

GUJARAT TECHNOLOGICAL UNIVERSITY
BE- SEMESTER-3 PAPER SOLUTION – SUMMER 2025

Subject Name & Code:
Engineering Thermodynamics- 3131905

	Marks
Q.1 (a) Define the terms: (1) Thermodynamics System (2) Property (3) Cycle	03

Answer:

(1) Thermodynamic System:

A thermodynamic system is a **specific quantity of matter or a region in space** selected for study. It is separated from its surroundings by a boundary.

- **Types:** Closed, Open, Isolated
-

(2) Property:

A property is any measurable **characteristic** of a system, such as pressure, temperature, volume, or enthalpy, which helps define the system's state.

(3) Cycle:

A cycle is a **series of thermodynamic processes** that return a system to its initial state. The net change in internal energy over a cycle is zero.

(b) Explain thermodynamic equilibrium briefly.	04
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Answer:

A system is said to be in **thermodynamic equilibrium** when it is in **mechanical, thermal, and chemical equilibrium** simultaneously.

Types:

1. **Thermal Equilibrium:**

No temperature difference within the system or between the system and surroundings.

2. **Mechanical Equilibrium:**

No unbalanced forces; pressure remains uniform throughout the system.

3. **Chemical Equilibrium:**

No chemical reactions or composition change over time.

Example:

A gas inside a sealed, insulated cylinder with a piston that is not moving and at uniform temperature is in thermodynamic

equilibrium.

- (c) Derive S.F.E.E. clearly stating assumptions. Reduce it for turbine.

07

Answer:

Steady Flow Energy Equation (S.F.E.E.) Derivation:

S.F.E.E. is based on the **First Law of Thermodynamics** for a **steady-flow system**:

$$Q - W = \Delta H + \Delta KE + \Delta PE$$

Per unit mass:

$$q - w = (h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(Z_2 - Z_1)$$

Where:

- q: heat supplied per unit mass
- w: work done per unit mass
- h: specific enthalpy
- V: velocity
- Z: elevation
- g: acceleration due to gravity

Assumptions:

1. Steady flow (mass & energy flow rates constant)
2. One inlet, one outlet
3. No accumulation of energy
4. Uniform flow at inlet and outlet

S.F.E.E. for a Turbine:

- Heat transfer $q=0$ (assumed adiabatic)
- Change in potential energy ≈ 0
- So:

$$w = h_1 - h_2 + \frac{V_1^2 - V_2^2}{2}$$

If change in kinetic energy is also negligible:

$$w = h_1 - h_2$$

This is the **work done by turbine per unit mass**.

- Q.2 (a) Show that the COP of a heat pump is always greater than the COP of refrigerator. 03

Answer:

We know:

$$COP_{refrigerator} = \frac{Q_L}{W}, \quad COP_{heat\ pump} = \frac{Q_H}{W}$$

From **first law**:

$$Q_H = Q_L + W \Rightarrow COP_{heat\ pump} = \frac{Q_L + W}{W} = \frac{Q_L}{W} + 1 \Rightarrow \boxed{COP_{HP} = COP_{refrigerator} + 1}$$

Conclusion:

The **COP of a heat pump** is always **one more** than the COP of a refrigerator operating between the same two temperature limits.

- (b) Explain PMM of kind I and II. 04

Answer:

Perpetual Motion Machine (PMM):

A **PMM** is a hypothetical machine that violates the **laws of thermodynamics**.

PMM-I (Violates First Law):

- Produces **work without energy input**
- Impossible due to energy conservation

Example: A machine that keeps running and generating power forever without fuel

PMM-II (Violates Second Law):

- Extracts **heat from single reservoir** and converts it entirely into work without loss

Example: A machine absorbing heat from ocean and giving 100% work output

Conclusion:

Both PMMs are **non-physical** and **impossible**.

- (c) Steam enters a nozzle at 7 bar pressure and 20° C (initial enthalpy = 2850 kJ/kg) and leaves at a pressure of 1.5 bar. The initial and final velocities of steam is 40 m/s and 700 m/s respectively through the nozzle. The mass flow rate is 1400 kg/hr and heat loss from the nozzle is 11705 kJ/hr. Specific volume at exit is 1.24 m³/kg. Determine final enthalpy and exit area. 07

Answer:

Step 1: Convert mass flow rate to kg/s

$$\dot{m} = \frac{1400}{3600} = 0.3889 \text{ kg/s}$$

Step 2: Apply Steady Flow Energy Equation (S.F.E.E.)

