CBCS SCHEME

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BME304

Third Semester B.E./B.Tech. Degree Examination, Dec.2024/Jan.2025

Basic Thermodynamics

Time: 3 hrs.

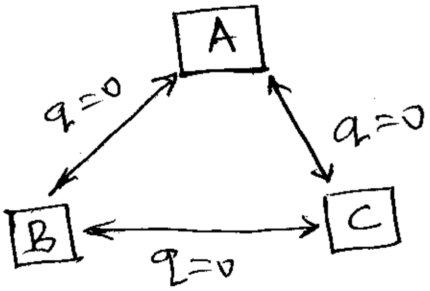
Max. Marks: 100

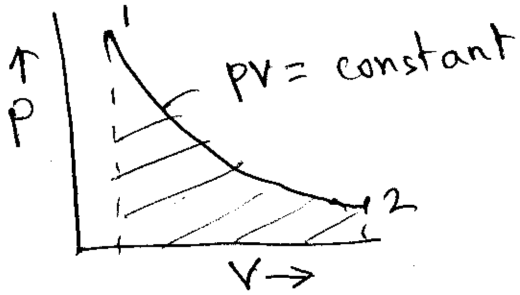
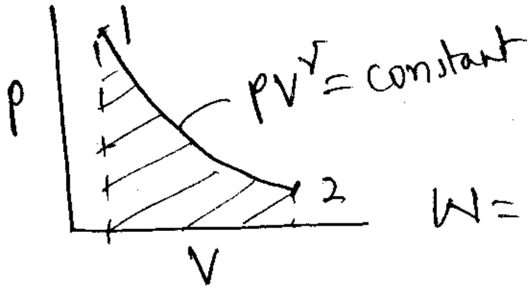
Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks , L: Bloom's level , C: Course outcomes.
3. Use of steam table and thermodynamics data hand is permitted.

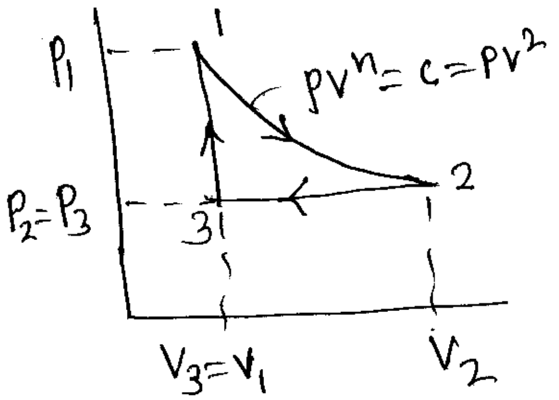
		Module – 1	**M**	**L**	**C**
Q.1	**a.**	State and explain zeroth law of thermodynamics.	**10**	**L1**	**CO1**
	b.	Two Celsius thermometers 'A' and 'B' agree at ice point and steam point and the related equation is $t_A = L + Mt_B + Nt_B^2$, where L, M and N are constants, when both thermometer are immersed in fluid, 'A' registers 26°C while 'B' registers 25°C. determine the reading of 'A' when 'B' reads 37.4°C	**10**	**L3**	**CO1**
		OR			
Q.2	**a.**	Derive an expression for work done during : i) Isothermal process ii) Adiabatic process.	**10**	**L2**	**CO1**
	b.	A cylinder contains 1 kg of a certain fluid at an initial pressure of 20 bar. The fluid is allowed to expand reversibly behind a piston according to a law PV^2 = constant until the volume is doubled. The fluid is then cooled reversibly at constant pressure until the piston regains its original position, heat is then added reversibly with the piston firmly locked in position until the pressure rises to the original value of 20 bar. Calculate the network done by the fluid for an initial volume of 0.05 m^3 and draw a neat PV diagram.	**10**	**L3**	**CO1**
		Module – 2			
Q.3	**a.**	Explain Joule's experiment with sketch.	**10**	**L1**	**CO2**
	b.	Air flows steady at the rate of 0.4 kg/s through an air compressor, entering at 6 m/s with a pressure of 1 bar and a specific volume of 0.85 m^3/kg and leaving at 4.5 m/s with a pressure of 6.9 bar and a specific volume of 0.16 m^3/kg. The internal energy of the air leaving is 88 kJ/kg greater than that of the air entering. Cooling water in a jacket surrounding the cylinder absorbs heat from the air at the rate of 59 W. Calculate the power required to drive the compressor and the inlet and outlet cross-sectional areas.	**10**	**L3**	**CO2**
		OR			
Q.4	**a.**	Derive Steady Flow Energy Equation (SFEE) with a neat sketch.	**10**	**L2**	**CO2**
	b.	A turbine operates in a steady flow conditions, receiving steam at the following state : pressure 1.2 MPa, temperature 188°C, enthalpy 2785 kJ/kg, velocity 34 m/s, and elevation 3 m. The steam leaves the turbine at the following state : pressure 20 KPa, enthalpy 2512 kJ/kg, velocity 100 m/s and elevation 0 m. Heat is lost to the surroundings at the rate of 0.29 kJ/s. If the rate of the steam flow through the turbine is 0.42 kg/s. What is the power output of the turbine in KW?	**10**	**L3**	**CO2**
		Module – 3			
Q.5	**a.**	State and explain Kelvin – Plank and clausius statements of II law of thermodynamics.	**10**	**L2**	**CO3**
	b.	A heat engine receives half of its heat at 1000 K and the rest at 500 K while rejecting heat to a sink at 300 K. What is the maximum possible efficiency of this heat engine?	**10**	**L3**	**CO3**

