	OR			
11	Explain the working of an air refrigeration system with a schematic and T-S diagram. Derive the expression for COP.	L3	CO5	10 M

PVP 23

Code: 23ES1302

II B.Tech - I Semester – Regular / Supplementary Examinations
NOVEMBER 2025

THERMODYNAMICS
(MECHANICAL ENGINEERING)

Duration: 3 hours Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level CO – Course Outcome

PART – A

		BL	CO
1.a)	Distinguish between macroscopic and microscopic viewpoints in thermodynamics.	L2	CO1
1.b)	Define intensive property and extensive property.	L1	CO1
1.c)	State the Zeroth Law of Thermodynamics.	L1	CO2
1.d)	Define enthalpy and write its mathematical expression.	L1	CO2
1.e)	Define entropy and state the principle of entropy increase.	L1	CO3
1.f)	State Carnot's principle.	L1	CO3
1.g)	Define dryness fraction and write its mathematical expression.	L1	CO4
1.h)	State the Clausius-Clapeyron equation.	L1	CO4
1.i)	List the four processes of Otto cycle.	L1	CO5

1.j)	Define sensible heat, latent heat, and sensible heat factor.	L1	CO5

PART – B

		BL	CO	Max. Marks
	UNIT-I			
2	Define and differentiate between open, closed, and isolated systems with examples.	L2	CO1	10 M
	OR			
3	Explain the concept of thermodynamic equilibrium. Illustrate with suitable examples.	L2	CO1	10 M
	UNIT-II			
4	Define and differentiate between point functions and path functions. Give examples of each and explain their significance in thermodynamic analysis.	L2	CO2	10 M
	OR			
5	Derive the Steady Flow Energy Equation (SFEE) and explain its application to turbines, compressors, and nozzle.	L3	CO2	10 M
	UNIT-III			
6	State the Kelvin-Planck and Clausius statements of the Second Law of Thermodynamics. Show their equivalence with a neat diagram.	L2	CO3	10 M
	OR			

7	An insulated rigid vessel is divided into two chambers of equal volumes. One chamber contains air at 500 K and 2 MPa. The other chamber is evacuated. If the two chambers are connected d, what would be the entropy change?	L3	CO3	10 M
	UNIT-IV			
8	A vessel of volume 0.04 m^3 contains a mixture of saturated water and saturated steam at a temperature of 250°C. The mass of the liquid present is 9 kg. Find the pressure, the mass, the specific volume, the enthalpy, the entropy, and the internal energy.	L3	CO4	10 M
	OR			
9	Explain the construction and use of Mollier (h-s) chart for steam.	L2	CO4	10 M
	UNIT-V			
10	An engine of 250 mm bore and 375 mm stroke works on an Otto cycle. The clearance volume is 0.00263 m^3. The initial pressure and temperature are 1 bar and 50°C. If the maximum pressure is limited to 25 bar, find the following: (i) The air standard efficiency of the cycle. (ii) The mean effective pressure for the cycle. For air : $\gamma = 1.4$, $C_v = 0.718$ kJ/kg K, $C_p = 1.005$ kJ/kg K	L3	CO5	10 M

Scheme of Evaluation.
II. B.Tech - I-semester
November - 2025
Thermodynamics - 23ES1302
Mechanical Engineering.

1. a. Any two points — 2 marks

b. Two definitions — 2 marks

c. statement — 2 marks

d. Definition — 1 mark } — 2 marks
Expression — 1 mark }

e. definition — 1 mark } — 2 marks
statement — 1 mark }

f. statement — 2 marks

g. Definition — 1 mark } — 2 marks
expression — 1 mark }

h. equation — 2 marks

i Four processes — 2 marks

j. Definitions — 2 marks.

