

UNIT-3

Air Refrigeration

Definition

An **Air Refrigeration System** is a refrigeration system that uses **air as the refrigerant**. It works on the **Reversed Brayton Cycle (Bell-Coleman Cycle)**.

Principle

Cooling is produced by:

1. Compressing air.
2. Cooling the compressed air.
3. Expanding the air to a low pressure.
4. The expanded air attains a very low temperature and absorbs heat from the refrigerated space.

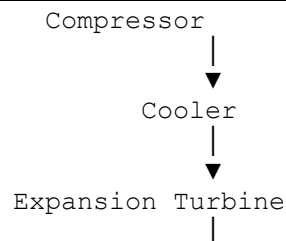
Main Components

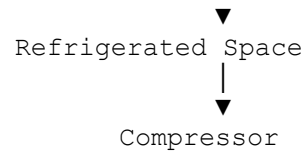
- Compressor
- Cooler (Heat Exchanger)
- Expansion Turbine (Expander)
- Refrigerated Space

Working

1. Air is compressed in the compressor.
2. Compressed air is cooled in the cooler.
3. The cooled high-pressure air expands in the expansion turbine.
4. Air temperature drops significantly.
5. Cold air enters the refrigerated space and absorbs heat.
6. The cycle repeats.

Simple Diagram





Bell-Coleman Cycle

The Bell-Coleman cycle consists of:

1. Isentropic Compression
2. Constant Pressure Cooling
3. Isentropic Expansion
4. Constant Pressure Heating

Cycle Representation

Compression → Cooling → Expansion → Refrigeration Effect

Advantages

- Air is freely available.
- Safe and non-toxic.
- No leakage problems.
- Simple construction.
- Environment-friendly.

Disadvantages

- Low COP compared to VCRS.
- Large compressor size required.
- Higher power consumption.

Applications

- Aircraft refrigeration systems.
- Gas turbine cooling.
- Military aircraft.
- Air transport refrigeration.
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Aircraft Refrigeration Systems

Applications of Air Refrigeration

Air refrigeration systems are mainly used in:

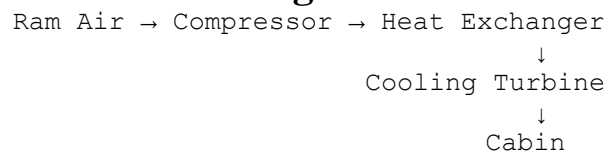
- Aircraft air-conditioning
- Military aircraft
- Passenger aircraft
- Spacecraft environmental control systems
- Gas turbine cooling systems

1. Simple Aircraft Refrigeration System

Working

1. Ram air enters the compressor.
2. Air is compressed, increasing pressure and temperature.
3. Compressed air is cooled in a heat exchanger.
4. Air expands through a cooling turbine.
5. Low-temperature air enters the aircraft cabin for cooling.

Diagram



Advantages

- Simple construction
- Lightweight
- Reliable operation

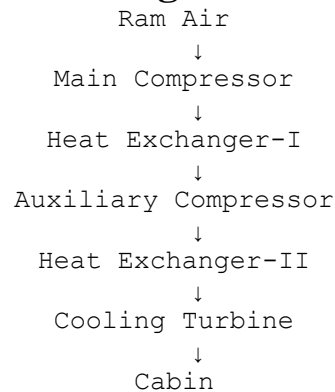
Disadvantages

- Lower COP
- Limited cooling capacity

2. Bootstrap Aircraft Refrigeration System Working

1. Air is compressed in the main compressor.
2. Air is cooled in the first heat exchanger.
3. Air is further compressed by an auxiliary compressor.
4. Air is cooled again in the second heat exchanger.
5. Air expands through the turbine and enters the cabin.

Diagram



Advantages

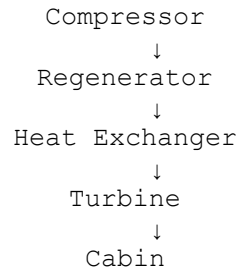
- Better cooling effect
- Higher COP
- Widely used in modern aircraft

3. Regenerative Aircraft Refrigeration System

Working

- A heat exchanger (regenerator) is added.
- Cold air leaving the turbine cools compressed air before expansion.
- Improves efficiency and reduces turbine inlet temperature.

Diagram



Advantages

- Improved COP
- Better cooling performance
- Reduced power consumption

4. Reduced Ambient Aircraft Refrigeration System Working

- Uses an evaporative cooling system to reduce ambient air temperature before entering the main heat exchanger.
- Provides greater cooling effect in hot climates.

Advantages

- Higher refrigeration effect
- Better performance at high ambient temperatures
- Improved cabin comfort

Important Formulae for Numerical Problems Refrigeration Effect

$$RE = C_p(T_1 - T_2)$$

Where:

- RE = Refrigeration effect (kJ/kg)
- C_p = Specific heat of air
- T_1, T_2 = Temperatures (K)

Compressor Work

$$W_c = C_p(T_2 - T_1) \quad W_{c,p} = C_p(T_2 - T_1) \quad W_c = C_p(T_2 - T_1)$$

Turbine Work

$$W_t = C_p(T_3 - T_4) \quad W_{t,p} = C_p(T_3 - T_4) \quad W_t = C_p(T_3 - T_4)$$

COP of Air Refrigeration System

$$\text{COP} = \frac{\text{Refrigeration Effect}}{\text{Net Work Input}} \quad \text{COP} = \frac{\text{Refrigeration Effect}}{\text{Net Work Input}}$$

Steam Jet Refrigeration System

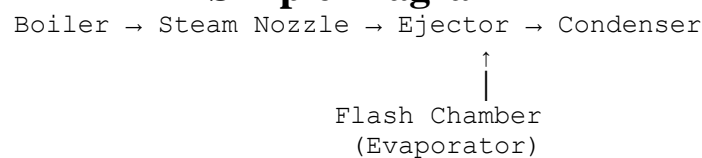
Definition

A **Steam Jet Refrigeration System** is a refrigeration system that uses **high-pressure steam** to produce a vacuum and obtain refrigeration. Water acts as the refrigerant.