		OR			
Q.6	**a.**	State and prove clausius inequality.	**10**	**L1**	**CO3**
	b.	A heat engine working on a Carnot cycle absorbs heat from three thermal reservoirs at 1000 K 800 K and 600 K respectively. The engine does 10 KW of net work and rejects 400 kJ/min of heat to the sink at 800 K, if heat supplied by the reservoir at 1000 K 60% heat supplied by reservoir at 600 K. Find the quantifier of heat supplied by each reservoir.	**10**	**L3**	**CO3**
		Module – 4			
Q.7	**a.**	Explain the concept of available and unavailable energy referred to a cycle.	**10**	**L1**	**CO4**
	b.	In a steam generator, water evaporated at 260°C, while the combustion gas (C_P = 1.08 kJ/kg K) is cooled from 13000°C to 320°C. The surrounding are at 30°C. Determine loss in energy available due to the above heat transfer per kg of water evaporated (Latent heat of vaporization of water at 260°C = 1662.5 m^3 kgmole.	**10**	**L3**	**CO4**
		OR			
Q.8	**a.**	Sketch and explain throttling calorimeter.	**10**	**L2**	**CO4**
	b.	A vessel of 0.04 m^3 contains a mixing of saturated water and saturated steam at temperature of 240°C. The mass of the liquid is 8 kg. Find the pressure, specific volume, enthalpy, entropy and internal energy.	**10**	**L3**	**CO4**
		Module – 5			
Q.9	**a.**	Explain : i) Vander Waal's equation of state ii) Compressibility factor iii) Law of corresponding states.	**10**	**L2**	**CO5**
	b.	1 kg of CO_2 has a volume of 0.86 m^3 at 120°C compute pressure using : i) Ideal gas equation ii) Vander Waal's equation. Take Vander Waal's constants for CO_2 a = 365.6 KNM^4/kg mole and b = 0.0423 m^3/kg mole.	**10**	**L3**	**CO5**
		OR			
Q.10	**a.**	Discuss Maxwell's equations and Tds equation.	**10**	**L2**	**CO5**
	b.	Volumetric analysis of a gaseous mixture yields the following results : CO_2 = 12%, O_2 = 4%, N_2 = 82%, CO = 2%. Determine the analysis on mass basis, molecular weight and gas constant for the mixture, assume ideal gas behavior.	**10**	**L3**	**CO5**

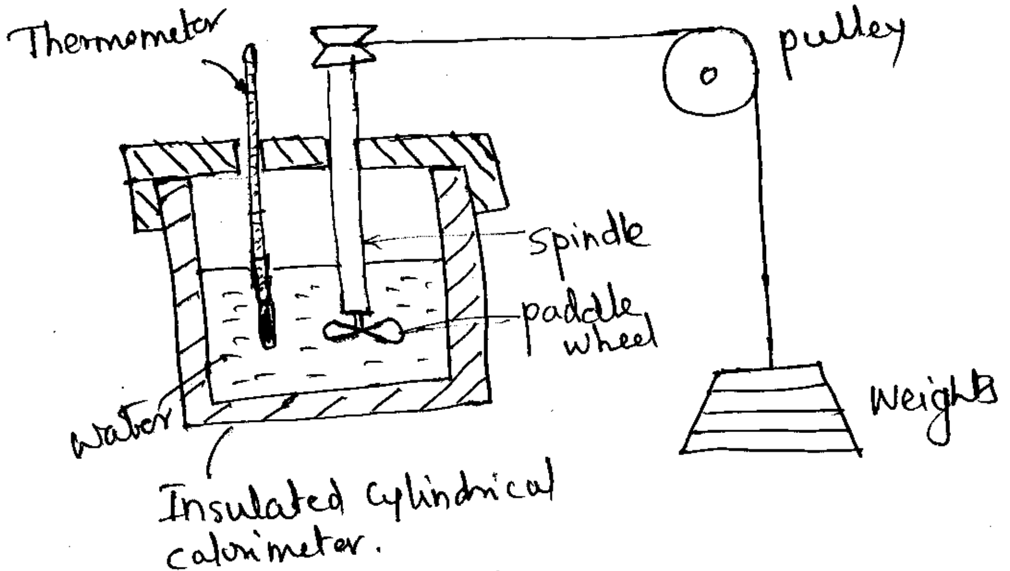
* * * * *

Q.No.	Solution and Scheme	Marks
1. a	The Zenth law of thermodynamics states that if two systems are each in thermal equillibrium with a third system, then they are also in thermal equillibrium with each other.	2
	This law establishes a concept of temperature and thermal equillibrium, implying that objects at the same temperature will not exchange heat when brought into contact.	4
	Imagine three systems A, B and C. If system 'A' is in thermal equillibrium with system C, and system 'B' is also in thermal equillibrium with system 'C', then according to zenth law of thermodynamics, System 'A' and system 'B' are also in thermal equillibrium with each other. 	4
b.	L=0 at ice point — — — — —	2
	$M+100N=1$, $N=-\frac{1}{1875}$ — — — —	2
	$M=\frac{1975}{1875}=1.0533$ — — —	2
	$t_A=38.6°C$ at $t_B=37.4°C$ — — —	4