2. Three definitions — 8 marks } — 10 marks
Examples — 2 marks }

3. Statement and explanation — 7 marks } — 10 marks
Example — 3 marks

4. Statements — 8 marks } — 10 marks
Examples — 2 marks

5. Definition — 2 marks } — 10 marks
Derivation — 4 marks
Applications — 4 marks

6. Statements — 5 marks } — 10 marks
Explanation — 5 marks

7. Given Data — 4 marks } — 10 marks
Solution — 6 marks

8. Given Data — 2 marks } — 10 marks
Solution — 8 marks

9. Diagram — 4 marks } — 10 marks
Explanation — 6 marks

10. Given Data — 4 marks } — 10 marks
Solution — 6 marks

11. Diagram — 4 marks } — 10 marks
Explanation — 6 marks

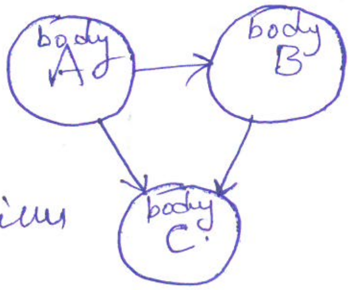
Scheme of Evaluation
II B.Tech - I Semester
November-2025
Thermodynamics - 23ES1302
Mechanical Engineering.

1. a. In macroscopic view point the average values of molecules behaviour is taken into consideration. This is also known as classical thermodynamics. In microscopic view point the behaviour of individual molecules is taken into consideration. This is also known as statistical thermodynamics.

b. Intensive property :- Intensive properties are independent of size or mass.

Extensive property :- Extensive properties are dependent of size or mass.

c. when a body "A" is in thermal equilibrium with body "B" and body "B" is in thermal equilibrium body "C" separately body "A" and body "C" are in thermal equilibrium.



d). Enthalpy is defined as the sum of internal energy and product of pressure & volume.

$$H = U + P.V$$

e) Entropy is a measure of molecular disorderness in the system.

Entropy of system can increase, can decrease or it can be remains constant. Similarly entropy of surroundings can increase, can decrease or can remains constant but the overall change in entropy of universe can never decrease and this is known as the principle of increase of entropy.

f). For various cycles operating between same temperature limits non has efficiency greater than reversible cycle efficiency.

g) Dryness fraction is defined as the ratio of mass of vapour to total mass. It is denoted by "x".

$$x = \frac{m_v}{m_t} = \frac{m_v}{m_v + m_l}$$

h). $$\frac{dP}{dT} = \frac{P(LH)}{RT^2} \quad (\text{or})$$

$$\frac{dP}{dT} = \frac{LH}{T_{sat}(v_g - v_f)}$$

where, L·H = latent Heat.

i) Process 1-2: Isentropic compression process

Process 2-3: constant volume Process

Process 3-4: Isentropic expansion Process

Process 4-1: Constant volume process

j. Sensible Heat; The energy transfer due to temp-erature change is known sensible heat.

Latent Heat: The energy transfer due to phase change is known as Latent heat.

Sensible Heat factor: The ratio of sensible heat to total heat (sensible heat + latent heat) is known as sensible heat factor.

2. Open System:- open system is one in which both mass Transfer as well energy transfer crosses the system and boundary then the system is known as open system.

Ex:- Turbine, compressor, pump ... etc.

Closed System:- closed system is one in which Mass Transfer is constant but energy crosses the system and boundary then it is known as closed system.

Ex:- piston cylinder arrangement without values.

Isolated system:- Isolated system is one in which no mass transfer aswell as no energy transfer crosses the system and boundary then it is known as isolated system.

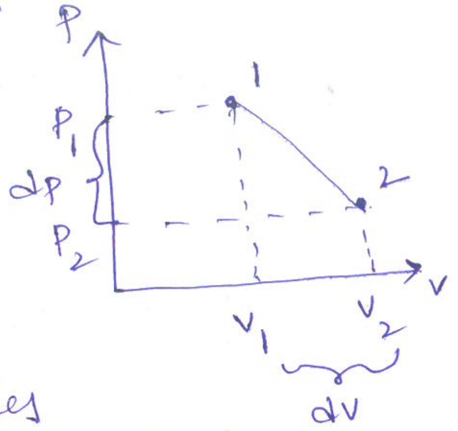
Ex:- Hot coffee in a well insulated flask.

