Refrigeration and Air Conditioning

Short notes for B.Tech Mechanical · GATE ME

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1. Basics of Refrigeration

- **Refrigeration** = removing heat from a space and keeping it below the surrounding temperature.
- By the second law (Clausius), this needs work or heat input; heat does not flow from cold to hot on its own.
- **Refrigerating effect** (RE) = heat absorbed from the cold space per kg of refrigerant.
- **Unit**: 1 tonne of refrigeration (TR) = heat removal needed to freeze 1 ton of water at 0°C in 24 hours = 3.5167 kW (≈ 211 kJ/min).

FORMULA COP of refrigerator = RE / W = Q2 / W. COP of heat pump = Q1 / W = COP_R + 1.

➤ Reversed Carnot cycle

- The ideal (highest COP) cycle between two temperatures. Not practical: wet compression and isentropic expansion are hard.

FORMULA COP (Carnot refrigerator) = T2 / (T1 − T2), with T2 = cold temperature, T1 = hot temperature (in K).

EXAMPLE Carnot refrigerator between −10°C and 40°C. Find COP and power for 1 TR.

- T2 = 263 K, T1 = 313 K. COP = 263 / 50 = 5.26.
- Power = 3.5167 / 5.26 = 0.669 kW.
- COP rises when the evaporator is warmer or the condenser is cooler.

2. Air Refrigeration

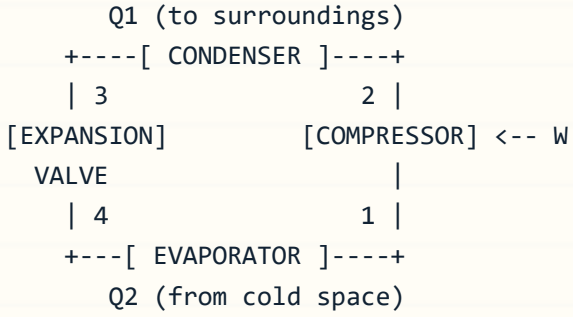
- Working fluid: air (no phase change). Safe and light, but low COP.
- **Bell–Coleman (reversed Brayton / Joule) cycle**: isentropic compression → constant pressure cooling → isentropic expansion → constant pressure heat absorption.

FORMULA COP (Bell–Coleman) = 1 / (rp^((γ−1)/γ) − 1), rp = pressure ratio.

- Used in **aircraft cabin cooling**: low weight, air is easily available, and the cooled air is used directly. Types: simple, bootstrap, regenerative, reduced ambient.

3. Vapour Compression Refrigeration System (VCRS)

- Four parts: **compressor**, **condenser**, **expansion device**, **evaporator**.



Process	Device	What happens
1-2	Compressor	Isentropic compression, vapour becomes superheated
2-3	Condenser	Heat rejected at constant pressure, vapour → liquid
3-4	Expansion valve	Throttling, h3 = h4 (isenthalpic)
4-1	Evaporator	Heat absorbed, liquid → vapour

FORMULA RE = h1 − h4. Compressor work W = h2 − h1. COP = (h1 − h4)/(h2 − h1). Heat rejected = h2 − h3.

FORMULA Refrigerant flow m = cooling capacity / RE. Compressor power = m (h2 − h1).

EXAMPLE A 5 TR plant has (from tables) h1 = 395, h2 = 425, h3 = h4 = 255 kJ/kg. Find COP, flow and power.

- RE = 395 − 255 = 140 kJ/kg. W = 425 − 395 = 30 kJ/kg. COP = 140/30 = **4.67**.
- Capacity = 5 x 3.5167 = 17.58 kW. m = 17.58 / 140 = **0.126 kg/s**.
- Power = 0.126 x 30 = **3.77 kW**.

➤ Effect of changes on VCRS

Change	Effect on COP
Subcooling the liquid	RE increases, COP increases
Superheating at the evaporator outlet	RE increases, work also increases; COP may go up or down (depends on refrigerant)
Lower evaporator pressure	COP decreases
Higher condenser pressure	COP decreases

- **p–h chart** (pressure–enthalpy) is the most useful chart for VCRS: throttling is a vertical line, and enthalpies are read directly.

4. Refrigerants

- Desired properties: low boiling point, high latent heat, moderate pressures, non-toxic, non-flammable, chemically stable, **zero ODP and low GWP**, cheap.

FORMULA Halocarbon number R-(m − 1)(n + 1)(p) for CmHnFpClq. Inorganic: R-7XX, XX = molecular mass.

Refrigerant	Formula	Note
R-12	CCl2F2	CFC, high ODP, banned
R-22	CHClF2	HCFC, being phased out
R-134a	CH2F–CF3	HFC, zero ODP, high GWP; cars, fridges
R-1234yf	HFO	Very low GWP; newer car AC
R-717	NH3 (ammonia)	Excellent thermal properties, toxic; cold storage, ice plants
R-744	CO2	Natural, GWP = 1, very high pressure
R-290 / R-600a	Propane / isobutane	Natural, flammable; domestic fridges and ACs

- **ODP** (ozone depletion potential): due to chlorine (and bromine). R-11 is the reference (ODP = 1).

- **GWP** (global warming potential): compared to CO2 (GWP = 1).
- Montreal Protocol phases out ozone-depleting CFCs and HCFCs; the Kigali Amendment phases down high-GWP HFCs.
- Ammonia is not used with copper (it attacks copper); steel is used.

5. Vapour Absorption Refrigeration System (VARS)

- Replaces the compressor with an **absorber + pump + generator**. It uses heat (steam, waste heat, solar) instead of large shaft work.
- Pump work is very small, since it pumps a liquid.