Q.No.	Solution and Scheme	Marks
2 a.	(i) Isothermal Process	
		2
	$W = \int_1^2 p\,dv$ — — — ①	2
	$pv = \text{constant}$	
	$P_1V_1 = P_2V_2 = PV$	
	$P = \frac{P_1V_1}{V}$ — — — —	2
	Substituting in eq ①	
	$W = \int_1^2 P_1V_1 \frac{dv}{V}$	
	$= P_1V_1 \ln\left(\frac{V_2}{V_1}\right) = P_2V_2 \ln\left(V_2/V_1\right)$ - -	4
	(ii) Adiabatic Process	
	 $P_1V_1^\gamma = P_2V_2^\gamma = PV^\gamma$ - -	2
	$P = \frac{P_1V_1^\gamma}{V^\gamma} = P_1V_1^\gamma V^{-\gamma}$ - -	2
	$W = \int_1^2 P_1V_1^\gamma V^{-\gamma}\,dv$ - - - -	2
	$= P_1V_1^\gamma \frac{\left(V_2^{-\gamma+1} - V_1^{-\gamma+1}\right)}{1-\gamma}$ - - -	2
	$= \frac{P_2V_2 - P_1V_1}{1-\gamma}$	
	$= \frac{P_1V_1 - P_2V_2}{\gamma - 1}$ - - -	2

Q.No.	Solution and Scheme	Marks
2 b.	 $P_1 = 20$ bar $m = 1$ kg $n = 2$ $V_2 = 2V_1 = 0.1 m^3$ $V_1 = 0.05 m^3$	2
	$P_2 = 5$ bar. $W_{1-2} = \frac{P_1V_1 - P_2V_2}{n-1} = 50$ KJ	3
	Process 2-3 $W_{2-3} = P(V_3 - V_2) = -25$ KJ (work done on the system)	1
	Process 3-1 $W_{3-1} = 0$ (constant volume process)	1
	Net work done $W_{net} = W_{1-2} + W_{2-3} + W_{3-1}$ $= 50 - 25 + 0 = 25$ KJ	3
3a.	Joule's experiment demonstrated the mechanical equivalent of heat, showing that mechanical work can be converted into heat energy and vice versa. the experiment involved a system with paddle wheel immersed in water, where the potential energy of falling weights was converted into the kinetic energy of the paddle wheel, which in turn increases the water's temperature.	

Q.No.	Solution and Scheme	Marks



paddle wheel is made to rotate by raising and lowering of weight, pulley rotates during this.

As the paddle wheel rotates, the intermolecular collision takes place between water molecules causing temperature of the water to raise, Kinetic energy of water molecules increases.

After repeated experiments, Joule calculated the work done and proportional heat generated. Then the relation between mechanical work and heat was established which is

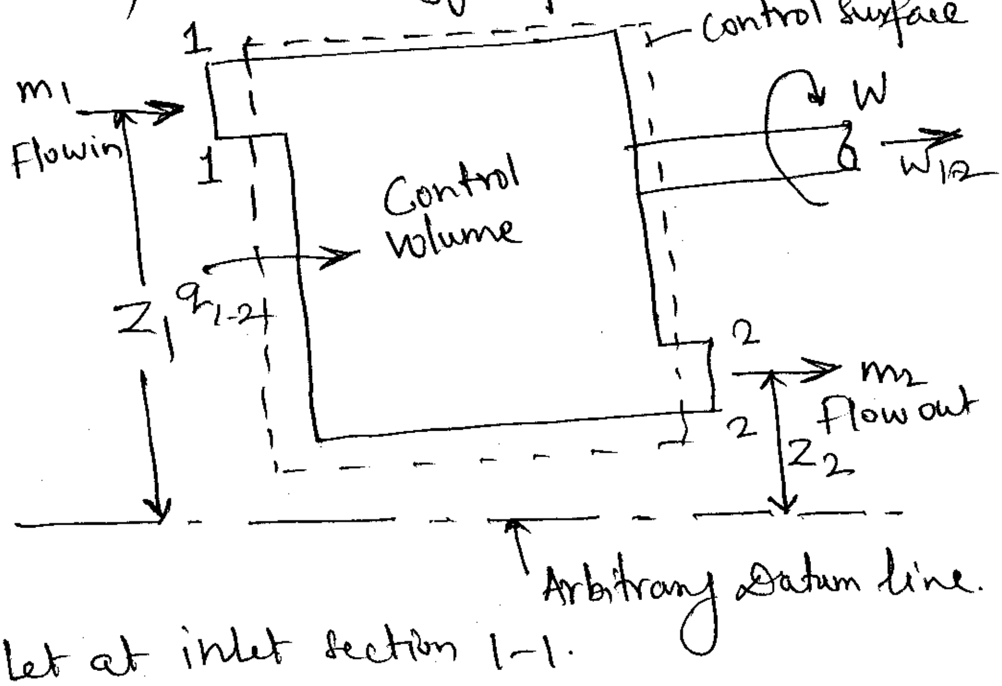
$$W = J \cdot Q$$
$$W = 4.186\, Q$$

3 b. $m = 0.4\ Kg/s$, $V_1 = 6\ m/s$, $P_1 = 1\,bar$, $v_1 = 0.85\ m^3/Kg$
$V_2 = 4.5\ m/s$, $P_2 = 6.9\,bar$, $v_2 = 0.16\ m^3/Kg$.
$u_2 = 88\ KJ/Kg + u_1$, $Q = 59W$. $A_1 = ?$ $A_2 = ?$, $W = ?$