3. A body is said to be in Thermodynamic equilibrium if it is thermal equilibrium (equality of temperature), mechanical equilibrium (equality of force / pressure) and chemical equilibrium (equality of chemical potential)

Ex:- Gas enclosed in a sealed container

- A rigid sealed perfectly insulated container filled with gas.
- In thermal equilibrium - no heat enters or leaves.
- In mechanical equilibrium - no change in volume / pressure gradient.
- In chemical equilibrium - no chemical reaction.

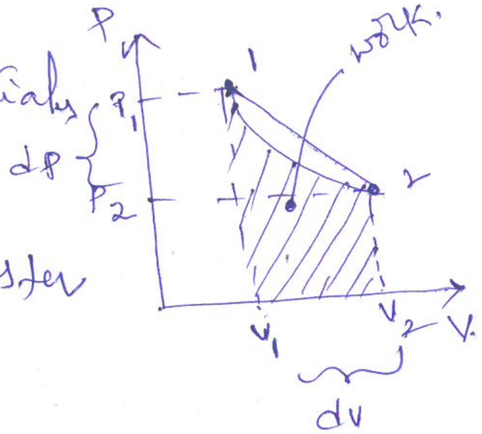
4. point functions are those properties whose values depends on end points / states.



$dp = P_2 - P_1$
$dv = V_2 - V_1$ } Exact differentials

Ex:- Pressure, volume.

Path functions are those properties whose values depends upon the path taken by the system.

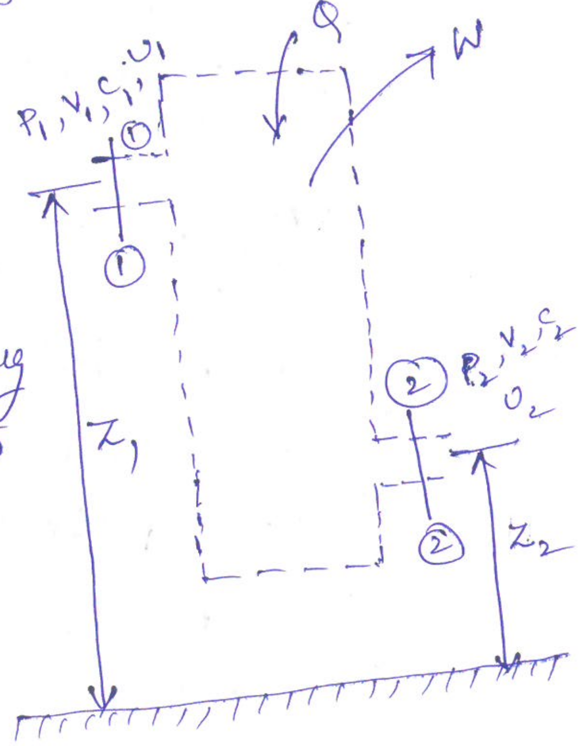


$dw \neq w_2 - w_1$

$đW = W_{1-2}$ — are inexact differentials

Ex:- Heat Transfer, work Transfer

5. A flow is said to be steady flow if the properties donot vary with respect to time at any given section.



For steady flow there is no eccumilation of mass and energy in the control volume i.e mass entering is equal to mass leaving and energy entering is equal to energy leaving.

