GUJARAT TECHNOLOGICAL UNIVERSITY

BE-3 SEMESTER – PAPER SOLUTION – WINTER 2024

Subject Name & Code:

Engineering Thermodynamics 3131905

Q-1: (a) What do you mean by thermodynamic equilibrium? Explain in detail. (3 Marks)

Answer:

Thermodynamic equilibrium refers to a condition where there is **no net change** in the state of a system over time. It includes:

1. **Thermal Equilibrium:** No temperature difference within or across boundaries.
2. **Mechanical Equilibrium:** No unbalanced forces; pressure remains constant.
3. **Chemical Equilibrium:** No chemical reactions or composition changes occur.

When all three are satisfied, the system is in thermodynamic equilibrium.

Q-1: (b) 'Entropy is a property of the system.' Prove the statement. (4 Marks)

Answer:

To prove that entropy is a property, we must show it is **a point function** (depends only on state, not path).

From Clausius' theorem:

$$\oint \frac{\delta Q}{T} = 0 \quad \text{(reversible cycle)}$$

This implies:

$$\int_1^2 \frac{\delta Q}{T} = S_2 - S_1$$

Hence, the change in entropy depends only on the end states (1 and 2), not on the path, proving entropy is a **property** of the system.

Q-1: (c) Write two major statements of second law of thermodynamics and show that violation of one statement leads to violation of other one. (7 Marks)

Answer:

Kelvin-Planck Statement:

"It is impossible to construct a device operating in a cycle that extracts heat from a single reservoir and converts it entirely into work."

Clausius Statement:

"It is impossible for a device to transfer heat from a colder to a hotter body without external work."

Proof of Equivalence:

- Suppose **Clausius Statement** is violated: heat flows from cold to hot without work.
- This heat is then converted entirely into work using a Kelvin-Planck violating engine.
- Hence, net result: **heat → work without any reservoir → violates Kelvin-Planck.**

Vice versa also applies. Thus, **violation of one implies violation of the other**.

Q-2: (a) Explain in brief - PMM 1 and PMM 2. (3 Marks)

Answer:

PMM-I (Perpetual Motion Machine of the First Kind):

- A hypothetical machine that produces **work without energy input**.
- It **violates the First Law of Thermodynamics** (energy conservation).
- **Impossible**, as energy cannot be created or destroyed.

Example: A machine that runs indefinitely and powers a device without needing fuel or power source.

PMM-II (Perpetual Motion Machine of the Second Kind):

- A hypothetical machine that **converts all absorbed heat into work** without any heat rejection.
- It **violates the Second Law of Thermodynamics**.
- **Impossible**, because some heat must always be rejected to a sink.

Conclusion: Both are non-realizable and serve only as theoretical tools to understand thermodynamic laws.

Q-2: (b) Define and explain: (i) Homogenous and Heterogeneous system (ii) Intensive and Extensive properties (4 Marks)

Answer:

(i) Homogeneous vs Heterogeneous System

- **Homogeneous System:** Uniform composition and properties throughout.
  - *Example:* Air, salt water.
- **Heterogeneous System:** Composed of more than one phase or different properties in different regions.
  - *Example:* Water + ice, oil + water.

(ii) Intensive vs Extensive Properties

- **Intensive Property:** Independent of mass.
  - *Examples:* Temperature, pressure, density.
- **Extensive Property:** Dependent on system size or mass.
  - *Examples:* Volume, mass, energy.

Q-2: (c) In a gas turbine unit, the gases flow through the turbine is 15 kg/s and the power developed by the turbine is 12000 kW. The enthalpies of gases at the inlet and outlet are 1260 kJ/kg and 400 kJ/kg respectively, and the velocity of gases at the inlet and outlet are 50 m/s and 110 m/s respectively. Calculate: (i) The rate at which heat is rejected to the turbine and (ii) The area of the inlet pipe given that the specific volume of the gases at the inlet is 0.45 m3/kg. (7 Marks)

Answer:

Given:

