Refrigeration and Air Conditioning (DI05019051)

GTU Course Presentation

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Agenda

- 1.1 Definition of Refrigeration and air-conditioning.

1.1 Definition of Refrigeratio - Part 1

- Refrigeration is the process of removing heat.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.1 Definition of Refrigeratio - Part 2

- It reduces and maintains the temperature.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.1 Definition of Refrigeratio - Part 3

- Air conditioning also controls humidity.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.1 Definition of Refrigeratio - Part 4

- Comfort AC is for human comfort.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.1 Definition of Refrigeratio - Part 5

- Industrial AC is for processes.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.1 Definition of Refrigeratio - Part 6

- Additional detail 6
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.1 Definition of Refrigeratio - Part 7

- Additional detail 7
- Detailed explanation of the concept.
- Relevant theory and practical example.

Summary

Key Takeaways

Critical understanding of 1.1 Definition of Refrigeration and air-conditioning. is essential for proper refrigeration and air conditioning system design.

Agenda

- 1.2 Refrigerating effect, unit of refrigeration, Coefficient of performance.

1.2 Refrigerating effect, unit - Part 1

- Refrigerating Effect (RE): Amount of heat extracted.
- Detailed explanation of the concept.
- Relevant theory and practical example.

- Ton of Refrigeration (TR).
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.2 Refrigerating effect, unit - Part 3

- 1 TR = 3.5 kW or 210 kJ/min.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.2 Refrigerating effect, unit - Part 4

- Coefficient of Performance (COP) = RE / Work Input.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.2 Refrigerating effect, unit - Part 5

- COP is always greater than efficiency.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.2 Refrigerating effect, unit - Part 6

- Additional detail 6
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.2 Refrigerating effect, unit - Part 7

- Additional detail 7
- Detailed explanation of the concept.
- Relevant theory and practical example.

Summary

Key Takeaways

Critical understanding of 1.2 Refrigerating effect, unit of refrigeration, Coefficient of performa... is essential for proper refrigeration and air conditioning system design.

Agenda

- 1.3 Types of Refrigeration-Ice, dry ice, Steam jet, Throttling, Liquid nitrogen refrigeration
- 1.4 Carnot refrigeration Cycle on PV & TS diagrams

1.3 Types of Refrigeration-Ice - Part 1

- Ice Refrigeration: Uses latent heat (335 kJ/kg).
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.3 Types of Refrigeration-Ice - Part 2

- Dry Ice (Solid CO_2): Sublimes directly.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.3 Types of Refrigeration-Ice - Part 3

- Steam Jet: Uses ejectors and water.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.3 Types of Refrigeration-Ice - Part 4

- Liquid Nitrogen: Used for rapid freezing.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.3 Types of Refrigeration-Ice - Part 5

- Different methods suit different applications.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.3 Types of Refrigeration-Ice - Part 6

- Additional detail 6
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.3 Types of Refrigeration-Ice - Part 7

- Additional detail 7
- Detailed explanation of the concept.
- Relevant theory and practical example.

Key Takeaways

Critical understanding of 1.3 Types of Refrigeration-Ice, dry ice, Steam jet, Throttling, Liquid n... is essential for proper refrigeration and air conditioning system design.

- 1.5 Air refrigeration cycle (Reverse Brayton or Bell - Coleman cycle) on PV& TSdiagrams.

1.5 Air refrigeration cycle (R - Part 1

- Reversed Brayton Cycle uses air.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.5 Air refrigeration cycle (R - Part 2

- Isentropic compression, isobaric heat rejection.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.5 Air refrigeration cycle (R - Part 3

- Uses a compressor and an expander.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.5 Air refrigeration cycle (R - Part 4

- Cycle shape on T-S and P-V diagrams.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.5 Air refrigeration cycle (R - Part 5

- Bell-Coleman cycle.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.5 Air refrigeration cycle (R - Part 6

- Additional detail 6
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.5 Air refrigeration cycle (R - Part 7

- Additional detail 7
- Detailed explanation of the concept.
- Relevant theory and practical example.

Summary

Key Takeaways

Critical understanding of 1.5 Air refrigeration cycle (Reverse Brayton or Bell - Coleman cycle) on... is essential for proper refrigeration and air conditioning system design.

Agenda

- 1.6 Advantages, disadvantages and applications of air refrigeration cycles.
- 1.7 Simple numerical on Reverse Brayton cycle.

1.6 Advantages, disadvantages - Part 1

- Advantages: Air is free, safe, non-toxic.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.6 Advantages, disadvantages - Part 2

- Highly used in aircraft refrigeration.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.6 Advantages, disadvantages - Part 3

- Disadvantages: Low COP, high running cost.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.6 Advantages, disadvantages - Part 4

- Large volume of air handled.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.6 Advantages, disadvantages - Part 5

- Operating pressure ratio must be high.
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.6 Advantages, disadvantages - Part 6

- Additional detail 6
- Detailed explanation of the concept.
- Relevant theory and practical example.

1.6 Advantages, disadvantages - Part 7

- Additional detail 7
- Detailed explanation of the concept.
- Relevant theory and practical example.

Summary

Key Takeaways

Critical understanding of 1.6 Advantages, disadvantages and applications of air refrigeration cycles. is essential for proper refrigeration and air conditioning system design.

Agenda

- 2.1 Flow diagram with basic components of Vapor Compression Refrigeration system.

2.1 Flow diagram with basic co - Part 1

- VCRS has four main components.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.1 Flow diagram with basic co - Part 2

- Compressor, Condenser, Expansion Valve, Evaporator.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.1 Flow diagram with basic co - Part 3

- Refrigerant undergoes phase changes.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.1 Flow diagram with basic co - Part 4

- High efficiency compared to gas cycles.
- Detailed explanation of the concept.
- Relevant theory and practical example.

- Most common refrigeration cycle.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.1 Flow diagram with basic co - Part 6

- Additional detail 6
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.1 Flow diagram with basic co - Part 7

- Additional detail 7
- Detailed explanation of the concept.
- Relevant theory and practical example.

Summary

Key Takeaways

Critical understanding of 2.1 Flow diagram with basic components of Vapor Compression Refrigeratio... is essential for proper refrigeration and air conditioning system design.

Agenda

- 2.1 Flow diagram with basic components of Vapor Compression Refrigeration system.

2.1 Flow diagram with basic co - Part 1

- VCRS has four main components.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.1 Flow diagram with basic co - Part 2

- Compressor, Condenser, Expansion Valve, Evaporator.
- Detailed explanation of the concept.
- Relevant theory and practical example.

- Refrigerant undergoes phase changes.
- Detailed explanation of the concept.
- Relevant theory and practical example.

- High efficiency compared to gas cycles.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.1 Flow diagram with basic co - Part 5

- Most common refrigeration cycle.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.1 Flow diagram with basic co - Part 6

- Additional detail 6
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.1 Flow diagram with basic co - Part 7

- Additional detail 7
- Detailed explanation of the concept.
- Relevant theory and practical example.

Summary

Key Takeaways

Critical understanding of 2.1 Flow diagram with basic components of Vapor Compression Refrigeratio... is essential for proper refrigeration and air conditioning system design.

Agenda

- 2.2 Representation of the vapor compression cycle on P-H, T-S & P-V Diagram;

2.2 Representation of the vapo - Part 1

- P-H diagram: Evaporation and condensation are horizontal.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.2 Representation of the vapo - Part 2

- T-S diagram: Evaporation is horizontal in wet region.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.2 Representation of the vapo - Part 3

- P-V diagram is rarely used.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.2 Representation of the vapo - Part 4

- Isenthalpic expansion is vertical on P-H.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.2 Representation of the vapo - Part 5

- Visualizing the cycle is crucial.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.2 Representation of the vapo - Part 6

- Additional detail 6
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.2 Representation of the vapo - Part 7

- Additional detail 7
- Detailed explanation of the concept.
- Relevant theory and practical example.

Summary

Key Takeaways

Critical understanding of 2.2 Representation of the vapor compression cycle on P-H, T-S & P-V Diag... is essential for proper refrigeration and air conditioning system design.

Agenda

- 2.3 Expression for Refrigerating effect and coefficient of performance.

2.3 Expression for Refrigerati - Part 1

- RE = h1 - h4.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.3 Expression for Refrigerati - Part 2

- Work of compression (W) = h2 - h1.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.3 Expression for Refrigerati - Part 3

- COP = (h1 - h4) / (h2 - h1).
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.3 Expression for Refrigerati - Part 4

- Power required (kW) = mass flow rate * W.
- Detailed explanation of the concept.
- Relevant theory and practical example.

- Enthalpy values from charts.
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.3 Expression for Refrigerati - Part 6

- Additional detail 6
- Detailed explanation of the concept.
- Relevant theory and practical example.

2.3 Expression for Refrigerati - Part 7

- Additional detail 7
- Detailed explanation of the concept.
- Relevant theory and practical example.

Summary

Key Takeaways

Critical understanding of 2.3 Expression for Refrigerating effect and coefficient of performance. is essential for proper refrigeration and air conditioning system design.

Title Slide I

Course: Refrigeration and AC

- Unit: Vapor Refrigeration Systems
- Lecture 10: 2.4 Effects of changes in operating conditions (sub-cooling, super heating of suction vapor and change in suction pressure of compressor) on performance of vapor compression refrigeration cycle.

Overview of Operating Conditions I

In actual practice, the operating conditions of a Vapor Compression Refrigeration System (VCRS) deviate from the standard theoretical design due to environmental changes, load variations, and system design limitations.

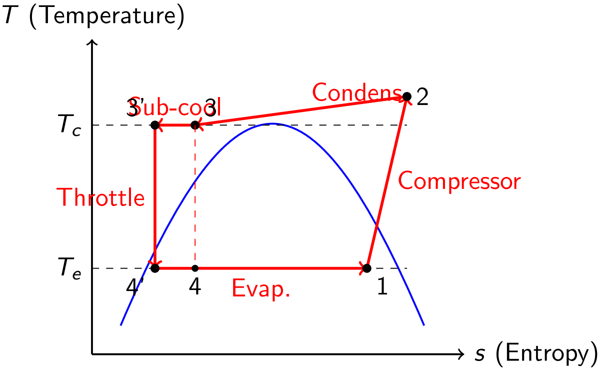
- Operating pressures are determined by the heat source (evaporator) and heat sink (condenser) temperatures.
- Deviations from standard parameters directly affect the volumetric efficiency, compressor work, refrigeration effect, and overall Coefficient of Performance (COP).
- Key parameter variations analyzed in this lecture: liquid sub-cooling, vapor superheating, and reduction in compressor suction pressure.

Effect of Sub-cooling of Liquid I

Sub-cooling is the process of cooling the liquid refrigerant below its saturation temperature at the condenser pressure before it enters the expansion device.

- Refrigerating Effect increases: The state of the refrigerant entering the evaporator shifts to a lower enthalpy region, reducing flash gas formation.
- Compressor Work remains constant: Since the suction pressure and discharge pressure remain unchanged, the enthalpy difference across the compressor does not vary.
- Overall COP increases: Since COP is the ratio of Refrigerating Effect to Compressor Work, any increase in the refrigerating effect directly improves the COP.
- System volumetric capacity is enhanced, allowing a smaller compressor displacement for the same refrigeration load.

T-s Diagram of VCRS with Sub-cooling I



- State 3 to 3' represents sub-cooling of liquid in the condenser or a separate subcooler.

T-s Diagram of VCRS with Sub-cooling II

- The throttling path shifts from 3-4 to 3'-4', reducing the dryness fraction of the mixture at the evaporator inlet.
- Refrigerating effect increases by the enthalpy difference (h4 - h4').

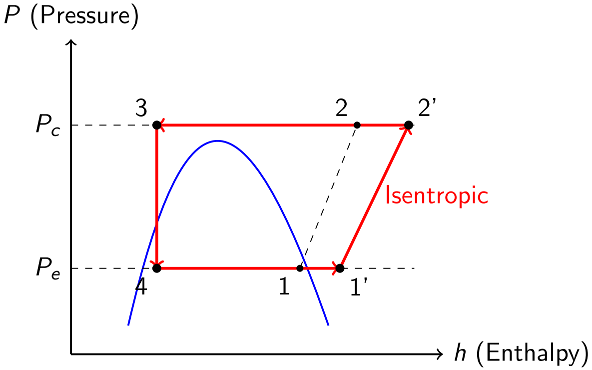
Effect of Superheating of Suction Vapor I

Superheating is the process of raising the temperature of the vapor refrigerant above its saturation temperature at the evaporator pressure before it enters the compressor suction valve.

- Useful Superheating: Occurs inside the evaporator coils, thereby increasing the useful refrigerating effect.
- Useless Superheating: Occurs in the suction piping due to heat transfer from surroundings, which does not contribute to the cooling load but increases specific volume.
- Compressor Work Input: Increases because the isentropic compression lines on a P-h diagram diverge at higher temperatures.
- Specific Volume: Increases the specific volume of vapor at compressor inlet, which reduces the mass flow rate of refrigerant for a fixed displacement compressor.

Effect of Superheating of Suction Vapor II

- Overall COP: Varies depending on the refrigerant type. For R-134a, COP may slightly improve; for Ammonia (R-717) and R-22, COP decreases due to a high rate of increase in compression work.



- State 1 to 1' indicates superheating of the suction vapor at constant pressure Pe.

P-h Diagram of VCRS with Superheating II

- The compression path shifts from 1-2 to 1'-2', ending at a higher discharge temperature T2'.
- If superheating is useful, the refrigerating effect increases from (h1 - h4) to (h1' - h4).

Effect of Decrease in Suction Pressure I

A drop in suction pressure occurs when the evaporator is operated at lower temperatures to meet low-temperature cooling requirements, or due to restricted heat transfer in the evaporator.

- Refrigerating Effect decreases: The enthalpy of vapor at compressor suction (h1) decreases, reducing the cooling capacity per unit mass flow.
- Pressure Ratio increases: The ratio Pc/Pe increases, which results in higher specific compressor work (h2 - h1).
- Specific Volume increases: Lower suction pressure leads to a larger specific volume of vapor at compressor suction, reducing the mass flow rate.
- Volumetric Efficiency drops: Higher pressure ratio causes more expansion of clearance pocket vapor, reducing the intake of fresh refrigerant vapor.

Effect of Decrease in Suction Pressure II

- Overall COP decreases: The combination of reduced refrigerating effect and increased compressor work significantly degrades system COP.

Quantitative Impact of Suction Pressure I

Evaluating how system parameters change quantitatively as the compressor suction temperature drops.

- Every 1 degree Celsius drop in evaporator temperature increases compressor power consumption by approximately 2% to 3%.
- Lower suction pressures lead to high discharge temperatures, causing oil carbonization and accelerated wear of compressor valves.
- Compression ratios exceeding 8:1 due to low suction pressure often necessitate multi-stage compression with intercooling.
- Thermodynamically, suction pressure should be maintained as high as possible, consistent with the required refrigeration temperature.

Comparison of Operating Parameters I

A summary comparison showing the directional effects of key operating variables on VCRS cycle performance indicators.

- Sub-cooling: Refrigerating Effect (Increases), Work Input (No Change), Volumetric Efficiency (No Change), COP (Increases).
- Superheating (Useful): Refrigerating Effect (Increases), Work Input (Increases), Volumetric Efficiency (Decreases), COP (Varies).
- Decreased Suction Pressure: Refrigerating Effect (Decreases), Work Input (Increases), Volumetric Efficiency (Decreases), COP (Decreases).
- Increased Discharge Pressure: Refrigerating Effect (Decreases), Work Input (Increases), Volumetric Efficiency (Decreases), COP (Decreases).

Engineering Design Guidelines I

Practical strategies for engineers to optimize Vapor Compression Refrigeration Systems based on thermodynamic operating conditions.

- Minimize temperature difference between evaporator refrigerant and cold space to keep suction pressure as high as possible.
- Utilize a liquid-to-suction regenerator (heat exchanger) to achieve both sub-cooling of liquid and superheating of suction vapor.
- Prevent useless superheating by insulating the suction line piping between the evaporator exit and the compressor inlet.
- Implement variable speed drives on compressors to match displacement requirements under fluctuating suction pressures.

Course: Refrigeration and AC

- Unit: Vapor Refrigeration Systems
- Topic: 2.5 Simple Vapor absorptions cycle and its flow diagram;
- Instructor: Professor of Mechanical Engineering

Introduction & Limitations of VCRS I

Why transition from Vapor Compression (VCRS) to Vapor Absorption Systems (VARS)?

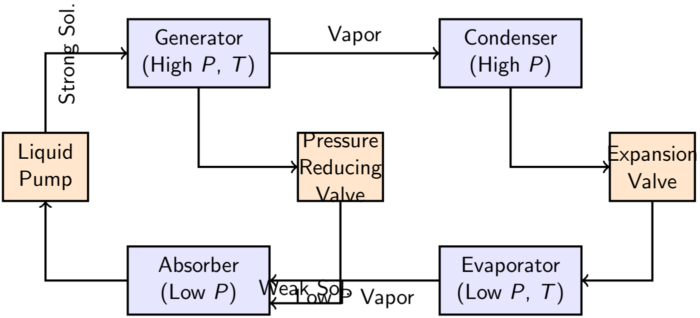
- Vapor Compression systems require high-grade mechanical/electrical energy input for the compressor.
- The work input required for a compressor is proportional to the specific volume of the vapor: $W_c = \int v\, dp$.
- Because vapor has a high specific volume (v), compressing it requires substantial electrical work.
- Vapor Absorption Systems (VARS) replace the compressor with a pump and thermal devices, reducing high-grade energy dependency.
- VARS can utilize low-grade thermal energy, such as waste heat, steam, or solar energy, as the primary source of power.

The Basic Operating Principle of VARS I

Understanding the affinity between refrigerants and absorbents.

- VARS operates on the principle of chemical affinity: a refrigerant vapor is readily absorbed by a compatible absorbent liquid.
- The solubility of a gas in a liquid decreases as the temperature of the liquid increases.
- Common working fluid pairs: Ammonia-Water (NH_3-H_2O) and Water-Lithium Bromide (H_2O-$LiBr$).
- In the NH_3-H_2O pair, Ammonia (NH_3) acts as the refrigerant and Water (H_2O) acts as the absorbent.
- In the H_2O-$LiBr$ pair, Water (H_2O) acts as the refrigerant and Lithium Bromide ($LiBr$) is the absorbent.

Flow Diagram of a Simple VARS I



- Refrigerant circuit: Evaporator → Absorber → Pump → Generator → Condenser → Expansion Valve → Evaporator.
- Absorbent circuit: Absorber (Strong Solution) → Pump → Generator → Pressure Reducing Valve (Weak Solution) → Absorber.

Flow Diagram of a Simple VARS II

- The mechanical compressor is replaced by the thermal assembly: Absorber, Pump, PRV, and Generator.
- Heat inputs are at the Generator (Q_G) and Evaporator (Q_E); heat rejection occurs at the Condenser (Q_C) and Absorber (Q_A).

Detailed Component Analysis: Evaporator & Condenser I

Functions of the primary heat exchangers in the refrigeration loop.

- Evaporator: Low-temperature, low-pressure liquid refrigerant absorbs heat (Q_E) from the refrigerated space and evaporates.
- This evaporation produces the useful cooling/refrigeration effect (Q_E).
- Condenser: High-pressure vapor leaving the generator enters the condenser and rejects latent heat (Q_C) to a cooling medium (water or air).
- The refrigerant condenses back to a high-pressure liquid state.
- Expansion Valve: Throttles the high-pressure liquid from the condenser to low pressure, reducing its temperature before entering the evaporator.

Detailed Component Analysis: Absorber & Pump I

How low-pressure vapor is converted into a high-pressure liquid solution.

- Absorber: The low-pressure refrigerant vapor from the evaporator is introduced into the absorber where it contact-mixes with a weak solution.
- As the weak solution absorbs the vapor, it becomes a strong solution (rich in refrigerant).
- The absorption process is exothermic; the heat of absorption (Q_A) must be rejected to cooling water to maintain high absorption capacity.
- Liquid Pump: Drawing strong solution from the absorber, the pump increases its pressure to the generator pressure level.
- The pump work (W_p) is negligible: $W_p = v_{liq}(P_{high} - P_{low})$, and since $v_{liq} \ll v_{vap}$, electrical consumption is very low.

Detailed Component Analysis: Generator & PRV I

Separation of refrigerant and pressure balancing.

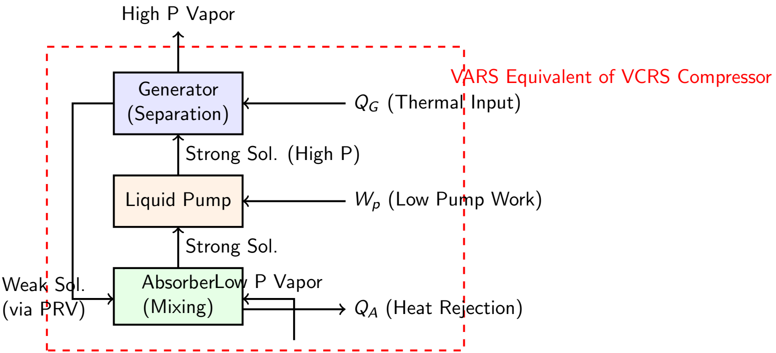
- Generator: The high-pressure strong solution enters the generator where external thermal energy (Q_G) is supplied.
- Heating boils off the volatile refrigerant from the solution, producing high-pressure refrigerant vapor.
- The high-pressure vapor travels directly to the condenser, while the remaining weak solution accumulates at the bottom of the generator.
- Pressure Reducing Valve (PRV): Restricts the flow of the high-pressure weak solution back to the absorber.
- The PRV drops the pressure of the weak solution to match the low-pressure absorber, maintaining the system's pressure boundary.

Thermodynamic Analysis & COP of VARS I

Energy balance and calculation of the coefficient of performance.

- First Law Energy Balance: Neglecting kinetic/potential energy and pump work: $Q_G + Q_E = Q_C + Q_A$.
- Coefficient of Performance (COP): Defined as the ratio of refrigeration effect to external energy input: $COP = \frac{Q_E}{Q_G + W_p} \approx \frac{Q_E}{Q_G}$.
- Ideal COP (Carnot Limit): Derived by treating the generator-absorber loop as a heat engine driving a refrigeration cycle.
- Carnot Formula: $COP_{max} = \left(\frac{T_E}{T_O - T_E}\right) \times \left(\frac{T_G - T_O}{T_G}\right)$, where T_G is generator temp, T_E is evaporator temp, and T_O is environment temp.
- A typical simple vapor absorption system operates at an actual COP of 0.6 to 0.8, which is lower than VCRS but uses cheaper energy.

Comparison of Compressor vs. VARS Equivalent Assembly I



- The diagram shows how three components (Absorber, Pump, Generator) replace the VCRS compressor.

Comparison of Compressor vs. VARS Equivalent Assembly II

- The chemical absorption in the absorber mimics the intake stroke, and the generator heating mimics the discharge stroke.
- Low-pressure vapor is dissolved into liquid, pumped efficiently, and then boiled off at high pressure.
- Work input changes from high electrical compressor work to minimal pump work + thermal energy input.

Comparison & Key Takeaways I

Direct comparison of performance, mechanics, and applications of VCRS vs. VARS.

- Energy Source: VCRS runs on mechanical work (electricity); VARS runs on heat (solar, exhaust, process steam).
- Moving Parts: VCRS uses high-speed reciprocating/rotary compressors (high wear and noise); VARS uses a small, silent liquid pump (low wear).
- Capacity Control: VARS handles partial loads exceptionally well without a drastic drop in efficiency compared to VCRS.
- Refrigerant Leaks: VARS uses eco-friendly mixtures like Ammonia or Water, presenting zero ozone depletion potential.
- Applications: VARS is optimal where cheap heat energy is available (cogeneration plants, steel mills, solar cooling).

2.5 Simple Vapor Absorption Cycle and its Flow Diagram I

Course: Refrigeration and Air Conditioning (DI05019051)

- Lecture 12: Fundamentals of Vapor Absorption Refrigeration Systems (VARS)
- Comparison of thermal compression vs. mechanical compression
- Thermodynamic principles, flow path configuration, and COP limits

Thermodynamic Foundations of VARS I

The Vapor Absorption Refrigeration System (VARS) is a thermal-driven refrigeration cycle that replaces the power-consuming mechanical compressor with a chemical compressor system.

- Driven by low-grade thermal energy, such as industrial waste heat, solar thermal energy, or exhaust steam.
- Replaces the mechanical compressor of a VCRS with three distinct components: an absorber, a liquid pump, and a generator.
- Relies on the chemical affinity between a refrigerant and an absorbent to achieve pressure elevation at minimal mechanical work input.

Working Fluids in Absorption Systems I

The performance of a VARS is highly dependent on the thermodynamic properties of the binary mixture (refrigerant-absorbent pair).

- Aqua-Ammonia (NH3-H2O) System: Ammonia (NH3) acts as the refrigerant and Water (H2O) acts as the absorbent. Suitable for low-temperature applications (-10°C to -30°C).
- Lithium Bromide-Water (LiBr-H2O) System: Water (H2O) acts as the refrigerant and Lithium Bromide (LiBr) salt solution acts as the absorbent. Limited to air conditioning (¿0°C).
- Selection Criteria: High mutual solubility at low temperatures, large boiling point difference (to facilitate separation), and low heat of mixing.