For steady flow

Energy in = Energy out

$$E_1 = E_2$$

$$\frac{1}{2}mc_1^2 + mgz_1 + U_1 + Q_1 = \frac{1}{2}mc_2^2 + mgz_2 + U_2 + W$$

$$\frac{1}{2}mc_1^2 + mgz_1 + U_1 + Q_1 = \frac{1}{2}mc_2^2 + mgz_2 + U_2 + (-P_1V_1 + P_2V_2 + W_{c.v})$$

$$\frac{1}{2}mc_1^2 + mgz_1 + U_1 + P_1V_1 + Q = \frac{1}{2}mc_2^2 + mgz_2 + U_2 + P_2V_2 + W_{c.v}$$

$$H_1 + \frac{1}{2}mc_1^2 + mgz_2 + Q = H_2 + \frac{1}{2}mc_2^2 + mgz_2 + W_{cv}$$

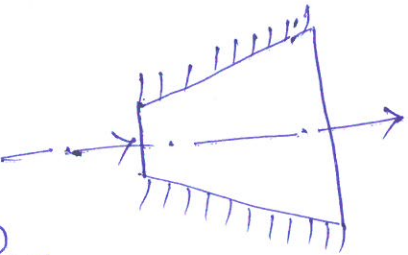
$$\frac{H}{m} = h, \quad \frac{Q}{m} = q, \quad \frac{W_{c.v}}{m} = w_{c.v}$$

$$h_1 + \frac{c_1^2}{2} + z_1 g + q = h_2 + \frac{c_2^2}{2} + z_2 g + w_{c.v}$$

This is the first law of thermodynamics for an open system under steady flow conditions.

Turbine

$$h_1 + \frac{c_1^2}{2} + z_1 g + q = h_2 + \frac{c_2^2}{2} + z_2 g + w_{c.v}$$



Assumptions

1. steady flow
2. potential energy changes are neglected
3. kinetic energy changes are neglected
4. perfectly insulated.

$$h_1 = h_2 + w_{c.v}$$

$$\boxed{w_{cv} = h_2 - h_1}$$

compressor :-

$$h_1 + \frac{c_1^2}{2} + z_1 g + q = h_2 + \frac{c_2^2}{2} + z_2 g + w_{c.v}$$

Assumptions

1. steady flow.
2. potential energy changes are negligible.
3. kinetic energy changes are negligible.
4. perfectly insulated.

$$w = h_1 - h_2$$

$$w = -(h_1 - h_2)$$

$$\boxed{w_{comp} = h_2 - h_1}$$

Nozzle :-

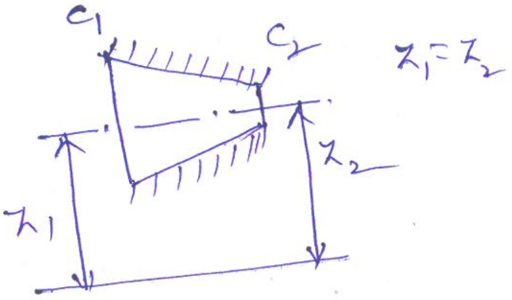
$$h_1 + \frac{c_1^2}{2} + \cancel{z_1 g}^{0} + \cancel{q}^{0} = h_2 + \frac{c_2^2}{2} + \cancel{z_2 g}^{0} + \cancel{w_{c.v.}}^{0}$$