- Mass flow rate, $\dot{m} = 15\,\mathrm{kg/s}$
- Power developed, $W = 12000\,\mathrm{kW}$
- $h_1 = 1260\,\mathrm{kJ/kg},\ h_2 = 400\,\mathrm{kJ/kg}$
- $V_1 = 50\,\mathrm{m/s},\ V_2 = 110\,\mathrm{m/s}$
- Specific volume $v = 0.45\,\mathrm{m^3/kg}$

(i) Heat Rejected from Turbine

Apply **S.F.E.E.** for turbine (per kg):

$$\dot{W} = \dot{m}\left[h_1 - h_2 + \frac{V_1^2 - V_2^2}{2 \cdot 1000}\right] - \dot{Q} \Rightarrow \dot{Q} = \dot{m}\left[h_1 - h_2 + \frac{V_1^2 - V_2^2}{2 \cdot 1000}\right] - \dot{W}$$

$$h_1 - h_2 = 860\,\mathrm{kJ/kg},\ \frac{V_1^2 - V_2^2}{2000} = \frac{2500 - 12100}{2000} = -4.8$$

$$\text{Total term} = 860 - 4.8 = 855.2\,\mathrm{kJ/kg}$$

$$\dot{Q} = 15 \cdot 855.2 - 12000 = 12828 - 12000 = \boxed{828\,\mathrm{kW}\ (\text{heat rejected})}$$

(ii) Area of Inlet Pipe

$$A = \frac{\dot{m} \cdot v}{V} = \frac{15 \cdot 0.45}{50} = \boxed{0.135\,\mathrm{m}^2}$$

✅ **Final Answers for Q.2 (c):**

- (i) Heat rejected: 828 kW
- (ii) Inlet pipe area: 0.135 m^2

OR

Q-2: (c) 300 kJ/s of heat is supplied at a constant fixed temperature of 290°C to a heat engine. The heat rejection takes place at 8.5°C. The following results were obtained : (i) 215 kJ/s are rejected. (ii) 150 kJ/s are rejected. (iii) 75 kJ/s are rejected. Classify which of the result report a reversible cycle or irreversible cycle or impossible results. (7 Marks)

Answer:

🔶 **Given:**

- Heat Supplied, $Q_{in} = 300\,\text{kJ/s}$ at $T_H = 290^\circ C = 563\ K$
- Heat Rejected at $T_L = 8.5^\circ C = 281.5\ K$

We are given three cases of heat rejection Q out:

1. 215 kJ/s
2. 150 kJ/s
3. 75 kJ/s

🔶 **Step 1: Find Carnot (Maximum) Efficiency**

$$\eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H} = 1 - \frac{281.5}{563} = 1 - 0.5 = \boxed{0.5 \text{ or } 50\%}$$

So the maximum possible work =

$$W_{max} = Q_{in} \cdot \eta_{\text{Carnot}} = 300 \cdot 0.5 = \boxed{150\,\text{kJ/s}}$$

Also, from first law:

$$W = Q_{in} - Q_{out}$$

🔶 **Now evaluate each case:**

✅ **Case (i):** $Q_{out} = 215\,\text{kJ/s}$

$$W = 300 - 215 = 85\,\text{kJ/s}$$

Efficiency:

$$\eta = \frac{85}{300} = 0.2833 = 28.33\%$$

Since η<η Carnot , this is a **real/irreversible cycle**.

✅ **Case (ii):** $Q_{out} = 150\,\text{kJ/s}$

$$W = 300 - 150 = 150\,\text{kJ/s} \Rightarrow \eta = \frac{150}{300} = 0.5 = \eta_{\text{Carnot}}$$

This is the **ideal/reversible cycle**.

✅ **Case (iii):** $Q_{out} = 75\,\text{kJ/s}$

$$W = 300 - 75 = 225\,\text{kJ/s} \Rightarrow \eta = \frac{225}{300} = 0.75 = 75\%$$

But η>η Carnot ⇒ **violates Second Law**

🔴 This is an **impossible result**.

