UNIT-2
Production of low temperature

Definition

The **production of low temperature** is the process of removing heat from a space or substance and maintaining it at a temperature below the surrounding atmosphere using refrigeration systems.

Methods of Producing Low Temperature

1. Vapour Compression Refrigeration System (VCRS)

- Most common method.
- Uses compressor, condenser, expansion valve, and evaporator.
- Refrigerant absorbs heat in the evaporator and produces cooling.

2. Vapour Absorption Refrigeration System (VARS)

- Uses heat energy instead of mechanical work.
- Common refrigerant-absorbent pairs:
  - Ammonia–Water
  - Water–Lithium Bromide

3. Air Refrigeration System

- Uses air as the refrigerant.
- Based on the reversed Brayton cycle.
- Used in aircraft refrigeration.

4. Cascade Refrigeration System

- Uses two or more refrigeration cycles connected in series.
- Produces very low temperatures (below –40°C).
- Used in liquefaction of gases and deep freezing.

5. Multi-Stage Compression System

- Refrigerant is compressed in stages with intercooling.
- Suitable for low-temperature applications.

Applications of Low Temperature Production

- Cold storage of fruits and vegetables.
- Ice manufacturing.
- Food freezing and preservation.
- Medical and pharmaceutical storage.
- Liquefaction of gases such as oxygen and nitrogen.

- Chemical and process industries.

Simple Block Diagram

```
   Compressor
        |
        ▼
   Condenser
        |
        ▼
Expansion Valve
        |
        ▼
   Evaporator
        |
(Cooling Effect)
```

Advantages

- Preserves food quality.
- Increases shelf life of products.
- Supports industrial and medical processes.
- Enables storage of temperature-sensitive materials.

Liquefaction of Gases

Definition

Liquefaction of gases is the process of converting a gas into a liquid by reducing its temperature below its critical temperature and/or increasing its pressure above the critical pressure.

Principle

A gas can be liquefied by:

- **Cooling** the gas.
- **Compressing** the gas.
- **Expansion** of the gas to produce a cooling effect (Joule–Thomson effect).

Methods of Liquefaction

1. Linde Process

- Gas is compressed to high pressure.
- Cooled in a heat exchanger.
- Expanded through a throttle valve.
- Temperature decreases and part of the gas liquefies.
- Remaining gas is recirculated.

2. Claude Process

- Similar to the Linde process.
- Uses an expansion engine (expander) in addition to a throttle valve.
- Produces lower temperatures and has higher efficiency.

Simple Flow Diagram

```
        Gas
         │
         ▼
     Compressor
         │
         ▼
       Cooler
         │
         ▼
   Heat Exchanger
         │
         ▼
  Expansion Valve
         │
         ▼
Liquid Gas Collector
```

Conditions for Liquefaction

- Temperature must be below the **critical temperature**.
- Pressure must be sufficiently high.
- Proper cooling and expansion arrangements are required.

Applications

- Production of liquid oxygen (LOX).
- Production of liquid nitrogen (LIN).
- Liquefied Natural Gas (LNG).
- Liquid hydrogen and helium production.
- Cryogenic engineering.
- Medical and industrial gas storage.

Advantages

- Reduces gas volume greatly.
- Easier storage and transportation.
- Useful in cryogenic and industrial applications.

Disadvantages

- High energy consumption.
- Expensive equipment.

- Requires careful insulation and handling.

Liquefaction of Hydrogen and Heliu

1. Liquefaction of Hydrogen

Definition

Hydrogen is liquefied to obtain **liquid hydrogen (LH_2)**, which is used as a fuel in rockets and in cryogenic applications.

Properties of Hydrogen

- Boiling point: **−252.9°C (20.3 K)**
- Very low density
- Highly flammable

Process

1. Hydrogen gas is compressed.
2. The gas is precooled using refrigeration systems.
3. Hydrogen is further cooled through heat exchangers.
4. Expansion through a valve or turbine lowers the temperature.
5. At about **20 K**, hydrogen liquefies and is collected in insulated storage tanks.

Applications

- Rocket fuel
- Space research
- Cryogenic cooling
- Fuel cell technology

2. Liquefaction of Helium

Definition

Helium is liquefied to produce **liquid helium (LHe)**, one of the coldest liquids known.

Properties of Helium

- Boiling point: **−268.9°C (4.2 K)**

- Chemically inert
- Lowest boiling point of all elements

Simple Diagram

```
Gas → Compressor → Heat Exchanger
                          ↓
                  Expansion Valve
                          ↓
                   Liquid Storage
```

Process

1. Helium gas is compressed.
2. It is precooled using liquid nitrogen and refrigeration stages.
3. The gas expands through expansion engines and valves.
4. Repeated cooling and expansion reduce the temperature below **4.2 K**.
5. Helium liquefies and is stored in cryogenic containers.