$$h_1 + \frac{c_1^2}{2} = h_2 + \frac{c_2^2}{2}$$

$$c_1 << c_2$$

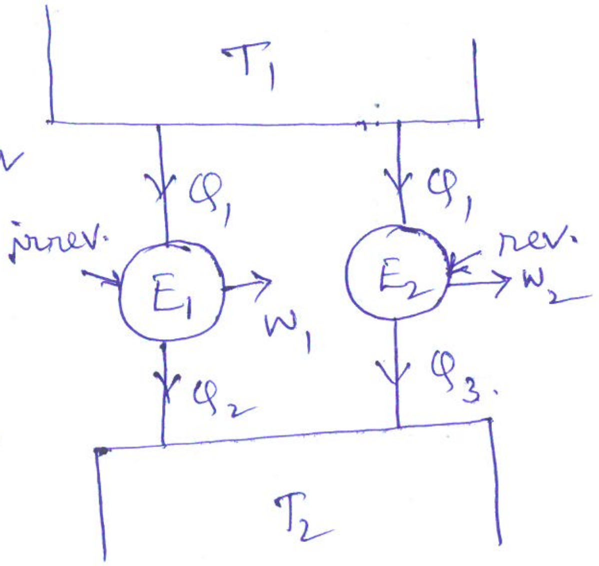
$$h_1 = h_2 + \frac{c_2^2}{2}$$

$$c_2 = \sqrt{2(h_1 - h_2)},$$



6. Kelvin-plank statement :- It is impossible to develope ~~man~~ a device operating on a cycle producing work while exchanging heat with a single reservoir. This device is known as PMM-II and the efficiency of PMM-II is 100% and therefore 100% efficiency is impossible from the second law of Thermo-dynamics.

clausius statement:- It is impossible to transfer heat from lower temperature to higher temperature without any external input.



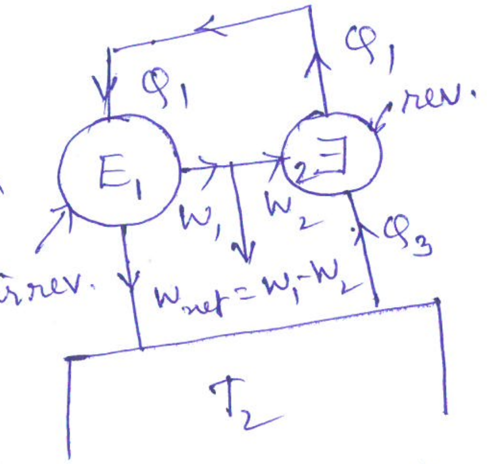
Let us consider two engines E_1 & E_2. Let E_1 be ~~ir~~ irreversible engine and E_2 be reversible engine.

let us assume $\eta_{irrev.} > \eta_{rev.}$

$$\eta_{irrev.} = \frac{W_1}{Q_1}, \quad \eta_{rev.} = \frac{W_2}{Q_1}$$

$$\frac{W_1}{Q_1} > \frac{W_2}{Q_1} \Rightarrow \boxed{W_1 > W_2}$$

As E_2 is a reversible engine. let us reverses the engine.



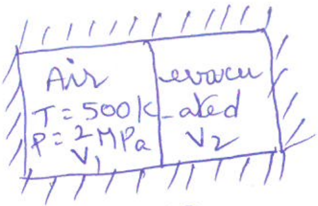
This is violation of kelvin plank statement and hence our assumption is wrong. similarly if we take both effencies of the engines are same. then it would lead to violation of clausius statement. Therefore it is not possible. Efficiency of a reversible cycle is always greater than the efficiency of irreversible cycle operating between same temperature limits.

7. Given Data

$T = 500\,K$

$P = 2\,MPa$

$\Delta S = ?$



$$\cancelto{0}{\delta Q} = \Delta U + \cancelto{0}{W}$$

$$\Delta U = 0$$

$\Delta U \Rightarrow T_2 - T_1 = 0$

$T_2 = T_1 = 500\,K$

volume, $V_2 = 2V_1$

For isothermal expansion

$$\Delta S = mR\ln\left(\frac{V_2}{V_1}\right) = mR\ln\left(\frac{2V_1}{V_1}\right)$$

$$= mR\ln(2)$$

$$= R\ln(2)$$

$$= 0.287 \times \ln(2)$$

$$= 0.199\ KJ/kg\cdot K$$

The specific entropy change of air $= 0.199\ KJ/kg\cdot K$.

8. Given Data

$V = 0.04\ m^3$

$m_f = 9\ kg$

$T = 250^\circ C$

The properties of steam at $250^\circ C$

$P_{sat} = 39.76$ bar

$v_f = 0.001257\ m^3/kg$

$v_g = 0.05020\ m^3/kg$

$u_f = 1081$ ~~k~~kJ/kg

$u_g = 2602$ kJ/kg.

$h_f = 1086$ kJ/kg.

$h_g = 2801$ kJ/kg.