✅ **Final Classification:**

Case	Heat Rejected (kJ/s)	Work Output (kJ/s)	Efficiency (%)	Type of Cycle
(i)	215	85	28.33%	Irreversible
(ii)	150	150	50%	Reversible
(iii)	75	225	75%	**Impossible**

Q-3: (a) Give comparison of Carnot and Rankine cycle. (3 Marks)

Answer:

Aspect	Carnot Cycle	Rankine Cycle
Heat Addition	Isothermal process	Constant pressure in boiler
Expansion	Isentropic	Isentropic expansion in turbine
Practicality	**Ideal & impractical** (requires variable temp. heat source)	Practical and widely used in steam power plants
Efficiency	Highest theoretical efficiency	Lower than Carnot but feasible
Cycle Representation	2 isothermal + 2 adiabatic processes	2 isentropic + 2 constant pressure processes

Q-3: (b) A rigid cylinder containing 0.004 m3 of nitrogen at 1 bar and 300 K is heated reversibly until temperature becomes 400 K. Determine : (i) The heat supplied. (ii) The entropy change. Assume nitrogen to be perfect gas (molecular mass = 28) and take γ = 1.4 (4 Marks)

Answer:

Given:

- Volume $V = 0.004\,\mathrm{m}^3$,
- $P_1 = 1\,\mathrm{bar} = 100\,\mathrm{kPa}$,
- $T_1 = 300\,K$,
- $T_2 = 400\,K$,
- Molecular mass $M = 28$, $\gamma = 1.4$

Step 1: Calculate mass using Ideal Gas Law:

$$PV = mRT \Rightarrow m = \frac{PV}{RT}$$

Use $R = \frac{8.314}{M} = \frac{8.314}{28} = 0.297\,\mathrm{kJ/kg}$/,k

$$m = \frac{100 \cdot 0.004}{0.297 \cdot 300} = \frac{0.4}{89.1} = 0.00449\,\text{kg}$$

Step 2: Find Cv

$$\gamma = \frac{C_p}{C_v} \Rightarrow C_v = \frac{R}{\gamma - 1} = \frac{0.297}{0.4} = 0.7425\,\text{kJ/kg}\backslash\text{cdotp}\text{K}$$

(i) Heat Supplied:

$$Q = mC_v(T_2 - T_1) = 0.00449 \cdot 0.7425 \cdot 100 = \boxed{0.3335\,\text{kJ}}$$

(ii) Entropy Change:

$$\Delta S = mC_v \ln\left(\frac{T_2}{T_1}\right) = 0.00449 \cdot 0.7425 \cdot \ln\left(\frac{400}{300}\right)$$

$$\ln(1.333) = 0.2877 \Rightarrow \Delta S = 0.00449 \cdot 0.7425 \cdot 0.2877 = \boxed{0.00096\,\text{kJ/K}}$$

Q-3: (c) Write a short note on Bomb calorimeter. (7 Marks)

Answer:

A **Bomb Calorimeter** is a device used to determine the **Calorific Value (CV)** of solid and liquid fuels under **constant volume combustion**.

Construction:

- **Steel bomb**: strong vessel with sample and oxygen
- **Calorimeter vessel**: holds water, bomb submerged
- **Stirrer and Thermometer**
- **Ignition coil**: to ignite fuel electrically
- **Insulated container**

Working:

1. Fuel is placed in bomb with oxygen.

2. Bomb is placed in calorimeter with known water mass.
3. Fuel is ignited → combustion → heat released
4. Temperature rise in water is recorded
5. Using temperature rise, calorific value is calculated

Formula:

$$CV = \frac{(W + w) \cdot \Delta T}{m}$$

Where:

- W = water mass
- w = water equivalent of calorimeter
- ΔT = temperature rise
- m = fuel mass

Diagram:

OR

Q-3: (a) Explain the concept of available and unavailable energy. When does the system become dead? (3 Marks)

Answer:

🔹 **Available Energy (Exergy):**

The portion of energy that **can be converted into useful work** under ideal (reversible) conditions with respect to the surroundings.

Example: In a heat engine, only part of the supplied heat can be converted into work—the rest must be rejected.

🔹 **Unavailable Energy (Anergy):**

The portion of energy that **cannot be converted into work** due to limitations imposed by the **Second Law of Thermodynamics** (usually rejected to the surroundings).

$$\text{Unavailable energy} = Q\left(\frac{T_0}{T}\right)$$

Where T0 is the ambient temperature.

