of a refrigeration system is expressed by a term known as the "**co-efficient of performance**", which is defined as the ratio of heat absorbed by the refrigerant while passing through the evaporator to the work input required to compress the refrigerant in the compressor; in short it is the ratio between heat extracted and work done (in heat units).

If, R_n = Net refrigerating effect,
 W = Work expanded in by the machine during
the same interval of time,

Then,
$$\text{C.O.P.} = \frac{R_n}{W}$$

and **Relative C.O.P.** =
$$\frac{\text{Actual C.O.P.}}{\text{Theoretical C.O.P.}}$$

where, **Actual C.O.P.** = Ratio of R_n and W actually
measured during a test

One tonne of refrigeration

It's defined as the amount of heat required to freeze one ton of water at 0°C (32°F) into ice at the same temperature over a 24-hour period.

Agricultural Refrigeration

Agricultural refrigeration is the process of removing heat from agricultural products to slow down biological, chemical, and physical changes that lead to spoilage. It plays a vital role in maintaining the quality, safety, and shelf life of perishable commodities such as fruits, vegetables, dairy products, meat, fish, and flowers.

- **Purpose and Importance**
- **Preservation of Quality:** Reduces metabolic activity, respiration rate, and moisture loss in fresh produce.
- **Extension of Shelf Life:** Slows down microbial growth and enzymatic reactions.
- **Reduction in Post-Harvest Losses:** Minimizes spoilage during storage, transport, and distribution.
- **Market Flexibility:** Allows storage for longer periods, enabling supply when demand or prices are favorable.
- **Food Safety:** Inhibits the growth of harmful bacteria and pathogens.
- **Applications in Agriculture**
- **Cold Storage of Produce:**
 - Fruits (apples, grapes, mangoes)
 - Vegetables (potatoes, onions, tomatoes)
- **Dairy and Meat Processing:**
 - Milk chilling, cheese maturation, meat freezing
- **Seed Preservation:**
 - Storing seeds under controlled temperature and humidity
- **Floriculture:**
 - Refrigerated storage of flowers to extend freshness
- **Transport:**

- Refrigerated trucks and containers for long-distance movement

REFRIGERANTS

R-22 (Chlorodifluoromethane)

- **Type:** HCFC (Hydrochlorofluorocarbon)
- **Chemical Formula:** CHClF_2
- **Applications:** Widely used in older agricultural cold storages, air conditioners, and heat pumps.
- **GWP:** ~1,760
- **ODP:** 0.055 (significant, contributes to ozone layer depletion)
- **Status:** Being phased out under the Montreal Protocol due to its ODP; replaced by HFCs and natural refrigerants.

R-134a (1,1,1,2-Tetrafluoroethane)

- **Type:** HFC (Hydrofluorocarbon)
- **Chemical Formula:** $\text{C}_2\text{H}_2\text{F}_4$
- **Applications:** Domestic refrigerators, automobile ACs, medium-temperature refrigeration in agriculture.
- **GWP:** ~1,430
- **ODP:** 0 (no ozone depletion)
- **Status:** Still used in some applications but being phased down due to high GWP under the **Kigali Amendment**.

R-290 (Propane)

- **Type:** Hydrocarbon (Natural Refrigerant)
- **Chemical Formula:** C_3H_8
- **Applications:** Small commercial refrigeration, agricultural cold storage units, freezers.
- **GWP:** ~3 (very low)
- **ODP:** 0 (no ozone depletion)
- **Status:** Increasingly used as an eco-friendly alternative; **highly flammable** (A3 safety classification), so safety precautions are essential.
- **GWP in refrigeration** refers to Global Warming Potential, a measure of how much heat a greenhouse gas traps in the atmosphere compared to carbon dioxide. In the context of refrigeration, GWP is crucial because refrigerants with high GWPs contribute significantly to climate change.

Refrigerant	Type	GWP (100-year)	Notes
R-22	HCFC	1,810	Being phased out due to ozone depletion potential.
R-134a	HFC	1,430	Common in automotive and domestic refrigeration.
R-404A	HFC blend	3,922	High GWP; used in commercial refrigeration.
R-410A	HFC blend	2,088	Used in residential and commercial air conditioning.
R-32	HFC	675	Lower GWP alternative to R-410A.
R-1234yf	HFO	<1	Ultra-low GWP; replacing R-134a in vehicles.
R-744 (CO ₂)	Natural	1	Non-toxic, non-flammable; used in various applications.
R-717 (NH ₃)	Natural	0	Ammonia; efficient but toxic; used in industrial refrigeration.
R-290	Natural	3	Propane; flammable but low GWP; used in small systems.

Fluids suitable for refrigeration purposes can be classified into **primary and secondary refrigerants**. **Primary refrigerants** are those fluids, which are used directly as working fluids, for example in vapour compression and vapour absorption refrigeration systems. When used in compression or absorption systems, these fluids provide refrigeration by undergoing a phase change process in the evaporator.