$S_f = 2.794$ kJ/kg.K

$S_g = 6.073$ kJ/kg.K.

mass, $m = m_f + m_g$

$\vartheta_f = m_f \times \vartheta_f$

$= 9 \times 0.001257$

$V_f = 0.011313\ m^3$

$V_g = V - V_f$

$= 0.04 - 0.011313$

$= 0.028687\ m^3$

$m_g = \frac{V_g}{\vartheta_g} = \frac{0.028687}{0.0502}$

$m_g = 0.571454$ kg

$m = m_f + m_g = 9 + 0.571454$

$m = 9.571454$ kg

~~x~~dryness fraction.

$x = \frac{m_g}{m} = \frac{0.571454}{9.571454}$

$x = 0.0597$

Specific volume, $\vartheta = v_f + x(v_g - v_f)$

$= 0.001257 + 0.0597(0.05020 - 0.00147)$

$= 0.00417889\ m^3/kg$

Enthalpy

$h = h_f + x(h_g - h_f)$

$= 1081 + 0.0597(2801 - 1086)$

$h = 1188.38$ kJ/kg

Entropy

$S = S_f + x(S_g - S_f)$

$= 2.794 + 0.0597(6.073 - 2.794)$

$= 2.9897$ kJ/kg.K.

Internal energy

$u = u_f + x(u_g - u_f)$

$= 1081 + 0.0597(2602 - 1081)$

$= 1171.8$ kJ/kg.

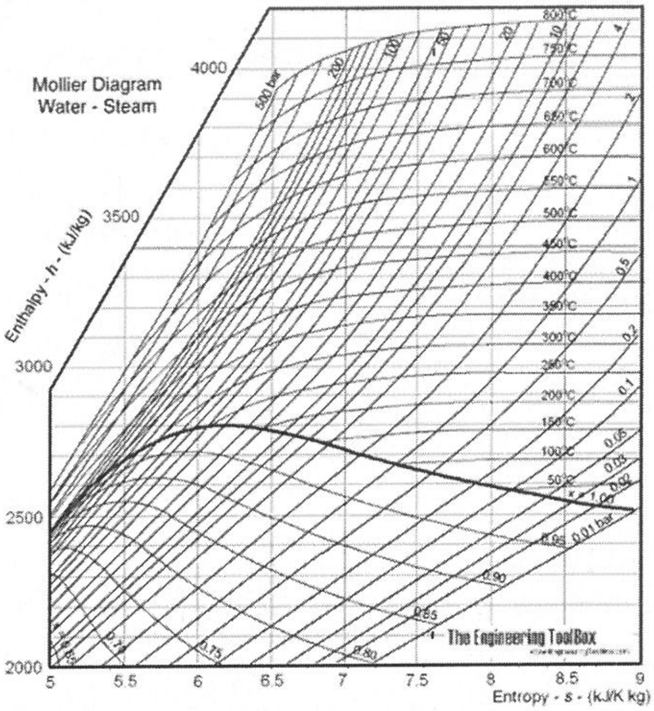
(or)

Internal Energy.

$h = u + P\vartheta$

$u = h - P\vartheta$.

9. Construction of the Mollier Chart (h–s Diagram)



The Mollier chart is a graphical representation of the enthalpy (h) versus entropy (s) of steam. It is widely used in thermodynamics and power plant engineering.

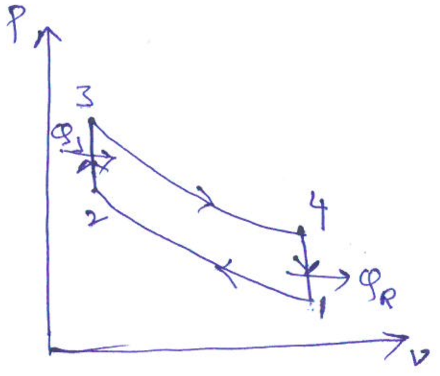
(a) Axes Horizontal axis (X-axis): Entropy, s (kJ/kg·K) Vertical axis (Y-axis): Enthalpy, h (kJ/kg)