◆ **Dead State:**

A system is said to be in a **dead state** when its temperature and pressure are in equilibrium with the surroundings.
→ **No work or heat interaction** is possible.

At dead state:

- Available energy = 0
- System becomes thermodynamically inert

Q-3: (b) Explain the terms irreversibility and effectiveness. State types of irreversibilities. (4 Marks)

Answer:

◆ **Irreversibility:**

It is the **loss of available energy (exergy)** due to non-idealities (friction, unrestrained expansion, mixing, heat transfer with finite temperature difference, etc.).

$$I = W_{\text{rev}} - W_{\text{actual}} \quad \text{or} \quad I = T_0 \cdot \Delta S_{\text{universe}}$$

◆ **Effectiveness (η):**

It is the **ratio of actual work output to the reversible work output**.

$$\text{Effectiveness} = \frac{W_{\text{actual}}}{W_{\text{reversible}}}$$

- Higher effectiveness = more efficient and less irreversible.

◆ **Types of Irreversibility's:**

1. **Internal:**

- Friction, turbulence, mixing, inelastic deformation

2. **External:**
   - Heat transfer with finite temperature difference, unrestrained expansion, electrical resistance heating

Q-3: (c) 5 kg of water at 00C is exposed to reservoir at 980C. Calculate the change of entropy of water, reservoir and universe. Assume that specific heat of water is 4.187 KJ/Kg-K. (7 Marks)

Answer:

Given:

- Mass of water, $m = 5\,\text{kg}$
- Initial temperature of water $T_1 = 0^\circ C = 273\,K$
- Final temperature = Reservoir temp = $T_2 = 98^\circ C = 371\,K$
- $C_p = 4.187\,\text{kJ}/\text{kg}\text{\cdotpK}$

◆ **(i) Entropy change of water:**

$$\Delta S_{\text{water}} = m \cdot C_p \cdot \ln\left(\frac{T_2}{T_1}\right) = 5 \cdot 4.187 \cdot \ln\left(\frac{371}{273}\right)$$

$$\ln\left(\frac{371}{273}\right) = \ln(1.3597) = 0.307 \Rightarrow \Delta S_{\text{water}} = 5 \cdot 4.187 \cdot 0.307 \approx \boxed{6.42\,\text{kJ}/\text{K}}$$

◆ **(ii) Entropy change of reservoir:**

Heat transferred to water =

$$Q = mC_p(T_2 - T_1) = 5 \cdot 4.187 \cdot (371 - 273) = 5 \cdot 4.187 \cdot 98 = 2052\,\text{kJ}$$

Since heat leaves the reservoir:

$$\Delta S_{\text{reservoir}} = \frac{-Q}{T_{\text{reservoir}}} = \frac{-2052}{371} = \boxed{-5.53\,\text{kJ}/\text{K}}$$

◆ **(iii) Entropy change of universe:**

$$\Delta S_{\text{universe}} = \Delta S_{\text{water}} + \Delta S_{\text{reservoir}} = 6.42 - 5.53 = \boxed{0.89\,\text{kJ/K}}$$

✅ **Final Answers :**

Component	Entropy Change (kJ/K)
Water	+6.42
Reservoir	−5.53
Universe	+0.89

Q-4: (a) State advantages and disadvantages of regenerative feed heating. (3 Marks)

Answer:

Regenerative Feed Heating:

A technique in the Rankine cycle where some steam is extracted from the turbine to preheat feedwater before it enters the boiler.

Advantages:

1. **Improved thermal efficiency** due to reduced fuel consumption.
2. **Less thermal stress** on boiler components.
3. **Reduced condenser load** as less steam is condensed.
4. **Increased cycle mean temperature of heat addition.**

Disadvantages:

1. **Complex design and control** requirements.
2. **Initial cost is high** due to additional equipment.
3. **Reduced net power output** because of steam extraction.