SFEE

$$m\left(u_1 + P_1 v_1 + \frac{V_1^2}{2} + z_1\right) + Q$$
$$= m\left(u_2 + P_2 v_2 + \frac{V_2^2}{2} + Z_2\right) + W$$

2

Q.No.	Solution and Scheme	Marks
	$W = m\left[(u_1-u_2)+(p_1v_1-p_2v_2)+\frac{V_1^2-V_2^2}{2}+z_1-z_2\right]+Q$ $=0.4\left[-88+(100\times0.85-6.9\times10^{2}\times0.16)+\frac{6^2-4.5^2}{2}\times10^{-3}+0\right]+59\times10^{-3}$ $=-45.416$ KW — — —	4
	$m=0.4=\frac{A_1V_1}{v_1}=\frac{A_2V_2}{v_2}$ $A_1=\frac{mv_1}{V_1}=\frac{0.4\times0.85}{6}=0.0567\,m^2$ — —	2
	$A_2=\frac{mv_2}{V_2}=\frac{0.4\times0.16}{4.5}=0.0142\,m^2$ — — —	2
4 a.	Steady Flow Energy Equation (SFEE) 	4
	Let at inlet section 1-1. p_1 = pressure of working fluid (N/m²) v_1 = Sp. volume (m³/Kg) V_1 = velocity of working fluid u_1 = Sp. internal energy (KJ/Kg) z_1 = height above datum line (m)	

IIIly at outlet section 2-2

P_2, v_2, V_2, u_2, Z_2 be the corresponding values of working fluid leaving control volume

q_{1-2} be the heat supplied to control volume (KJ/kg)

W_{1-2} be the work done by the system (KJ/kg) 2

considering 1kg of mass of working fluid, m = 1kg

Energy entering the control volume is

e_1 = Internal energy + Displacement work + KE + PE + Heat supplied

$$e_1 = u_1 + P_1 v_1 + \frac{V_1^2}{2} + gz_1 + q_{1-2} \quad (KJ/kg)$$

Total energy leaving the control volume.

$$e_2 = u_2 + P_2 v_2 + \frac{V_2^2}{2} + gz_2 + W_{1-2}$$

Total energy entering = Total energy leaving

$$e_1 = e_2$$

$$u_1 + P_1 V_1 + \frac{V_1^2}{2} + gz_1 + q_{1-2} = u_2 + P_2 v_2 + \frac{V_2^2}{2} + gz_2 + W_{1-2}$$ 4

$$h_1 + \frac{V_1^2}{2} gz_1 + q_{1-2} = h_2 + \frac{V_2^2}{2} + gz_2 + W_{1-2}$$

Above equation is called SFEE

4b. $P_1 = 1.2 \times 10^3$ KN/m², $T_1 = 188°C$, $h_1 = 2785$ KJ/kg.

$V_1 = 34$ m/s, $Z_1 = 3$ m

$P_2 = 20$ KN/m², $h_2 = 2512$ KJ/kg. $V_2 = 100$ m/s, $Z_2 = 0$

$Q = -0.29$ KJ/s, $m = 0.42$ Kg/s. $W_{1-2} = ?$

SFEE

$$m\left(h_1 + \frac{V_1^2}{2} + gz_1\right) + Q = m\left(h_2 + \frac{V_2^2}{2} + gZ_2\right) + W.$$

Q.No.	Solution and Scheme	Marks

$$0.42\left(2785+\frac{34^2}{2}\times10^{-3}+9.81\times3\times10^{-3}\right)-0.29$$

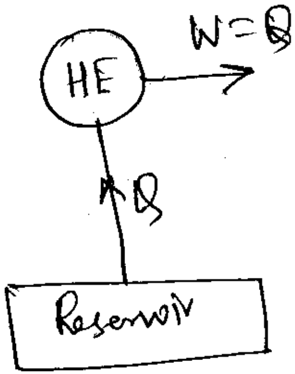
$$=0.42\left(2512+\frac{100^2}{2}\times10^{-3}+9.81\times0\times10^{-3}\right)+W$$

$W = 112.515$ KW.