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2} + q$$

Where:

- $h_1 = 2850 \text{ kJ/kg}$
- $V_1 = 40 \text{ m/s}, V_2 = 700 \text{ m/s}$
- $q = \frac{11705}{1400} = 8.36 \text{ kJ/kg}$ (heat lost per kg)

Step 3: Solve for Final Enthalpy h_2

$$h_2 = h_1 + \frac{V_1^2 - V_2^2}{2 \cdot 1000} - q$$

Convert velocities to kJ/kg:

$$\frac{V_1^2 - V_2^2}{2 \cdot 1000} = \frac{40^2 - 700^2}{2 \cdot 1000} = \frac{1600 - 490000}{2000} = -244.2 \text{ kJ/kg}$$

$$h_2 = 2850 - 244.2 - 8.36 = \boxed{2597.44 \text{ kJ/kg}}$$

✓ Final Enthalpy at Exit:

$$\boxed{h_2 = 2597.44 \text{ kJ/kg}}$$

Step 4: Find Exit Area

Use continuity equation:

$$\dot{m} = \frac{A_2 \cdot V_2}{v_2} \Rightarrow A_2 = \frac{\dot{m} \cdot v_2}{V_2}$$

$$A_2 = \frac{0.3889 \cdot 1.24}{700} = \frac{0.4812}{700} = 6.87 \times 10^{-4} \text{ m}^2$$

$$\boxed{A_2 = 687 \text{ mm}^2}$$

✓ Final Answers for Q.2 (c):

- **Final Enthalpy:** 2597.44 kJ/kg
- **Exit Area:** 687 mm²

OR

- (c) An inventor claims that his engine develops 75 kW of power while operating between 1023K and 298K temperature. The amount of fuel(C.V. of fuel = 74500 kJ/kg) burnt per hour is 3.9 kg. Comment about the validity of his claim and justify your comment.

07**Answer:****Step 1: Maximum possible efficiency (Carnot Efficiency):**

$$\eta_{max} = 1 - \frac{T_L}{T_H} = 1 - \frac{298}{1023} = 0.7087 \text{ or } 70.87\%$$

Step 2: Energy input per hour from fuel:

$$\text{Energy Input} = \text{Fuel consumed per hour} \times \text{C.V.} = 3.9 \times 74500 = 290550 \text{ kJ/hr}$$

Step 3: Maximum possible output:

$$\begin{aligned} \text{Max Output} &= \eta_{max} \times \text{Energy Input} = 0.7087 \times 290550 = 205976.3 \text{ kJ} \\ &= \frac{205976.3}{3600} \approx 57.2 \text{ kW} \end{aligned}$$

Step 4: Comparison:

- Claimed power: **75 kW**
- Maximum theoretical power: $\approx 57.2 \text{ kW}$

✓ Conclusion:

Since the claimed output (**75 kW**) exceeds the **maximum possible Carnot output (57.2 kW)**, the claim is invalid. It violates the second law of thermodynamics.

Q.3 (a) State and prove Clausius theorem.

03

Answer:

Clausius Theorem (Statement):

For any cyclic process, the cyclic integral of heat transferred divided by temperature is less than or equal to zero:

$$\oint \frac{\delta Q}{T} \leq 0$$

Equality holds for **reversible cycles**

- Inequality for **irreversible cycles**

Proof (Reversible Cycle):

For a reversible Carnot cycle operating between TH and TL:

- Heat absorbed = QH at TH
- Heat rejected = QL at TL

Then:

$$\oint \frac{\delta Q}{T} = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0$$

This holds true for **reversible processes**. For **irreversible processes**, entropy increases:

$$\oint \frac{\delta Q}{T} < 0$$

Hence, **Clausius theorem** supports the **second law of thermodynamics**.

- (b) Show that efficiency of a reversible heat engine operating between two constant temperatures is maximum. 04

Answer:

Let:

- QH: Heat absorbed at high temperature TH
- QL: Heat rejected at low temperature TL

Efficiency of Reversible Engine:

$$\eta_{rev} = 1 - \frac{T_L}{T_H}$$

This depends **only on temperature limits**, not on working substance or mechanism.

Now for an Irreversible Engine:

Let η_{irr} be its efficiency. From second law:

$$\eta_{irr} < \eta_{rev}$$

Therefore, among all heat engines operating between the same temperatures, the **reversible engine has the maximum possible efficiency**.