Applications

- MRI scanners
- Superconducting magnets
- Particle accelerators
- Space and scientific research

1. Hydrogen Liquefaction System Applications

a) Rocket Propulsion

- Liquid hydrogen (LH_2) is used as rocket fuel.
- Provides very high energy and efficiency.
- Used in space launch vehicles.

b) Fuel Cells

- Hydrogen is used in fuel cells to generate electricity.
- Used in automobiles and power plants.

c) Cryogenic Research

- Used for low-temperature experiments in laboratories.

d) Energy Storage

- Liquid hydrogen stores large amounts of energy in a small volume.

e) Aerospace Industry

- Used in spacecraft and satellite propulsion systems.

Advantages of Liquefaction Systems

- Easier storage and transportation of gases.
- Significant reduction in gas volume.
- Essential for cryogenic applications.
- Improves efficiency in industrial processes.

Dry Ice System

Definition

A **Dry Ice System** is a refrigeration system that uses **dry ice (solid carbon dioxide, CO_2)** as the cooling medium. Dry ice sublimates directly from solid to gas without becoming liquid.

Properties of Dry Ice

- Chemical Formula: **CO_2**
- Temperature: **−78.5°C**
- Color: White solid
- Non-toxic and non-flammable
- Sublimates directly into gas

Working Principle

1. Dry ice is placed inside an insulated container.
2. It absorbs heat from the surroundings.
3. Dry ice changes directly from solid to carbon dioxide gas (sublimation).
4. Heat removal produces the cooling effect.

Simple Diagram

```
Heat from Product
        ↓
   ┌─────────┐
   │ Dry Ice │
   └─────────┘
        ↓
     CO₂ Gas
```

Advantages

- Produces very low temperatures.
- No electrical power required.
- Easy transportation and storage.
- Leaves no liquid residue.
- Suitable for emergency cooling.

Disadvantages

- Limited cooling duration.
- Requires proper ventilation due to CO_2 gas release.
- Not suitable for continuous refrigeration.

Applications

- Food preservation and transportation.
- Ice cream and frozen food transport.
- Medical and pharmaceutical storage.
- Laboratory sample transportation.
- Special effects in theatres and movies.

Vapour Absorption Refrigeration System (VARS)

Definition

A **Vapour Absorption Refrigeration System (VARS)** is a refrigeration system in which the compressor is replaced by an **absorber, pump, generator, and pressure-reducing valve**. It uses **heat energy** instead of mechanical work to produce refrigeration.

Common Refrigerant–Absorbent Pairs

1. **Ammonia–Water (NH_3–H_2O)**
   - Refrigerant: Ammonia
   - Absorbent: Water
2. **Water–Lithium Bromide (H_2O–LiBr)**
   - Refrigerant: Water
   - Absorbent: Lithium Bromide

Main Components

- Evaporator
- Absorber
- Pump
- Generator
- Condenser
- Expansion Valve

Working Principle

1. In the **evaporator**, refrigerant absorbs heat and produces cooling.
2. Refrigerant vapor enters the **absorber** and is absorbed by the absorbent.
3. The solution is pumped to the **generator**.
4. Heat is supplied to the generator, separating the refrigerant vapor.
5. Refrigerant vapor flows to the **condenser** and condenses into liquid.
6. Liquid refrigerant passes through the **expansion valve** and enters the evaporator.
7. The cycle repeats.

Simple Diagram

```
Generator → Condenser → Expansion Valve → Evaporator
     ↑                                          ↓
     |                                          |
   Pump ← Absorber ← Refrigerant Vapour ←───────┘
```

Advantages

- Uses low-grade heat energy (steam, solar energy, waste heat).
- Low electricity consumption.
- Quiet operation.
- Fewer moving parts.
- Low maintenance.

Disadvantages

- Lower COP compared to Vapour Compression System.
- Larger size.
- Higher initial cost.
- Slow response to load changes.

Applications

- Large air-conditioning plants.
- Hotels and hospitals.
- Industrial refrigeration.
- Solar-powered refrigeration systems.
- Locations where waste heat is available.

Simple and Modified Aqua–Ammonia System & Representation on Enthalpy–Concentration (h–x) Diagram

1. Simple Aqua–Ammonia Absorption System

Definition

In a simple aqua–ammonia system:

- **Ammonia (NH_3)** acts as the refrigerant.
- **Water (H_2O)** acts as the absorbent.

Main Components

- Generator
- Condenser
- Expansion Valve
- Evaporator
- Absorber
- Pump

Working

1. Ammonia vapor is generated in the generator by heating the strong aqua-ammonia solution.
2. High-pressure ammonia vapor flows to the condenser and condenses.
3. Liquid ammonia passes through the expansion valve.
4. In the evaporator, ammonia evaporates and produces cooling.
5. Ammonia vapor enters the absorber and is absorbed by water.

6.The strong solution is pumped back to the generator and the cycle repeats.

Simple Diagram

```
Generator → Condenser → Expansion Valve → Evaporator
     ↑                                          ↓
     |                                          |

        Pump ← Absorber ← Ammonia Vapour ←──────┘
```

2. Modified Aqua–Ammonia System

Additional Components

- Analyzer
- Rectifier

Purpose

Water vapor may leave the generator along with ammonia vapor. The analyzer and rectifier remove water vapor and ensure that nearly pure ammonia reaches the condenser.