The Absorber and Pump (Low-Pressure Side) I

The absorber and liquid pump perform the suction and compression functions of a standard compressor by utilizing mass transfer and liquid pumping.

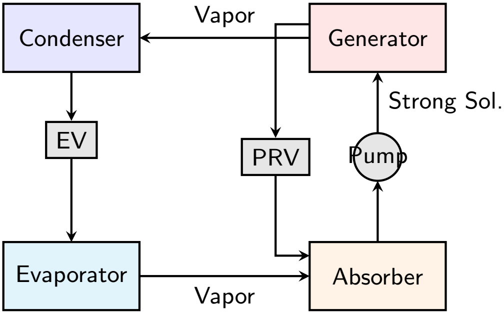
- Low-pressure refrigerant vapor from the evaporator enters the absorber and is dissolved in a weak solution of absorbent.
- The absorption process is highly exothermic; cooling water must circulate through the absorber to remove the heat of absorption and maintain high absorption capacity.
- The resulting strong solution is pumped to the high-pressure generator. Because liquid is nearly incompressible, the pump work (W_p) is negligible compared to compressor work in VCRS.

The Generator and Pressure Regulators (High-Pressure Side) I

The generator utilizes thermal energy to separate the refrigerant from the absorbent, restoring the absorbent's capability to cycle.

- High-pressure strong solution in the generator is heated externally (via steam or waste heat), boiling off the refrigerant due to its lower boiling point.
- The high-pressure refrigerant vapor flows to the condenser to continue the refrigeration cycle.
- The remaining hot, weak solution returns to the low-pressure absorber through a pressure reducing valve (PRV), regulating the pressure difference.

Schematic Flow Diagram of Simple VARS I



- Generator: High-pressure vapor generation via external heat input.
- Condenser: Vapor condensation by rejecting heat to the environment.

Schematic Flow Diagram of Simple VARS II

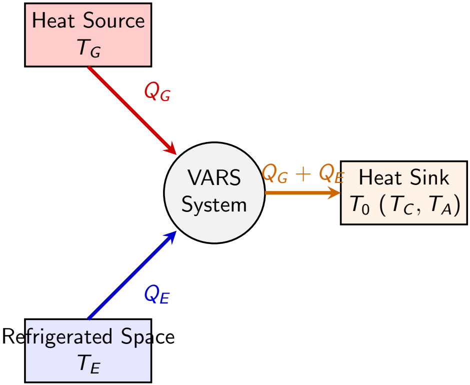
- Expansion Valve (EV) & Evaporator: Pressure drop and heat absorption from space.
- Absorber, Pump, and PRV: Absorption of vapor into weak solution, pumping of strong solution, and returning weak solution.

Energy Balance and COP of VARS I

Analysis of the Vapor Absorption Cycle requires applying the First and Second Laws of Thermodynamics to all individual components.

- Energy inputs: Heat added in generator (Q_G), heat added in evaporator (Q_E), and pump work (W_P).
- Energy outputs: Heat rejected in condenser (Q_C) and heat rejected in absorber (Q_A).
- Coefficient of Performance: COP = Q_E / (Q_G + W_P). Since W_P is very small compared to Q_G, it is neglected: COP \{}approx Q_E / Q_G.

Thermodynamic Cycle Limits (Carnot COP) I



- VARS acts as a combination of a Carnot engine (operating between T_G and T_0) driving a Carnot refrigerator (operating between T_E and T_0).

Thermodynamic Cycle Limits (Carnot COP) II

- Carnot engine thermal efficiency: \{}eta_{th} = (T_G - T_0) / T_G.
- Carnot refrigerator COP: COP_R = T_E / (T_0 - T_E).
- Maximum theoretical COP of VARS: COP_{max} = \{}eta_{th} \{}cdot COP_R = \{}left(\{}frac{T_G - T_0}{T_G}\{}right) \{}cdot \{}left(\{}frac{T_E}{T_0 - T_E}\{}right).

Performance Comparison: VARS vs. VCRS I

Understanding the design trade-offs between Vapor Absorption and Vapor Compression Systems.

- Energy Quality: VCRS requires high-grade electrical/mechanical energy. VARS runs on low-grade thermal energy.
- Operation: VCRS has high vibration and noise due to moving pistons/rotors. VARS is quiet with only a small pump.
- Part-load performance: VARS maintains relatively high efficiency at partial loads, whereas VCRS efficiency drops due to throttling losses.

Practical Modifications: Analyzer & Rectifier I

A simple Aqua-Ammonia cycle has issues with water vapor carryover into the condenser, which must be resolved using rectification.

- Problem: Water has a relatively high vapor pressure and evaporates along with ammonia, carrying over to the expansion valve where it freezes.
- Analyzer: A distillation column placed directly on top of the generator that condenses out water vapor from the rising mixture using the cooler incoming strong solution.
- Rectifier: A final water-cooled heat exchanger (dehydrator) that subcools the vapor to condense remaining water, returning it as reflux.

Title Slide I

Course: Refrigeration and AC Unit: Vapor Refrigeration Systems
Lecture 13: 2.6 Simple Electrolux System for Domestic Units

- Introduction to the Platen-Munters three-fluid refrigeration system.
- Engineered specifically for silent domestic refrigeration without a pump.
- Overview of working fluids: Ammonia, Water, and Hydrogen.

Three-Fluid Absorption Concept I

The Electrolux system is a vapor absorption system that completely eliminates the mechanical pump by introducing a third fluid (Hydrogen) to create pressure differentials naturally.

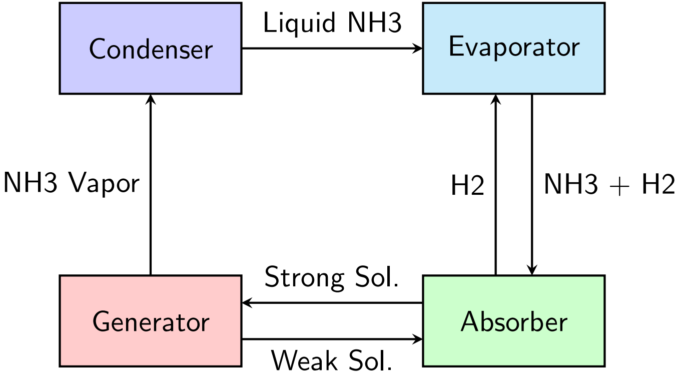
- Ammonia (NH_3) acts as the primary refrigerant due to favorable thermodynamic properties.
- Water (H_2O) acts as the solvent to carry ammonia between absorber and generator.
- Hydrogen gas (H_2) maintains low partial pressure of ammonia in the evaporator.

Dalton's Law of Partial Pressures I

Dalton's law is the theoretical foundation that enables this system to work under a uniform total system pressure without mechanical components.

- Total system pressure is constant (15-20 bar) to allow flow by gravity and density gradients.
- High pressure side (Generator/Condenser): Ammonia pressure is equal to total pressure.
- Low pressure side (Evaporator): Ammonia partial pressure is low, while Hydrogen supplies the balance.
- $P_{total} = P_{NH3} + P_{H2}$. Low P_{NH3} leads to a low saturation temperature, enabling evaporation.

Electrolux System Circuit Schematic I



- Schematic shows the flow circuits of the three fluids: Ammonia, Water, and Hydrogen.

Electrolux System Circuit Schematic II

- Ammonia vapor moves from generator to condenser, and liquid ammonia flows under gravity to evaporator.
- Hydrogen gas circulates locally between the evaporator and absorber.
- Strong and weak solutions circulate between the generator and absorber.

The Thermo-Siphon Bubble Pump I

The bubble pump is the engine of the Electrolux system, lifting liquid strong solution from the low-level absorber to the high-level generator without moving parts.

- Consists of a narrow vertical tube heated at the bottom.
- Heat causes ammonia to vaporize and form bubbles within the strong solution.
- As bubbles rise and expand in the narrow tube, they push liquid slugs upward.
- Achieves fluid circulation solely through thermal energy and buoyancy.

Condenser and Evaporator Dynamics I

These components facilitate heat rejection and heat absorption to achieve the cooling effect.

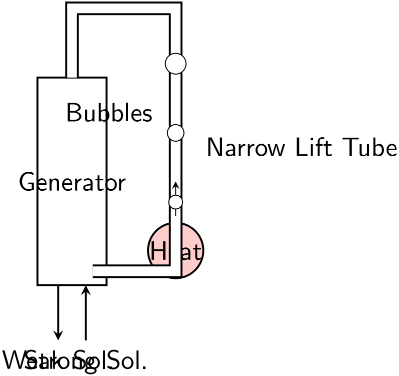
- Condenser: Air-cooled coil where high-pressure ammonia vapor condenses to liquid.
- Evaporator: Liquid ammonia meets hydrogen gas, reducing ammonia's partial pressure.
- The drop in partial pressure causes ammonia to evaporate at a low temperature, absorbing heat.
- A heavy mixture of ammonia and hydrogen sinks down towards the absorber.

Absorber and Liquid Heat Exchanger I

The absorber recovers ammonia from the gas mixture, while the heat exchanger optimizes system efficiency.

- Absorber: Weak solution from the generator absorbs ammonia from the sinking gas mixture.
- Hydrogen, being insoluble and light, rises back up to the evaporator.
- Strong solution forms at the bottom and flows back to the bubble pump.
- Liquid Heat Exchanger: Preheats cold strong solution using heat from hot weak solution.

Thermosiphon (Bubble Pump) Principle I



- Detail of bubble pump rising flow showing gas bubbles pushing liquid slugs.

Thermosiphon (Bubble Pump) Principle II

- The tube diameter must be narrow enough to prevent bubbles from bypassing the liquid.
- A continuous heat input at the base maintains the siphon pumping action.
- Fluid level differences between absorber and generator are balanced by this pump.

Key Engineering Advantages I

The Electrolux system possesses characteristics that make it uniquely suited for domestic and remote applications.

- No moving parts: Completely silent operation (no compressor or mechanical pump vibration).
- High durability: Absence of wear and tear results in an extremely long operational life.
- Fuel versatility: Can be powered by electric heaters, gas burners, kerosene, or solar energy.
- No pressure control valves or safety cut-outs needed due to uniform operating pressure.

Limitations and Applications I

Despite its advantages, thermodynamic constraints limit the system's widespread industrial use.

- Low Coefficient of Performance (COP): Typically ranges from 0.15 to 0.30.
- Highly sensitive to orientation: Must be kept perfectly level for gravity-driven flow.
- Difficult to control capacity: Thermal inertia makes rapid cooling adjustments slow.
- Applications: Domestic refrigerators, hotel room mini-bars, recreational vehicles (RVs).

Title Slide I

Course: Refrigeration and AC

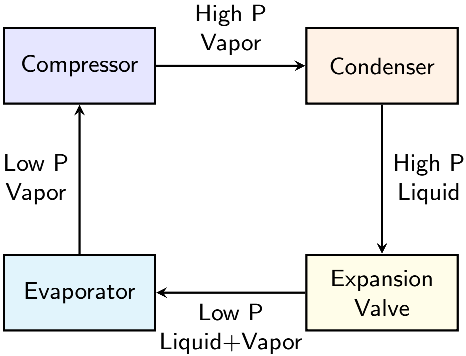
- Unit: Vapor Refrigeration Systems
- Lecture 14: 2.7 Comparison of Vapor absorption and vapor compression system.
- A detailed comparative analysis of work-operated and heat-operated refrigeration systems.

Vapor Compression Refrigeration System (VCRS) I

VCRS is a work-operated cycle utilizing mechanical/electrical work as primary energy to achieve refrigeration.

- Major components: Compressor, Condenser, Expansion Device, and Evaporator.
- Driven by high-grade mechanical/electrical energy input to the compressor (W_in).
- High Coefficient of Performance (COP) typically in the range of 3.0 to 5.0.
- Compact footprint, quick response to cooling load changes, but high maintenance due to moving parts.

Vapor Compression Cycle Diagram I



- Schematic of the standard VCRS loop.
- Compressor increases the pressure and temperature of refrigerant vapor.

Vapor Compression Cycle Diagram II

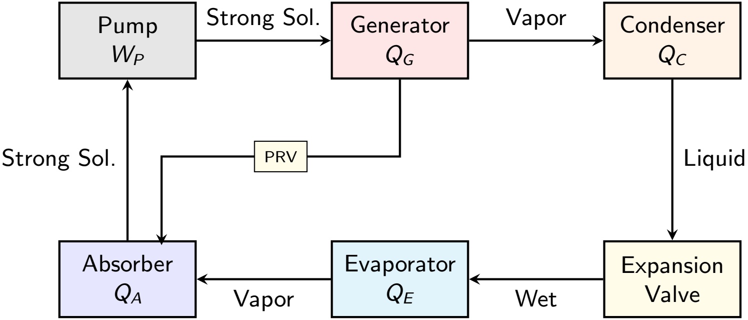
- Condenser rejects heat (Q_out) at high pressure, changing vapor to liquid.
- Expansion device drops pressure via a throttling process.
- Evaporator absorbs heat (Q_in) from the refrigerated space at low pressure.

Vapor Absorption Refrigeration System (VARS) I

VARS is a heat-operated cycle where the compressor is replaced by a chemical/thermal absorption and generation unit.

- Key components: Absorber, Pump, Generator, Condenser, Expansion Valve, and Evaporator.
- Driven by low-grade thermal energy input (Q_G) and small liquid pump work (W_P).
- Lower Coefficient of Performance (COP) typically in the range of 0.4 to 1.2.
- Utilizes waste heat, steam, or solar thermal energy, making it highly eco-friendly.

Vapor Absorption Cycle Diagram I



- Schematic of the standard VARS loop.
- Absorber absorbs low-pressure refrigerant vapor into weak solution, releasing heat.
- Pump raises the pressure of strong solution to generator pressure with minimal work.

Vapor Absorption Cycle Diagram II

- Generator separates refrigerant vapor from strong solution using external heat source.
- Pressure Reducing Valve (PRV) returns weak solution to the absorber.

Thermodynamic and Energy Input Comparison I

Analyzing exergy grades of input energy and their effects on system COP.

- VCRS is a work-operated cycle (electrical energy, high-grade exergy).
- VARS is a heat-operated cycle (thermal energy, low-grade exergy).
- Maximum VARS COP is the product of Carnot engine and Carnot refrigerator efficiencies: $COP_{max} = \frac{T_E}{T_C - T_E} \times \frac{T_G - T_O}{T_G}$.
- Since VARS utilizes low-grade heat, its COP is much lower (0.4 - 1.2) compared to VCRS (3 - 5).

Mechanical Complexity, Noise, and Maintenance I

Comparative evaluation of mechanical components and maintenance overhead.

- VCRS requires a high-speed compressor (reciprocating/rotary), resulting in high noise and vibration.
- VARS features a near-static design with only a small liquid pump as a moving part, ensuring silent operation.
- VCRS requires frequent lubrication, has higher wear and tear, and is prone to refrigerant leakage.
- VARS has minimal mechanical wear, offering higher reliability and longer system life.

Refrigerants and Environmental Profile I

Working fluids and their impact on global warming and ozone depletion.

- VCRS uses halogenated hydrocarbons (HFCs, HFOs) which can have high Global Warming Potential.
- VARS uses natural, environmentally benign refrigerants: Ammonia (NH_3) or Water (H_2O).
- Ammonia-Water (NH_3-H_2O) pair is suitable for sub-zero cooling, but Ammonia is toxic and corrosive to copper.
- Water-Lithium Bromide (H_2O-$LiBr$) is safe and non-toxic, but limited to temperatures above $0^\circ C$.

Operating Pressures and Part-Load Operation I

Operational pressure ranges and efficiency variations under fluctuating loads.

- VCRS operates at elevated pressures, requiring thick-walled piping and compression fittings.
- Water-LiBr VARS operates under deep vacuum (less than 10 mmHg), requiring airtight sealing.
- VCRS part-load efficiency drops significantly due to constant-speed compressor limitations.
- VARS handles load fluctuations efficiently by regulating solution flow rates or heat input.

Direct Comparison Matrix Summary I

Summary table of the core differences between VCRS and VARS.

- Type of Energy: VCRS uses mechanical/electrical work; VARS uses thermal energy.
- COP Value: VCRS is high (3 to 5); VARS is low (0.4 to 1.2).
- Moving Parts: VCRS has a compressor; VARS has a small liquid pump.
- Waste Heat: VCRS cannot utilize waste heat; VARS is designed specifically to utilize it.
- Capacity Limits: VCRS is limited by compressor frame size; VARS can scale up to very large capacities.

Title Slide I

Course: Refrigeration and AC (DI05019051) Lecture 15: 2.8 Simple numerical on vapor compression cycle.

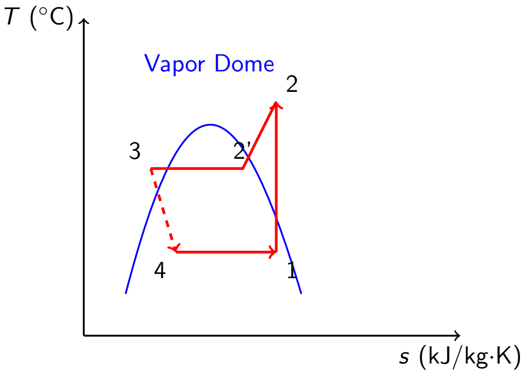
- Thermodynamic analysis of standard vapor compression refrigeration systems
- Understanding representation of cycles on T-s and p-h planes
- Step-by-step mathematical calculation of cycle performance parameters

Thermodynamic Processes of the Simple VCR Cycle I

A standard vapor compression refrigeration cycle consists of four basic processes carried out in series.

- Process 1-2: Isentropic compression of saturated vapor in the compressor ($s1 = s2$), raising the pressure to condenser level and superheating the refrigerant.
- Process 2-3: Constant pressure heat rejection in the condenser ($p2 = p3$). The refrigerant is desuperheated, condensed to saturated liquid, and optionally subcooled.
- Process 3-4: Isenthalpic expansion through a capillary tube or thermostatic expansion valve ($h3 = h4$), generating a low-pressure, low-temperature liquid-vapor mixture.
- Process 4-1: Constant pressure heat absorption in the evaporator ($p4 = p1$). The refrigerant absorbs the cooling load from the space and evaporates back to saturated vapor.

Temperature-Entropy (T-s) Diagram I

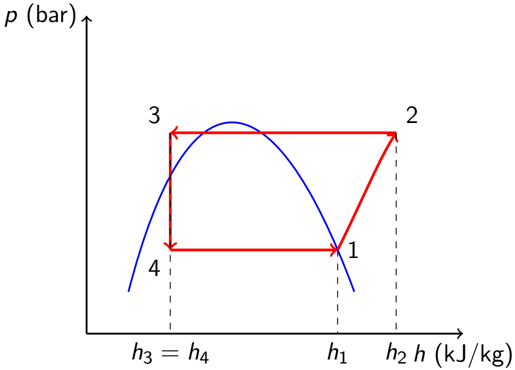


- Process 1-2 is shown as a vertical line, illustrating constant entropy during ideal compression.

Temperature-Entropy (T-s) Diagram II

- Constant pressure condensation (2-2'-3) shows a decrease in entropy and temperature during desuperheating, followed by isothermal phase change.
- Expansion 3-4 is shown as a dashed line sloping down and to the right, reflecting an increase in entropy due to process irreversibility.
- Evaporation 4-1 is a constant temperature horizontal line inside the vapor dome.

Pressure-Enthalpy (p-h) Diagram I



- Isentropic compression 1-2 slopes upwards to the right, showing simultaneous increases in pressure and enthalpy.

Pressure-Enthalpy (p-h) Diagram II

- Isobaric condensation 2-3 is depicted as a horizontal line at the condenser pressure level.
- Isenthalpic expansion 3-4 is represented as a vertical line, showing no change in enthalpy ($h3 = h4$).
- Isobaric evaporation 4-1 is a horizontal line at the evaporator pressure level.

Key Governing Equations I

Performance indicators are derived from energy balances across each component of the VCRS.

- Refrigerating Effect (RE): The amount of heat absorbed from the cold space per unit mass of refrigerant, calculated as RE = h1 - h4 = h1 - h3 (in kJ/kg).
- Compressor Work (Wc): The specific mechanical work input required by the compressor to compress the refrigerant, calculated as Wc = h2 - h1 (in kJ/kg).
- Coefficient of Performance (COP): The ratio of desired refrigeration effect to work input, given by COP = RE / Wc = (h1 - h3) / (h2 - h1) (dimensionless).
- Mass Flow Rate (m_dot): The rate of refrigerant circulation required to meet a given cooling load, calculated as m_dot = Capacity (kW) / RE (kJ/kg).

Key Governing Equations II

- Compressor Power: The total rate of work input to the compressor, calculated as Power = m_dot * Wc = m_dot * (h2 - h1) (in kW).

Numerical Problem Specification I

A simple vapor compression plant produces 5 tonnes of refrigeration using R-134a. The condensing temperature is 40°C and the evaporating temperature is -10°C. Saturated liquid leaves the condenser, and saturated vapor enters the compressor.

- Cooling Capacity: 5 TR (Tons of Refrigeration). Converting to SI units: 1 TR = 3.517 kW, hence Capacity = 5 * 3.517 = 17.585 kW.
- Operating Limits: Evaporator temperature (T_{evap}) = -10°C, Condenser temperature (T_{cond}) = 40°C.
- Evaporator Inlet/Outlet: Enthalpy of saturated vapor entering compressor at -10°C is h1 = 247.37 kJ/kg, entropy s1 = 0.9373 kJ/kg.K.
- Condenser Outlet: Saturated liquid leaving the condenser at 40°C has an enthalpy h3 = 108.39 kJ/kg.

Numerical Problem Specification II

- Compressor Outlet state is determined using isentropic relation $s2 = s1 = 0.9373$ kJ/kg.K, yielding a superheated vapor enthalpy $h2 = 282.11$ kJ/kg at condensing pressure.

Numerical Solution: State Points Evaluation I

Using properties of R-134a to identify enthalpy values at all state points of the cycle.

- State 1 (Compressor Inlet): Located on the saturated vapor line at T = -10°C. Reading thermodynamic tables for R-134a: h1 = 247.37 kJ/kg, s1 = 0.9373 kJ/kg.K.
- State 2 (Compressor Outlet): Superheated vapor at the condenser pressure. Since compression is isentropic, s2 = s1 = 0.9373 kJ/kg.K. From superheat tables, h2 = 282.11 kJ/kg.
- State 3 (Condenser Outlet): Saturated liquid at T = 40°C. From saturated liquid tables, enthalpy h3 = 108.39 kJ/kg.
- State 4 (Evaporator Inlet): Located in the liquid-vapor region. Since expansion is an adiabatic throttling process, enthalpy remains constant: h4 = h3 = 108.39 kJ/kg.

Numerical Solution: COP and Mass Flow Rate I

Apply the governing equations using the determined state enthalpies.

- Step 1: Calculate Refrigerating Effect: RE = h1 - h4 = 247.37 - 108.39 = 138.98 kJ/kg of refrigerant circulated.
- Step 2: Calculate Specific Compressor Work: Wc = h2 - h1 = 282.11 - 247.37 = 34.74 kJ/kg of refrigerant compressed.
- Step 3: Compute COP: COP = RE / Wc = 138.98 / 34.74 = 3.999 (rounded to 4.0), indicating the cycle yields 4 units of cooling per unit of work input.
- Step 4: Calculate Mass Flow Rate: m_dot = Capacity / RE = 17.585 kW / 138.98 kJ/kg = 0.1265 kg/s (approx. 7.59 kg/min).

Numerical Solution: Compressor Power and Condenser Duty I

Finalize system performance indicators by calculating total power and heat rejected.

- Compressor Power Input: Power = m_dot * Wc = 0.1265 kg/s * 34.74 kJ/kg = 4.394 kW. This is the theoretical power required to run the compressor.
- Heat Rejection in Condenser: Q_cond = m_dot * (h2 - h3) = 0.1265 kg/s * (282.11 - 108.39 kJ/kg) = 0.1265 * 173.72 = 21.976 kW.
- Energy Balance Verification: Total Heat Out (Q_cond) must equal Total Heat In (RE_capacity + Power_compressor). 17.585 kW + 4.394 kW = 21.979 kW (which matches Q_cond within rounding limits).

Numerical Solution: Compressor Power and Condenser Duty II

- Overall System COP: Calculated alternatively as COP = Cooling Capacity / Compressor Power = 17.585 kW / 4.394 kW = 4.002.

Engineering Analysis and Conclusions I

Understanding how operating temperatures affect performance in simple vapor compression cycles.