- (c) A block of 100 kg of iron at temperature 100°C is immersed in 50 kg of water at a temperature of 20°C. Determine the entropy change for combined system of iron and water. Take Cp of iron and water as 0.42 kJ/kgK and 4.18 kJ/kgK respectively. 07

Answer:

Step 1: Use heat lost = heat gained

$$m_{Fe} \cdot C_{p,Fe} \cdot (T_i - T_f) = m_w \cdot C_{p,w} \cdot (T_f - T_i)$$

Let T_f = final temperature (K)

$$100 \cdot 0.42(373 - T_f) = 50 \cdot 4.18(T_f - 293)$$

$$42(373 - T_f) = 209(T_f - 293)$$

$$15666 - 42T_f = 209T_f - 61237 \Rightarrow 251T_f = 76903 \Rightarrow T_f = 306.3 \text{ K} = 33.3$$

Step 2: Entropy change of Iron:

$$\begin{aligned} \Delta S_{Fe} &= m \cdot C_p \cdot \ln \left(\frac{T_f}{T_i} \right) = 100 \cdot 0.42 \cdot \ln \left(\frac{306.3}{373} \right) = 42 \cdot \ln(0.821) \\ &= 42 \cdot (-0.1975) = -8.3 \text{ kJ/K} \end{aligned}$$

Step 3: Entropy change of Water:

$$\Delta S_w = 50 \cdot 4.18 \cdot \ln \left(\frac{306.3}{293} \right) = 209 \cdot \ln(1.045) = 209 \cdot 0.044 = 9.2 \text{ kJ}$$

Total Entropy Change:

$$\Delta S_{total} = -8.3 + 9.2 = \boxed{+0.9 \text{ kJ/K}}$$

This is **positive**, satisfying the **second law of thermodynamics**.

OR

Q.3 (a) Define: (i) Availability (ii) Irreversibility and (iii) Dead state. **03**

Answer:

(i) Availability:

It is the maximum useful work possible during a process that brings the system into equilibrium with its surroundings.

(ii) Irreversibility:

It is the difference between useful work done in a reversible process and actual work done in an irreversible process.

(iii) Dead State:

It is the condition when a system is in complete thermal and mechanical equilibrium with its surroundings (no useful work can be obtained).

(b) Explain Guoy-Stodola theorem. **04**

Answer:

The **Guoy-Stodola Theorem** relates irreversibility to the loss of available work due to entropy generation.

$$\text{Loss of work } (W_{lost}) = T_0 \cdot S_{gen}$$

Where:

- T_0 = Ambient temperature
- S_{gen} = Entropy generated in the process

Explanation:

- Any irreversibility in a process (like friction, unrestrained expansion, etc.) causes entropy generation.
- The greater the entropy generation, the greater the loss of useful (available) work.

Example:

If $S_{gen} = 0.5 \text{ kJ/kg}\cdot\text{K}$ and $T_0 = 300\text{K}$,
Then $W_{lost} = 300 \times 0.5 = 150 \text{ kJ/kg}$

(c) Explain principle of increase of entropy. Apply it for the heat transfer through a finite temperature difference. **07**

Answer:

Principle of Entropy Increase:

- For **any process**, total entropy change (system + surroundings) ≥ 0 .

$$\bullet \quad \{\text{Total}\} = \{\text{system}\} + \{\text{surroundings}\}$$

Case 1: Reversible process

$$\Delta S_{total} = 0$$

Case 2: Irreversible process

$$\Delta S_{total} > 0$$

Application to Heat Transfer:

Let:

- Heat Q flows from hot reservoir at temperature T_H to cold body at T_C

Entropy change of hot body (heat loss):

$$\Delta S_H = -\frac{Q}{T_H}$$

Entropy change of cold body (heat gain):

$$\Delta S_C = \frac{Q}{T_C}$$

Total entropy change:

Since $T_H > T_C$,

$\Delta S_{total} > 0 \Rightarrow$ Irreversible process

$$\Delta S_{total} = \frac{Q}{T_C} - \frac{Q}{T_H}$$

✓ Conclusion:

Whenever heat is transferred through a finite temperature difference, entropy increases, indicating irreversibility.

Q.4 (a) Enlist desirable properties of good refrigerant.