As the name implies, **secondary refrigerants** are those liquids, which are used for transporting thermal energy from one location to other. Secondary refrigerants are also known under the name brines or antifreezes. Ofcourse, if the operating temperatures are above 0°C, then pure water can also be used as secondary refrigerant, for example in large air conditioning systems. Antifreezes or brines are used when refrigeration is required at sub-zero temperatures. Unlike primary refrigerants, the secondary refrigerants do not undergo phase change as they transport energy from one location to other.

Refrigerant selection criteria:

Selection of refrigerant for a particular application is based on the following requirements:

- ♣ Thermodynamic and thermo-physical properties
- ♣ Environmental and safety properties, and
- ♣ Economics Thermodynamic and thermo-physical properties:

The requirements are: a) Suction pressure: At a given evaporator temperature, the saturation pressure should be above atmospheric for prevention of air or moisture ingress into the system and ease of leak detection. Higher suction pressure is better as it leads to smaller compressor displacement

- b) Discharge pressure: At a given condenser temperature, the discharge pressure should be as small as possible to allow light-weight construction of compressor, condenser etc.
- c) Pressure ratio: Should be as small as possible for high volumetric efficiency and low power consumption
- d) Latent heat of vaporization: Should be as large as possible so that the required mass flow rate per unit cooling capacity will be small.

In addition to the above properties; the following properties are also important:

- a) Isentropic index of compression: Should be as small as possible so that the temperature rise during compression will be small
- b) Liquid specific heat: Should be small so that degree of subcooling will be large leading to smaller amount of flash gas at evaporator inlet
- c) Vapour specific heat: Should be large so that the degree of superheating will be small
- d) Thermal conductivity: Thermal conductivity in both liquid as well as vapour phase should be high for higher heat transfer coefficients
- e) Viscosity: Viscosity should be low

Environmental and safety properties:

Next to thermodynamic and thermophysical properties, the environmental and safety properties are very important. In fact, at present the environment friendliness of the refrigerant is a major factor in deciding the usefulness of a particular refrigerant.

The important environmental and safety properties are: a) Ozone Depletion Potential (ODP): According to the Montreal protocol, the ODP of refrigerants should be zero, i.e., they should be non-ozone depleting substances. Refrigerants having non-zero ODP have either already been phased-out (e.g. R 11, R 12) or will be phased-out in near-future (e.g. R22). Since ODP depends mainly on the presence of chlorine or bromine in the molecules, refrigerants having either chlorine (i.e., CFCs and HCFCs) or bromine cannot be used under the new regulations .

ODP in refrigeration refers to Ozone Depletion Potential, a measure of the potential of a refrigerant to deplete the stratospheric ozone layer.

- **Importance of ODP- Ozone Layer Protection:**
- Refrigerants with high ODPs contribute to the depletion of the ozone layer, which protects the Earth from harmful ultraviolet (UV) radiation.- Regulations: The Montreal Protocol, an international treaty, aims to phase out substances with high ODPs to protect the ozone layer.

b) **Global Warming Potential (GWP):** Refrigerants should have as low a GWP value as possible to minimize the problem of global warming. Refrigerants with zero ODP but a high value of GWP (e.g. R134a) are likely to be regulated in future. c) Total Equivalent Warming Index (TEWI): The factor TEWI considers both direct (due to release into atmosphere) and indirect (through energy consumption) contributions of refrigerants to global warming. Naturally, refrigerants with as a low a value of TEWI are preferable from global warming point of view

What GWP Means in Refrigeration

- Refrigerants can leak during manufacturing, operation, or servicing. Since many refrigerants are powerful greenhouse gases, GWP helps compare their climate impact.
- Higher GWP → More contribution to global warming if released.

- Lower GWP → More environmentally friendly.

Low-GWP refrigerants are designed to minimize their impact on climate change while maintaining efficiency and performance in cooling applications.- Examples: Some common low-GWP refrigerants include - Hydrofluoroolefins (HFOs): Like HFO-1234yf and HFO-1234ze, with significantly lower GWPs compared to traditional hydrofluorocarbons (HFCs). - Natural Refrigerants: Like propane (R-290), ammonia (R-717), and carbon dioxide (R-744), which have very low or zero GWPs.

c) **Total Equivalent Warming Index (TEWI):** The factor TEWI considers both direct (due to release into atmosphere) and indirect (through energy consumption) contributions of refrigerants to global warming. Naturally, refrigerants with as a low a value of TEWI are preferable from global warming point of view.

d) **Toxicity:** Ideally, refrigerants used in a refrigeration system should be non- toxic. However, all fluids other than air can be called as toxic as they will cause suffocation when their concentration is large enough. Thus toxicity is a relative term, which becomes meaningful only when the degree of concentration and time of exposure required to produce harmful effects are specified. Some fluids are toxic even in small concentrations. Some fluids are mildly toxic, i.e., they are dangerous only when the concentration is large and duration of exposure is long. Some refrigerants such as CFCs and HCFCs are nontoxic when mixed with air in normal condition. However, when they come in contact with an open flame or an electrical heating element, they decompose forming highly toxic elements (e.g. phosgene-COCl₂).