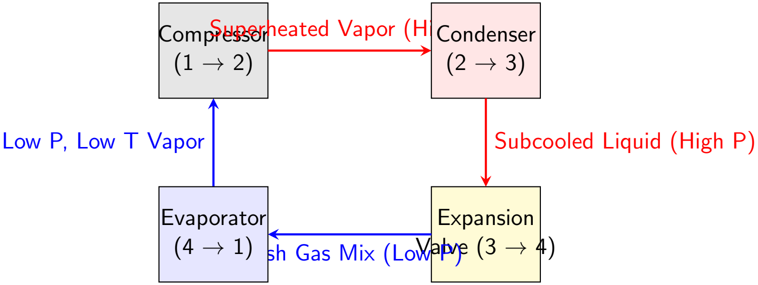
- Effect of Evaporating Temp: Lowering T_evap decreases density of suction vapor, reduces mass flow rate, increases compression ratio, and degrades overall COP.
- Effect of Condensing Temp: Raising T_cond increases work of compression, reduces refrigeration effect due to higher h3, and reduces COP.
- Importance of Liquid Subcooling: Subcooling shifts state 3 to the left, reducing h3 and increasing RE to h1 - h3', which directly improves system COP.
- Suction Superheating: Superheating in the evaporator or suction line ensures no liquid droplets enter the compressor cylinder, although it may slightly increase specific volume and work.

Title Slide I

Course: Refrigeration and AC

- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Vapour Compression Refrigeration System (VCRS) Layout I



- The four fundamental components of a VCRS are: Compressor, Condenser, Expansion Device, and Evaporator.
- Compressor elevates vapor pressure; Condenser rejects heat to ambient; Expansion Valve causes pressure drop; Evaporator absorbs heat from space.

Vapour Compression Refrigeration System (VCRS) Layout II

- Thermodynamic cycles are modeled on Pressure-Enthalpy (p-h) and Temperature-Entropy (T-s) coordinate systems.

Refrigeration Compressors: Classification I

Compressors are the heart of VCRS, driving the flow of refrigerant through the system.

- Classification by working principle: Positive Displacement (Reciprocating, Rotary, Scroll, Screw) and Dynamic (Centrifugal).
- Classification by hermeticity: Open type (separate motor), Semi-Hermetic (bolted casing), and Hermetically Sealed (welded casing, motor & compressor in one shell).
- Reciprocating compressors are ideal for high pressure ratio, low flow applications; Centrifugal compressors are used for very high volumetric flow at low pressure ratios.

Positive Displacement: Reciprocating vs Rotary I

Comparing the two most common compressor designs in domestic and commercial refrigeration.

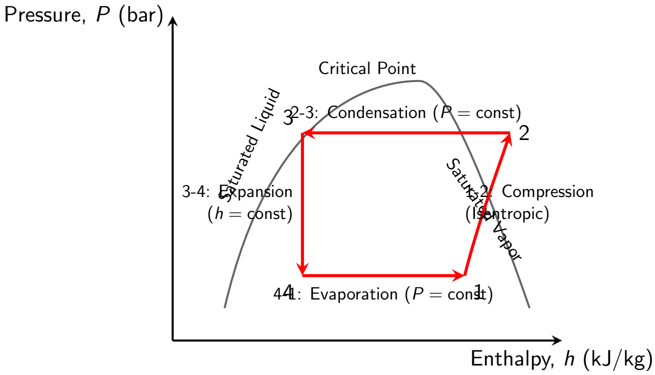
- Reciprocating Compressors: Advantages include high efficiency at high pressure ratios, ease of capacity control via cylinder unloading, and flexibility. Disadvantages include vibration/noise due to reciprocating mass, and presence of valves that reduce volumetric efficiency.
- Rotary Compressors (Rolling Piston/Vane): Advantages include fewer moving parts, compact size, low vibration, and continuous discharge. Disadvantages include high clearance pocket wear, susceptibility to liquid slugging, and lower pressure limits.

Advanced Compressors: Scroll & Screw I

Used widely in medium to large commercial systems and chillers.

- Scroll Compressors: Consist of one fixed scroll and one orbiting scroll. Advantages: Extremely quiet, high volumetric efficiency (nearly 100%), no clearance volume, minimal vibration. Disadvantage: Complex manufacturing tolerances.
- Screw Compressors (Twin-screw): Utilize mating helical rotors. Advantages: Excellent part-load performance via slide valve, handles liquid slugging well, high reliability. Disadvantages: High cost, requires complex oil separator/cooling system.

VCRS Pressure-Enthalpy (p-h) Diagram I



- Process 1-2: Isentropic compression of saturated vapor inside the compressor.

VCRS Pressure-Enthalpy (p-h) Diagram II

- Process 2-3: Isobaric heat rejection in the condenser, changing state from vapor to liquid.
- Process 3-4: Isenthalpic throttling/expansion, reducing pressure and forming a liquid-vapor mixture.
- Process 4-1: Isobaric and isothermal heat absorption in the evaporator.

Condensers: Classification and heat transfer I

Condensers reject the heat absorbed in the evaporator plus the heat of compression.

- Air-Cooled Condensers: Natural convection (low capacity, domestic) or forced convection (chillers). Advantages: simple, low maintenance. Disadvantages: high condensing temperatures, large footprint.
- Water-Cooled Condensers: Shell-and-tube, shell-and-coil, or double-pipe. Advantages: high heat transfer coefficient, compact. Disadvantages: scale formation, requires cooling towers and water treatment.
- Evaporative Condensers: Uses both air flow and water spray. Heat rejection is governed by latent heat of evaporation. Advantages: lowest condensing temperatures. Disadvantages: heavy maintenance, water consumption.

Expansion Devices: Capillary to Electronic I

Expansion devices reduce pressure and regulate refrigerant flow based on system demand.

- Fixed Orifice / Capillary Tube: Simple copper tube of small diameter. Advantages: no moving parts, low cost, allows pressure equalization during off-cycle. Disadvantage: non-regulating, inefficient at off-design conditions.
- Thermostatic Expansion Valve (TEV): Uses a sensing bulb to maintain constant superheat at evaporator outlet. Advantages: regulates flow dynamically, maximizes evaporator utilization. Disadvantage: complex mechanical parts.
- Electronic Expansion Valve (EEV): Controlled by stepper motors based on temperature and pressure sensors. Advantages: precise superheat control, high efficiency. Disadvantage: high cost, requires power.

Evaporators: Classification & Heat Absorption I

Evaporators facilitate heat transfer from the cooled space to the boiling refrigerant.

- Classification by flow arrangement: Dry Expansion (DX) - refrigerant expands completely into vapor; Flooded - evaporator is kept filled with liquid refrigerant with a surge drum.
- DX Evaporators: Simple oil return, low charge. But lower heat transfer coefficient due to dryout region near outlet.
- Flooded Evaporators: Excellent heat transfer coefficient since entire inner surface is wetted. But requires large refrigerant charge, oil return is complex, and needs a surge drum.
- Types by construction: Bare tube (liquid chilling), Plate-surface (freezers), Finned (air cooling), Shell-and-tube (water chillers).

System Integration and Optimization I

A well-designed VCRS requires precise capacity matching of all four components.

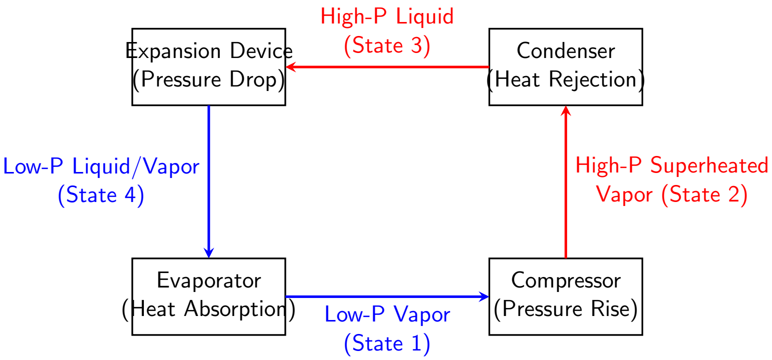
- Component Matching: The compressor displacement must match the mass flow rate dictated by the evaporator load and condenser capacity.
- Sizing Impact: Under-sizing the condenser increases discharge pressure, lowering COP and increasing compressor work.
- Thermodynamic Trade-offs: Proper choice of expansion device and superheat control prevents compressor liquid slugging while maximizing evaporator capacity.

Title Slide I

Course: Refrigeration and AC (DI05019051) Lecture 17: 3.1 Common Equipments of Vapor Compression Refrigeration System with Classification, Advantages, and Disadvantages

- Introduction to the core thermodynamic cycle and component layout.
- Detailed classification of Compressors, Condensers, Expansion Devices, and Evaporators.
- Engineering tradeoffs, working principles, and performance characteristics of each equipment.

Vapor Compression Refrigeration System Cycle Layout I



- Compressor raises pressure from Evaporator pressure to Condenser pressure (State 1 to 2).

Vapor Compression Refrigeration System Cycle Layout II

- Condenser rejects heat at high pressure, condensing vapor to liquid (State 2 to 3).
- Expansion device drops pressure, causing partial flashing (State 3 to 4).
- Evaporator absorbs heat at low pressure, vaporizing the liquid refrigerant (State 4 to 1).

Compressors: Classification & Working Principles I

Compressors are classified based on their mechanical design and mode of compression, catering to different pressure and volumetric flow requirements.

- Reciprocating Compressors: Piston-cylinder arrangement. Best for high pressure differences and low volume flow rates.
- Rotary Compressors: Employs a roller and blade or screw mechanism. Suitable for small to medium systems (window units).
- Scroll Compressors: Uses two interleaving scrolls (one fixed, one orbiting) to compress gas. Excellent for quiet, high-efficiency applications.
- Centrifugal Compressors: Uses dynamic impellers to convert kinetic energy into pressure. Best for high volume flow rates and low pressure ratios.

Compressors: Advantages & Disadvantages I

Choosing the correct compressor requires balancing mechanical reliability, efficiency, sound output, and system cost constraints.

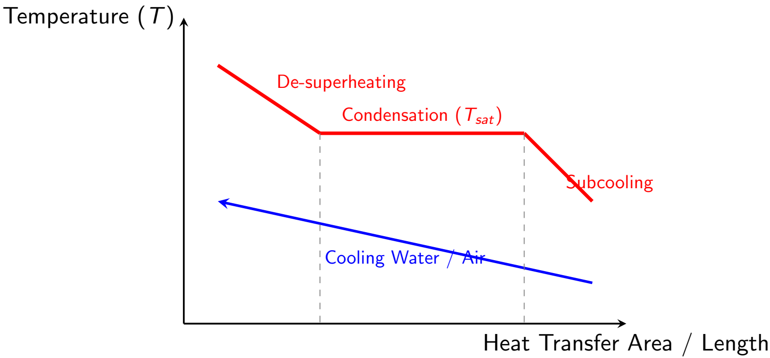
- Reciprocating: [Advantages] Highly flexible, cheap, handles high pressure. [Disadvantages] Pulsating flow, high vibration, wear on valves.
- Scroll: [Advantages] Fewer moving parts, continuous suction and discharge, silent. [Disadvantages] High manufacturing precision needed, non-repairable hermetic units.
- Centrifugal: [Advantages] High volumetric flow rate capacity, low maintenance, vibration-free. [Disadvantages] High initial cost, susceptible to surging at low loads.

Condensers: Thermal Classification I

Condensers reject both the cooling load and the work input of the compressor, using air, water, or a combination of both.

- Air-Cooled (Natural Convection): Wire-on-tube design. Maintenance-free, but low heat transfer capacity (domestic units).
- Air-Cooled (Forced Convection): Uses high-speed fans to blow air over copper tube-aluminum fin assemblies (split AC outdoor units).
- Water-Cooled (Shell and Tube): Highly efficient heat exchanger with water circulating inside tubes and refrigerant condensing in the shell.
- Evaporative Condensers: Water is sprayed over the condenser coil while air is blown, evaporating water to absorb heat directly.

Condenser Temperature Profile I



- De-superheating: High temperature vapor cools down to the saturation temperature corresponding to condenser pressure.
- Condensation: Latent heat rejection occurs at constant saturation temperature (T_{sat}), converting vapor to liquid.

Condenser Temperature Profile II

- Subcooling: Liquid refrigerant is cooled below its saturation temperature to prevent premature vapor flashing.
- Counterflow Cooling Medium: Optimizes the temperature difference across the heat exchanger for maximal effectiveness.

Condensers: Advantages & Disadvantages I

Condenser selection depends heavily on local environment, water availability, municipal regulations, and operating budgets.

- Air-Cooled: [Advantages] Simple, low installation cost, zero water consumption. [Disadvantages] High condensing pressure in summer, large surface area.
- Water-Cooled: [Advantages] High heat transfer rate, lower condensing pressure, improves overall system COP. [Disadvantages] High maintenance, scaling, water treatment cost.
- Evaporative: [Advantages] Lowest condensing temperature among all types, low water consumption. [Disadvantages] Legionella risk, scaling, requires continuous blowdown.

Expansion Devices: Classification & Flow Control I

Expansion devices drop refrigerant pressure from condenser to evaporator level and regulate flow rate to match evaporator load.

- Capillary Tube: Long constant-bore tube. Flow is governed by friction pressure drop. Simple, cheap, no moving parts.
- Thermostatic Expansion Valve (TXV): Adjusts orifice area via a diaphragm connected to a sensing bulb, maintaining constant superheat.
- Automatic Expansion Valve (AEV): Maintains constant evaporator pressure via spring balance against evaporator pressure.
- Electronic Expansion Valve (EEV): Stepper-motor operated valve driven by electronic controllers. Extremely precise and responsive.

Evaporators: Classification & Phase Change I

Evaporators transfer thermal energy from the cold space or fluid to the boiling, low-pressure liquid refrigerant.

- Dry Expansion (DX) Evaporator: Refrigerant vaporizes completely within the tubes, exiting with minor superheat (common in DX air handling units).
- Flooded Evaporator: Tubes are flooded with liquid refrigerant. Liquid level maintained by float valve. Highly efficient, used in large chillers.
- Bare Tube & Plate-Type: Simple coils or plates. Minimal air flow restriction, used for freezers and cooling of static products.
- Finned-Tube Evaporator: Employs external metal fins to increase the gas-side heat transfer area (standard in fan-coil and duct evaporators).

Evaporator & Expansion Valve Selection Trade-offs I

Correct matching of the expansion device and evaporator style determines the reliability and COP of the entire VCRS cycle.

- Capillary Tube + DX: Ideal for low-cost, constant-load domestic appliances. Permits system pressure equalization on shutdown.
- TXV + DX: Standard for variable loads. Protects compressor from liquid slugging by maintaining constant superheat at the evaporator outlet.
- Flooded Evaporator + Float Valve: High heat transfer coefficient (fully wetted surfaces), but requires larger refrigerant charge and oil recovery systems.

Title Slide I

Course: Refrigeration and AC

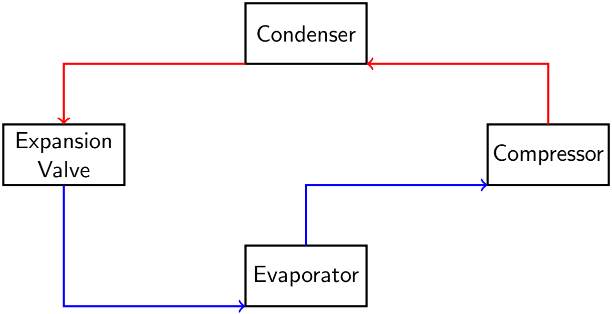
- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

VCRS Cycle Overview I

The vapor compression refrigeration cycle relies on four primary components to transfer heat from a cold reservoir to a hot reservoir.

- Compressor: Increases pressure and temperature of refrigerant vapor, driving the cycle.
- Condenser: Condenses the high-pressure vapor into liquid by rejecting heat to a cooling medium.
- Expansion Valve: Throttles the liquid refrigerant, dropping its pressure and temperature.
- Evaporator: Absorbs heat from the target space, vaporizing the low-pressure liquid-vapor mixture.

VCRS Schematic & Component Layout I



- Diagram illustrates the flow loop and physical arrangement of components.
- Connecting lines represent refrigerant piping: red for high-pressure side, blue for low-pressure side.
- Compressor and expansion valve separate the high-pressure and low-pressure sides of the system.

Compressors: Functional Classification I

Compressors are the heart of VCRS, elevating refrigerant vapor pressure. They are classified by compression mechanism and hermeticity.

- Positive Displacement: Compresses by trapping a gas volume and reducing it (e.g. Reciprocating, Rotary, Scroll, Screw).
- Dynamic / Centrifugal: Compresses by imparting kinetic energy to the gas using a high-speed impeller and converting it to static pressure.
- Open Compressors: Motor is external and coupled to the compressor shaft via belt/direct drive; prone to shaft seal leakage.
- Hermetic Compressors: Motor and compressor are welded in a single steel shell; leak-proof, but non-serviceable.

Compressors: Pros and Cons I

Analysis of compressor types shows distinct performance trade-offs for varying applications.

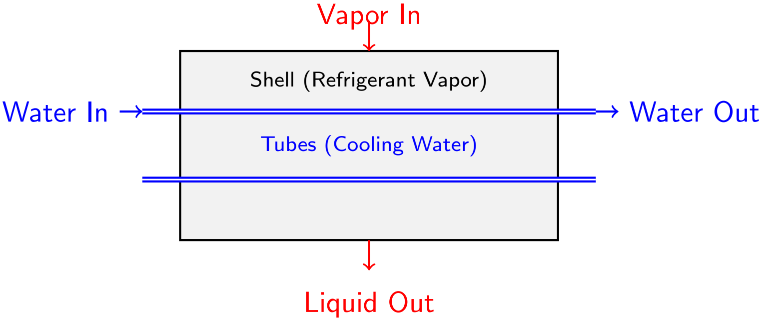
- Reciprocating: Advantages include high efficiency at high pressure ratios and flexibility; Disadvantages include vibration, noise, and valve wear.
- Centrifugal: Advantages include high volumetric flow, no vibration, and simple capacity control; Disadvantages include surge issues and unsuitability for small capacities.
- Scroll: Advantages include continuous compression (no valves), quiet operation, and minimal vibration; Disadvantages include low tolerance for liquid slugging and precision manufacturing needs.

Condensers: Classification & Operation I

Condensers reject heat absorbed in the evaporator and compressor to an external cooling medium.

- Air-Cooled: Classified into natural convection (domestic) and forced convection (commercial). Simple, low maintenance, but lower heat transfer.
- Water-Cooled: Classified into Tube-in-Tube, Shell-and-Coil, and Shell-and-Tube. High heat transfer coefficient, compact, but suffers from fouling.
- Evaporative Condensers: Uses both air and water spray, utilizing latent heat of water vaporization. High efficiency, but water intensive.

Water-Cooled Shell and Tube Condenser I



- Schematic of a single-pass shell and tube heat exchanger used as a condenser.
- Cooling water flows through the copper tubes to absorb latent heat.

Water-Cooled Shell and Tube Condenser II

- Refrigerant vapor enters from the top of the shell, condenses on tube surfaces, and collects at the bottom.

Expansion Devices: Types and Comparison I

Expansion devices reduce pressure to initiate vaporization and control refrigerant flow rate.

- Capillary Tube: Fixed restriction type. Advantages: Low cost, simple, allows pressure equalization during off-cycle. Disadvantages: Cannot adjust to load changes.
- Thermostatic Expansion Valve (TXV): Adjusts flow based on superheat. Advantages: High system efficiency, adjusts to load. Disadvantages: High cost, complex calibration.
- Electronic Expansion Valve (EEV): Microprocessor controlled. Advantages: Extremely fast and precise control over wide load ranges. Disadvantages: High cost, relies on electronics.

Evaporators: Classification & Performance I

Evaporators absorb heat from the cooling space or medium, converting liquid refrigerant to vapor.

- Direct Expansion (DX): Refrigerant vaporizes entirely inside the tubes. Low charge requirement, easy oil return, but lower overall heat transfer coefficient.
- Flooded: Shell is filled with liquid refrigerant, tubes carry secondary fluid. High heat transfer coefficient, but requires large refrigerant charge.
- Dry vs. Wet Expansion: DX is typically dry-expansion (exit is superheated), whereas flooded is wet-expansion (recirculating liquid).

Overall VCRS Performance & Limits I

A synthesis of VCRS advantages, disadvantages, and operating envelopes.

- Advantages: High Coefficient of Performance (COP), compact equipment footprint, and relatively low cost of major components.
- Disadvantages: Sensitivity to refrigerant leaks (environmental impact: GWP/ODP) and susceptibility to moisture and non-condensable contamination.
- Practical Limits: Compression ratios must be kept below 8-10 to prevent excessive discharge temperatures and volumetric efficiency loss.

Title Slide I

Course: Refrigeration and AC

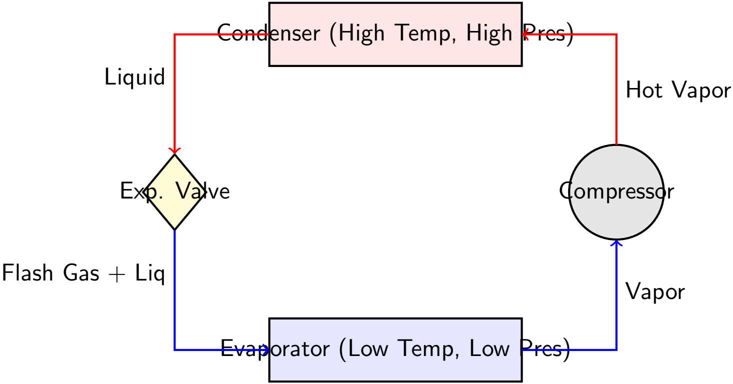
- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Overview of Vapor Compression Refrigeration System (VCRS) Equipments I

A standard Vapor Compression Refrigeration System (VCRS) relies on four primary components to execute its thermodynamic cycle. The compressor drives the system, the condenser rejects the heat, the expansion device regulates flow, and the evaporator absorbs heat from the target space.

- Compressor: Increases pressure and temperature of refrigerant vapor, driving cycle circulation.
- Condenser: Dissipates heat from high-pressure refrigerant to a cooling medium, causing phase change from gas to liquid.
- Expansion Device: Creates pressure drop, reducing liquid refrigerant pressure and regulating evaporator mass flow.
- Evaporator: Cools space by absorbing heat into low-pressure liquid refrigerant, vaporizing it.

Schematic of Vapor Compression Refrigeration System I



- Illustrates the closed-loop configuration of the basic refrigeration cycle.

Schematic of Vapor Compression Refrigeration System II

- Identifies the separation of high-pressure and low-pressure regions.
- Highlights the direction of flow and physical state transitions of the refrigerant.
- Enables engineers to visualize where work input occurs (compressor) and where heat transfer occurs (condenser, evaporator).

Compressors: Classification and Types I

Compressors are the mechanical heart of VCRS. They raise refrigerant vapor pressure to a level where its saturation temperature is higher than the cooling medium's temperature, facilitating heat rejection.

- Classification by Principle of Working: Positive Displacement (Reciprocating, Rotary, Scroll, Screw) vs. Dynamic (Centrifugal).
- Classification by Casing/Hermeticity: Open type, Semi-hermetic type, and Hermetic type.
- Positive Displacement: Compresses by reducing volume of a sealed chamber (e.g., piston movement in reciprocating).
- Dynamic Compressors: Compresses by transferring kinetic energy to the fluid (e.g., high-speed impeller in centrifugal).

Compressors: Advantages and Disadvantages I

Selecting a compressor requires evaluating factors like vibration, capacity, efficiency, maintenance, and noise level.

- Reciprocating: [Advantage] Simple design, high pressure ratio, economical; [Disadvantage] High vibration, noise, and wear due to reciprocating parts.
- Scroll/Rotary: [Advantage] Continuous compression, low noise, low vibration, high volumetric efficiency; [Disadvantage] Strict manufacturing tolerances, high repair cost.
- Centrifugal: [Advantage] Large capacity, high efficiency at full load, oil-free refrigerant circuit; [Disadvantage] Susceptible to surging, not suited for high pressure ratios.
- Screw: [Advantage] Excellent part-load performance, high reliability, handles liquid slugging better; [Disadvantage] High cost, complex oil separation system needed.

Condensers: Classification and Selection I

Condensers reject heat from high-pressure superheated vapor refrigerant to a cooling medium. The refrigerant undergoes desuperheating, condensation, and sometimes subcooling.

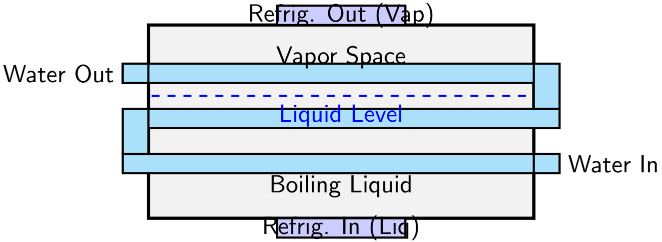
- Air-Cooled Condensers: Natural convection (domestic) or forced convection (industrial). Utilizes ambient air.
- Water-Cooled Condensers: Double pipe (tube-in-tube), Shell and coil, and Shell and tube. Utilizes water as the heat sink.
- Evaporative Condensers: Combines air flow and water spray to reject heat through latent heat of vaporization.
- Selection Criteria: Heat load, ambient dry-bulb and wet-bulb temperatures, availability of clean water, and space constraints.

Condensers: Advantages and Disadvantages I

Different condenser types trade operational costs against initial costs, water usage, and thermal efficiency.