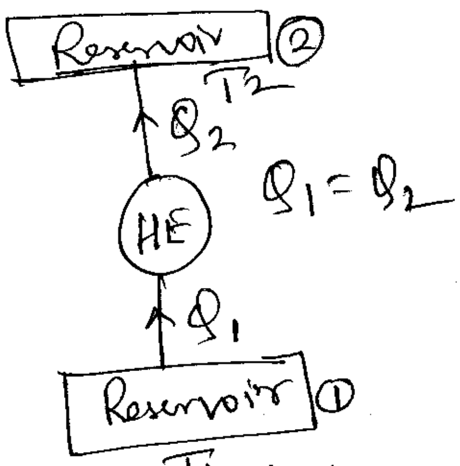
5 a, Kelvin-Plank statement states that it is impossible to construct an engine working in reversible cycle whose sole effect is transferring heat from reservoir and converting it into equivalent amount of work. It implies that 100% efficient machine is not possible. it puts restriction on energy conversion limits. 4

Clausius statement states it is impossible to transfer heat from lower temperature to higher temperature without the aid of external power supply. 4

It puts restriction on direction of flow of energy.



Voilation of Kelvin-Plant Statement



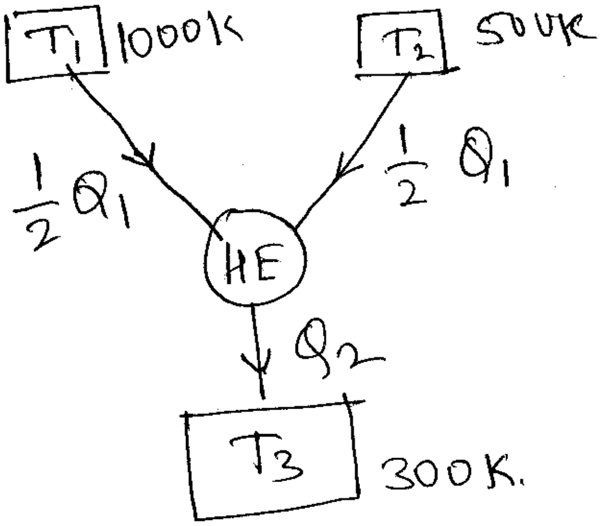
Voilation of clausius Statement.

2

Above figures represents the violation of both statements

Q.No. | **Solution and Scheme** | **Marks**

5 b.



2

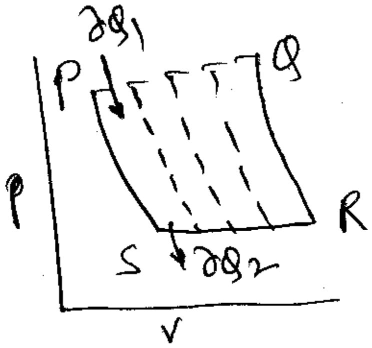
$$\frac{\frac{1}{2}Q_1}{T_1} + \frac{\frac{1}{2}Q_1}{T_2} - \frac{Q_2}{300} = 0$$ — — — 2

— — — — 2

$Q_2 = 0.45 Q_1$ — —

$$\eta = \frac{-Q_2 + Q_1}{Q_1} = \frac{Q_1 - 0.45Q_1}{Q_1} = 55\%$$ — — 4

6a.



Consider cycle PQRS in which PQ is reversible or irreversible process, other processes QR, RS, SP are reversible processes.

Deviding this cycle into large number of smaller cycle & considering any one of such cycles say 1-2-S-R1, the thermal efficiency is

$$\eta = 1 - \left(\frac{\delta Q_2}{\delta Q_1}\right) = 1 - \frac{T_2}{T_1}$$

for irreversible process cyclic integration of $\frac{\delta Q}{T}$ will never become zero. $\oint dQ/T \neq 0$.

$$\eta_{irr} \leqq \eta_{rev}$$

$$1 - (\delta Q_2/\delta Q_1)_{irr} \leqq 1 - (\delta Q_2/\delta Q_1)_{rev}$$

Q.No.	Solution and Scheme	Marks

$$\left(\frac{\delta Q_2}{\delta Q_1}\right)_{irr} \geqslant \left(\frac{\delta Q_2}{\delta Q_1}\right)_{rev}$$

$$\frac{\delta Q_2}{\delta Q_1} \geqslant \frac{T_2}{T_1}$$

$$\frac{\delta Q_2}{T_2} \geqslant \frac{\delta Q_1}{T_1}$$

$$\therefore \frac{\delta Q_1}{T_1} - \frac{\delta Q_2}{T_2} \leq 0$$

$$\frac{\delta Q_1}{T_1} - \left(-\frac{\delta Q_2}{T_2}\right) \leq 0 \quad (\because \delta Q_2 \text{ is } -\text{ve})$$

$$\therefore \frac{\delta Q_1}{T_1} + \frac{\delta Q_2}{T_2} \leq 0$$

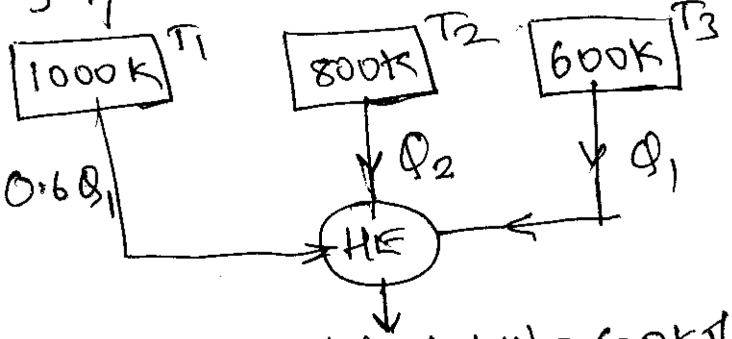
$\oint \frac{\delta Q}{T} \leq 0$ is clausius Inequality

$\oint \frac{\delta Q}{T} = 0$ For reversible cycle

$\oint \frac{\delta Q}{T} < 0$ For irreversible cycle.