03

Answer:

A good refrigerant should have the following properties:

Thermodynamic Properties:

1. **Low boiling point**
2. **High latent heat of vaporization**
3. **Low specific volume** in vapor phase
4. **High COP** (Coefficient of Performance)

Physical & Chemical Properties:

5. **Non-corrosive** to materials
6. **Non-toxic and non-flammable**
7. **Stable chemically**
8. **Easy to detect leaks**

Environmental Properties:

9. Low ozone depletion potential (ODP)
10. Low global warming potential (GWP)

- (b) For the same compression ratio and heat rejection, compare Otto, Diesel and Dual cycle. Explain with p-v and T-s diagram.

04

Answer:**Comparison:**

Cycle	Heat Addition	Compression	Efficiency (η)
Otto	At constant volume	Isentropic	Highest for same compression
Diesel	At constant pressure	Isentropic	Lower than Otto
Dual	Part at constant volume, part at constant pressure	Isentropic	Between Otto & Diesel

Efficiency Order (for same compression ratio):

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

p-v and T-s Diagrams:

1. **Otto:** Sharp heat addition at constant volume
2. **Diesel:** Heat addition follows rising pressure
3. **Dual:** Mixture of both — stepped heat addition

- (c) Draw Rankine cycle on P-v, T-s and h-s diagrams and derive an expression for its thermal efficiency with and without pump work.

07

Answer:**Process of Ideal Rankine Cycle:**

1. **1–2:** Isentropic compression in pump
2. **2–3:** Constant pressure heat addition in boiler
3. **3–4:** Isentropic expansion in turbine
4. **4–1:** Constant pressure heat rejection in condenser

Thermal Efficiency (with pump work):

$$\eta = \frac{W_{net}}{Q_{in}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2}$$

Neglecting Pump Work (common assumption):

$$\eta \approx \frac{h_3 - h_4}{h_3 - h_1}$$

Diagrams:

1. **P-v Diagram:** Shows pressure vs volume
2. **T-s Diagram:** Illustrates heat transfer and irreversibility
3. **h-s (Mollier) Diagram:** Useful for enthalpy-entropy visualization in turbines and boilers

OR

Q.4 (a) State the assumptions made for the analysis of air standard cycle. **03**

Answer:

The **Air Standard Cycle** is an idealized thermodynamic cycle for IC engine analysis. The assumptions made are:

1. **Working fluid is air** which behaves as an ideal gas and circulates continuously.
2. **Air has constant specific heats** (C_p and C_v) throughout the cycle.
3. **All processes are internally reversible.**
4. **Combustion process is replaced** by heat addition from an external source.
5. **Heat rejection** occurs to a cold reservoir.
6. **No chemical reactions** occur.
7. **Compression and expansion** are adiabatic and reversible.

(b) Explain simple regenerative Rankine cycle. **04**

Answer:

In a **Simple Regenerative Rankine Cycle**, part of the steam from the turbine is extracted before complete expansion and used to **preheat the feedwater** entering the boiler. This improves cycle efficiency.

Process Flow:

1. Steam is generated in the boiler and expanded in the high-pressure turbine.
2. A portion of this steam is extracted and used in a **feedwater heater**.
3. Remaining steam continues expansion in the low-pressure turbine.
4. Condensate from condenser is mixed with extracted steam condensate.
5. Preheated water enters the boiler.

Advantages:

- Reduces fuel consumption
- Increases thermal efficiency
- Improves boiler performance by feeding warmer water

Diagram:

- (c) A diesel engine has compression ratio of 20. The compression begins at 0.1 MPa and 35°C. The heat added is 1700 kJ/kg. Calculate maximum pressure and temperature of cycle, work done per kg of air and cycle efficiency.

Answer:

Given:

- Compression ratio, $r = 20$
- Initial pressure $P_1 = 0.1 \text{ MPa}$
- Initial temperature $T_1 = 35^\circ\text{C} = 308 \text{ K}$
- Heat added $Q_{in} = 1700 \text{ kJ/kg}$
- Assume air-standard properties: $\gamma = 1.4$, $C_v = 0.718 \text{ kJ/kg}\cdot\text{K}$

Step 1: Compression process (1–2)

$$T_2 = T_1 \cdot r^{\gamma-1} = 308 \cdot (20)^{0.4} \approx 308 \cdot 3.32 = 1022 \text{ K}$$