System	Refrigerant	Absorbent	Use
Aqua-ammonia	Ammonia	Water	Below 0°C, needs analyser and rectifier to remove water vapour
LiBr-water	Water	Lithium bromide	Air conditioning only (above 0°C), vacuum operation

FORMULA Max COP of VARS = ((Tg − T0)/Tg) x (Te / (T0 − Te)), Tg = generator, T0 = ambient (condenser/absorber), Te = evaporator temperature.

- COP of VARS (about 0.6–1.2) is much lower than VCRS, but it uses low-grade heat.
- **Electrolux (three-fluid) refrigerator**: ammonia, water and hydrogen; no pump, no moving parts.

6. System Components

- **Compressors**: reciprocating (small–medium), rotary, scroll (home AC), screw (large), centrifugal (very large, water chillers).
  - Hermetic: motor and compressor sealed together (fridges, home AC). Open type: motor outside (ammonia plants).
- **Condensers**: air cooled, water cooled (shell and tube), evaporative.
- **Expansion devices**: capillary tube (fridges, small AC; no moving parts), thermostatic expansion valve (keeps constant superheat), automatic (constant

pressure) valve, float valve, electronic expansion valve.

- **Evaporators**: flooded, dry expansion; bare tube, finned, plate.

> **TIP** A capillary tube gives a fixed restriction, so pressures equalise when the compressor stops. That allows a low starting torque motor.

7. Psychrometry

- **Psychrometry** = study of moist air (dry air + water vapour).

Term	Meaning
Dry bulb temperature (DBT)	Temperature by an ordinary thermometer
Wet bulb temperature (WBT)	Thermometer with a wet wick; lower due to evaporation
Dew point temperature (DPT)	Temperature at which vapour starts condensing on cooling at constant ω
Specific humidity ω	kg of water vapour per kg of dry air
Relative humidity ϕ	p_v / p_s at the same temperature
Degree of saturation μ	ω / ω_s

> **FORMULA** $\omega = 0.622\ p_v / (p - p_v)$. $\phi = p_v / p_s$. Enthalpy $h = 1.005\ t + \omega\ (2500 + 1.88\ t)$ kJ/kg dry air.

- For saturated air: DBT = WBT = DPT. For unsaturated air: DBT > WBT > DPT.
- **Wet bulb depression** = DBT − WBT; zero at 100% RH.

> **EXAMPLE** Air at 30°C, p_v = 0.025 bar, p = 1.01325 bar, p_s at 30°C = 0.04246 bar. Find ω, ϕ and h.

- $\omega = 0.622 \times 0.025 / (1.01325 - 0.025) = 0.01555 / 0.98825 =$ **0.0157 kg/kg dry air**.
- $\phi = 0.025 / 0.04246 =$ **58.9%**.
- $h = 1.005 \times 30 + 0.0157 \times (2500 + 1.88 \times 30) = 30.15 + 40.2 =$ **70.4 kJ/kg dry air**.

➤ Psychrometric processes

Process	What stays constant	Example
Sensible heating / cooling	ω (horizontal line)	Heating coil, cooling above DPT
Cooling and dehumidification	Neither (both t and ω fall)	Summer AC coil
Heating and humidification	Neither (both rise)	Winter AC
Evaporative (adiabatic) cooling	WBT (about constant h)	Desert cooler
Chemical dehumidification	About constant h (WBT); t rises, ω falls	Silica gel
Adiabatic mixing	Mass and energy balance	Fresh + recirculated air

FORMULA Bypass factor BPF = (t2 − t_ADP)/(t1 − t_ADP). Coil efficiency = 1 − BPF. (ADP = apparatus dew point = coil surface temperature)

FORMULA Sensible heat factor SHF = SH / (SH + LH). Room SHF line slope is drawn on the psychrometric chart.

8. Air Conditioning

- **Air conditioning** controls temperature, humidity, air movement and cleanliness at the same time.
- **Human comfort** (approx.): 22–26°C DBT and 40–60% RH, air velocity about 0.1–0.25 m/s.
- **Effective temperature**: one index combining DBT, humidity and air motion that gives the same comfort feeling.

➤ Types of AC systems

System	Idea	Example
Unitary	Self-contained unit	Window AC, split AC
Central	Plant in one place, ducts to rooms	Malls, offices
All-air / all-water / air–water	Medium that carries cooling to rooms	VAV, fan-coil units
VRF / VRV	One outdoor unit, many indoor units, variable flow	Offices, hotels

➤ Cooling load

- **Sensible load**: heat through walls, roof and glass (solar), people (sensible part), lights, equipment, infiltration and ventilation air.
- **Latent load**: moisture from people, infiltration, ventilation and cooking.
- Summer AC: cooling + dehumidification, then sometimes reheating. Winter AC: heating + humidification.
- **Cooling towers** reject condenser heat to air by evaporation; approach = water outlet temperature − air WBT.

9. Most Asked Questions (practice)

1. Define TR and COP. Derive COP of a reversed Carnot cycle.
2. Explain the Bell–Coleman cycle and its use in aircraft.
3. Draw VCRS on T–s and p–h charts and derive its COP.
4. Explain the effect of subcooling and superheating on COP.
5. Explain refrigerant numbering. Discuss ODP, GWP and eco-friendly refrigerants.
6. Explain aqua–ammonia and LiBr–water absorption systems. Find max COP of VARS.
7. Compare VCRS and VARS.
8. Define DBT, WBT, DPT, specific humidity and RH. Solve a psychrometric problem.
9. Show psychrometric processes on a chart. Explain bypass factor and SHF.
10. Explain summer and winter air conditioning systems with sketches.

TIP In GATE ME, expect COP of Carnot / VCRS from given enthalpies, TR conversions, psychrometric calculations (ω, RH, h) and bypass factor. Draw the p–h chart for every VCRS question.