$\oint \frac{\delta Q}{T} > 0$ For impossible cycle.

6b.



$Q_2 = 400$ KJ/min

$W = 10\,kW = 600$ KJ/min

$$0.6Q_1 - Q_2 + Q_1 = W = 600$$

$$1.6Q_1 - 400 = 600$$

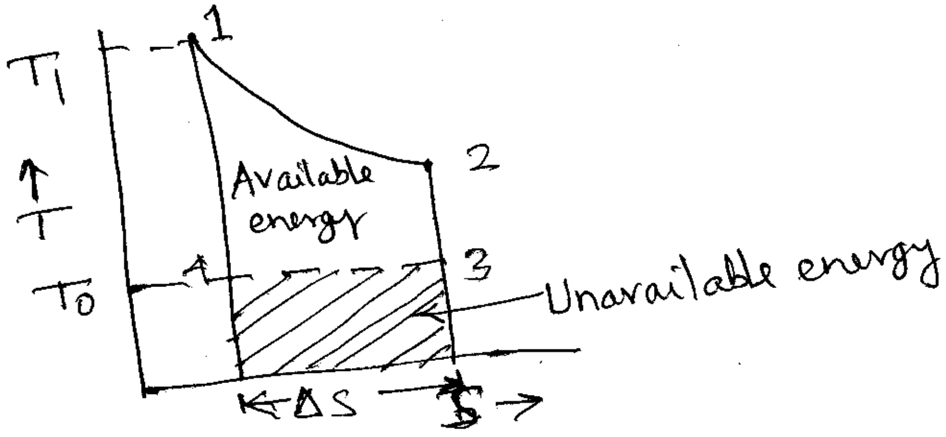
$$Q_1 = 625 \text{ KJ/min}$$

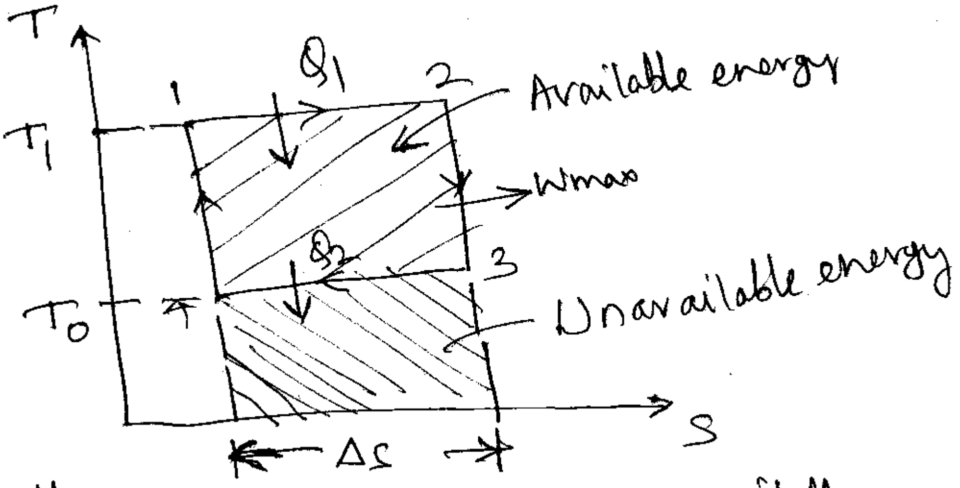
$Q_2 = 400$ KJ/min

7 a. The available energy or availability of a given system is defined as the maximum useful work that can be obtained in a process until a system reaches equillibrium with surroundings or dead state. It can be completely converted into useful work.

The unavailable energy is the other part of energy which cannot be converted into useful work.

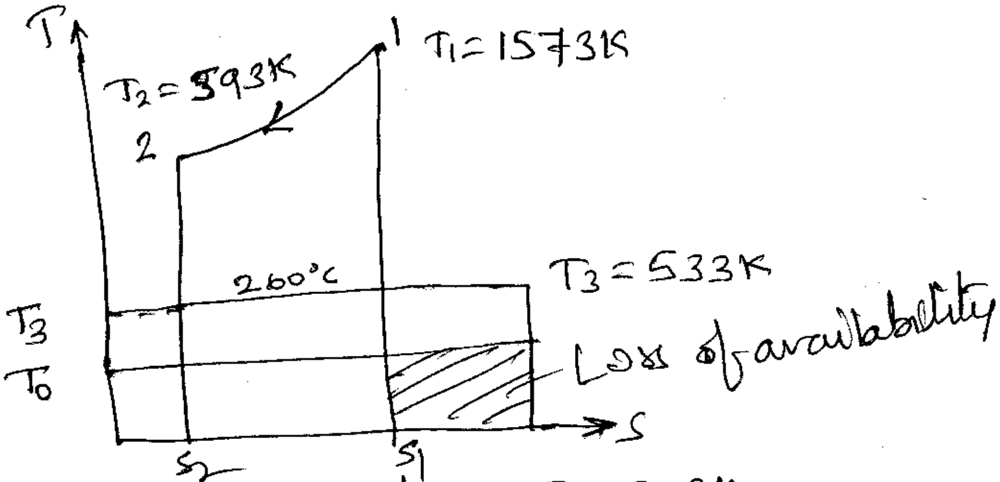
The available and unavailable energy for a closed system undergoing cyclic process is shown below