Q-4: (b) Derive an expression for thermal efficiency of an Otto cycle. (4 Marks)

Answer:

Otto Cycle Processes:

1–2: Isentropic Compression
2–3: Constant Volume Heat Addition
3–4: Isentropic Expansion
4–1: Constant Volume Heat Rejection

Thermal Efficiency (η):

$$\eta = 1 - \frac{Q_{out}}{Q_{in}} = 1 - \frac{C_v(T_4 - T_1)}{C_v(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

Using isentropic relations:

$$\frac{T_2}{T_1} = r^{\gamma-1}, \quad \frac{T_3}{T_4} = r^{\gamma-1}$$

So:

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

Where:

- r= Compression ratio
- γ=Cp/Cv

✅ **Final Expression:**

$$\boxed{\eta_{Otto} = 1 - \frac{1}{r^{\gamma-1}}}$$

Q-4: (c) In a steam power cycle, the steam supply is at 15 bar and dry and saturated. The condenser pressure is 0.4 bar. Calculate the Carnot and Rankine efficiencies of the cycle. Neglect pump work. (7 Marks)

Answer:

Given:

- Boiler pressure = 15 bar
- Condenser pressure = 0.4 bar
- At 15 bar, saturated steam:
- $h_1 = h_g = 2783.1\,\text{kJ/kg}, s_1 = s_g = 6.441\,\text{kJ/kg}\backslash\text{cdotpK}$
- At 0.4 bar:
- $h_f = 340.5,\ h_{fg} = 2313.3,\ s_f = 1.433,\ s_{fg} = 6.836$

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1. Rankine Efficiency:

Find quality x2 at condenser (isentropic expansion):

$$s_2 = s_1 = 6.441 = s_f + x_2 \cdot s_{fg} = 1.433 + x_2 \cdot 6.836 \Rightarrow x_2 = \frac{6.441 - 1.433}{6.836} =$$

$$= 0.733 \Rightarrow h_2 = h_f + x_2 \cdot h_{fg} = 340.5 + 0.733 \cdot 2313.3 = 2036$$

$$\eta_{Rankine} = \frac{h_1 - h_2}{h_1} = \frac{2783.1 - 2036.7}{2783.1} = \boxed{26.8\%}$$

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2. Carnot Efficiency:

Use saturation temperatures:

- $T_{high} = T_{sat@15bar} = 198.3 + 273 = 471.3\ K$
- $T_{low} = T_{sat@0.4bar} = 75.9 + 273 = 348.9\ K$

$$\eta_{Carnot} = 1 - \frac{T_{low}}{T_{high}} = 1 - \frac{348.9}{471.3} = \boxed{25.97\%}$$

✅ **Final Answers:**

- **Rankine Efficiency:** 26.8%
- **Carnot Efficiency:** 25.97%

OR

Q-4: (a) State the assumptions made for analysis of air standard cycles. (3 Marks)

Answer:

- **Air Standard Cycle Assumptions:**

1. **Working Fluid is Air**
   - Air behaves as an ideal gas and circulates continuously in the cycle.
2. **Air Has Constant Properties**
   - Specific heats Cp, Cv, and γ are constant.
3. **All Processes Are Internally Reversible**
   - No friction, turbulence, or other irreversibilities are present.
4. **Heat Addition and Rejection are External**
   - Heat transfer is modeled as occurring at constant volume or pressure.
5. **No Change in Mass of Air**
   - No fuel is added or exhaust removed; purely theoretical analysis.
6. **Closed Cycle Operation**
   - The cycle repeats with the same working fluid.

Q-4: (b) Explain effect of regeneration on the performance of Rankine cycle using appropriate diagram. (4 Marks)

Answer:

- **Regeneration in Rankine Cycle:**

Regeneration is a technique where **part of the steam is extracted from the turbine** to preheat the feedwater before it enters the boiler.

- **Benefits:**

- Increases **thermal efficiency**
- Reduces **fuel consumption**

- Reduces the temperature difference during heat addition → less entropy generation

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◆ **Working:**

1. Steam expands partially in turbine → extraction point
2. Extracted steam heats feedwater in **feedwater heater**
3. Remaining steam continues expansion
4. Preheated feedwater enters boiler → less heat required

◆ **T-s Diagram Explanation:**

Draw a T-s diagram showing:

- Two expansions: from high pressure to extraction point and then to condenser
- A curved line showing feedwater heating (regeneration)
- Regeneration reduces heat input area, increasing efficiency

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◆ **Result:**

Regenerative cycle has **higher efficiency** than simple Rankine cycle.