- Air-Cooled: [Advantage] Easy installation, low maintenance, no water availability issues; [Disadvantage] Lower heat transfer rate, higher condensing pressure, lower COP in high ambients.
- Water-Cooled: [Advantage] High heat transfer coefficients, lower condensing temperature, higher system COP; [Disadvantage] Scaling/corrosion risks, requires cooling tower, pumps, and water treatment.
- Evaporative: [Advantage] Lower condensing temperatures than air-cooled, low power draw; [Disadvantage] High water consumption, scaling risk, intensive maintenance.

Evaporators: Schematic of a Flooded Shell and Tube Evaporator I



- Illustrates a flooded type evaporator layout.
- Refrigerant boils in the shell, submerging the water tubes.
- High heat transfer coefficient is maintained because tubes remain completely wetted.
- A separator is often needed to prevent liquid refrigerant droplets from carrying over to the compressor suction line.

Expansion Devices: Classification and Selection I

Expansion devices drop refrigerant pressure from high (condenser) to low (evaporator) and regulate the refrigerant mass flow rate matching the evaporative load.

- Capillary Tube: Fixed restriction device. [Advantage] Cheap, simple, allows system pressure equalization during off-cycles; [Disadvantage] Non-adjustable, inefficient at off-design loads.
- Thermostatic Expansion Valve (TXV): Employs a sensing bulb on the evaporator outlet. [Advantage] Regulates flow to maintain constant superheat, prevents liquid slugging; [Disadvantage] More expensive, complex moving parts.
- Electronic Expansion Valve (EEV): Employs electronic sensors and microprocessors. [Advantage] Extremely precise control, fast response, energy-efficient; [Disadvantage] High cost, depends on electrical power.

Expansion Devices: Classification and Selection II

- Float Valves: Low-side and high-side variants. Maintains constant liquid levels in flooded evaporators or condensers respectively.

Summary of Advantages, Disadvantages, and System Tradeoffs I

Optimizing a VCRS involves selecting matching components that balance initial system cost, energy efficiency (COP), maintenance requirements, and operational safety.

- System Cost vs. Efficiency: Cheap components (capillary tube, reciprocating compressor) reduce CAPEX but increase OPEX due to lower COP.
- Maintenance Tradeoffs: Water-cooled systems require continuous descaling and water chemical treatment, unlike simpler air-cooled setups.
- Safety and Control: Precision components like EEVs and TXVs protect the compressor from liquid carryover but add system complexity.

Summary of Advantages, Disadvantages, and System Tradeoffs II

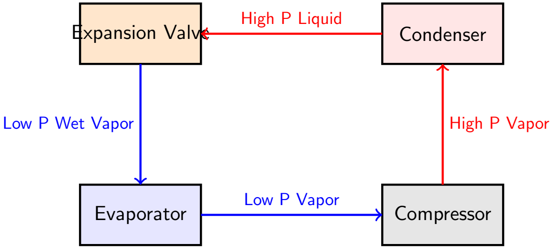
- Environmental Impact: Modern systems must balance component efficiency with eco-friendly refrigerant compatibility and low GWP options.

Title Slide I

Course: Refrigeration and AC

- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Vapor Compression Refrigeration Cycle (VCRS) Layout I



- The VCRS is the most widely used refrigeration cycle, utilizing the latent heat of vaporization of a refrigerant.
- Four primary stages: Compression (constant entropy assumed), Condensation (constant pressure heat rejection), Expansion (throttling/isenthalpic), Evaporation (constant pressure heat absorption).

Compressors: Functional Classification I

The compressor serves as the heart of the system, raising refrigerant pressure and driving circulation.

- Positive Displacement Compressors: Increase pressure by reducing volume (Reciprocating, Rotary Scroll, Screw, Vane).
- Dynamic Compressors: Increase pressure by continuous transfer of kinetic energy to velocity/pressure (Centrifugal).
- Casing Configurations: Hermetically sealed (leak-free, non-serviceable), Semi-hermetic (serviceable, bolted), Open (externally driven, prone to shaft seal leakage).

Compressor Selection: Pros & Cons I

Engineering trade-offs in compressor selection depend on load, efficiency, and maintenance capabilities.

- Reciprocating: High pressure ratio capability, simple controls, but high vibration and noise.
- Scroll: Quiet operation, fewer moving parts, high volumetric efficiency, but sensitive to liquid slugging.
- Centrifugal: Excellent for very large capacities (chillers), high efficiency at full load, but prone to surging at low loads.

Condensers: Thermal Classifications I

Condensers reject heat to external media to convert high-pressure superheated vapor into subcooled liquid.

- Air-Cooled: Natural draft (domestic refrigerators, silent but low capacity) and Forced draft (uses fans, higher heat transfer coefficient).
- Water-Cooled: Double tube (small units), Shell and coil (medium systems), Shell and tube (large industrial installations, high heat transfer).
- Evaporative: Uses water sprays and fan-induced air currents to utilize the latent heat of water evaporation, lowering condensing temperatures.

Condenser Selection: Pros & Cons I

Choosing a condenser involves balancing environmental constraints, water availability, and cost.

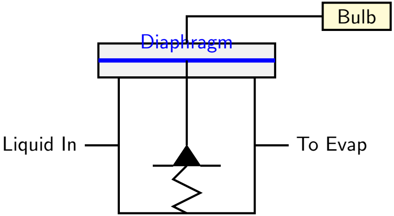
- Air-Cooled: Simple, zero water usage, low maintenance, but high condensing temperatures in summer reduce COP.
- Water-Cooled: High heat transfer coefficient, compact size, high COP, but prone to scaling/fouling and requires chemical water treatment.
- Evaporative: Highest COP in hot/dry climates due to wet-bulb temperature limits, but high water consumption and intensive maintenance requirements.

Expansion Devices: Throttling & Control I

Expansion devices regulate the flow of liquid refrigerant into the evaporator while dropping its pressure.

- Capillary Tube: Fixed restriction device. Constant cross-section copper tube. Low cost, simple, but cannot adapt to variable thermal loads.
- Thermostatic Expansion Valve (TEV): Modulates refrigerant flow to maintain a preset superheat at the evaporator outlet.
- Electronic Expansion Valve (EEV): Controlled by a stepper motor and microprocessor, providing fast, precise flow regulation for high energy efficiency.

Thermostatic Expansion Valve (TEV) Diagram I



- The TEV acts as a self-regulating proportional controller based on load feedback.
- Operating Forces: Bulb pressure (opening force) acts on top of diaphragm; evaporator pressure and spring force (closing forces) act underneath.
- By maintaining constant superheat, TEV prevents liquid refrigerant floodback to the compressor, protecting it from damage.

Evaporators: Classification & Heat Exchange I

Evaporators facilitate heat absorption from the space/medium to be cooled, vaporizing the refrigerant.

- Construction Types: Bare-tube (liquid cooling), Plate-surface (contact freezing), Finned-tube (air cooling, increases external surface area).
- Expansion Method: Dry Expansion (DX, refrigerant vaporizes completely by outlet, lower charge) and Flooded (evaporator filled with liquid refrigerant, very high heat transfer).
- Heat Transfer Media: Direct-expansion air coolers (direct cooling) vs. chillers/brine coolers (indirect cooling using secondary refrigerants).

Evaporator Pros & Cons & VCRS Coordination I

Designing high-efficiency refrigeration requires matching evaporator characteristics to the compressor.

- DX Evaporators: Simple oil return, low refrigerant charge, but lower heat transfer due to dry vapor zone near outlet.
- Flooded Evaporators: High heat transfer coefficient, uniform temp, but requires surge drums, large charge, and complex oil recovery.
- Coordination: Evaporator capacity must match compressor displacement and condenser heat rejection at target evaporating and condensing temperatures.

Title Slide I

Course: Refrigeration and AC

- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Overview of VCRS Components I

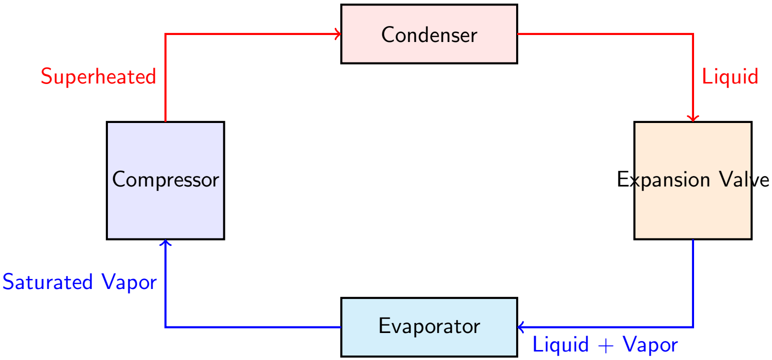
A Vapor Compression Refrigeration System (VCRS) utilizes a circulating liquid refrigerant as the medium which absorbs and rejects heat. The four primary components are the Compressor, Condenser, Expansion Device, and Evaporator, working in a closed loop to maintain refrigeration.

- Compressor: The heart of the system, it draws low-pressure, low-temperature vapor from the evaporator and compresses it to high-pressure, high-temperature vapor.
- Condenser: A heat exchanger that rejects heat from the refrigerant to a cooling medium (air or water), converting vapor into high-pressure liquid.
- Expansion Device: Reduces the refrigerant pressure to the evaporator level and controls the rate of flow, causing partial flash evaporation.

Overview of VCRS Components II

- Evaporator: The cooling unit where low-pressure liquid-vapor refrigerant absorbs heat from the surrounding space, vaporizing completely.

Thermodynamic Flow Schematic of VCRS I



- Diagram represents the thermodynamic flow loop of a standard VCRS cycle.
- High-pressure side: Compressor discharge line to the Expansion Valve inlet.

Thermodynamic Flow Schematic of VCRS II

- Low-pressure side: Expansion Valve outlet to the Compressor inlet.
- Phase changes: Condensation occurs in the condenser (vapor to liquid); evaporation occurs in the evaporator (liquid to vapor).

Compressors: Classification and Operating Principles I

Compressors are classified based on their working principle into Positive Displacement and Dynamic (Turbo) compressors. Positive displacement compressors trap a volume of vapor and reduce its volume to raise pressure, whereas dynamic compressors increase pressure by imparting kinetic energy to the vapor.

- Reciprocating Compressors: Use pistons and cylinders; common in small/medium systems (domestic refrigerators, window ACs). Suitable for high pressure ratios and low volume flows.
- Rotary Compressors: Use rolling pistons or rotating vanes; highly compact, low vibration, common in split ACs.
- Scroll Compressors: Use one fixed and one orbiting scroll; low noise, high efficiency, fewer moving parts, popular in residential/commercial ACs.

Compressors: Classification and Operating Principles II

- Screw Compressors: Use twin helical screws; excellent part-load efficiency, used in medium-to-large chillers.
- Centrifugal Compressors: Dynamic type using rotating impellers; best for very large capacities and high volume flows, but low pressure ratios.

Compressor Types: Comparison I

Choosing the correct compressor depends on system capacity, operating conditions, cost, and maintenance requirements. The table below outlines key trade-offs between major compressor categories.

- Reciprocating - Advantages: High pressure ratios, low initial cost, simple maintenance. Disadvantages: Noise, vibration, volumetric efficiency losses due to clearance volume, wear of valves/rings.
- Rotary & Scroll - Advantages: High volumetric efficiency (no valves/clearance volume), smooth operation, compact. Disadvantages: High manufacturing precision required, higher cost.
- Screw - Advantages: Continuous flow, variable capacity control, robust. Disadvantages: High cost, complex oil separation and cooling systems required.

Compressor Types: Comparison II

- Centrifugal - Advantages: Large capacity, no wear from friction, low maintenance, oil-free refrigerant circuits. Disadvantages: Susceptible to surging, poor part-load efficiency without vane control.

Condensers: Classification and Heat Transfer Mechanisms I

Condensers reject the heat absorbed in the evaporator and the work input of the compressor. They are classified into Air-Cooled, Water-Cooled, and Evaporative Condensers based on the cooling medium used.

- Air-Cooled Condensers: Heat is rejected directly to the air. Can be natural convection (domestic fridges) or forced convection (finned tubes with fans in split ACs).
- Water-Cooled Condensers: Heat is rejected to water. Types include Tube-in-Tube (double pipe), Shell-and-Coil, and Shell-and-Tube (most common in large plants).
- Evaporative Condensers: Combine air and water cooling. Water is sprayed over condenser coils while air is blown over them; cooling is achieved primarily by evaporation of water.

Condensers: Classification and Heat Transfer Mechanisms II

- Subcooling: A key function of the condenser is to cool the liquid refrigerant below its saturation temperature to increase the refrigeration effect.

Condenser Types: Comparison I

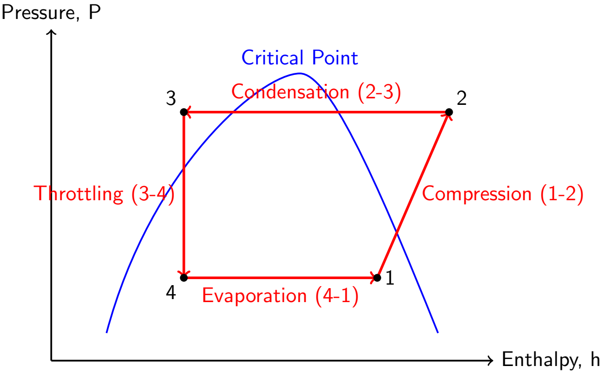
Condenser selection affects the condensing pressure (discharge pressure), which directly impacts the compressor work and overall Coefficient of Performance (COP).

- Air-Cooled - Advantages: Simple design, low maintenance, no water piping, zero water consumption. Disadvantages: Higher condensing temperatures (reduces COP), noisy fans, high ambient air dependency.
- Water-Cooled - Advantages: Low condensing temperatures due to lower wet-bulb/dry-bulb temperatures of water, high heat transfer coefficient, higher COP. Disadvantages: Water scale formation, fouling, cooling tower maintenance, high water consumption.

Condenser Types: Comparison II

- Evaporative - Advantages: Lower condensing temperatures than air-cooled, uses less water than water-cooled systems. Disadvantages: Scale buildup on coils, water treatment required, high maintenance.

VCRS Pressure-Enthalpy (P-h) Diagram I



- State 1 to 2: Isentropic compression where work ($W_c = h_2 - h_1$) is added to the system.

VCRS Pressure-Enthalpy (P-h) Diagram II

- State 2 to 3: Isobaric heat rejection ($Q_{out} = h_2 - h_3$) in the condenser, desuperheating and condensing the refrigerant.
- State 3 to 4: Isenthalpic throttling ($h_3 = h_4$) in the expansion device, reducing pressure and generating flash gas.
- State 4 to 1: Isobaric heat absorption ($Q_{in} = h_1 - h_4$) in the evaporator, representing the refrigeration effect.

Expansion Devices: Types and Operation I

Expansion devices reduce refrigerant pressure from condensing to evaporating pressure, regulating flow to match evaporator load. They can be fixed opening or variable opening (metering) devices.

- Capillary Tube: Simple copper tube of small diameter and long length. Advantages: Low cost, zero moving parts, allows pressure equalization during off-cycle. Disadvantages: Cannot adjust to load variations, risk of clogging.
- Thermostatic Expansion Valve (TEV): Uses a sensing bulb to monitor evaporator outlet superheat. Advantages: High efficiency, adapts to load variations, prevents liquid floodback. Disadvantages: High cost, complex mechanism.
- Automatic Expansion Valve (AEV): Maintains constant pressure in the evaporator. Advantages: Simple, compact. Disadvantages: Poor response to load changes, not suitable for variable loads.

Expansion Devices: Types and Operation II

- Electronic Expansion Valve (EEV): Controlled by a stepper motor and microprocessor. Advantages: Extremely precise, fast response, maximizes COP. Disadvantages: Highly expensive, requires electrical power.

Evaporators: Classification and Performance I

Evaporators facilitate heat transfer from the space or substance to be cooled to the refrigerant. They are classified by feed type (Flooded vs. Dry Expansion) and by construction (Bare Tube, Plate, Finned, or Shell-and-Tube).

- Dry Expansion (DX) Evaporators: Refrigerant feeds from the bottom and exits fully superheated. Advantages: Low refrigerant charge, simple oil return. Disadvantages: Lower heat transfer coefficient than flooded type.
- Flooded Evaporators: Evaporator is mostly filled with liquid refrigerant, ensuring high boiling heat transfer. Advantages: Maximum heat transfer rates, higher COP. Disadvantages: Large refrigerant charge, complex oil return.

Evaporators: Classification and Performance II

- Finned Evaporators: Bare tubes equipped with metal fins. Advantages: Greatly increases air-side heat transfer area, ideal for air-cooling. Disadvantages: Ice accumulation requires defrosting, difficult to clean.
- Shell-and-Tube Evaporators: Used for liquid chilling. Advantages: Highly compact, handles high heat loads. Disadvantages: Risk of freezing damage if water flow stops.

Course: Refrigeration and AC

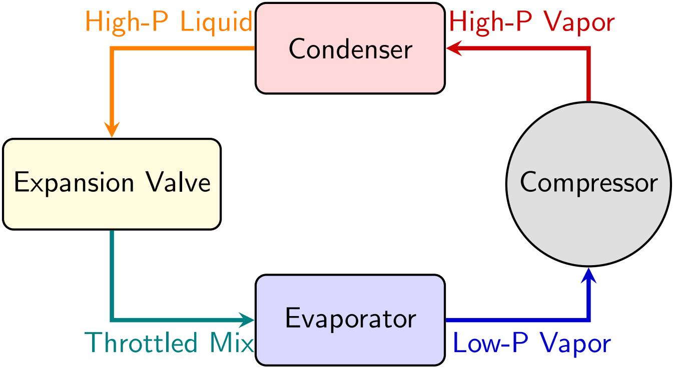
- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Introduction to VCRS Components I

Vapor Compression Refrigeration Systems (VCRS) require four primary components to complete a thermodynamic cycle: compressor, condenser, expansion device, and evaporator.

- The compressor increases refrigerant pressure and temperature, acting as the driving force of the system.
- The condenser rejects heat to the environment, converting high-pressure vapor back into a high-pressure liquid.
- The expansion device drops the pressure, causing partial flashing and preparing the liquid for heat absorption.
- The evaporator absorbs heat from the space to be cooled, vaporizing the low-pressure liquid refrigerant.

VCRS Schematic and Cycle Layout I



- Thermodynamic closed loop showing the flow paths connecting the high-pressure side and the low-pressure side.
- State of refrigerant: Superheated vapor enters the condenser; subcooled or saturated liquid enters the expansion device.

VCRS Schematic and Cycle Layout II

- Throttling process: Isenthalpic expansion produces a low-temperature, low-pressure liquid-vapor mixture.
- Compression process: Isentropic compression raises the refrigerant temperature above the condenser cooling medium temperature.

Compressors: Functional Classification I

Compressors are classified by their working mechanism (positive displacement vs. dynamic) and their hermetic sealing methods.

- Positive Displacement: Reciprocating (piston-cylinder), Rotary (rolling piston/vane), Scroll (orbiting scrolls), and Screw (intermeshing rotors).
- Dynamic/Kinematic: Centrifugal compressors increase pressure by converting kinetic energy (velocity) into static pressure via a diffuser.
- Hermetic Compressors: Motor and compressor are sealed in a single welded casing, eliminating shaft seal leaks but preventing field repairs.
- Open Compressors: Compressor and motor are separate, connected by a belt or coupling, suitable for large systems using ammonia (R-717).

Compressors: Advantages & Disadvantages I

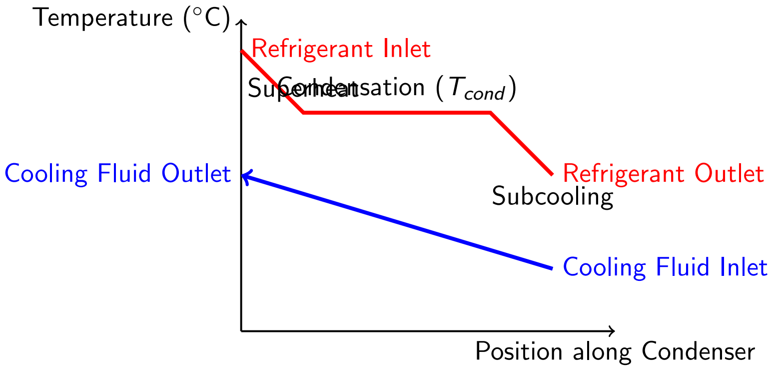
Selecting a compressor type depends on the required refrigeration capacity, pressure ratio, efficiency, cost, and reliability constraints.

- Reciprocating: High pressure ratios and efficiency, but high vibration, noise, and losses due to clearance volume and valves.
- Rotary & Scroll: Low vibration, fewer moving parts, continuous flow, but scroll requires high manufacturing precision to limit leakage.
- Centrifugal: Excellent for high volumetric flow rates and large capacities, but prone to 'surging' at low loads and low pressure ratios.
- Screw: Handles liquid slugging well, high reliability, but requires complex oil injection and separation systems for cooling and sealing.

Condensers: Heat Rejection and Classifications I

Condensers reject the total heat load ($Q_{cond} = Q_{evap} + W_{comp}$) and are classified by their cooling medium: air, water, or evaporative.

- Air-Cooled: Natural convection (low capacity, e.g., domestic refrigerators) or forced convection (fans, higher capacity).
- Water-Cooled: Double-tube, shell-and-coil, and shell-and-tube designs. Typically used in high-capacity systems due to high heat transfer coefficients.
- Evaporative Condensers: Use latent heat of vaporization of water sprayed over coils, achieving lower condensing temperatures than dry air-cooled.
- Fouling Factor: Scale formation in water-cooled tubes acts as an insulator, increasing thermal resistance, condensing pressure, and compressor work.



- Desuperheating: Sensible heat rejection cools superheated vapor from compressor discharge to saturated vapor state.

Condenser Temperature Profile II

- Condensation: Latent heat rejection converts saturated vapor to saturated liquid at constant pressure and temperature.
- Subcooling: Sensible heat rejection cools the saturated liquid further, reducing flashing during expansion and increasing refrigeration effect.
- Counter-Flow Arrangement: Fluid temperatures flow in opposite directions, maintaining a more uniform temperature difference and higher efficacy.

Expansion Devices: Working Principles & Types I

Expansion devices drop the pressure of the liquid refrigerant from condenser to evaporator level and regulate flow rate to match cooling loads.

- Capillary Tube: A long, narrow-bore copper tube. Simple, cheap, no moving parts, but cannot adjust flow rate to variable load demands.
- Thermostatic Expansion Valve (TEV/TXV): Uses a sensing bulb at the evaporator outlet to control flow and maintain constant superheat.
- Automatic Expansion Valve (AEV): Regulates flow to maintain a constant evaporator pressure. Unsuitable for variable load systems.
- Electronic Expansion Valve (EEV): Uses a stepper motor controlled by a microprocessor. Provides extremely precise control under wide load fluctuations.

Evaporators: Classification & Heat Transfer I

Evaporators absorb heat from the space or fluid being cooled. They are classified by construction and design parameters.

- Bare Tube Evaporators: Copper or steel coils. Used in liquid chilling or low-velocity air applications with minimal frost concerns.
- Plate Evaporators: Coils are bonded or embossed onto metal plates, maximizing contact area. Common in domestic freezers.
- Finned Evaporators: Coils are fitted with external metal plates/fins to increase surface area, compensating for low air-side heat transfer coefficient.
- Shell and Tube Evaporators: Used in larger liquid chillers. High heat transfer surface area, requiring robust design to prevent freezing.

Evaporator Feed Methods: DX vs. Flooded I

Refrigerant feed methods in evaporators determine heat transfer efficiency, refrigerant charge quantity, and system complexity.

- Dry Expansion (DX): Refrigerant leaves the evaporator completely vaporized and slightly superheated. Low refrigerant charge, simple oil return.
- Flooded Evaporator: The heat transfer surfaces are fully wetted with liquid refrigerant, while a surge drum separates and returns vapor to the compressor.
- Flooded Advantages: Higher overall heat transfer coefficient compared to DX, since the inner tube surface is always in contact with boiling liquid.
- Flooded Disadvantages: Requires a large refrigerant charge, an active oil management/rectification system, and has higher capital costs.

Title Slide I

Course: Refrigeration and AC

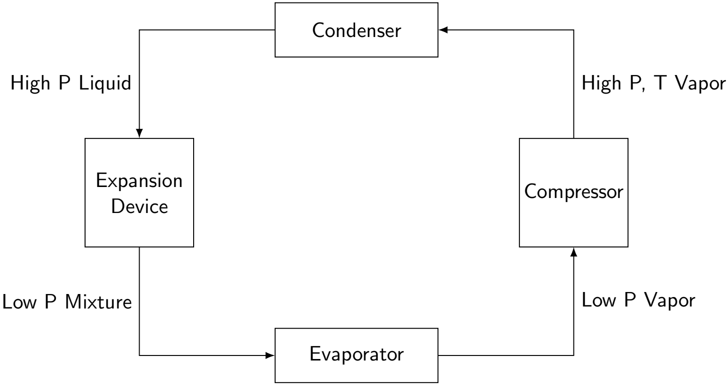
- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Overview of VCRS Components I

A Vapor Compression Refrigeration System (VCRS) relies on four primary components to complete the thermodynamic cycle: Compressor, Condenser, Expansion Device, and Evaporator. Auxiliary equipments like accumulators, receivers, and filters are also used to enhance performance and protect the components.