(b) **Saturation Lines** A saturated liquid line and a saturated vapor line are plotted. The region between these two lines represents the wet steam zone. The area to the right of the saturated vapor line represents superheated steam. (c) **Constant Pressure Lines** Several isobars (constant-pressure lines) are drawn. In the superheated region, these lines slope upward. In the wet region, they are almost vertical. (d) **Constant Temperature** Lines Temperature lines are approximately parallel in the superheated region. At the saturation curve, they intersect. (e) **Constant Quality** (Dryness Fraction) Lines In the wet region: Curved lines represent constant dryness fraction (x) values. x = 0 is saturated water; x = 1 is saturated vapor. (f) Additional Lines Constant volume lines, Constant superheat lines, Critical point is clearly marked. 2. Use of the Mollier Chart (a) To Determine Steam Properties Given any two properties (e.g., pressure and temperature), the corresponding: enthalpy, entropy, dryness fraction, specific volume can be directly read from the chart. (b) For Turbine Calculations The Mollier chart is extremely useful for: Determining expansion work in steam turbines. Locating the initial and final states of steam. Calculating turbine efficiency, heat drop, and moisture content at turbine exit. (c) For Boiler Calculations Used to find: Enthalpy of feed water, Enthalpy of superheated steam, Heat supplied in the boiler. (d) For Nozzle and Throttling Processes Throttling processes occur at constant enthalpy (h = constant). Nozzle flows can be analyzed to find exit velocities using enthalpy drop.

(e) For Refrigeration and Conditioning Systems When using steam as the working fluid, the chart helps determine: Heating load, Humidification requirements.

10.

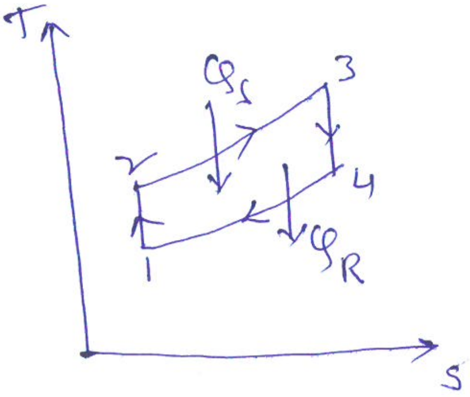
Given Data



bore; $d = 250\ mm = 0.25\ m$

Stroke, $L = 375\ mm = 0.375\ m.$

clearance volume, $V_c = 0.00263\ m^3$



$P_1 = 1$ bar

$T_1 = 50^\circ C = 50 + 273 = 323\ K$

$P_3 = 25$ bar

$\gamma = 1.4$, $C_p = 1.005\ kJ/kg \cdot K$

$C_v = 0.718\ kJ/kg \cdot K$

V_s = swept volume = Area x stroke Length

$$= \frac{\pi}{4} d^2 \times L = \frac{\pi}{4} \times (0.25)^2 \times 0.375$$

$$= 0.7854 \times 0.25^2 \times 0.375$$

$$= 0.0184\ m^2$$

compression ratio, $r = \dfrac{V_s + V_c}{V_c} = \dfrac{0.0184 + 0.00263}{0.00263} = 7.99$

$r \simeq 8$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1} \Rightarrow T_2 = T_1 r^{\gamma-1} = 323 \times 8^{1.4-1}$$

$$\boxed{T_2 = 742.0\ K.}$$

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$P_2 = \left(\frac{V_1}{V_2}\right)^\gamma = r^\gamma$$

$$P_2 = 8^{1.4} = 18.37 \text{ bar}$$

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

$$T_3 = T_2 \times \frac{P_3}{P_2}$$

$$= 742 \times \frac{25}{18.37}$$

$$\boxed{T_3 = 1009.79 \text{ K}}$$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1}$$

$$T_4 = \frac{T_3}{r^{\gamma-1}} = \frac{1009.79}{8^{1.4-1}} = 439.53 \text{ K}$$