Step 2: Heat addition (2–3) [Constant Pressure in Diesel Cycle]

$$Q_{in} = C_p(T_3 - T_2) \Rightarrow T_3 = T_2 + \frac{Q_{in}}{C_p}$$

$$C_p = \gamma \cdot C_v = 1.4 \cdot 0.718 = 1.005 \text{ kJ/kg}\cdot\text{K}$$

$$T_3 = 1022 + \frac{1700}{1.005} \approx 1022 + 1691 = 2713 \text{ K}$$

Step 3: Maximum Pressure

$$\frac{P_3}{P_2} = \frac{T_3}{T_2} \Rightarrow P_3 = P_2 \cdot \frac{T_3}{T_2}$$

$$P_2 = P_1 \cdot r^\gamma = 0.1 \cdot 20^{1.4} \approx 0.1 \cdot 66.3 = 6.63 \text{ MPa}$$

$$P_3 = 6.63 \cdot \frac{2713}{1022} \approx 6.63 \cdot 2.65 = 17.58 \text{ MPa}$$

Step 4: Work Output (W_{net})

$$W_{net} = Q_{in} - Q_{out}$$

Let's calculate T_4 using expansion from T_3 :

$$\text{Let cut-off ratio } r_c = \frac{T_3}{T_2} = \frac{2713}{1022} \approx 2.65$$

$$T_4 = T_3 \cdot \left(\frac{1}{r}\right)^{\gamma-1} = 2713 \cdot (1/20)^{0.4} \approx 2713 \cdot 0.301 = 817 \text{ K}$$

$$Q_{out} = C_v(T_4 - T_1) = 0.718 \cdot (817 - 308) = 0.718 \cdot 509 = 365.96 \text{ kJ/kg}$$

$$W_{net} = 1700 - 365.96 = 1334.04 \text{ kJ/kg}$$

Step 5: Efficiency:

$$\eta = \frac{W_{net}}{Q_{in}} = \frac{1334.04}{1700} \approx 0.7847 = 78.47\%$$

✔ **Final Answers:**

- **Maximum Pressure:** ≈ 17.58 MPa
- **Maximum Temperature:** ≈ 2713 K
- **Work done per kg:** ≈ 1334 kJ/kg
- **Cycle Efficiency:** $\approx 78.47\%$

- Q.5 (a)** Define the following terms related to combustion process: (i) HCV (ii) LCV (iii) Enthalpy of formation **03**

Answer:

(i) HCV – Higher Calorific Value:

- Total heat released when a unit mass of fuel is completely burnt and **water vapor formed is condensed.**
- Includes **latent heat of steam.**
- Also called **Gross Calorific Value (GCV).**

(ii) LCV – Lower Calorific Value:

- Heat released when fuel is burned and **water remains in vapor form.**
- Latent heat of condensation is **not recovered.**
- Also called **Net Calorific Value (NCV).**

(iii) Enthalpy of Formation:

- The **heat change** during the formation of **1 mole of compound** from its elements in standard state at 25°C and 1 atm pressure.
- Denoted by ΔH_f°

- (b)** Explain Bomb calorimeter with neat sketch. **04**

Answer:

A **Bomb Calorimeter** is used to determine the **Calorific Value (CV)** of solid or liquid fuels through **complete combustion** under constant volume conditions.

Construction:

- A **strong steel bomb** containing fuel sample and oxygen
- Placed in a **calorimeter vessel** with known quantity of water
- Surrounded by **stirrer and thermometer**
- Electrical ignition wire ignites the sample

Working:

1. Fuel is ignited electrically.
2. It burns completely in excess oxygen.
3. Heat released raises water temperature.
4. Temperature rise is used to compute calorific value.

Formula:

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

Where:

- W = Mass of water
- w = Water equivalent of calorimeter
- ΔT = Temperature rise
- m = Mass of fuel

(c) Discuss factors affecting performance of VCR cycle.

07

Answer:

Vapor Compression Refrigeration (VCR) Cycle:

The performance of a VCR cycle is measured by **COP (Coefficient of Performance)**. Several factors affect it:

1. Evaporator Temperature:

- **Higher** evaporator temperature increases COP.
- Lower temperatures require more work from compressor.

2. Condenser Temperature:

- **Lower** condenser temperature improves COP.
- Higher temperatures cause more compression work.

3. Superheating and Subcooling:

- **Subcooling** increases refrigerating effect.
- **Superheating** increases work input, reducing COP.

4. Compressor Efficiency:

- **Higher isentropic efficiency** improves overall performance.