- Compressor: Increases pressure and temperature of refrigerant vapor, driving the flow.
- Condenser: Rejects heat from the high-pressure refrigerant to a cooling medium (air/water).
- Expansion Device: Throttles high-pressure liquid to low-pressure wet vapor (isenthalpic process).
- Evaporator: Absorbs heat from the space to be cooled, vaporizing the low-pressure refrigerant.

Vapour Compression Refrigeration Cycle Schematic I



- The diagram represents the standard closed-loop vapor compression cycle.
- State 1 to 2: Isentropic compression in the Compressor.

Vapour Compression Refrigeration Cycle Schematic II

- State 2 to 3: Constant pressure heat rejection in the Condenser.
- State 3 to 4: Isenthalpic expansion in the Throttling Valve.
- State 4 to 1: Constant pressure heat absorption in the Evaporator.

Refrigeration Compressors I

Compressors are the heart of VCRS. They raise the pressure of the refrigerant vapor so it can condense at a higher temperature. Main classifications include Reciprocating, Rotary, Centrifugal, and Screw compressors.

- Reciprocating: Uses piston-cylinder mechanism. High pressure ratio, high efficiency at low volumes, but noisy and has high vibration.
- Rotary (Rolling Piston/Vane): Quiet, fewer moving parts, compact. Limited to small capacities (domestic refrigerators).
- Centrifugal: Uses dynamic impellers. Excellent for large capacities and variable loads, but prone to surging at low loads.
- Screw: Helical rotors mesh to compress. High efficiency, continuous flow, handles liquid slugging well, but expensive.

Condensers: Classifications & Working I

Condensers reject the heat absorbed by the refrigerant in the evaporator and the work added in the compressor. They classify into Air-Cooled, Water-Cooled, and Evaporative Condensers.

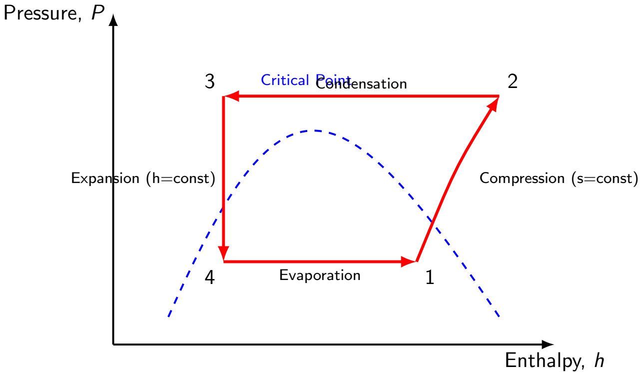
- Natural Convection Air-Cooled: Low heat transfer coefficient, used in domestic fridges, zero maintenance.
- Forced Convection Air-Cooled: Uses fans to increase air velocity, common in split ACs, compact design.
- Water-Cooled (Shell & Tube / Tube-in-Tube): High heat transfer rates, ideal for large industrial plants, requires cooling towers.
- Evaporative: Combines air and water cooling. Water is sprayed over coils while air is blown, highly energy-efficient but prone to scaling.

Condenser Selection & Trade-offs I

Selecting the right condenser depends on capacity, water availability, maintenance resources, and ambient conditions. Each type has distinct operational pros and cons.

- Air-Cooled Pros: Simple construction, no water piping, no scaling or corrosion issues, easy installation.
- Air-Cooled Cons: Lower heat transfer rate, high condensing temperature in summer leads to lower COP.
- Water-Cooled Pros: Very high heat transfer coefficient, lower condensing temperature, high cycle efficiency.
- Water-Cooled Cons: High initial cost, water treatment required to prevent scaling/fouling, needs continuous water supply.

Pressure-Enthalpy (P-h) Diagram of VCRS I



- Process 1-2: Non-isentropic compression increases enthalpy and pressure.

Pressure-Enthalpy (P-h) Diagram of VCRS II

- Process 2-3: Desuperheating and condensation at constant high-side pressure.
- Process 3-4: Throttling expansion at constant enthalpy, reducing pressure and temperature.
- Process 4-1: Evaporative heat absorption at constant low-side pressure.

Expansion Devices: Capillary & TXV I

Expansion devices drop the refrigerant pressure from condenser to evaporator level and regulate flow. Common types include Capillary Tubes and Thermostatic Expansion Valves (TXV).

- Capillary Tube: Simple, fixed length and diameter tube. No moving parts, cheap, allows pressure equalization during off-cycle (reduces starting torque of compressor).
- Capillary Tube Drawbacks: Cannot adapt to varying loads, risk of clogging, requires precise refrigerant charge.
- TXV: Modulates refrigerant flow based on evaporator load by sensing superheat at evaporator outlet.
- TXV Drawbacks: Expensive, complex mechanism, risk of hunting (unstable modulation) if improperly sized.

Evaporators: Types & Heat Transfer I

Evaporators absorb heat from the space or fluid being cooled, vaporizing the liquid refrigerant. They are classified by construction (Bare Tube, Finned, Plate) and feed method (Flooded vs. Dry Expansion).

- Bare Tube: Simple copper or steel coils. Used in liquid cooling or low-velocity air cooling where frost accumulation is expected.
- Finned Evaporator: Fins added to external surface to increase heat transfer area. Widely used in air conditioning units.
- Plate Evaporator: Plates welded together with channels for refrigerant flow. Highly compact, efficient, used in domestic freezers.
- Flooded Evaporator: Evaporator is filled with liquid refrigerant, maximizing heat transfer. Requires accumulator to prevent liquid slugging.

Evaporator Selection & Lecture Summary I

The selection of evaporator depends on the medium to be cooled (air, water, or solids) and temperature requirements. To optimize COP, the entire system's equipment must be matched.

- Dry Expansion (DX) Evaporators: Simple, oil return is easy because refrigerant vapor velocity is high, but lower heat transfer efficiency compared to flooded.
- Flooded Evaporators: High heat transfer coefficient, but requires large refrigerant charge and oil separators.
- Matching Components: A VCRS system's performance depends on balancing compressor capacity, condenser heat rejection, expansion valve flow, and evaporator absorption.
- Lecture Summary: We analyzed classifications, operational principles, advantages, and limitations of all key VCRS components.

Title Slide I

Course: Refrigeration and AC

- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Classification of Refrigerants I

Refrigerants are chemical working fluids used in a refrigeration cycle to absorb heat from a low-temperature source and reject it at a high-temperature sink.

- Primary Refrigerants: Fluids that undergo phase change to produce refrigeration (e.g., Halocarbons, Hydrocarbons, Inorganic compounds).
- Secondary Refrigerants: Fluids that transport thermal energy without phase change (e.g., Water, Brines, Glycols).
- Halocarbon Compounds: Synthesized from hydrocarbons (methane, ethane) by replacing hydrogen with chlorine, fluorine, or bromine.
- Azeotropes (500 series) and Zeotropes (400 series): Mixtures of refrigerants with constant or variable boiling points respectively.

Thermodynamic Property Requirements I

Thermodynamic performance dictates the efficiency, operating pressures, and sizing of system components.

- High Latent Heat of Vaporization: Minimizes mass flow rate required per unit cooling capacity, reducing compressor size.
- Suction Pressure: Must be above atmospheric pressure to prevent air and moisture infiltration into the low-pressure side.
- Discharge Pressure: Moderate pressures prevent heavy mechanical construction requirements for the compressor and condenser.
- Low Compression Ratio: Lowers power consumption and maintains high volumetric efficiency.
- Critical Temperature: Must be well above the condensing temperature to enable efficient heat rejection in the subcritical regime.

Chemical and Physical Properties I

Safety, longevity, and cost depend on the chemical stability and physical attributes of the refrigerant.

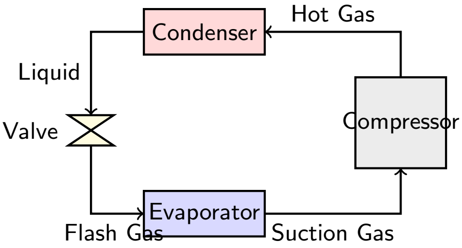
- Chemical Stability: Must not decompose or react with compressor materials, sealing materials, or lubricants under high temperatures.
- Flammability and Toxicity: Rated by ASHRAE Standard 34 (A1, A2L, A3, B1, B2L, B3). Class A1 is non-toxic and non-flammable.
- Thermal Conductivity: High conductivity improves heat transfer coefficients in the evaporator and condenser.
- Viscosity: Low liquid and vapor viscosity reduces friction pressure drops in piping and heat exchangers.

Environmental Impacts: ODP and GWP I

Modern refrigerant selection is heavily constrained by environmental protocols (Montreal Protocol, Kigali Amendment).

- Ozone Depletion Potential (ODP): Measure of chlorine/bromine concentration's relative impact on stratospheric ozone (R-11 = 1.0).
- Global Warming Potential (GWP): Measure of greenhouse warming potential relative to carbon dioxide ($CO_2 = 1.0$).
- CFCs (e.g., R-12): High ODP and GWP, phased out completely.
- HCFCs (e.g., R-22): Low ODP but high GWP, undergoing phase-out.
- HFCs (e.g., R-134a): Zero ODP but high GWP, currently being phased down.
- Natural Refrigerants: CO_2 (R-744), NH_3 (R-717), and HCs (R-290, R-600a) with zero ODP and negligible GWP.

Vapor Compression Cycle Diagram I



- Refrigerant flows through the four primary components, carrying lubricant throughout the loop.
- Compressor discharge line carries vapor and entrained oil droplets to the condenser.
- Evaporator must be designed to ensure sufficient velocity for oil return to the compressor suction.

Role of Lubricants I

Lubricating oil is essential for reducing friction, sealing clearance volumes, and cooling moving parts in refrigeration compressors.

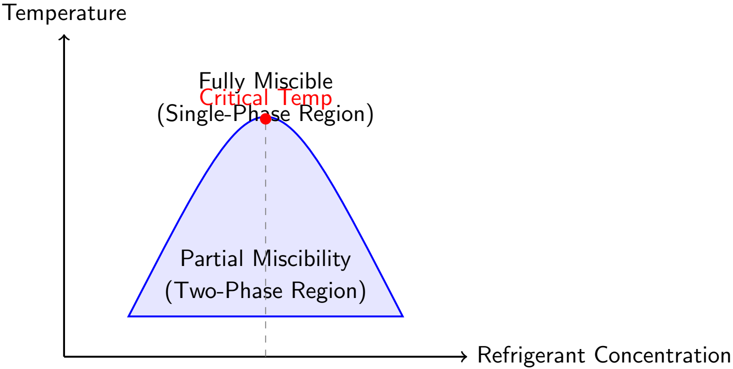
- Friction Reduction: Minimizes wear on bearings, pistons, cylinder walls, and shafts.
- Sealing: Fills micro-clearances between moving parts (e.g., screw rotors, piston rings) to prevent refrigerant blow-by.
- Heat Dissipation: Carries heat away from hot friction surfaces to the compressor sump or cooling jacket.
- Damping: Reduces acoustic noise and vibration during compressor operation.

Lubricant Requirements and Selection Criteria I

Compressor lubricants must withstand extreme temperature ranges and chemical exposure without degrading.

- Viscosity: Must maintain adequate viscosity at high discharge temperatures to prevent wear, and low viscosity at low temperatures to flow.
- Pour Point and Floc Point: Pour point must be low enough to prevent wax solidification in the evaporator. Floc point is the temperature at which wax precipitates from the oil-refrigerant mixture.
- Dielectric Strength: Essential for hermetic and semi-hermetic compressors where motor windings are exposed to oil and refrigerant.
- Chemical Stability: Must resist chemical reactions with the refrigerant, metal piping, and system contaminants.

Refrigerant-Lubricant Miscibility Dome I



- Miscibility determines whether oil and refrigerant form a single phase or separate.

Refrigerant-Lubricant Miscibility Dome II

- Under the dome, the mixture splits into a refrigerant-rich phase and an oil-rich phase.
- High miscibility is critical in the evaporator to prevent oil accumulation on heat transfer surfaces.

Compatibility and Retrofitting I

Retrofitting systems to eco-friendly refrigerants requires careful consideration of lubricant compatibility.

- CFC/HCFC systems used Mineral Oil (MO) or Alkylbenzene (AB) which are highly miscible with chlorine-containing refrigerants.
- HFC systems require synthetic lubricants like Polyolester (POE) or Polyalkylene Glycol (PAG) due to polar nature.
- HFO systems typically utilize POE or Polyvinyl Ether (PVE) oils for optimal stability and miscibility.
- Incompatibility Hazards: High wear, oil logging in evaporator, copper plating, and catastrophic compressor failure.

Title Slide I

Course: Refrigeration and AC (DI05019051) Lecture 25: 3.2 Refrigerants and Lubricants

- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.
- Instructor: Professor of Mechanical Engineering
- Focus: In-depth chemical, physical, thermodynamic, and environmental properties of refrigerants, alongside lubricant compatibility and behavior in VCRS cycles.

Introduction and Classification of Refrigerants I

Refrigerants are the working fluids in a refrigeration cycle that absorb heat at low temperature and pressure and reject heat at high temperature and pressure.

- Primary Refrigerants: Fluids that directly undergo phase change (evaporation and condensation) to produce refrigeration effect (e.g., Halocarbons, Hydrocarbons, Inorganics).
- Secondary Refrigerants: Fluids that act as heat transfer mediums without changing phase within the application loop, cooling by sensible heat transfer only (e.g., Water, Brines, Ethylene Glycol).
- Synthetic vs. Natural: Synthetic refrigerants (chlorofluorocarbons, hydrofluorocarbons) are engineered for stability, while natural refrigerants (ammonia, carbon dioxide, hydrocarbons) exist in nature.

Introduction and Classification of Refrigerants II

- Key selection factors include thermodynamic performance, chemical stability, compatibility with construction materials, safety, and environmental impact.

Chemical Nomenclature of Refrigerants I

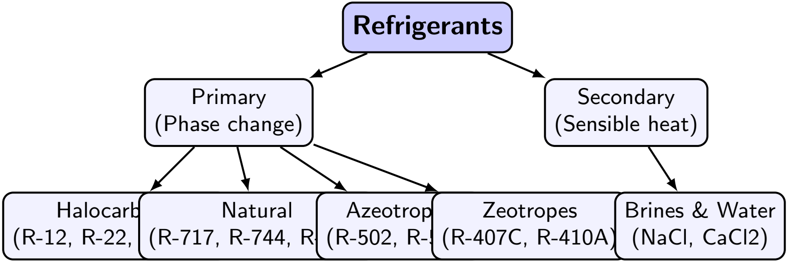
ASHRAE Standard 34 establishes a systematic numbering system for refrigerants based on their chemical structure.

- The standard naming convention follows the prefix R- followed by numbers: R-(C-1)(H+1)(F). Example: R-134a has C-1=1 -¿ C=2, H+1=3 -¿ H=2, F=4. Chemical formula: C2H2F4.
- For inorganic compounds, the number is R-700 plus the molecular weight. Example: Ammonia (NH3, MW = 17) is R-717; Carbon dioxide (CO2, MW = 44) is R-744; Water is R-718.
- Isomers (same chemical formula but different structural arrangements) are distinguished by lowercase letters (a, b, c) appended to the number, representing increasing asymmetry.

Chemical Nomenclature of Refrigerants II

- Zeotropic blends are assigned numbers in the 400 series (e.g., R-407C, R-410A) and exhibit temperature glide. Azeotropic blends are in the 500 series (e.g., R-502, R-507A) and boil at a constant temperature.

Refrigerant Classification Diagram I



- Primary refrigerants undergo latent heat exchange, absorbing heat during vaporization in the evaporator.
- Secondary refrigerants act as sensible heat transport mediums, widely used in large central air conditioning plants and district cooling.
- Zeotropic mixtures (400-series) experience concentration shifts and temperature glide during phase change.

Refrigerant Classification Diagram II

- Azeotropic mixtures (500-series) behave as pure substances with identical vapor and liquid composition at a given pressure.

Thermodynamic and Physical Properties I

The selection of a refrigerant requires balancing several critical thermodynamic and physical criteria to optimize coefficient of performance (COP) and system design.

- Boiling Point: Must be low at atmospheric pressure to enable evaporation below the target refrigeration temperature without creating deep vacuums in the evaporator.
- Critical Temperature and Pressure: The critical temperature should be well above the condensing temperature to ensure high COP and prevent transcritical operations (e.g., CO2 has a low critical temperature of 31.1°C).
- Latent Heat of Vaporization: High latent heat is preferred to reduce the mass flow rate required per unit cooling capacity, leading to smaller compressor displacement and piping sizes.
- Specific Volume: Low specific volume of vapor at the compressor inlet minimizes compressor size and work input.

Thermodynamic and Physical Properties II

- Thermal Conductivity and Viscosity: High thermal conductivity improves heat transfer coefficients in heat exchangers; low viscosity reduces pressure drops in piping and valves.

Environmental Metrics and Safety Classifications I

Modern refrigeration design is heavily constrained by environmental footprint and safety risks, governed by global treaties like the Montreal and Kigali Protocols.

- Ozone Depletion Potential (ODP): Measures the relative degradation of the ozone layer compared to R-11 (ODP = 1.0). CFCs and HCFCs have non-zero ODP due to chlorine content, while HFCs, HFOs, and Natural refrigerants have ODP = 0.
- Global Warming Potential (GWP): Represents the heat-trapping capacity of a gas relative to CO_2 (GWP = 1.0) over a 100-year horizon. High GWP HFCs (e.g., R-410A, GWP = 2088) are being phased down.

Environmental Metrics and Safety Classifications II

- Safety Group Classification: Defined by ASHRAE Standard 34 based on toxicity (Class A = low toxicity, Class B = high toxicity) and flammability (1 = no flame propagation, 2L = lower flammability, 2 = flammable, 3 = highly flammable).
- Transition to HFOs and Naturals: Hydrofluoroolefins (HFOs like R-1234yf, GWP ¡ 1, A2L) and natural refrigerants like Propane (R-290, GWP = 3, A3) and CO2 (R-744, GWP = 1, A1) are the future.

Lubricants in VCRS: Role and Essential Properties I

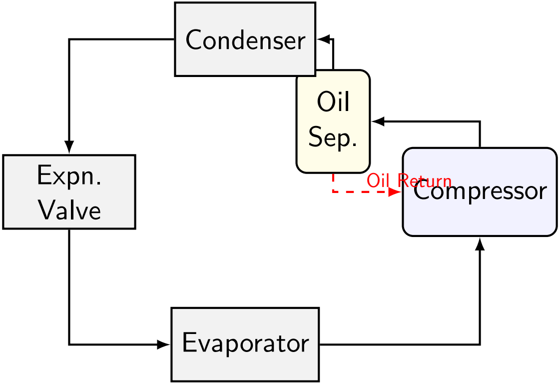
Lubrication is vital for compressor longevity, sealing, and heat dissipation, but the lubricant inevitably circulates through the entire cycle.

- Primary Function: Reduce friction and wear in moving compressor parts (pistons, bearings, scrolls), seal compression chambers, and cool motor windings.
- Viscosity index: Must remain stable over a wide temperature range, ensuring high viscosity at compressor discharge temperatures for wear protection, and low viscosity at low evaporator temperatures for fluid return.
- Floc Point: The temperature at which wax precipitates from the oil when mixed with refrigerant. High floc points lead to restricted expansion devices and coated heat exchanger tubes.

Lubricants in VCRS: Role and Essential Properties II

- Pour Point: The lowest temperature at which oil flows. The pour point must be significantly lower than the evaporator temperature to prevent oil immobilization.
- Dielectric Strength: Essential for hermetic and semi-hermetic compressors where the motor is exposed to the refrigerant-oil mixture; prevents electrical short circuits.

Oil Circulation and Separation in the VCRS Loop I



- Compressor discharge gas carries oil droplets into the high-pressure line.

Oil Circulation and Separation in the VCRS Loop II

- The Oil Separator uses centrifugal force, baffles, and velocity reduction to separate oil, returning it to the compressor crankcase via a float-controlled return line.
- Unseparated oil travels through the condenser, expansion valve, and evaporator, where it can form an insulating film, reducing heat transfer coefficients.
- At low temperatures in the evaporator, oil becomes highly viscous; maintaining adequate vapor velocity is crucial to carry oil back to the compressor.

Lubricant Types and Chemical Compatibility I

Chemical compatibility between refrigerants and lubricants is crucial; immiscibility or chemical reactions can cause system failure.

- Mineral Oils (MO): Derived from petroleum (naphthenic or paraffinic). Highly compatible with CFCs and HCFCs (like R-12 and R-22) due to mutual solubility.
- Synthetic Oils: Specifically engineered for modern chlorine-free refrigerants. Includes Polyolester (POE), Polyalkylene Glycol (PAG), and Polyalphaolefin (PAO).
- Polyolester (POE): Highly hygroscopic (absorbs water rapidly) but offers excellent miscibility with HFCs (like R-134a, R-410A) and HFOs. Used in stationary AC systems.
- Polyalkylene Glycol (PAG): Extremely hygroscopic, highly miscible with HFCs and HFOs, primarily used in automotive air conditioning systems.

Lubricant Types and Chemical Compatibility II

- Alkylbenzene (AB): Synthetic lubricant with good thermal stability, compatible with HCFCs and HCFC/HFC blends.

Solubility Behavior and Selection Criteria I

The interaction between refrigerant and lubricant determines system performance, oil return, and oil foaming during startup.

- Miscibility (Solubility): Fully miscible mixtures behave as a single phase, preventing oil log-up in heat exchangers. Immiscible systems require active mechanical separation.
- Viscosity Reduction: Dissolved refrigerant decreases lubricant viscosity, which helps oil flow at low temperatures but can compromise lubrication in bearings if dilution is excessive.
- Oil Foaming: During compressor startup, rapid pressure drop causes dissolved refrigerant to flash out of the oil, generating foam. Crankcase heaters are used to preheat oil and minimize dissolution.

Solubility Behavior and Selection Criteria II

- Selection Checklist: System operating limits, evaporator temperatures, safety classification (ASHRAE A1 vs A2L/A3), environmental regulations, and chemical compatibility with elastomers.

Course: Refrigeration and AC

- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Classification of Refrigerants I

Refrigerants are working fluids that undergo phase transitions (liquid-to-gas and vice versa) to transfer heat in a vapor compression cycle. They are divided into primary and secondary categories based on their operational mechanism.

- Primary refrigerants: Fluids that directly undergo cyclic phase changes within the refrigeration loop to absorb heat (e.g., Halocarbons, Hydrocarbons, Zeotropes, Azeotropes, and Inorganic compounds).
- Secondary refrigerants: Liquids used as heat-transfer media to carry heat from the refrigerated space to the evaporator without phase change (e.g., water, brines, ethylene/propylene glycol).
- Key selection criteria: Thermodynamic efficiency, environmental safety, chemical stability, compatibility, and economic viability.

ASHRAE Refrigerant Designation System I

ASHRAE Standard 34 defines a systematic alphanumeric numbering convention for refrigerants based on their chemical structure, particularly for halocarbons (C_n H_a F_b Cl_c where $a+b+c = 2n+2$).

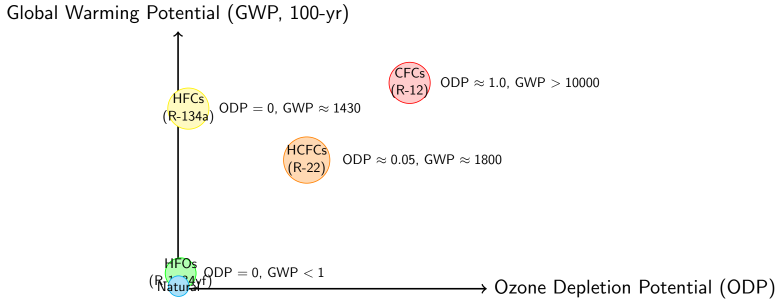
- Numbering rule: R-(C-1)(H+1)(F) where C = number of Carbon atoms, H = number of Hydrogen atoms, and F = number of Fluorine atoms.
- Chlorine content check: The number of Chlorine atoms is calculated as $Cl = (2C + 2) - H - F$.
- Isomer designations: For identical chemical formulas, lowercase suffixes (a, b, c) are appended based on molecular symmetry (e.g., R-134a is an isomer of tetrafluoroethane).
- Inorganic refrigerants: Numbered in the 700 series by adding their molecular mass (e.g., Ammonia R-717, Carbon Dioxide R-744, Water R-718).

Critical Thermophysical Properties I

An ideal refrigerant must exhibit superior thermodynamic and transport properties to minimize compressor work and maximize cooling capacity.

- Low boiling point and high latent heat of vaporization: Minimizes the mass flow rate required per unit of refrigeration capacity.
- High critical temperature: Must be well above the condensing temperature to ensure condensation occurs in the subcritical region with low throttling losses.
- High thermal conductivity and low viscosity: Enhances heat transfer coefficients in the evaporator/condenser and minimizes pressure drop in piping.
- High vapor density at suction: Reduces the compressor displacement volume requirement, resulting in a more compact compressor design.