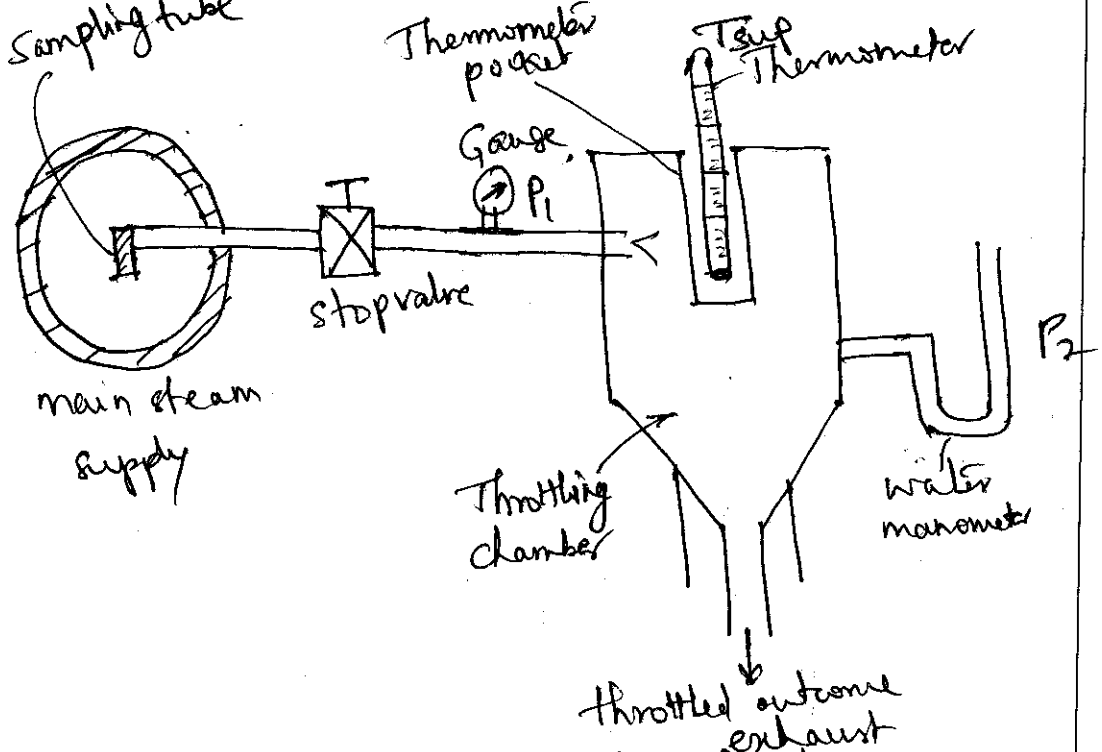


Available energy = Heat supplied − Unavailable energy

$$= Q_1 - T_0 \Delta S$$

Q.No.	Solution and Scheme	Marks
7 b	 C_p of gas = 1.08 KJ/kgK, $T_0 = 303K$, $h_{fg} = 1662.5$ KJ/Kg	2
	$AE_{gas} = h_1 - h_2 - T_0(s_1 - s_2)$ $= m c_p (T_1 - T_2) - T_0 \ln(T_1/T_2)$ $= m_g \times 1.08 [(1573 - 593)] - 303 \ln(1573/593)$ $= m_g \times 739.16$ KJ	3
	$AE_{water} = (T_3 - T_0) m_w h_{fg} / T_3$ $= (533 - 303) \times 1662.5/533$ $= m_w 717.4$ KJ $(m_w = 1 kg)$	3
	$m_g c_{pg} (T_2 - T_1) = m_w h_{fg}$ $AE_{gas} = 1161.1$ KJ Loss of availability $= AE_{gas} - A_W$ $= 1161.1 - 717.4$ $= 443.7$ KJ	2

8a



Throttling colorimeter is used when the steam is dry. First stop valve is opened fully so that the steam is not partially throttled as it passes through the apparatus for a while to allow pressure and temperature to stabilise. If the pressure is very close to atmospheric, the saturation should be around 100°C, it may be assumed that the steam is superheated.
When the steady condition is reached, gauge pressure is noted. After throttling, the temperature and pressure from thermometer and manometer are recorded. The barometric pressure is also recorded.

$$h_1 = h_2$$

$$h_w \text{ at } P_1 = h_{sup} \text{ at } P_2$$

$$h_{f_1} + x h_{fg_1} = h_{g_2} + C_p(T_{sup} - T_{sat})$$

Dryness fraction, $x = \dfrac{h_{g_2} + C_p(T_{sup} - T_{sat}) - h_{f_1}}{h_{fg_1}}$