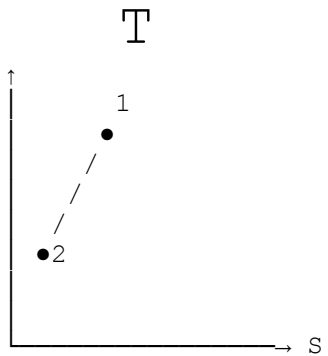
Working Principle

1. High-pressure steam passes through a nozzle at high velocity.
2. The steam jet creates a vacuum in the flash chamber (evaporator).
3. Due to low pressure, water evaporates at a low temperature.
4. Evaporation absorbs heat and produces cooling.
5. The vapor is drawn into the ejector and discharged to the condenser.
6. Condensed water is pumped back to the boiler.

Simple Diagram



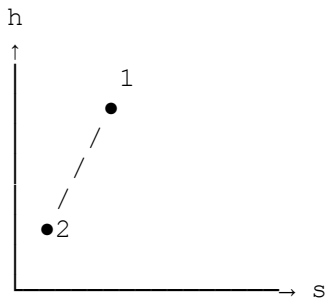
T–S (Temperature–Entropy) Diagram



Processes

- **1–2** : Expansion of steam through the nozzle.
- Cooling and evaporation occur at low pressure.

h–s (Mollier) Diagram



Processes

- **1–2** : Expansion of steam in the ejector nozzle.
- Enthalpy decreases while kinetic energy increases.

Advantages

- Simple construction.
- Few moving parts.
- Low maintenance.
- Uses water as refrigerant (environment-friendly).
- Can utilize waste steam.

Limitations

- Low COP (typically 0.2–0.6).
- Requires a continuous steam supply.
- Large equipment size.
- Not suitable for very low temperatures.
- High water consumption.

Applications

- Large buildings
- Hotels
- Hospitals

Industrial Cooling

- Chemical plants
- Textile industries
- Food processing industries

COP of Steam Jet Refrigeration System

$$COP = \frac{\text{Refrigerating Effect}}{\text{Steam Energy Input}}$$

Unconventional Refrigeration Systems

Unconventional refrigeration systems produce cooling without the conventional vapour compression cycle. Important types are:

1. Thermoelectric Refrigeration System
2. Vortex Tube Refrigeration System
3. Pulse Tube Refrigeration System

1. Thermoelectric Refrigeration System

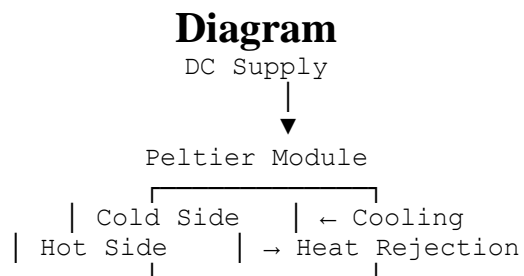
Principle

It works on the **Peltier Effect**.

Peltier Effect: When direct current passes through two dissimilar semiconductor materials, one junction absorbs heat (cooling) and the other rejects heat (heating).

Working

1. DC current is supplied to thermoelectric modules.
2. One side becomes cold and absorbs heat.
3. The other side becomes hot and rejects heat to the surroundings.
4. Continuous current flow produces continuous cooling.



Advantages

- No moving parts.
- Silent operation.
- Compact size.
- Environment-friendly.

Applications

- Portable refrigerators.
- Electronic cooling.
- Medical equipment.
- Spacecraft cooling.

2. Vortex Tube Refrigeration System

Principle

It works on the **Ranque–Hilsch Vortex Effect**.

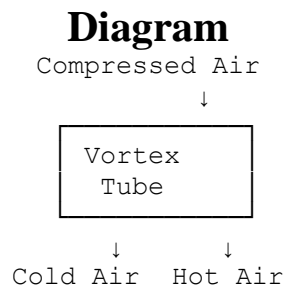
Compressed air entering a vortex tube separates into:

- Hot air stream
- Cold air stream

without any moving parts.

Working

1. Compressed air enters tangentially into the vortex tube.
2. Air rotates at very high speed.
3. Outer air layers become hot.
4. Inner air layers become cold.
5. Separate hot and cold air streams are obtained.



Advantages

- No moving parts.
- Simple construction.

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- Low maintenance.
- Instant cooling.

Applications

- Spot cooling of machines.
- Electronic equipment cooling.
- Industrial process cooling.

3. Pulse Tube Refrigeration System

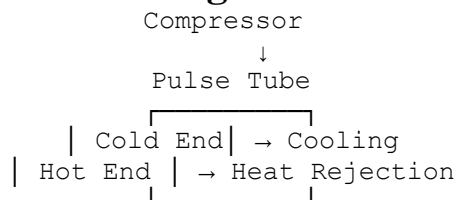
Principle

Cooling is produced by periodic compression and expansion of gas inside a tube.

Working

1. High-pressure gas enters the pulse tube.
2. Gas undergoes cyclic compression and expansion.
3. Heat is transferred from the cold end to the hot end.
4. The cold end produces refrigeration.

Diagram



Advantages

- No moving parts at the cold end.
- High reliability.
- Long service life.
- Low vibration.

Applications

- Cryogenic refrigeration.
- Space research.
- Infrared sensors.
- Superconducting devices.