5. Refrigerant Type:

- Refrigerants with **high latent heat** and favorable pressure-temperature characteristics provide better performance.

6. Pressure Drops and Heat Losses:

- Frictional losses in pipes and improper insulation reduce system efficiency.

7. Expansion Device Performance:

- Throttling losses should be minimized for better performance.

✔ Conclusion:

Efficient operation of a VCR system requires optimal control of temperature levels, minimal losses, and proper refrigerant selection.

OR

Q.5 (a) Explain Stoichiometric air fuel ratio in detail.

03

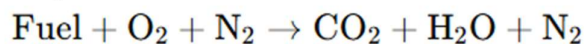
Answer:

The **Stoichiometric Air-Fuel Ratio (AFR)** is the ideal ratio of air to fuel at which **complete combustion** occurs, meaning: All the carbon in fuel is converted to CO₂ and all the hydrogen to

H₂O without any leftover oxygen or fuel.

For Hydrocarbon Fuels:

The general form:



Example:

For gasoline (approx. C₈H₁₈), the stoichiometric AFR is about:

$$\boxed{14.7 : 1} \text{ (14.7 kg of air per 1 kg of fuel)}$$

Importance:

- Ensures maximum power output
- Prevents unburnt fuel or excess oxygen
- Standard for engine tuning and emissions control

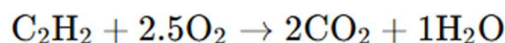
- (b) Calculate the amount of theoretical air required for the combustion of 1 kg of acetylene (C₂H₂) to CO₂ and H₂O. 04

Answer:

Balanced Reaction:



Per 1 mole of C₂H₂:



Step 1: Molar mass of C₂H₂ = 26 g/mol

$$1 \text{ kg} = \frac{1000}{26} = 38.46 \text{ mol}$$

Step 2: O₂ required = 2.5 mol per mole of C₂H₂

$$\text{Total O}_2 = 38.46 \times 2.5 = 96.15 \text{ mol}$$

$$\text{Mass of O}_2 = 96.15 \times 32 = 3076.8 \text{ g} = \mathbf{3.077 \text{ kg}}$$

Step 3: Air contains 23% O₂ by mass

So, theoretical air required:

$$\text{Air} = \frac{3.077}{0.23} = \boxed{13.38 \text{ kg of air}}$$

- (c) In a steam power cycle, the dry saturated steam supplied at 15 bar. The condenser pressure is 0.4 bar. Calculate the Carnot and Rankine efficiencies of the cycle. Neglect pump work. 07

Answer:

Given:

- Boiler pressure = 15 bar (dry saturated steam)
- Condenser pressure = 0.4 bar
- Assume steam tables for enthalpy and entropy:

From Steam Table:

At 15 bar (saturated):

- $h_1 = h_g = 2783.1 \text{ kJ/kg}$
- $s_1 = s_g = 6.441 \text{ kJ/kg} \cdot \text{K}$

At 0.4 bar:

- $h_2 = h_f + xh_{fg}$; but for ideal Rankine, we assume isentropic expansion,
 $s_2 = s_1 = 6.441 \text{ kJ/kg} \cdot \text{K}$

From tables at 0.4 bar:

- $s_f = 1.433 \text{ kJ/kg} \cdot \text{K}$, $s_{fg} = 6.836$

So:

$$x = \frac{s_2 - s_f}{s_{fg}} = \frac{6.441 - 1.433}{6.836} = 0.733 \Rightarrow h_2 = h_f + x$$

$$= 340.5 + 0.733 \times 2313.3 = 340.5 + 1696.2 = 2036.7 \text{ kJ/kg}$$

Step 1: Rankine Efficiency:

$$\eta_{\text{Rankine}} = \frac{h_1 - h_2}{h_1} = \frac{2783.1 - 2036.7}{2783.1} = \frac{746.4}{2783.1} = \boxed{26.8\%}$$

Step 2: Carnot Efficiency:

Use saturation temperatures:

- $T_{\text{boiler}} = T_{\text{sat}@15\text{bar}} = 198.3 + 273 = 471.3 \text{ K}$
- $T_{\text{condenser}} = T_{\text{sat}@0.4\text{bar}} = 75.9 + 273 = 348.9 \text{ K}$

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

✓ Final Answers:

- **Rankine Efficiency:** $\approx 26.8\%$
- **Carnot Efficiency:** $\approx 25.97\%$

(Note: Slight variations may occur based on steam table values used.)