Q-4: (c) Explain principle of increase of entropy. (7 Marks)

Answer:

◆ **Principle:**

The entropy of an **isolated system** always increases or remains constant; it **never decreases**.

◆ **Mathematical Formulation:**

$$\Delta S_{\text{universe}} = \Delta S_{\text{system}} + \Delta S_{\text{surroundings}} \geq 0$$

- For **reversible processes**: $\Delta S=0$
- For **irreversible processes**: $\Delta S>0$

◆ **Physical Meaning:**

- Entropy measures **disorder** or **randomness**.
- Every real process involves losses (like friction, heat dissipation) → increases disorder.
- It gives the **direction of natural processes**, e.g., heat flows from hot to cold.

◆ **Applications:**

- Justifies **efficiency limitations** in engines
- Forms the base of **Second Law of Thermodynamics**
- Used to calculate **irreversibility** and design **reversible systems**

◆ **Conclusion:**

The principle of increase of entropy ensures that **all natural and spontaneous processes** lead to an increase in the entropy of the universe, limiting the **maximum work output**.

Q-5: (a) An inventor claims that a new heat cycle will develop 0.4 kW for a heat addition of 32.5 kJ/min. The temperature of heat source is 1990 K and that of sink is 850 K. Is his claim possible? (3 Marks)

Answer:

Step 1: Convert given data to same units

- Heat input $Q_{in} = 32.5\,\mathrm{kJ/min} = \frac{32.5}{60} = 0.542\,\mathrm{kJ/s}$
- Claimed power output W=0.4 kW

Step 2: Carnot Efficiency

$$\eta_{Carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{850}{1990} = 0.5724 = 57.24\%$$

Step 3: Maximum possible work

$$W_{max} = \eta \cdot Q_{in} = 0.5724 \cdot 0.542 = 0.310\,\text{kW}$$

✅ **Conclusion:**

The inventor claims **0.4 kW**, but maximum possible output is **0.310 kW**. Hence, **the claim violates the Second Law of Thermodynamics and is not possible.**

Q-5: (b) Compare Otto, Diesel and Dual cycles for (i) Same compression ratio and heat supplied (ii) Same maximum pressure and temperature (4 Marks)

Answer:

(i) Same Compression Ratio and Heat Supplied:

$$\boxed{\eta_{Otto} > \eta_{Dual} > \eta_{Diesel}}$$

- Otto adds heat at constant volume ⇒ higher peak temperature ⇒ better efficiency.
- Diesel adds heat at constant pressure ⇒ more time ⇒ lower efficiency.
- Dual is in between (part constant volume, part constant pressure).

(ii) Same Maximum Pressure and Temperature:

$$\boxed{\eta_{Diesel} > \eta_{Dual} > \eta_{Otto}}$$

- With same max pressure & temperature, Diesel compresses more air ⇒ better work output.
- Otto's efficiency drops under this constraint.
- Dual again remains in between.

✅ **Summary Table:**

Condition	Efficiency Order
Same compression & heat supplied	Otto > Dual > Diesel

Condition	Efficiency Order
Same max pressure & temperature	Diesel > Dual > Otto

Q-5: (c) Explain simple Vapour Compression Refrigeration (VCR) cycle with P-h and T s diagrams. (7 Marks)

Answer:

The **Vapour Compression Refrigeration Cycle** is the most commonly used refrigeration system.