Environmental Metrics: ODP and GWP I

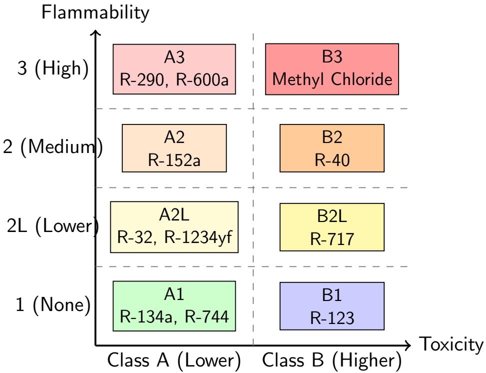


- Ozone Depletion Potential (ODP): Relative measure of degradation caused by a chemical to the ozone layer, referenced to R-11 (ODP = 1.0). Driven by Chlorine/Bromine atoms.

Environmental Metrics: ODP and GWP II

- Global Warming Potential (GWP): Measure of heat-trapping capability relative to Carbon Dioxide (GWP $= 1.0$) over a 100-year horizon.
- Montreal Protocol (1987): Mandated phase-out of CFCs (chlorofluorocarbons) and HCFCs (hydrochlorofluorocarbons).
- Kigali Amendment (2016): Added HFCs (hydrofluorocarbons) to the phased-out list due to their high GWP, driving transition to HFOs (hydrofluoroolefins) and natural fluids.

Safety: Toxicity and Flammability Matrix I



- ASHRAE Standard 34 assigns safety ratings using a letter for toxicity (A or B) and a number/letter for flammability (1, 2L, 2, or 3).

Safety: Toxicity and Flammability Matrix II

- Toxicity: Class A represents lower toxicity (no evidence at concentrations of 400 ppm or less); Class B represents higher toxicity (evidence at concentrations below 400 ppm).
- Flammability: Class 1 (non-flammable), Class 2L (mildly flammable, burning velocity of 10 cm/s or less), Class 2 (low flammability), Class 3 (highly flammable / hydrocarbons).
- Design impact: A3 and B3 refrigerants require explosion-proof electrical components, leak detection systems, and strict charge limits (e.g., in domestic refrigeration).

Introduction to Compressor Lubricants I

Lubricating oils are vital for vapor compression systems, coexisting with the refrigerant within the compressor and circulating throughout the system circuit.

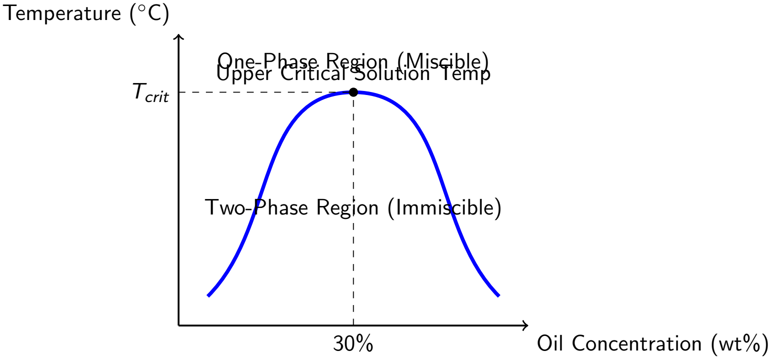
- Primary functions: Lubricating moving parts (shaft, pistons, valves), sealing clearances to prevent high-to-low pressure leakage, and cooling the compressor motor/stator.
- Key properties: High thermal stability (no carbonization at high discharge temperatures), low pour point (remains fluid at evaporator temperatures), and high dielectric strength.
- Viscosity selection: Must maintain sufficient load-carrying viscosity at compressor operating temperatures while not excessively increasing drag or pressure drop.
- Chemical compatibility: Must not chemically react with the refrigerant, gasket materials, electrical insulation, or system metals.

Mineral vs. Synthetic Lubricants I

Different refrigerant generations dictate distinct lubricant chemical formulations due to compatibility and chemical structure variations.

- Mineral Oils (MO): Naphthenic or paraffinic base oils. Highly compatible with non-polar CFCs and HCFCs (e.g., R-12, R-22) due to matching polarity.
- Polyolester (POE) Oils: Synthetic oils designed for polar HFCs (e.g., R-134a, R-410A). Highly hygroscopic (absorbs moisture rapidly), requiring careful handling.
- Polyalkylene Glycol (PAG) Oils: Synthetic oils primarily used in mobile A/C systems with R-134a and HFO-1234yf. Highly soluble in refrigerants but highly corrosive if moisture enters.
- Alkylbenzene (AB) & Polyalphaolefin (PAO): Semi-synthetic and synthetic lubricants often paired with HCFC blends or low-temperature ammonia systems.

Miscibility and Oil Return Dynamics I



- Miscibility: The ability of the refrigerant and lubricant to dissolve in one another to form a single liquid phase under system pressures and temperatures.

Miscibility and Oil Return Dynamics II

- Evaporator concerns: In the cold evaporator, the refrigerant-oil mixture may hit a miscibility gap (two-phase region), leading to oil separation, convective heat transfer reduction, and tube clogging.
- Oil Return: High velocity vapor is required in the suction line to mechanically drag separated oil back to the compressor, especially in horizontal/vertical risks.
- Oil Separators: Placed in the compressor discharge line to capture oil droplets from the hot gas before they enter the condenser and evaporator, routing them back to the crankcase.

Future Trends and Summary I

The industry is transitioning toward ultra-low GWP refrigerants, emphasizing natural alternatives and advanced synthetic blends.

- Natural Refrigerants: R-744 (Carbon Dioxide) for commercial refrigeration/heat pumps, R-290 (Propane) for small sealed systems, R-717 (Ammonia) for large-scale industrial plants.
- HFOs (Hydrofluoroolefins): Unsaturated HFCs with double carbon bonds (e.g., R-1234yf, R-1234ze) that decompose rapidly in the atmosphere, leading to near-zero GWP.
- Zeotropic Blends (400 Series) & Azeotropic Blends (500 Series): Engineered mixtures designed to match the properties of phased-out refrigerants while lowering GWP.
- Lubricant Integration: Advanced synthetic PVE (polyvinyl ether) and modified POE oils are being formulated to handle the unique solubility characteristics of new low-GWP blends.

3.2 Refrigerants and Lubricants: Overview I

Course: Refrigeration and AC (DI05019051) — Lecture 27

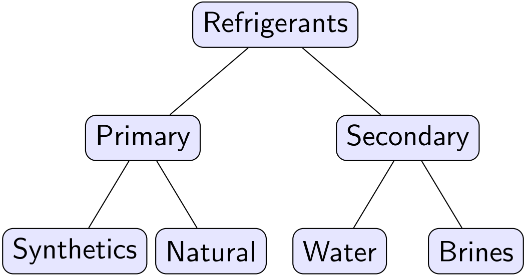
- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.
- Key topics covered: Classification of refrigerants, properties, designation, and environmental regulations.
- We will also cover compressor lubricant properties and their compatibility/miscibility with refrigerants.

Thermodynamic and Physical Selection Criteria I

Selecting a refrigerant involves a trade-off between thermodynamic performance, safety, and system cost.

- Low boiling point: Allows evaporation at sub-zero temperatures without going below atmospheric pressure, preventing air and moisture ingress.
- High latent heat: Minimizes the mass flow rate of refrigerant required, reducing compressor displacement and pipe sizes.
- High critical temperature: Ensures the refrigerant can be condensed at typical ambient temperatures without entering supercritical states.
- Low specific volume of vapor: Reduces compressor size and associated power consumption.

Classification of Refrigerants I



- Primary refrigerants absorb heat through phase changes in a closed loop.
- Secondary refrigerants act as sensible heat transfer fluids to move cooling capacity without phase change.
- Synthetic refrigerants are man-made chemicals (mainly halocarbons).

Classification of Refrigerants II

- Natural refrigerants occur in nature and include ammonia, carbon dioxide, and hydrocarbons.

Chemical Nomenclature and Designation I

Saturated halocarbon refrigerants are designated by the ASHRAE standard numbering system.

- Numbering rule: R-(n-1)(m+1)(p) for chemical formula $C_n H_m F_p Cl_q$, where $2n+2 = m+p+q$.
- Example: R-134a has 2 Carbons (n-1=1), 2 Hydrogens (m+1=3), and 4 Fluorines (p=4), with 'a' denoting a specific isomer.
- Inorganic compounds are numbered as R-(700 + Molecular Weight). e.g., Ammonia (MW=17) is R-717, Carbon Dioxide (MW=44) is R-744.
- Azeotropic mixtures are in the 500 series, while Zeotropic mixtures are in the 400 series.

Chemical and Safety Properties I

Safety and chemical stability are critical parameters for residential and commercial applications.

- Toxicity: ASHRAE Safety Group Class A indicates low toxicity (e.g., R-134a), Class B indicates high toxicity (e.g., R-717 ammonia).
- Flammability: Class 1 indicates no flame propagation, Class 2/2L indicates low flammability, Class 3 indicates high flammability (e.g., R-290 propane).
- Chemical stability: The refrigerant must not decompose or react with compressor materials, lubricants, or moisture.
- Leak detection: Easily detectable leaks through odor (ammonia) or specialized electronic/halide torch detectors.

Environmental Impacts: ODP and GWP I

Global treaties mandate the phase-out of substances that destroy the ozone layer or contribute to climate change.

- Ozone Depletion Potential (ODP): Measures the ozone-destroying capacity relative to CFC-11 (ODP = 1.0).
- Global Warming Potential (GWP): Measures the radiative forcing relative to CO2 (GWP = 1.0) over a 100-year timeframe.
- CFCs have extremely high ODP and GWP. HCFCs have lower ODP but still high GWP.
- HFCs have zero ODP but remain strong greenhouse gases, leading to their global phase-down.

Evolution of Refrigerant Generations I

CFC (e.g. R-12) → HCFC (e.g. R-22) → HFC (e.g. R-134a) → HFO (e.g. R-1234yf)

- First generation (CFCs): High ODP & high GWP, phased out under the Montreal Protocol (1987).
- Second generation (HCFCs): Transition fluids with low ODP, currently being phased out.
- Third generation (HFCs): Zero ODP, but high GWP, regulated for phase-down by the Kigali Amendment (2016).
- Fourth generation (HFOs & Naturals): Zero ODP, ultra-low GWP, and short atmospheric lifetimes.

Introduction to Compressor Lubricants I

Compressor lubricants reduce friction, seal gas leakage, and cool moving parts, but must coexist with the refrigerant.

- High viscosity index: Ensures oil maintains adequate lubrication at high temperatures and remains fluid at low temperatures.
- Low pour point: Prevents oil from freezing or becoming wax-like in the coldest parts of the system (evaporator).
- Dielectric strength: Crucial for hermetic and semi-hermetic compressors where motor windings are submerged in the refrigerant-oil mixture.
- Chemical inertness: Must not react with the refrigerant, metals, or elastomer seals under high discharge temperatures.

Miscibility and Oil Return Challenges I

Refrigerant and lubricant miscibility determines how oil behaves as it circulates through the cycle.

- Miscibility is the ability of the refrigerant and oil to dissolve completely to form a single homogenous phase.
- In miscible systems (e.g., mineral oil in CFC-12), oil carried over to the evaporator easily dissolves and returns to the compressor.
- In immiscible systems (e.g., mineral oil in ammonia), oil separates and forms a film in the heat exchangers, requiring oil separators.
- Poor oil return leads to oil logging in the evaporator, reducing heat transfer coefficients and starving the compressor of oil.

Matching Lubricants with Refrigerants I

Lubricants must be carefully matched to the chemical composition of the refrigerant to ensure miscibility and durability.

- Mineral Oils (MO): Used with CFCs and HCFCs (e.g., R-12, R-22) because of non-polar compatibility.
- Alkylbenzenes (AB): Synthetic lubricant offering better thermal stability and compatibility with HCFCs at low temperatures.
- Polyol Esters (POE): Highly polar synthetic oils used with HFCs (e.g., R-134a, R-410A) and HFOs.
- Polyalkylene Glycols (PAG): Used in automotive AC systems with R-134a/HFO-1234yf; highly hygroscopic.
- Polyalphaolefins (PAO): Ideal for ammonia systems where miscibility is not required but high stability is needed.

Title Slide I

Course: Refrigeration and AC

- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Classification of Refrigerants I

Refrigerants are divided into primary agents that undergo cyclic phase changes and secondary fluids that transport sensible heat.

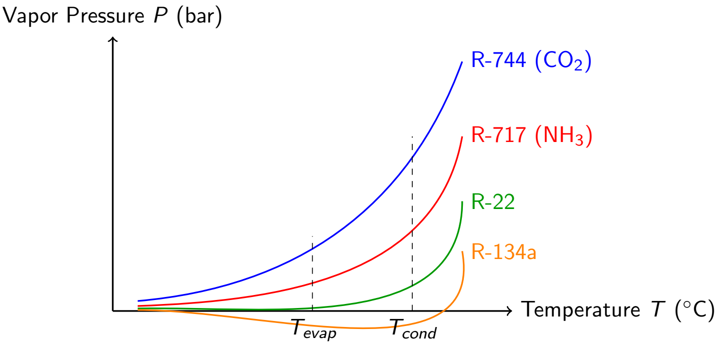
- Primary refrigerants actively absorb heat at low temperature/pressure and release it at high temperature/pressure.
- Halocarbons include CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), and HFCs (hydrofluorocarbons).
- Natural refrigerants comprise inorganic compounds such as Ammonia (R-717), Carbon Dioxide (R-744), Water (R-718), and Hydrocarbons (R-290, R-600a).

Standard ASHRAE Naming Convention I

ASHRAE Standard 34 assigns an alphanumeric designation to refrigerants based on chemical formula.

- For halocarbons, R-(C-1)(H+1)(F) is used where C is Carbon, H is Hydrogen, and F is Fluorine. The rest of the valence is filled by Chlorine.
- Inorganic refrigerants are designated by R-700 plus their molecular weight (e.g., Ammonia is R-717, Carbon Dioxide is R-744).
- Zeotropic mixtures are in the 400 series (e.g., R-407C) and have temperature glide, while azeotropes are in the 500 series (e.g., R-507A).

Thermodynamic Selection Criteria: Vapor Pressure Curves I



- Evaporating pressure must be higher than atmospheric pressure (1.013 bar) to prevent air and moisture leakage into the cycle.

Thermodynamic Selection Criteria: Vapor Pressure Curves II

- Condensing pressure should be moderately low to prevent heavy and expensive construction of piping, compressor, and heat exchangers.
- High critical temperature is crucial to enable condensation by heat rejection to standard ambient air or water sources.
- High latent heat of vaporization (h_{fg}) is preferred to minimize refrigerant mass flow rate and compressor displacement size.

Environmental Performance Criteria I

Modern refrigerant selection is heavily constrained by environmental legislation like the Montreal Protocol and the Kigali Amendment.

- Ozone Depletion Potential (ODP) measures chemical damage to the ozone layer relative to CFC-11, which is set to a baseline of 1.0.
- Global Warming Potential (GWP) evaluates the greenhouse gas impact relative to Carbon Dioxide (CO2 $=$ 1.0) over a 100-year horizon.
- Hydrofluorocarbons (HFCs) have zero ODP but exhibit high GWP values, necessitating their global phase-down.
- Hydrofluoroolefins (HFOs) represent a new generation of unsaturated HFCs with zero ODP and extremely low GWP (¡ 1).

	Lower Toxicity (A)	**Higher Toxicity (B)**
High Flammability (3)	A3 (e.g., R-290, R-600a)	B3
Lower Flammability (2/2L)	A2/A2L (R-1234yf, R-32)	B2/B2L (R-717 / NH_3)
No Flame Prop. (1)	A1 (R-134a, R-410A)	B1 (R-123)

- Toxicity is categorized as Class A (no toxicity detected at or below 400 ppm) or Class B (evidence of toxicity below 400 ppm).

ASHRAE Standard 34 Safety Group Matrix II

- Flammability is split into Class 1 (no propagation), Class 2L (mildly flammable, slow burning velocity ¡ 10 cm/s), Class 2, and Class 3.
- Natural hydrocarbons (propane R-290) are highly efficient but require strict charge limitations due to their A3 safety classification.
- Ammonia (R-717) is classified as B2L, combining higher toxicity with low flammability, which limits its use in direct expansion comfort cooling.

Refrigerant-Lubricant Compatibility I

Compressor lubricants must co-exist and interact dynamically with the refrigerant throughout the VCRS cycle.

- Miscibility is the ability of refrigerant and oil to mix and form a single homogeneous liquid phase at system operating temperatures.
- Miscible systems ensure oil is carried back to the compressor crankcase but can lower oil viscosity and cause foaming during startup.
- Immiscible systems require mechanical oil separators and oil return loops to prevent oil film buildup on evaporator heat transfer walls.
- Partially miscible pairs can undergo phase separation at low temperatures in the evaporator, leading to high-viscosity oil accumulation.

Types of Refrigeration Lubricants I

Lubricants are selected based on chemical nature, polarity, thermal stability, and mutual solubility with the refrigerant.

- Mineral Oils (MO) are non-polar naphthenic or paraffinic oils compatible with chlorine-containing CFC and HCFC refrigerants.
- Polyolester (POE) Oils are highly polar synthetic lubricants designed specifically for use with chlorine-free HFCs and HFOs.
- Polyalkylene Glycols (PAG) are synthetic oils utilized primarily in mobile air conditioning (MAC) systems running on R-134a and R-1234yf.
- Alkylbenzenes (AB) exhibit superior low-temperature performance and chemical stability when paired with HCFC-based refrigerant mixtures.

Tribological Challenges in VCRS Systems I

Lubricating films must remain stable under extreme pressure variations, high discharge temperatures, and chemical dilution.

- Refrigerant dilution reduces dynamic viscosity, potentially shifting bearing contact from hydrodynamic to boundary lubrication.
- Foaming occurs when rapid depressurization releases dissolved refrigerant from the oil, risking dry running of the oil pump.
- Lubricants must have a low pour point and floc point to ensure fluid return through the expansion device and evaporator tubes.
- Chemical stability is required up to 130 degrees C to prevent oil oxidation, acid formation, copper plating, and sludge accumulation.

Summary of Lubricant-Refrigerant Matching I

Properly aligning working fluids ensures high heat transfer performance, reliability, and thermodynamic efficiency.

- CFCs/HCFCs are matched with Mineral Oils (MO) or Alkylbenzenes (AB) due to chemical compatibility and mutual solubility.
- HFCs and HFOs require polar synthetic oils like Polyolester (POE) or Polyalkylene Glycols (PAG) to prevent phase separation.
- Ammonia (R-717) uses immiscible Mineral or Synthetic oils, requiring high-efficiency mechanical oil separators at the compressor discharge.
- Improper pairings lead to evaporator oil logging, reduced system COP, compressor starvation, and ultimate mechanical failure.

Title Slide I

Course: Refrigeration and AC

- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.
- Lecture 29: 3.2 Refrigerants and lubricants
- Instructor: Professor of Mechanical Engineering

Classification of Refrigerants I

Primary vs Secondary Refrigerants, Halocarbons, Hydrocarbons, Inorganic compounds, and Azeotropic/Zeotropic mixtures.

- Primary refrigerants undergo phase change to produce cooling directly in the evaporator.
- Secondary refrigerants (brines, water, glycols) act as heat transfer media without undergoing phase change.
- Halocarbon refrigerants (CFCs, HCFCs, HFCs, HFOs) are synthetically produced hydrocarbons where hydrogen atoms are replaced by chlorine, fluorine, or bromine.
- Inorganic refrigerants include ammonia (R-717), carbon dioxide (R-744), water (R-718), and air (R-729), designated by R-(700 + molecular weight).
- Azeotropic mixtures (500 series) behave as pure substances during phase change, while Zeotropic mixtures (400 series) exhibit temperature glide.

Key Thermodynamic Requirements I

Criteria for optimal cycle efficiency and operating pressures.

- Low boiling point and high latent heat of vaporization (h_fg) to minimize the required mass flow rate per kilowatt of cooling capacity.
- High critical temperature (well above the condensing temperature) to ensure condensation occurs efficiently with minimal throttling losses.
- Low freezing point (well below the evaporator temperature) to prevent solidification of the refrigerant in the evaporator tubes.
- Low specific volume of vapor at suction conditions to reduce compressor size, displacement, and input power requirements.
- Moderate discharge temperatures to prevent oil carbonization, valve damage, and excessive thermal stress on the compressor.

Physical and Chemical Properties I

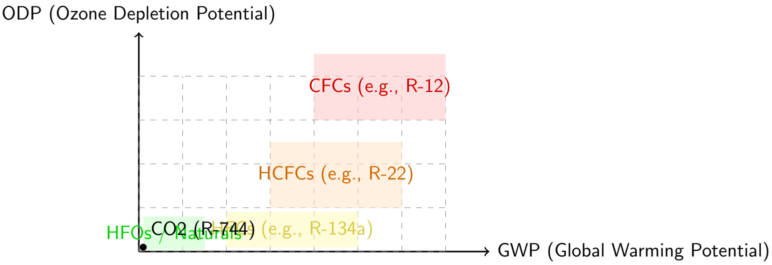
Safety, stability, and handling characteristics.

- Flammability and Toxicity: Evaluated under ISO 817 / ASHRAE Standard 34 classification (A1, A2L, A3, B1, B2L, B3).
- Chemical Stability: Refrigerants must remain chemically inert under operating temperatures and pressures in the presence of metals and lubricants.
- Leak Detection: Halocarbons are detected using electronic leak detectors or halide torches; Ammonia by sulfur sticks or litmus paper.
- Viscosity and Thermal Conductivity: High thermal conductivity and low viscosity are desired to maximize heat transfer coefficients and minimize pressure drops.

Physical and Chemical Properties II

- Dielectric Strength: Essential for hermetic and semi-hermetic compressors where the motor windings are in direct contact with the refrigerant.

Environmental Metrics & Evolution I



- Ozone Depletion Potential (ODP): Measures the relative ozone destruction compared to CFC-11 (ODP $= 1.0$). Montreal Protocol phased out CFCs and HCFCs.
- Global Warming Potential (GWP): Measures heat-trapping capability relative to CO_2 (GWP $= 1.0$) over 100 years. Kigali Amendment targets HFC phase-down.

Environmental Metrics & Evolution II

- First Generation (1830-1930s): Natural refrigerants (Ammonia, CO_2, SO_2) - highly toxic/flammable but zero ODP/GWP.
- Second Generation (1930-1990s): CFCs (R-12, R-11) and HCFCs (R-22) - high safety, but extreme ODP and GWP.
- Third & Fourth Generations (1990s-Present): HFCs (R-134a, R-410A) with zero ODP but high GWP, transitioning to HFOs (R-1234yf) and natural refrigerants with low GWP.

Functions and Requirements of Lubricants I

The role of compressor oil in vapor compression refrigeration systems.

- Primary function is to reduce friction and wear in moving compressor parts (crankshaft, connecting rod, pistons/rotors).
- Acts as a sealant to prevent refrigerant bypass leakage across clearance spaces (especially in rotary and screw compressors).
- Serves as a cooling medium, absorbing heat generated by friction and compression and transferring it to the compressor shell or oil cooler.
- Must possess high thermal and chemical stability to resist decomposition at high discharge valve temperatures.
- Low pour point and floc point to ensure the oil remains fluid at evaporator temperatures and does not form wax deposits.

Refrigerant-Lubricant Miscibility I

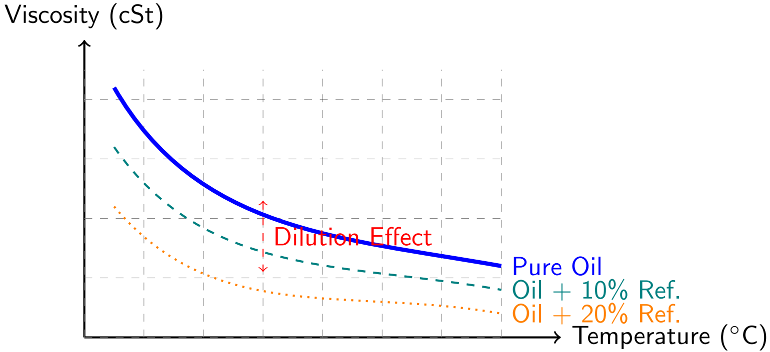
Mutual solubility characteristics and their impact on system performance.

- Fully Miscible: Refrigerant and oil dissolve completely in all proportions (e.g., CFC-12 and mineral oil), ensuring easy oil return to the compressor.
- Partially Miscible: Oil and refrigerant separate into two liquid phases under certain temperatures and concentrations (critical solution temperature).
- Immiscible: Refrigerant and oil do not dissolve (e.g., Ammonia and mineral oil). Requires an oil separator at the compressor discharge.
- Miscibility directly affects oil return from the evaporator. Poor oil return causes evaporator fouling, reducing heat transfer coefficient.

Refrigerant-Lubricant Miscibility II

- High solubility lowers refrigerant viscosity in the compressor, which may reduce lubricating film thickness and load-carrying capacity.

Oil-Refrigerant VLE & Viscosity Behavior I



- Daniel Chart: Plots pressure, temperature, and refrigerant concentration in oil to determine the resulting kinematic viscosity.

Oil-Refrigerant VLE & Viscosity Behavior II

- Refrigerant dilution significantly lowers oil viscosity, which must be accounted for in compressor bearing design.
- High pressure and low temperature promote refrigerant solubility in oil, causing maximum dilution in the crankcase during idle periods.
- Crankcase heaters are employed to maintain oil temperature above saturation, driving off dissolved refrigerant to prevent foaming at startup.
- Foaming occurs during startup when crankcase pressure drops rapidly, causing dissolved refrigerant to flash into vapor, starving bearings of oil.