Efficiency of the cycle, $\eta_{cycle} = 1 - \frac{1}{r^{\gamma-1}}$

$$= 1 - \frac{1}{8^{1.4-1}} = 0.5647 = 56.47\%$$

Mean effective pressure $P_m = \frac{W_{net}}{\cancel{V_s}} = \frac{Q_1 - Q_2}{V_s}$

Heat supplied, $Q_1 = C_v(T_3 - T_2) = 0.718 \times (1009.79 - 742)$

$$= 192.27 \text{ kJ/kg}.$$

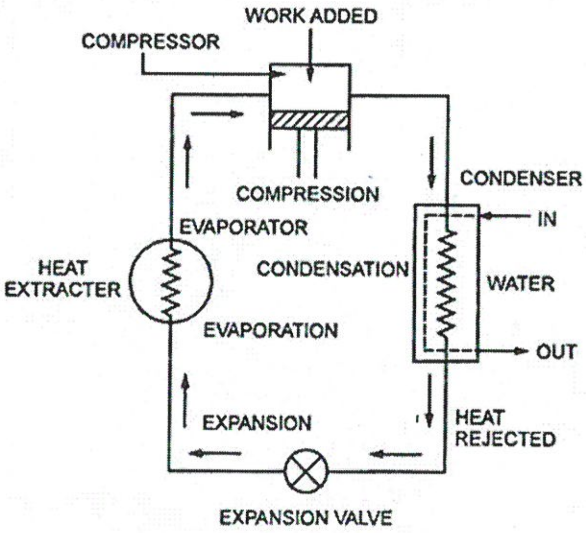
Heat Rejected, $Q_2 = C_v(T_4 - T_1) = 0.718 \times (439.53 - 323)$

$$= 83.66 \text{ kJ/kg}.$$

$$P_m = \frac{192.27 - 83.66}{0.0184} = 5902.7 \text{ KPa}$$

$$= 59.02 \text{ bar}$$

11.



The air refrigeration (Bell–Coleman) cycle uses **air** as the working fluid and is commonly used in aircraft refrigeration and some industrial cold stores. Main components and the sequence of processes:

1. **Compressor** — compresses cold air from low pressure P_1 to high pressure P_2 (state 1 → 2).
2. **Heat exchanger / Cooler (aftercooler)** — rejects heat to the atmosphere at (nearly) constant pressure P_2 (state 2 → 3).
3. **Expander (turbo-expander or piston expander)** — expands high-pressure air from P_2 to P_1 producing work and cooling the air (state 3 → 4).
4. **Cold space / Evaporator (room)** — air at low temperature absorbs heat from the refrigerated space at (approximately) constant pressure P_1 (state 4 → 1).
5. **Intercooler/regenerator (optional)** — often a heat exchanger between compressed hot air and cold returning air to improve efficiency.

- Vertical axis: **Temperature (T)** or Enthalpy; Horizontal: **Entropy (s).**
- 1 → 2: **Isentropic compression** (vertical up if ideal isentropic).
- 2 → 3: **Heat rejection at (approx.) constant pressure** (moves right and/or down toward ambient line).
- 3 → 4: **Isentropic (ideal) expansion** (vertical down).
- 4 → 1: **Heat absorption at low pressure** (moves right and up slightly across cold-space temperature).

When drawing, mark the saturated lines only if using steam; for air-cycle just draw the four processes forming a loop similar to Brayton cycle but reversed in purpose.

Definition:

$$\mathrm{COP} = \frac{\text{Refrigeration effect } Q_L}{\text{Net work input } W_{\text{net}}} = \frac{C_p(T_1 - T_4)}{C_p\left[(T_2 - T_1) - (T_3 - T_4)\right]}$$

Cancel C_p:

$$\boxed{\mathrm{COP} = \frac{T_1 - T_4}{(T_2 - T_1) - (T_3 - T_4)}}$$

This is the general ideal expression in terms of state temperatures (Kelvin).