Working

1. Generator produces ammonia-rich vapor.
2. Vapor passes through the analyzer and rectifier.
3. Water vapor is separated and returned to the generator.
4. Pure ammonia enters the condenser.
5. Remaining cycle is similar to the simple system.

Advantages

- Higher COP.
- Better refrigeration effect.
- Pure ammonia reaches the evaporator.
- Improved system efficiency.

Modified System Diagram

```
Generator → Analyzer → Rectifier → Condenser
       ↑                                  ↓
|                               Expansion Valve
       |                                  ↓
    Absorber ← Evaporator ←───────────────┘
                        ↑
                       Pump
```

3. Enthalpy–Concentration (h–x) Diagram

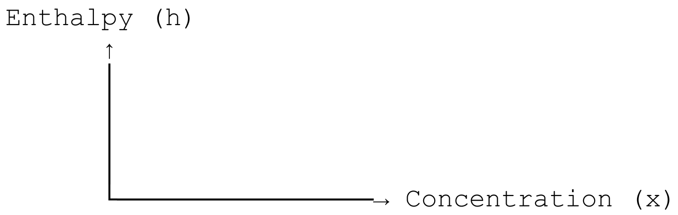
Definition

h–x diagram represents:

- **Enthalpy (h)** on the vertical axis.
- **Ammonia concentration (x)** on the horizontal axis.

It is used to analyze the performance of ammonia–water absorption systems.

Axes



Uses of h–x Diagram

- Determines heat supplied to the generator.
- Calculates refrigeration effect.
- Calculates heat rejected in absorber and condenser.
- Determines COP of the absorption system.
- Helps in system design and analysis.

Advantages of h–x Diagram

- Simplifies calculations.
- Easy performance analysis.
- Widely used for aqua–ammonia refrigeration systems.

Lithium Bromide System, Three-Fluid System, and COP

1. Lithium Bromide (LiBr) Absorption Refrigeration System

Definition

The **Lithium Bromide–Water (LiBr–H_2O) system** is a vapour absorption refrigeration system in which:

- **Water (H_2O)** acts as the refrigerant.
- **Lithium Bromide (LiBr)** acts as the absorbent.

Working Principle

1. Water evaporates in the evaporator and produces cooling.
2. Water vapor is absorbed by the LiBr solution in the absorber.
3. The strong solution is pumped to the generator.
4. Heat supplied to the generator separates water vapor from the solution.
5. Water vapor condenses in the condenser.
6. Condensed water passes through an expansion valve and returns to the evaporator.

Schematic Diagram

```
Heat Input
           ↑
     ┌─────────┐
     │Generator│
     └────┬────┘
      │ Water Vapour
          ▼
     ┌─────────┐
     │Condenser│
     └────┬────┘
      │ Liquid Water
          ▼
┌────────────────┐
│Expansion Valve │
└───────┬────────┘
          ▼
```

```
┌─────────┐
│Evaporator│
└────┬────┘
     │ Water Vapour
     ▼
┌─────────┐
│ Absorber │
└────┬────┘
     │ Strong LiBr Solution
     ▼
    Pump
     │
     ▼
┌─────────┐
│Generator│
```

Advantages

- High efficiency.
- Quiet operation.
- Low maintenance.
- Suitable for large air-conditioning systems.

Limitations

- Cannot operate below 0°C because water is the refrigerant.
- Requires vacuum conditions.

Applications

- Central air conditioning.
- Hotels and hospitals.
- Commercial buildings.

2. Three-Fluid Refrigeration System

A **three-fluid refrigeration system** is an absorption refrigeration system using:

1. **Ammonia (NH_3)** – Refrigerant
2. **Water (H_2O)** – Absorbent
3. **Hydrogen (H_2)** – Inert gas

This system is commonly known as the **Electrolux Refrigerator**.

Working Principle

1. Ammonia is generated in the generator.
2. It condenses in the condenser.
3. Liquid ammonia enters the evaporator.
4. Hydrogen lowers the partial pressure of ammonia, causing it to evaporate at low temperature.
5. Cooling is produced in the evaporator.
6. Ammonia vapor is absorbed by water in the absorber.
7. The cycle repeats.

Advantages

- No moving parts.
- Silent operation.
- Reliable and low maintenance.
- Can operate using gas, electricity, or solar heat.

Applications

- Hotel room refrigerators.
- Caravan refrigerators.
- Portable cooling units.

3. COP (Coefficient of Performance)

Definition

The **Coefficient of Performance (COP)** is the ratio of refrigeration effect produced to the energy supplied.

Formula

For Refrigeration Systems:

COP=QLWCOP=\frac{Q_L}{W}COP=WQL

Where:

- QLQ_LQL = Refrigeration effect (heat removed)

- WWW = Work input

For Absorption Systems:

COP=QEQG+WPCOP=\frac{Q_E}{Q_G+W_P}COP=QG+WPQE

:

- QEQ_EQE = Heat absorbed in evaporator
- QGQ_GQG = Heat supplied to generator
- WPW_PWP = Pump work (usually very small)

Factors Affecting COP

- Evaporator temperature
- Condenser temperature
- Generator temperature
- Refrigerant properties
- System design