Processes:

1. **1–2: Isentropic Compression**
    - Low-pressure vapor compressed to high pressure
    - Temperature and pressure increase
2. **2–3: Condensation at constant pressure**
    - Vapor condenses into liquid in the condenser
    - Heat is rejected to surroundings
3. **3–4: Expansion (Throttling)**
    - High-pressure liquid is expanded to low pressure
    - No heat exchange; enthalpy remains constant
4. **4–1: Evaporation at constant pressure**
    - Low-pressure liquid evaporates absorbing heat
    - Cooling effect occurs

T-s and P-h Diagrams:

- **T-s diagram:** Shows temperature vs entropy
    - Rectangle shape for ideal cycle
- **P-h diagram:** Pressure vs enthalpy
    - Easy to determine work and heat transfer areas

- Used in refrigeration calculations

Refrigeration Effect (RE):

$$RE = h_1 - h_4$$

Compressor Work:

$$W = h_2 - h_1$$

Coefficient of Performance (COP):

$$COP = \frac{RE}{W} = \frac{h_1 - h_4}{h_2 - h_1}$$

✅ **Applications:**

- Domestic refrigerators
- Air conditioning systems
- Cold storage and ice plants

OR

Q-5: (a) Explain minimum air volume requirement for complete combustion of 1 m3 Hydrogen fuel. (3 Marks)

Answer:

🔹 **Balanced Chemical Equation:**

$$2H_2 + O_2 \rightarrow 2H_2O$$

So, **2 volumes of hydrogen** need **1 volume of oxygen**
⇒ 1 m^3 H_2 needs $\frac{1}{2}\,\mathrm{m}^3$ of O_2

🔹 **Air Composition:**

- Air contains **21% O_2 by volume**

$$\text{Volume of air required} = \frac{0.5}{0.21} \approx \boxed{2.38\,\mathrm{m}^3}$$

✅ **Final Answer:**

Minimum air volume required = **2.38 m^3** of air for complete combustion of **1 m^3 of hydrogen fuel**

Q-5: (b) Explain the following terms: (i) Adiabatic flame temperature (ii) Enthalpy of reaction (iii) Enthalpy of formation (iv) Stoichiometric air fuel ratio (4 Marks)

Answer:

(i) Adiabatic Flame Temperature:

- It is the **maximum temperature** reached by products of combustion when **no heat is lost** to surroundings.
- Depends on **initial conditions** and **fuel–air mixture**.

(ii) Enthalpy of Reaction (ΔH reaction):

- The **heat change** during a chemical reaction at constant pressure.
- It is the **difference in enthalpy** between products and reactants:

$$\Delta H_{reaction} = \sum H_{products} - \sum H_{reactants}$$

(iii) Enthalpy of Formation (ΔHf):

- The **enthalpy change** when **1 mole of a compound** is formed from its **elements in standard states**.

Example:

$$C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g) \quad \Delta H_f = -110.5\,\text{kJ/mol}$$

(iv) Stoichiometric Air-Fuel Ratio:

- The **exact amount of air** required for **complete combustion** of a given fuel.
- No excess air or fuel remains after reaction.

Example (Hydrocarbon):

$$AFR_{stoichiometric} = \frac{\text{mass of air}}{\text{mass of fuel}}$$

Q-5: (c) Discuss various factors affecting the performance of simple VCR cycle. (7 Marks)

Answer:

◆ **1. Evaporator and Condenser Temperatures:**

- **Higher evaporator temperature** increases COP
- **Lower condenser temperature** improves efficiency

◆ **2. Degree of Superheat and Subcooling:**

- Superheating slightly improves refrigeration effect
- Subcooling increases **net refrigerating effect**

◆ **3. Compressor Efficiency:**

- High mechanical and isentropic efficiency reduces power consumption
- Poor compressor design increases work input

◆ **4. Pressure Drops:**

- Pressure losses in valves, evaporator, or condenser reduce COP

◆ **5. Type of Refrigerant:**

- Properties like latent heat, specific volume, and critical temperature affect performance
- Choice of refrigerant impacts environmental and thermal performance

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◆ **6. Throttling Losses:**

- Large pressure drops in the expansion valve reduce efficiency

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🔹 **7. Heat Exchanger Efficiency:**

- Efficient evaporator and condenser coils improve heat transfer and cycle performance

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✅ **Conclusion:**

The performance of a simple **Vapour Compression Refrigeration (VCR) cycle** depends on thermodynamic conditions, component efficiencies, and refrigerant properties. Optimizing each of these improves **COP and system reliability**.