Lubricant Types and Compatibility Matrix I

Matching mineral and synthetic oils with various refrigerant groups.

- Mineral Oils (MO): Used historically with CFCs and HCFCs due to excellent solubility and cheap availability.
- Alkylbenzene (AB) Oils: Synthetic oils offering better low-temperature solubility and stability than MO; compatible with CFCs and HCFCs.
- Polyol Ester (POE) Oils: Highly hygroscopic synthetic lubricants required for HFCs (R-134a, R-410A) and HFOs.
- Polyalkylene Glycol (PAG) Oils: Used primarily in automotive R-134a and HFO-1234yf systems; extremely hygroscopic but good solubility.
- Polyalphaolefin (PAO) Oils: Synthetic hydrocarbons used in low-temperature applications, often with ammonia (R-717) systems.

Practical Challenges & System Design I

Key hardware components and operational practices for oil management.

- Oil Separator: Installed in the discharge line before the condenser to intercept oil droplets and return them directly to the crankcase.
- Suction Line Velocity: Must be maintained above a minimum threshold (typically 4 m/s in horizontal and 8 m/s in vertical risers) to entrain oil back to the compressor.
- Oil Traps: Installed at the bottom of vertical suction risers to collect oil and assist in its entrainment under low-load conditions.
- Hygroscopic Nature: Synthetic oils (POE/PAG) absorb moisture rapidly from the air, forming acids that attack motor windings; require careful handling.

Practical Challenges & System Design II

- Filter Drier: Vital component containing desiccant (like molecular sieve) to remove moisture and acid, preventing expansion valve freeze-up.

Title Slide I

Course: Refrigeration and AC

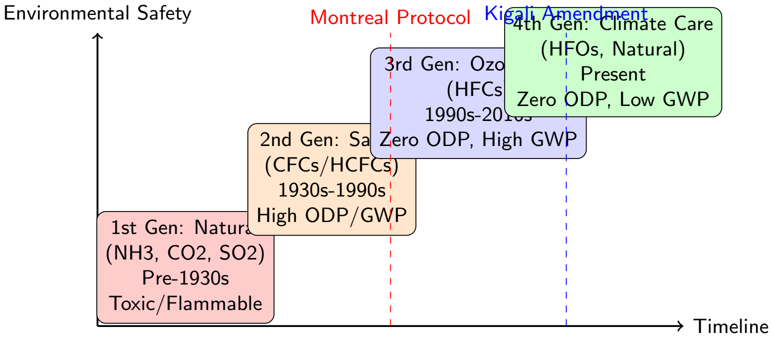
- Unit: Common Equipments and refrigerants of Vapor Compression Refrigeration System.

Refrigerant Classification & Nomenclature I

Categorization of refrigerants under ASHRAE Standard 34 based on chemical formulation.

- Primary chemical groups include Halocarbons (CFCs, HCFCs, HFCs, HFOs), Hydrocarbons (HCs), and Inorganics (Ammonia, Carbon Dioxide).
- Nomenclature rule for saturated hydrocarbons: R-(C-1)(H+1)(F), where C, H, and F represent the number of Carbon, Hydrogen, and Fluorine atoms.
- Inorganic refrigerants are designated by adding their molecular weight to 700 (e.g., R-717 for Ammonia, R-744 for Carbon Dioxide).
- Zeotropic mixtures (R-400 series) exhibit temperature glide during phase change, whereas Azeotropic mixtures (R-500 series) act like pure substances.

Environmental Metrics & Policy Evolution I



- Ozone Depletion Potential (ODP): Relative metric measuring the stratospheric ozone destruction capability compared to R-11 (ODP = 1.0).

Environmental Metrics & Policy Evolution II

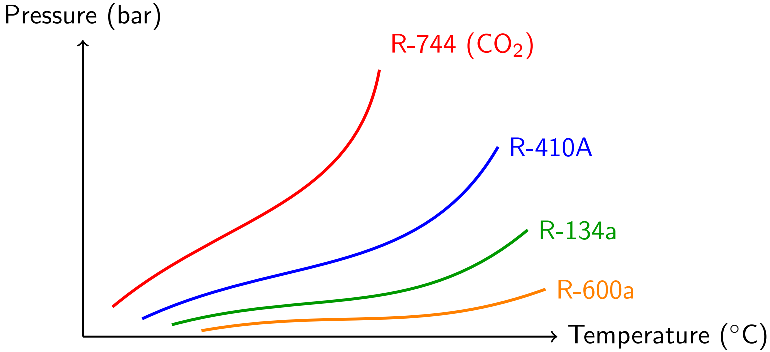
- Global Warming Potential (GWP): Measure of heat-trapping capacity in the atmosphere relative to Carbon Dioxide (GWP $= 1.0$) over a 100-year horizon.
- Montreal Protocol (1987) phased out high-ODP substances including Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs).
- Kigali Amendment (2016) mandates a phased reduction in high-GWP Hydrofluorocarbons (HFCs), pushing transition towards Hydrofluoroolefins (HFOs).

Thermodynamic Selection Criteria I

Key physical and thermodynamic properties determining refrigerant cycle performance and efficiency.

- Critical Temperature: Must be high relative to condensation temperatures to ensure operation remains in the subcritical region with stable heat rejection.
- Latent Heat of Vaporization: High values maximize cooling effect per unit mass flow, reducing the required refrigerant mass flow rate and system charge.
- Specific Suction Volume: Lower values reduce the required compressor stroke volume, minimizing compressor physical footprint.
- Pressure Ratio: Lower ratios decrease compressor work, reduce discharge temperature, and improve both volumetric and overall cycle efficiency (COP).

Vapor Pressure Curves of Key Refrigerants I



- Comparison of saturation pressure versus temperature profiles illustrates the mechanical design constraints of different refrigerants.

Vapor Pressure Curves of Key Refrigerants II

- R-744 (Carbon Dioxide) operates at very high pressures, demanding robust transcritical piping and compressor components.
- R-134a serves as a moderate-pressure refrigerant suitable for automotive and medium-scale commercial chillers.
- R-600a (Isobutane) operates under low pressures, making it excellent for domestic refrigeration applications due to low mechanical stress.

Chemical Safety & ASHRAE Standard 34 Classes I

Safety groups classifying refrigerants based on toxicity and flammability parameters.

- Toxicity Division: Class A denotes low toxicity (occupational limit ¿= 400 ppm); Class B denotes high toxicity (¡ 400 ppm).
- Flammability Division: Class 1 (no propagation), Class 2L (mildly flammable, slow burning), Class 2 (flammable), Class 3 (highly flammable).
- R-717 (Ammonia) is B2L: demonstrates low flammability but high toxicity, requiring mechanical ventilation and containment in industrial spaces.
- The 2L category was established to permit the use of lower-GWP alternatives like R-32 and HFOs (R-1234yf) in standard air conditioning systems.

Compressor Lubricants: Functions and Types I

Fundamental roles and chemical categories of refrigeration compressor lubricants.

- Primary lubrication action: Prevents metal-to-metal contact on critical compressor bearing surfaces, reducing frictional wear.
- Secondary actions: Dissipates thermal energy from compression and acts as a dynamic seal in compression chambers (e.g., scroll wraps).
- Mineral Oils (MO): Extracted from crude oil; compatible only with chlorine-containing CFC/HCFC refrigerants.
- Synthetic Oils: Polyol Esters (POE) and Polyalkylene Glycols (PAG) formulated for compatibility with polar HFC and HFO refrigerants.

Solubility, Miscibility, and Viscosity Interactions I

Tribological behavior of the refrigerant-lubricant mixture inside the compression cycle.

- Miscibility defines the ability of the lubricant and liquid refrigerant to blend into a single phase under low-temperature evaporator conditions.
- Poor low-temperature miscibility results in phase separation, leading to oil coating evaporator tubes and hindering heat transfer.
- Solubility represents the dissolved gaseous refrigerant inside the oil, which lowers oil viscosity and can compromise lubricating film thickness.
- To ensure continuous oil return, suction and liquid lines must maintain velocities sufficient to entrain and transport oil back to the crankcase.

Oil Management and Separator Engineering I

Design features used to prevent oil migration from the compressor crankcase into heat exchangers.

- Oil Carryover: High velocity discharge gas entrains lubricant droplets and transports them into the high-pressure side of the system.
- Oil Separator Location: Installed directly in the compressor discharge line before entering the condenser.
- Separation Methods: Coalescing filters, centrifugal separation, and mechanical impingement plates reduce gas velocity to drop out oil.
- Return Mechanism: A float valve assembly returns collected oil directly to the crankcase, preserving oil levels and preventing starvation.

Summary: System Design and Selection Compromise I

The complex trade-off between thermodynamic efficiency, environmental safety, and chemical compatibility.

- The Fluorine Dilemma: Higher fluorine content increases stability and safety (reduces flammability) but dramatically increases GWP and atmospheric lifespan.
- Chemical Matching: Mineral Oils (MO) pair with CFCs/HCFCs; Polyol Esters (POE) pair with HFCs/HFOs; Alkylbenzenes (AB) pair with HCFC blends.
- Natural refrigerants like R-744 (CO_2) require high-pressure piping and synthetic PAG/POE oils, representing a low-GWP, high-efficiency path.
- Modern system optimization focuses on low-GWP HFOs paired with low-viscosity synthetic oils to optimize boundary lubrication and overall system COP.

Title Slide I

Course: Refrigeration and Air Conditioning (DI05019051) Lecture 31: 4.1 Air conditioning: Introduction, classification and applications of Air conditioning.

- Instructor: Mechanical Engineering Professor
- Overview of fundamental thermodynamics, heat transfer, and psychrometrics applied to ambient control.
- Comprehensive classification based on seasons, applications, and equipment arrangement.

Defining Air Conditioning I

Air conditioning is the simultaneous control of temperature, humidity, air motion (velocity), and purity (cleanliness) of the air within a designated space to meet the requirements of the occupants or industrial processes.

- Temperature Control: Heating in winter and cooling in summer using heat exchangers (evaporator/condenser/reheater coils).
- Humidity Control: Addition of moisture (humidification) or removal of moisture (dehumidification) to maintain comfort (typically 40% to 60% RH).
- Air Motion Control: Distributing conditioned air uniformly using blowers and ductwork to prevent stagnation or high-velocity drafts (standard air velocity: 0.15 to 0.25 m/s).
- Purity Control: Filtering out dust, pollen, soot, and chemical contaminants using filters (MERV-rated or HEPA filters depending on application).

Thermodynamics of Human Comfort I

Human body thermoregulation relies on heat dissipation through radiation, convection, conduction, and evaporation. Air conditioning facilitates these pathways to ensure the heat generated by metabolism (M) equals the heat dissipated (Q).

- Energy Balance Equation: M $\pm$ R $\pm$ C - E $= \pm$ S, where M is metabolic rate, R is radiation, C is convection, E is evaporative heat loss, and S is rate of heat storage (must be zero for steady-state thermal comfort).
- The Comfort Zone: Typically defined by ASHRAE Standard 55, generally bounded by 22°C to 26°C dry bulb temperature and 30% to 60% relative humidity.
- Metabolic Rate (Met): Units of heat generation (1 Met = 58.2 W/m^2 of body surface area), varying from sedentary (1.0 Met) to heavy labor (¿3.0 Met).

- Clothing Insulation (Clo): Thermal resistance of clothing (1 Clo $= 0.155$ m²K/W), which significantly affects the design setpoints for HVAC systems.

Classification of Air Conditioning Systems I

Air conditioning systems are broadly classified based on their primary function into Comfort Air Conditioning and Industrial Air Conditioning, each having distinct design standards and tolerances.

- Comfort Air Conditioning: Designed to provide a comfortable indoor environment for human occupants, where tolerances for temperature ($\pm$ 1°C) and humidity ($\pm$ 5%) are moderately flexible.
- Industrial Air Conditioning: Tailored to optimize chemical, physical, or biological processes rather than human comfort (e.g., semiconductor cleanrooms require precise temperature control within $\pm$ 0.1°C).
- Load Profile Differences: Comfort AC load is highly transient and dominated by solar radiation, ambient transmission, and occupancy; Industrial AC load is often steady-state and dominated by internal equipment heat.

Classification of Air Conditioning Systems II

- Ventilation Rates: Comfort systems emphasize fresh air intake for odor and CO_2 control; Industrial systems focus on contaminant dilution, filtration, and pressurized containment.

Classification based on Seasons I

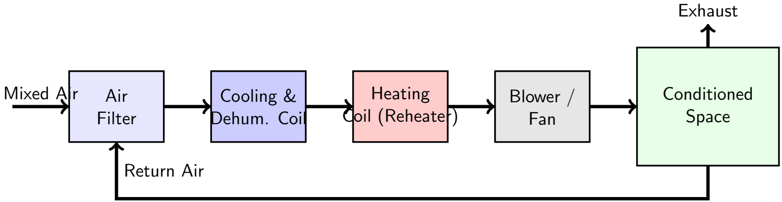
Based on the time of year and ambient meteorological conditions, systems are classified as Summer Air Conditioning, Winter Air Conditioning, or Year-Round Air Conditioning.

- Summer Air Conditioning: Focuses on cooling and dehumidifying ambient air. Ambient air is typically warm and humid, requiring it to be cooled below its dew point.
- Winter Air Conditioning: Focuses on heating and humidifying. Cold outdoor air has low moisture-holding capacity, requiring pre-heating, humidification, and reheat.
- Year-Round Air Conditioning: Integrates both cooling/dehumidification and heating/humidification sub-systems, automatically switching modes via automated dampers and controls.

Classification based on Seasons II

- Psychrometric Process Variations: Summer AC primarily utilizes cooling coils with a bypass factor, whereas Winter AC uses steam/spray humidifiers and heating coils.

Summer Air Conditioning System Schematic I



- Return air from the conditioned space is mixed with a portion of fresh outdoor air to ensure adequate ventilation.
- The mixed air passes through an Air Filter to remove particulate matter before entering the thermal conditioning section.
- The Cooling and Dehumidifying Coil cools the air below its dew-point temperature, causing moisture to condense and drain away.

Summer Air Conditioning System Schematic II

- A Reheater (heating coil) raises the dry-bulb temperature slightly to prevent draft discomfort and achieve the exact relative humidity setpoint.

Classification by Equipment Arrangement I

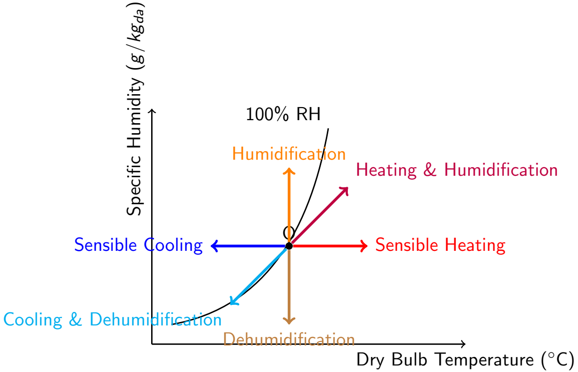
HVAC configurations are categorized by component distribution: Unitary systems (window/package), Split systems, and Central Air Conditioning systems.

- Unitary (Window/Through-Wall) Systems: Self-contained units containing evaporator, compressor, condenser, and fan in a single cabinet; typically limited to single-room cooling (¡5 kW capacity).
- Split Systems: Divide the low-pressure side (evaporator/blower indoors) from the high-pressure side (compressor/condenser outdoors) to isolate noise; connected via copper refrigerant lines.
- Central Systems: Centrally locate primary equipment (chillers, boilers, cooling towers) and distribute chilled water/steam to Air Handling Units (AHUs) or Fan Coil Units (FCUs) via piping.

Classification by Equipment Arrangement II

- Variable Refrigerant Flow (VRF): An advanced split system utilizing a single outdoor unit connected to multiple indoor units, modulating refrigerant flow via electronic expansion valves.

Psychrometric Processes of Air Conditioning I



- Sensible processes involve changing dry-bulb temperature at a constant humidity ratio (horizontal vectors on the psychrometric chart).

Psychrometric Processes of Air Conditioning II

- Latent processes involve changes in moisture content (humidity ratio) without changing dry-bulb temperature (vertical vectors).
- Cooling and Dehumidification (diagonal path down and left) is the standard summer conditioning process, achieved by passing air over a coil colder than the air's dew point.
- Heating and Humidification (diagonal path up and right) is the typical winter conditioning process, combining steam spray with heating coils.

Comfort Applications of Air Conditioning I

Comfort systems are designed to maximize human productivity, health, and psychological well-being by maintaining indoor environments within standard comfort envelopes.

- Residential: Single-family homes and multi-story apartments utilize split systems, package units, or variable refrigerant flow (VRF) units to ensure personal thermal comfort.
- Commercial: Retail stores, shopping malls, and office buildings use large-scale central systems (VAV or multi-zone systems) to handle highly variable sensible and latent loads.
- Assembly Spaces: Theaters, auditoriums, and stadiums have high occupancy densities, requiring high ventilation rates (fresh air intake) and quiet air distribution (low NC rating).
- Transportation: Automobiles, trains, and commercial aircraft require highly compact, vibration-resistant HVAC units capable of handling rapid external ambient fluctuations.

Industrial Applications of Air Conditioning I

Industrial systems prioritize the requirements of products and machinery over human comfort, often involving strict control of particulate contamination, humidity, and static electricity.

- Textile Manufacturing: High relative humidity (60%-70%) is critical to maintain fiber strength, prevent thread breakage, and minimize static electricity generation on looms.
- Precision Metrology and Semiconductors: Cleanrooms require Class 100/10 standard filtration (HEPA/ULPA) and micro-tolerances for temperature and humidity to prevent wafer defects.
- Printing and Paper Industry: Paper is highly hygroscopic; moisture content variations cause warping, curling, and registration errors in multi-color printing, requiring strict 50% RH.

Industrial Applications of Air Conditioning II

- Pharmaceutical and Food Processing: Requires sterile environments with positive pressure control to prevent cross-contamination, and specific low-humidity conditions for powder handling.

Introduction to Air Conditioning I

Course: Refrigeration and AC (DI05019051)

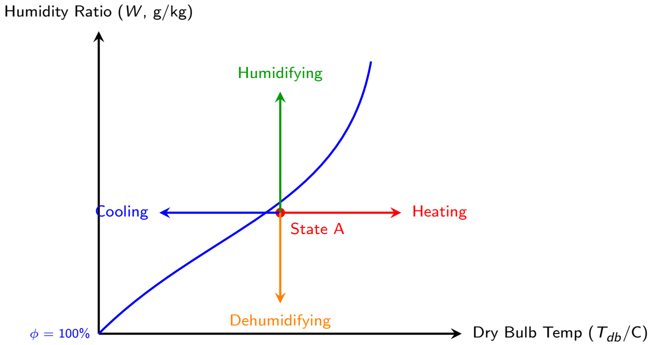
- Unit 4.1: Air conditioning: Introduction, classification and applications of Air conditioning.

Definition and Core Functions I

Air conditioning is defined as the simultaneous control of temperature, humidity, air movement, and purity within a given space.

- Temperature Regulation: Maintains design dry bulb temperature (cooling in summer, heating in winter).
- Moisture Regulation: Dehumidifies during summer cooling or adds moisture (humidification) in dry winter seasons.
- Air Distribution: Maintains velocity (0.15 - 0.25 m/s) to ensure uniform temperature and avoid drafts.
- Air Quality Control: Uses filtration to extract particulates and introduces fresh outdoor air to dilute carbon dioxide.

Psychrometric Processes in Air Conditioning I



- Sensible heating shifts state horizontally right on the psychrometric chart.
- Sensible cooling shifts state horizontally left towards the saturation curve.

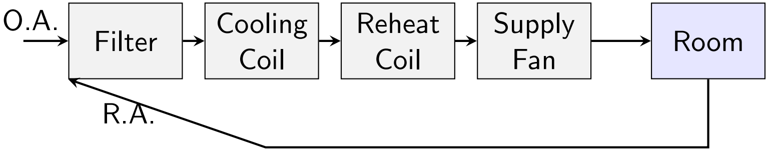
- Humidification increases the humidity ratio vertically upward.
- Dehumidification decreases moisture content vertically downward.

Classification of Air Conditioning Systems I

Air conditioning systems are classified according to their major purpose, operating season, and equipment arrangement.

- By Purpose: Comfort systems (occupant thermal satisfaction) and Industrial systems (process and product control).
- By Operating Season: Summer AC systems, Winter AC systems, and Year-Round AC systems.
- By Configuration: Unitary systems (individual window/split units) and Central systems (chilled water plant serving Air Handling Units).
- By Working Medium: All-Air systems, All-Water systems, and hybrid Air-Water systems.

Summer Air Conditioning System Layout I



- Outdoor Air (O.A.) and Recirculated Air (R.A.) mix before entering the filter.
- The air filter removes particulate contaminants to maintain indoor air quality.
- The cooling coil cools the air below its dew point temperature to dehumidify it.
- The reheat coil adjusts the supply air temperature to prevent overcooling the space.

Comfort Air Conditioning Principles I

Comfort air conditioning controls parameters to maintain human thermal comfort, balancing metabolic heat production and dissipation.

- Metabolic Heat Balance: The body regulates temperature via radiation, convection, and perspiration evaporation.
- Optimal Indoor Comfort Zone: Commonly accepted design conditions are 24°C DBT and 50% relative humidity.
- Effective Temperature (ET): An empirical index combining temperature, humidity, and air velocity into a single thermal sensation.
- Ventilation Needs: Dilutes carbon dioxide (CO_2), body odors, and indoor pollutants by supplying fresh air.

Industrial Air Conditioning: Process Control I

Industrial air conditioning prioritizes the temperature, moisture, and purity requirements of materials and processes rather than human comfort.

- Textile Industry: High relative humidity ($70 - 80\%$) is maintained to prevent yarn breakage and reduce static electricity.
- Printing Presses: Stringent humidity control is vital to avoid paper size fluctuations that cause color misalignment.
- Precision Machine Shops: Requires tight temperature control ($\pm 0.5^{\circ}$C) to limit thermal expansion errors in machining.
- Photographic Industry: Low humidity and temperature prevent chemical degradation of film and emulsion layers.

Applications in Electronics and Pharmaceuticals I

Modern semiconductor fabrication and pharmaceutical manufacturing demand extremely clean, controlled spaces.

- Semiconductor Cleanrooms: Requires strict particle limits (e.g., ISO Class 1 to 5) using HEPA/ULPA filtration.
- Static Control: Maintaining specific humidity ranges prevents electrostatic discharge damage to microchips.
- Pharmaceutical Processing: Low humidity is necessary during powder processing to prevent clumping and moisture absorption.
- Sterile Environments: Positive pressurization prevents external contaminant ingress into drug formulation areas.

Winter Air Conditioning Systems I

Winter air conditioning processes low-temperature dry air through heating and humidifying sequences to achieve room design conditions.

- Sensible Preheating: Raises the temperature of cold outdoor air to increase its capacity to absorb moisture.
- Humidification Methods: Air is passed through steam spray or a water washer to raise relative humidity.
- Reheating Stage: Adjusts the temperature and relative humidity to final delivery requirements.
- Winter Design Zone: Typically targeted at $20^{\circ}C - 22^{\circ}C$ dry bulb temperature and $30 - 40\%$ relative humidity.

Year-Round Air Conditioning and Energy Conservation I

Year-round systems integrate both summer cooling/dehumidification and winter heating/humidification circuits.

- System Integration: Incorporates dual cooling/heating coils or utilizes heat pump cycles for thermodynamic flexibility.
- Energy Recovery: Air-to-air energy exchangers (enthalpy wheels) recover heat and moisture from exhaust air.
- Economizer Cycle: Uses cool outdoor air for cooling when outdoor conditions permit, reducing chiller energy consumption.
- Variable Refrigerant Flow (VRF): Modulates refrigerant flow rate to match zone loads, maximizing seasonal efficiency.

Title Slide I

Course: DI05019051 - Refrigeration and Air Conditioning Lecture 33: 4.2 Psychometric Properties of air

- Unit: Air conditioning systems and analysis.
- Instructor: Mechanical Engineering Professor.
- Overview: Thermodynamic properties of moist air mixtures, their definitions, formulas, and practical significance in AC design.

Composition of Atmospheric Air I

Atmospheric air is a mixture of dry air, water vapor, and contaminants. For psychrometric analysis, we treat it as a binary mixture of dry air (a fixed mix of N2, O2, Ar, CO2) and water vapor.

- Dry air is treated as a pure substance with a constant molecular weight of approximately 28.97 kg/kmol.
- Water vapor has a molecular weight of 18.016 kg/kmol and behaves as an ideal gas at low partial pressures.
- Psychrometrics is the study of the thermodynamic properties of moist air and the processes affecting it.
- Water vapor content is highly variable, ranging from 0% in extremely cold/dry climates to about 4% by volume in hot, humid conditions.

Dalton's Law of Partial Pressures I

Dalton's Law states that the total pressure of a mixture of non-reactive gases is equal to the sum of the partial pressures of its individual components.