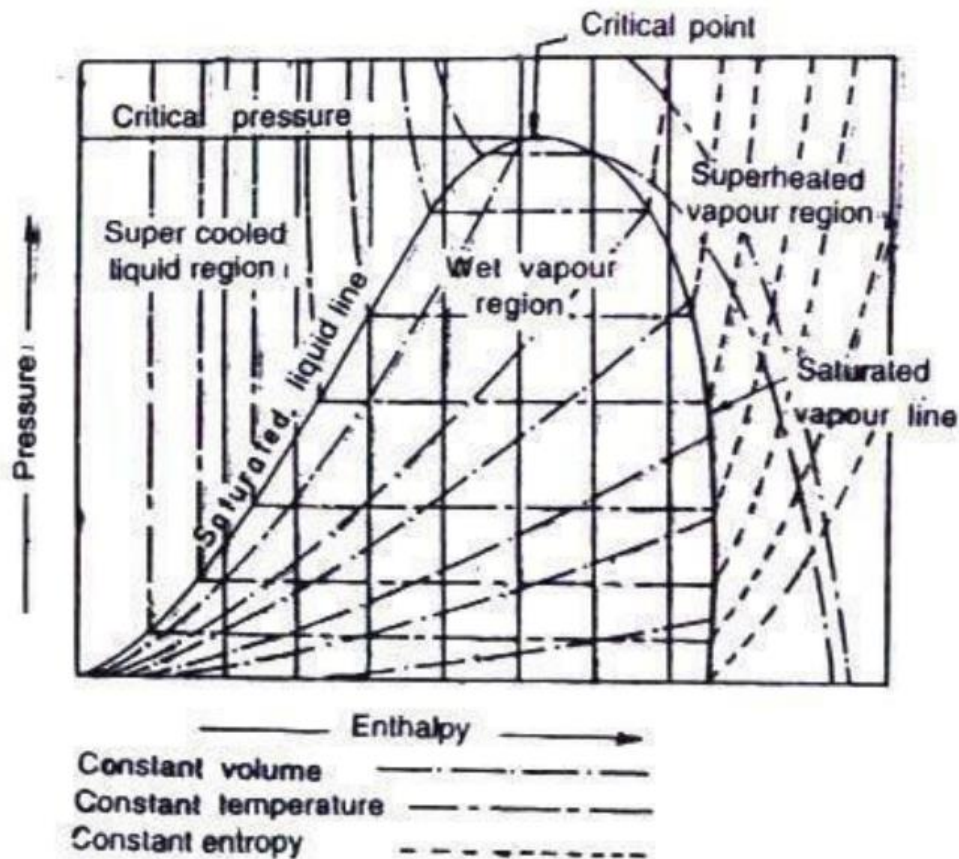
e) **Flammability:** The refrigerants should preferably be non-flammable and nonexplosive. For flammable refrigerants special precautions should be taken to avoid accidents.

Based on the above criteria, ASHRAE has divided refrigerants into six safety groups (A1 to A3 and B1 to B3). Refrigerants belonging to Group A1 (e.g. R11, R12, R22, R134a, R744, R718) are least hazardous, while refrigerants belonging to Group B3 (e.g. R1140) are most hazardous. Other important properties are:

f) **Chemical stability:** The refrigerants should be chemically stable as long as they are inside the refrigeration system. g) Compatibility with common materials of construction (both metals and non- metals)

h) **Miscibility with lubricating oils:** Oil separators have to be used if the refrigerant is not miscible with lubricating oil (e.g. ammonia). Refrigerants that are completely miscible with oils are easier to handle (e.g. R12). However, for refrigerants with limited solubility (e.g. R 22) special precautions should be taken while designing the system to ensure oil return to the compressor.

Pressure-Enthalpy (p-h) Chart



The most convenient chart for studying the behavior of a refrigerant is the p - h chart, in which the vertical ordinates represent pressure and horizontal ordinates represent enthalpy (i.e. total heat). The saturated liquid line and the saturated vapour line merge into one another at the critical point. A saturated liquid is one which has a temperature equal to the saturation temperature corresponding to its pressure. The space to the left of the saturated liquid line will, therefore, be subcooled liquid region. The space between the liquid and the vapour lines is called wet vapour region and to the right of the saturated vapour line is a superheated vapour region.

Regions on the Diagram

- **Subcooled Liquid:** Left of the dome—refrigerant is entirely liquid at conditions below saturation.
- **Two-Phase (Mixture):** Inside the dome—liquid and vapor coexist; **quality lines** show vapor fraction.

Superheated Vapor: Right of the dome—vapor is above its saturation point.

3. Important Isolines

- **Isotherms (constant temperature):** Vertical in superheated/subcooled regions; horizontal across the dome where temperature remains constant during phase change.
- **Quality Lines:** Vertical within the dome indicating percent vapor content.
- **Isentropes (constant entropy):** Slanted lines, typically showing the ideal compression path.
- **Isochores (constant volume):** Subtly angled lines in specific zones