Q.No.	Solution and Scheme	Marks
8.b	Volume of vessel = 0.04 m^3	
	T_{sat} = 240°c	
	Mass of liquid = m_l = 8 kg = liquid mass	
	from steam table, at T_{sat} = 240°c	
	P = 33 bar, h_f = 1034 KJ/kg, h_{fg} = 1770 KJ/kg	
	v_g = 0.0605 m^3/kg v_f = 0.001229 m^3/kg	
	h_g = 2802 KJ/kg, S_f = 2.703 KJ/kgK, S_{fg} = 3.439 KJ/kgK	
	S_g = 6.141 KJ/kgK.	
	Total volume of liquid occupied	
	$V_l = m_l \times V_f$ = 8×0.001224 = 0.009792 m^3	2
	Total volume occupied by steam (V_s)	
	$V = V_l + V_s$	
	$0.04 = 0.009792 + V_s$	2
	V_s = 0.030208 m^3	
	Mass of steam (m_s)	
	$m_s = \frac{V_s}{V_g} = \frac{0.030208}{0.0605}$ = 0.499 kg	2
	Mass of liquid and steam, $m = m_l + m_s$	
	= 8 + 0.499	
	= 8.499 kg	2
	Total sp. volume of the mixture	
	$v = V/m$ = 0.04/8.499 = 0.0047 m^3/kg	
	$v = v_f + x v_{fg}$	
	0.0047 = 0.001229 + x(0.0605 − 0.001229)	
	x = 0.058 ≃ 0.06	2
	$h = h_f + x h_{fg}$ = 1034 + 0.058×1770 = 1141 KJ/kg	
	$S = S_f + x S_{fg}$ = 2.703 + 0.058 (3.439) = 2.9 KJ/kg	

Q.No.	Solution and Scheme	Marks
	Internal Energy $u = h - Pv = 1141.5 - 33 \times 100 \times 0.0047$ $u = 1125.99$ KJ/Kg.	
9 a.	(i) Vander Waal's Equation. It is a modification in ideal gas-equation to take into account molecular size and molecular interaction forces. $\left[P + a\left(\frac{n}{V}\right)^2\right]\left[\frac{V}{n} - b\right] = RT$ The constants a, b are characteristic of individual gas	3
	(ii) compressibility factor: Real gases deviate from ideal gas behaviour. This deviation at given temperature and pressure can be accurately accounted by Introduction of correction factor called compressibility factor, Z. $Z = \frac{Pv}{RT}$ or $PV = ZRT$ $z = \frac{V_{act}}{V_{ideal}}$, for ideal gas, $z = 1$	3
	(iii) Laws of corresponding states: An additional assumption about real gases made by Vander waals was that all gases at corresponding states should behave similarly. The corresponding state that vander waals choose to use is called reduced state, which is based on deviation of conditions of a substance from its own critical condition. $P_R = P/P_c$, $V_R = V/V_c$, $T_R = T/T_c$ Vandar waals equation becomes $\left(P_R + \frac{3}{V_R^2}\right)\left(\bar{V}_R - \frac{1}{3}\right) = \frac{8}{3} T_R$ Critical parameter of gas can be expressed in terms of a and P parameters. $V_c = 3b$, $P_c = \frac{a}{27b^2}$, $T_c = \frac{8a}{27bR}$	4

Q.No.	Solution and Scheme	Marks
9. b.	(i) Using ideal gas equation $R = \frac{\bar{R}}{M} = 188.95$ Nm/kg-K	2
	$pv = mRT$ $p = \frac{mRT}{v} = 86.345$ KPa	2
	(ii) Using vander Waals equation $\left(p + \frac{a}{v^2}\right)(\bar{v} - b) = \bar{R}T$ $\bar{v} = V \times M/m = 37.84$ m³/kgm	2
	$p = \frac{RT}{\bar{v} - b} - \frac{a}{\bar{v}^2} = 86.44$ KPa	4
10a.	a) $du = Tds - pdv$ b) $dH = dU + pdv + vdp = Tds + vdp$ c) $dF = dU - Tds - sdT = -pdv - sdT$ d) $dG = dH - Tds - sdT = vdp - sdT$	4
	Simplifying $\left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial p}{\partial s}\right)_v, \left(\frac{\partial T}{\partial p}\right)_s = \left(\frac{\partial v}{\partial s}\right)_p$ $\left(\frac{\partial p}{\partial T}\right)_v = \left(\frac{\partial s}{\partial v}\right)_T, \left(\frac{\partial v}{\partial T}\right)_p = -\left(\frac{\partial s}{\partial p}\right)_T$	4
	Tds equations $T\left(\frac{\partial s}{\partial T}\right)_p = C_p$ & $\left(\frac{\partial s}{\partial p}\right)_T = -\left(\frac{\partial v}{\partial \cancel{p} T}\right)_p$ $Tds = C_p dT - T\left(\frac{\partial v}{\partial T}\right)_p dp$	2

Q.No.	Solution and Scheme	Marks
10.b.	Molecular weight of mixture	

$\Sigma X_i m = 30.08$

Content	Mass fraction
CO_2	0.1755
O_2	0.0425
N_2	0.764
CO	0.0186

Gas constant of Mixture

$$R_{mixture} = \frac{\bar{R}}{\Sigma XM} = 0.276 \text{ KJ/kg K.}$$

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