- Total atmospheric pressure: $p_t = p_a + p_v$, where p_a is the partial pressure of dry air and p_v is the partial pressure of water vapor.
- Both dry air and water vapor are assumed to occupy the same mixture volume V at the same mixture temperature T.
- The partial pressure of water vapor p_v cannot exceed the saturation pressure p_s of water at the dry-bulb temperature.
- When $p_v = p_s(T)$, the air is fully saturated with moisture, and any further cooling will result in condensation.

Dry-Bulb, Wet-Bulb, and Dew-Point Temperatures I

The state of moist air is characterized by three distinct temperature measurements: Dry-Bulb (DBT), Wet-Bulb (WBT), and Dew-Point (DPT) temperatures.

- Dry-Bulb Temperature (T_{db}): The actual temperature of air measured by a standard thermometer shielded from radiation.
- Wet-Bulb Temperature (T_{wb}): The temperature indicated by a thermometer wrapped in a wet wick exposed to rapidly moving air (evaporative cooling effect).
- Dew-Point Temperature (T_{dp}): The temperature at which water vapor begins to condense when moist air is cooled at constant pressure (i.e., $p_v = p_s(T_{dp})$).
- For unsaturated air, $T_{db} > T_{wb} > T_{dp}$. For saturated air, all three temperatures are equal: $T_{db} = T_{wb} = T_{dp}$.

Humidity Ratio (Specific Humidity) I

The humidity ratio or specific humidity, denoted by ω, is defined as the ratio of the mass of water vapor (m_v) to the mass of dry air (m_a) in a given volume of mixture.

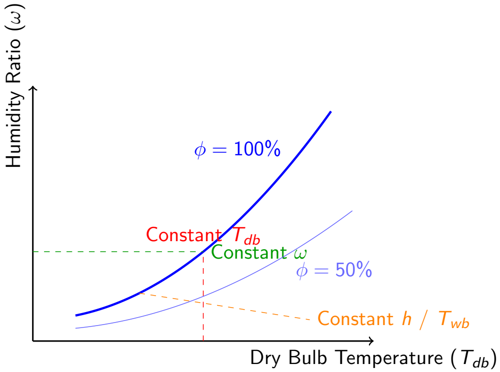
- Definition formula: $\omega = \frac{m_v}{m_a}$ (expressed in kg of water vapor per kg of dry air).
- Using the ideal gas equation: $m_v = \frac{p_v V}{R_v T}$ and $m_a = \frac{p_a V}{R_a T}$.
- Substituting gas constants ($R_a = 287.05$ J/kg K and $R_v = 461.5$ J/kg K) yields: $\omega = 0.622 \frac{p_v}{p_t - p_v}$.
- Specific humidity is independent of temperature changes unless condensation or moisture addition occurs.

Relative Humidity and Degree of Saturation I

Moisture content can be described relatively using Relative Humidity (ϕ) or Degree of Saturation (μ).

- Relative Humidity (ϕ): The ratio of the mole fraction of water vapor in a moist air sample to that in a saturated sample at the same temperature and pressure.
- Mathematical definition: $\phi = \frac{p_v}{p_s}\Big|_{T,p}$, where p_s is the saturation pressure at dry-bulb temperature.
- Degree of Saturation (μ): The ratio of the actual humidity ratio (ω) to the saturation humidity ratio (ω_s) at the same temperature and pressure.
- Formula: $\mu = \frac{\omega}{\omega_s} = \phi\left(\frac{p_t - p_s}{p_t - p_v}\right)$. Since $p_v < p_s$, μ is always slightly less than ϕ for unsaturated air.

Graphical Representation: The Psychrometric Chart I



- A psychrometric chart graphically represents the thermodynamic state of moist air at a constant barometric pressure.

Graphical Representation: The Psychrometric Chart II

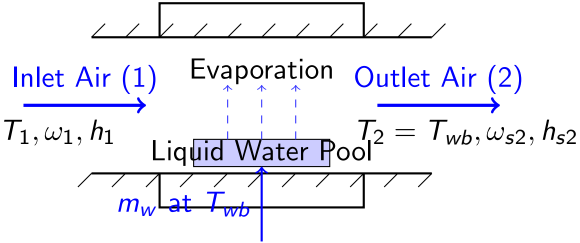
- The x-axis represents Dry Bulb Temperature (T_{db}), and the y-axis represents the Humidity Ratio (ω).
- Lines of constant relative humidity (ϕ) are curves, with the 100% curve representing saturated air.
- Lines of constant enthalpy (h) and constant wet-bulb temperature (T_{wb}) are parallel inclined lines sloping downwards to the right.

Enthalpy of Moist Air Mixture I

The total enthalpy of moist air is calculated as the sum of the enthalpy of the dry air and the enthalpy of the associated water vapor.

- Enthalpy formula: $h = h_a + \omega h_v$ (expressed in kJ per kg of dry air).
- For dry air (reference temperature 0°C): $h_a = C_{pa} T_{db} \approx 1.005\, T_{db}$ where C_{pa} is 1.005 kJ/kg K.
- For water vapor (reference liquid at 0°C): $h_v = h_g + C_{pv} T_{db} \approx 2501 + 1.88\, T_{db}$, where 2501 kJ/kg is the latent heat of vaporization at 0°C and $C_{pv} \approx 1.88$ kJ/kg K.
- Combined equation: $h = 1.005\, T_{db} + \omega(2501 + 1.88\, T_{db})$ kJ/kg of dry air.
- Humid specific heat (C_{pm}) is defined as $C_{pa} + \omega C_{pv} \approx 1.005 + 1.88\omega$ kJ/kg K.

Thermodynamic Wet-Bulb Temperature I



- The thermodynamic wet-bulb temperature is defined via an adiabatic saturation process in a steady-flow channel.
- As unsaturated air flows over a water pool in an insulated chamber, water evaporates, absorbing latent heat and lowering air temperature.
- Mass balance: $m_{a1} = m_{a2} = m_a$ and $m_a\omega_1 + m_w = m_a\omega_{s2}$.
- Energy balance: $m_a h_1 + (m_a\omega_{s2} - m_a\omega_1)h_{f2} = m_a h_{s2}$, leading to the relation: $h_1 - \omega_1 h_{f2} = h_{s2} - \omega_{s2} h_{f2}$.

Applications in Air Conditioning I

Understanding psychrometric properties is essential for the design, sizing, and analysis of HVAC systems and industrial drying processes.

- Human Comfort: Human body thermal comfort is highly sensitive to relative humidity, ideally maintained between 40% and 60%.
- Cooling Tower Design: Cooling towers utilize evaporative cooling to cool condenser water, governed by the wet-bulb temperature of the ambient air.
- AC Processes: Processes like sensible heating/cooling, cooling and dehumidification, and adiabatic mixing are mapped on psychrometric coordinates.
- System Calculations: Specific enthalpy changes determine the heating/cooling load, while humidity ratio changes determine humidification/dehumidification capacity.

4.2 Psychrometric Properties of Air I

Course: Refrigeration and Air Conditioning (DI05019051)

- Introduction to Psychrometry
- Composition of Moist Air
- Key Thermodynamic Properties of Air-Water Vapor Mixtures

Composition of Air and Dalton's Law I

Atmospheric air is modeled as a mixture of dry air and water vapor. Dalton's Law of Partial Pressures governs this mixture: $p\_t = p\_a + p\_v$, where p_t is total barometric pressure, p_a is partial pressure of dry air, and p_v is partial pressure of water vapor.

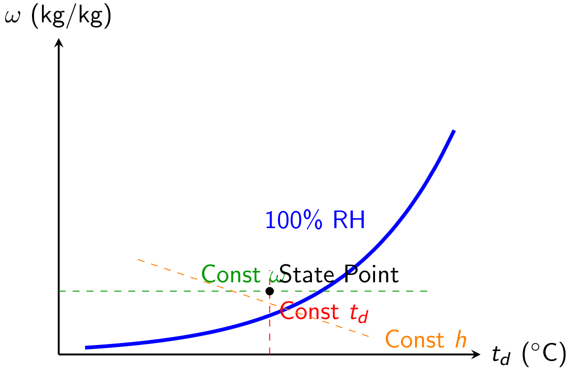
- Dry air is treated as a fixed composition mixture of nitrogen (78.08%), oxygen (20.95%), argon (0.93%), and carbon dioxide (0.04%).
- The molecular weight of dry air (M_a) is taken as 28.966 g/mol, and water vapor (M_v) is 18.016 g/mol.
- Water vapor content is highly variable, ranging from 0% in extremely cold/dry conditions to about 4% by volume in humid tropical environments.
- Dalton's Law of Partial Pressures states that the total pressure of a mixture of non-reactive gases is the sum of individual partial pressures.

Dry Bulb & Wet Bulb Temperatures I

Temperature is the most fundamental property in psychrometry. Dry Bulb Temperature (DBT, t_d) measures sensible heat, while Wet Bulb Temperature (WBT, t_w) indicates evaporative cooling capacity.

- Dry Bulb Temperature (t_d): Temperature of air measured by an ordinary thermometer shielded from radiation.
- Wet Bulb Temperature (t_w): Temperature indicated by a thermometer covered with a wet wick over which air is passed at high velocity (¿4.5 m/s).
- Wet bulb depression (t_d - t_w) is a direct measure of the dryness of air; it is zero when the air is fully saturated (t_d = t_w).
- Thermodynamic Wet Bulb Temperature is an adiabatic saturation temperature, representing the limit of evaporative cooling.

The Psychrometric Chart Structure I



- Abscissa represents Dry Bulb Temperature (DBT) along the horizontal axis.

The Psychrometric Chart Structure II

- Ordinate represents Specific Humidity / Humidity Ratio (\{}omega) along the vertical axis.
- The saturation curve bounds the chart on the left, corresponding to 100% Relative Humidity.
- Constant enthalpy (h) and constant wet-bulb temperature (t_w) lines run diagonally downwards from top-left to bottom-right.

Specific Humidity and Mixing Ratio I

Specific humidity or humidity ratio (\{}omega) is the mass of water vapor per unit mass of dry air: \{}omega = m_v / m_a. Under ideal gas assumptions: \{}omega = 0.622 * p_v / (p_t - p_v).

- The constant 0.622 represents the ratio of molecular weights of water vapor and dry air: M_v/M_a = 18.016 / 28.966 \{}u2248 0.622.
- Unlike relative humidity, specific humidity does not change when the air is heated or cooled sensibly (without adding/removing moisture).
- It is typically expressed in units of grams of water vapor per kilogram of dry air (g/kg_da) or kg/kg_da.
- In psychrometric calculations, calculations of mass balance of water are directly proportional to changes in \{}omega.

Relative Humidity vs. Degree of Saturation I

Relative Humidity (\{}phi) is the ratio of mole fraction of water vapor in moist air to that in saturated air at the same temperature and pressure: \{}phi = p_v / p_s. Degree of Saturation (\{}mu) is the ratio of actual humidity ratio to saturated humidity ratio: \{}mu = \{}omega / \{}omega_s.

- Relative humidity (\{}phi) measures how close the air is to saturation at its current temperature, expressed as a percentage.
- Partial pressure of water vapor in saturated air (p_s) depends solely on the temperature and can be calculated using equations like Antoine's.
- Relation between \{}phi and \{}mu: \{}mu = \{}phi * [(p_t - p_s) / (p_t - p_v)].

Relative Humidity vs. Degree of Saturation II

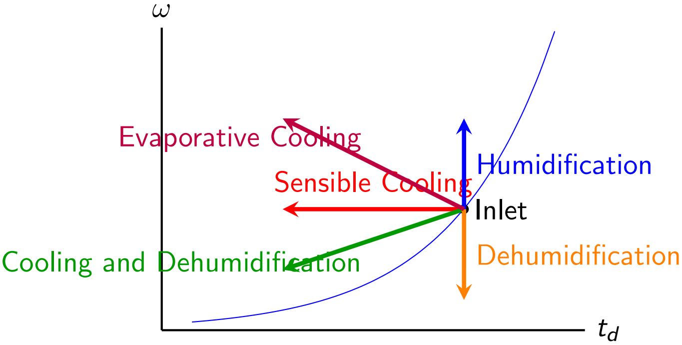
- At low moisture content (typical HVAC comfort zones), \{}phi and \{}mu are numerically very close, but they diverge at high temperatures and humidities.

Dew Point Temperature and Condensation I

Dew Point Temperature (DPT, t_{dp}) is the temperature to which moist air must be cooled at constant pressure and humidity ratio to reach saturation. At this point, condensation begins.

- If the dry bulb temperature is cooled below t_{dp}, water vapor condenses out of the mixture as liquid water (dew).
- For saturated air, Dry Bulb Temperature = Wet Bulb Temperature = Dew Point Temperature ($t_d = t_w = t_{dp}$).
- Dew point is a direct function of the partial pressure of water vapor (p_v); it corresponds to the saturation temperature of water at p_v.
- Measuring DPT is critical for preventing condensation on cold ducts, structural walls, and double-paned windows.

Sensible and Latent Processes on the Chart I



- Sensible Heating/Cooling: Horizontal path (constant \{}omega) to the right/left respectively.
- Humidification/Dehumidification: Vertical path (constant t_d) upwards/downwards respectively.

Sensible and Latent Processes on the Chart II

- Cooling and Dehumidification: Diagonal path moving left and down, typical of an air conditioner cooling coil process.
- Evaporative Cooling (Adiabatic Humidification): Diagonal path moving up-left along constant wet bulb temperature/enthalpy lines.

Enthalpy of Moist Air Mixture I

The total enthalpy of moist air (h) is the sum of enthalpies of dry air and water vapor: h = h_a + \{}omega * h_v. Approximating with sensible and latent terms: h = 1.005 * t_d + \{}omega * (2501 + 1.88 * t_d) kJ/kg_da (where t_d is in degrees C).

- Specific enthalpy is expressed per unit mass of dry air (kJ/kg of dry air) to keep the reference mass constant during moist processes.
- The term 1.005 * t_d is the sensible enthalpy of dry air (using specific heat c_{pa} \{}u2248 1.005 kJ/kg\{}u00b7K).
- The constant 2501 kJ/kg is the latent heat of vaporization of water (h_{fg}) at the reference state of 0 degrees C.
- The term 1.88 * t_d represents the sensible heat of superheated water vapor (using specific heat c_{pv} \{}u2248 1.88 kJ/kg\{}u00b7K).

Specific Volume and Density of Moist Air I

Humid volume (v) is the volume of moist air per unit mass of dry air: v = V / m_a = R_a * T / (p_t - p_v) = R_a * T / p_a m^3/kg_da. Density of moist air is the total mass divided by total volume: \{}rho = (m_a + m_v) / V = (1 + \{}omega) / v.

- Specific volume of dry air R_a is 287.055 J/kg\{}u00b7K, and temperature T must be in Kelvin.
- Humid volume is used to convert volumetric air flow rates (e.g., cubic meters per second) to mass flow rates (kg of dry air per second).
- Since the molecular weight of water vapor (18.016) is less than that of dry air (28.966), moist air is less dense than dry air at the same temperature and pressure.
- This density difference is the driving force for natural convection in meteorological cycles and cooling towers.

Title Slide I

Course: Refrigeration and AC

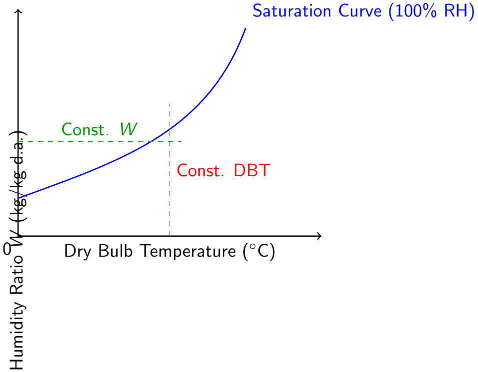
- Unit: Air conditioning.

Introduction to the Psychrometric Chart I

A psychrometric chart is a graphical representation of the thermodynamic properties of moist air at a constant barometric pressure (typically standard sea-level pressure of 101.325 kPa).

- It maps the mixture of dry air and water vapor, allowing engineers to visualize air conditioning processes without solving complex governing equations.
- The state of moist air is fixed by specifying any two independent thermodynamic properties (Gibbs Phase Rule for a binary two-phase system).
- Standard charts use Dry Bulb Temperature (DBT) on the horizontal axis and Humidity Ratio (W) on the vertical axis.
- Calculations for altitudes significantly above sea level require correction factors or altitude-specific psychrometric charts due to lower total pressure.

Basic Layout and Axes of the Psychrometric Chart I



- The horizontal axis (abscissa) represents the Dry Bulb Temperature (DBT), increasing from left to right.

Basic Layout and Axes of the Psychrometric Chart II

- The vertical axis (ordinate) on the right-hand side represents the Humidity Ratio (W), also called specific humidity, in kg of water vapor per kg of dry air.
- The curved boundary on the left represents the saturation curve where Relative Humidity (RH) is 100%.
- Any state point within the envelope represents unsaturated air; points on the curve represent saturated air.

Psychrometric Properties: DBT, W, and RH I

Dry Bulb Temperature (DBT), Humidity Ratio (W), and Relative Humidity (RH) form the primary grid of the psychrometric chart.

- Dry Bulb Temperature (DBT) lines are vertical, straight, and uniformly spaced parallel lines corresponding to the actual temperature of air.
- Humidity Ratio (W) lines are horizontal, straight, and parallel lines representing the mass of water vapor per unit mass of dry air.
- Relative Humidity (RH) lines are curved lines extending from the bottom-left to top-right, parallel to the 100% saturation curve.
- RH values decrease as we move further right and down from the saturation curve, indicating drier air at higher temperatures.

Wet Bulb and Dew Point Temperatures I

Wet Bulb Temperature (WBT) and Dew Point Temperature (DPT) are critical for evaluating evaporation rates and condensation thresholds.

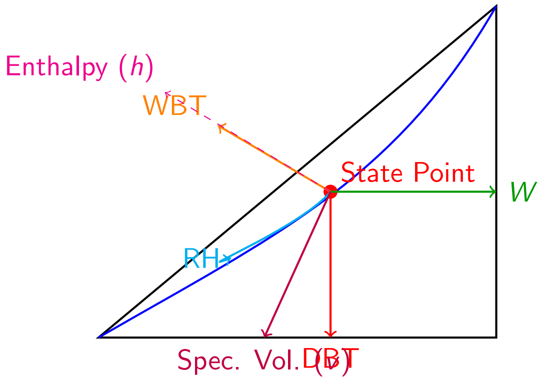
- Wet Bulb Temperature (WBT) lines are straight diagonal lines sloping downwards to the right, starting from the saturation curve.
- Dew Point Temperature (DPT) of a state point is found by moving horizontally to the left (constant W) until intersecting the saturation curve.
- At saturation (100% RH), the Dry Bulb, Wet Bulb, and Dew Point Temperatures are equal ($DBT = WBT = DPT$).
- For unsaturated air, DBT is always greater than WBT, which is greater than DPT ($DBT > WBT > DPT$).

Enthalpy and Specific Volume Lines I

Enthalpy represents the total heat content of moist air, while specific volume indicates its density characteristics.

- Enthalpy (h) lines are diagonal lines sloping downwards from top-left to bottom-right, representing energy in kJ/kg of dry air.
- Enthalpy lines are nearly parallel to WBT lines, but they differ slightly because adiabatic saturation and constant WBT processes are not thermodynamically identical.
- Specific volume (v) lines are diagonal lines with a much steeper slope than enthalpy lines, expressed in cubic meters per kilogram of dry air (m^3/kg d.a.).
- Specific volume increases with both temperature and moisture content, and is used to convert mass flow rates to volumetric flow rates.

Interrelation of Property Lines at a State Point I



- A single state point is fixed by the intersection of any two independent properties on the chart.

- Once the state point is located, all other five properties can be read directly from the corresponding intersecting lines.
- This diagram illustrates the directional changes: vertical shifts change moisture content, horizontal shifts change sensible temperature.
- Diagonal shifts along the WBT/enthalpy lines represent evaporative cooling or adiabatic humidification.

Representing Basic Psychrometric Processes I

Air conditioning processes correspond to paths on the psychrometric chart, reflecting shifts in sensible and latent heat.

- Sensible Heating/Cooling: Horizontal paths showing temperature change at constant humidity ratio (no moisture addition or removal).
- Humidification/Dehumidification: Vertical paths showing changes in moisture content at constant dry bulb temperature.
- Heating and Humidification: Diagonal path pointing up and to the right, typical of winter air conditioning systems.
- Cooling and Dehumidification: Diagonal path pointing down and to the left, which is the standard summer air conditioning process.

Practical Application: Mixing and Coil Performance I

Engineers use the chart to analyze air mixing and evaluate cooling coil parameters like Sensible Heat Factor (SHF).

- Adiabatic Mixing of two air streams: The state of the resulting mixture lies on a straight line connecting the two initial states, divided in inverse proportion to their dry air mass flow rates.
- Sensible Heat Factor (SHF) is the ratio of sensible heat to total heat ($SHF = Q_s/(Q_s + Q_l)$); it determines the slope of the process line.
- Apparatus Dew Point (ADP) is the effective surface temperature of a cooling coil, found where the cooling-dehumidification line intersects the saturation curve.
- Bypass Factor (BPF) represents the fraction of air that passes through the coil without contacting the cooling surfaces, calculated using temperature ratios.

Key Engineering Takeaways I

A summary of the psychrometric chart's utility in HVAC load calculations and design.

- The chart serves as an invaluable visual aid for troubleshooting and explaining air conditioning processes to clients and technicians.
- Accurate determination of state points allows the direct extraction of enthalpy values to calculate heating and cooling loads ($Q = m_{da} \times \Delta h$).
- Altitude adjustments are critical because a drop in barometric pressure increases the humidity ratio for the same vapor pressure.
- Mastery of the psychrometric chart is fundamental to designing energy-efficient, thermally comfortable HVAC systems.

Detailed Concept 1 I

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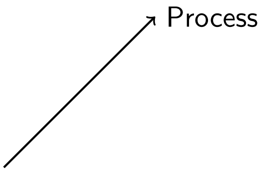

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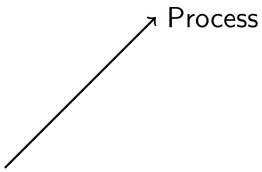

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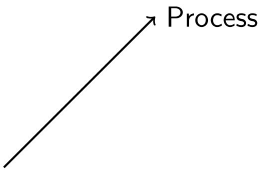

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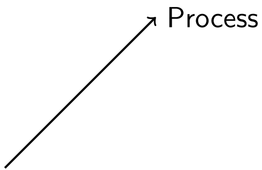

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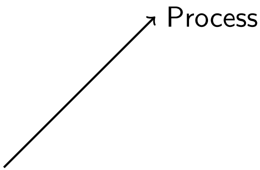

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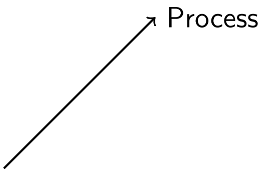

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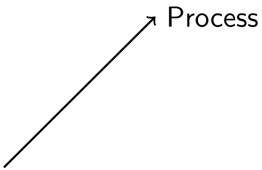

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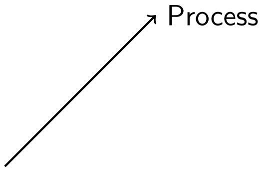

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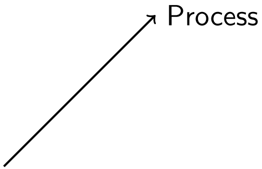

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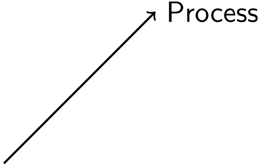

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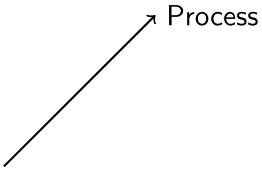

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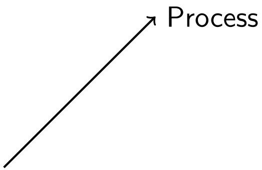

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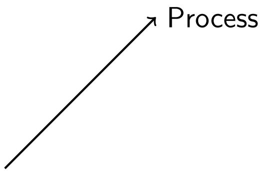

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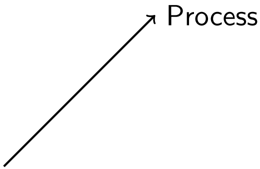

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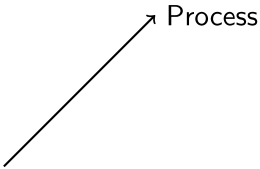

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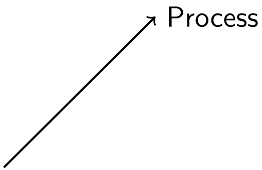

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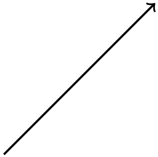

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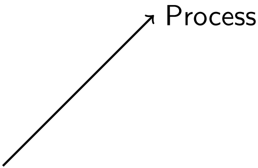

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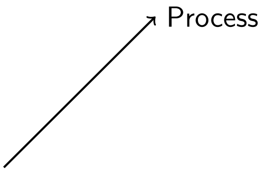

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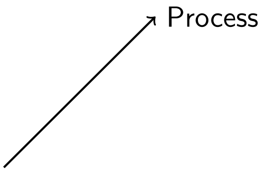

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