CBCS SCHEME

BME401

USN

Fourth semester B.E. Degree Examination, April/May 2024
Applied Thermodynamics

Time: 3 hrs. **Max. marks: 100**

Note: 1. Answer any five full questions, choosing ONE full question from each module.
2. Use of steam tables / Mollier chart / Psychrometric chart is permitted.

Module-1

Q.1 a) Derive an air standard efficiency of constant volume cycle. (10)

b) An air standard Otto cycle has a compression ratio of 8. The temperature and pressure at the beginning of the compression are 300k and 102kPa. If the maximum cycle temperature is 1900K, determine i) heat supplied /kg of air, ii) net work done /kg of air, iii) thermal efficiency. (10)

OR

Q.2 a) List the methods to find the frictional power of IC engine. Explain any two. (10)

b) A 4-cylinder four stroke I.C. engine develops 60kW of IP at mean effective pressure of 7bar. The bore and stroke of the engine is 70 mm and 100 mm respectively. If the engine speed is 3700 rpm, find the average misfires per minute and the actual power developed. (10)

Module-2

Q.3 a) List the applications of the gas turbine. Explain the intercooling method of improving the efficiency of gas turbine with a neat sketch. (10)

b) Air enters the compressor of an open cycle constant pressure gas turbine at a pressure of 1 bar and temperature of 20^0C. The pressure of air after the compression is 4 bar. The isentropic efficiencies of compressor and turbine are 80% and 85% resp. The air fuel ratio used is 90:1, if flow rate of air is 3kg/s find the power developed. (10)

OR

Q.4 a) With a neat sketch, explain the working of Turboprop engine. (10)

b) A gas turbine plant works between the temperature limits of 300 K and 1000K and a pressure of 1 bar and 16 bar. The compression is carried out in two stages with perfect intercooling in between. Calculate the net power output of the plant. (10)

Module-3

Q.5 a) Explain with a neat sketch reheat cycle. (10)

b) A steam power plant incorporates an ideal reheat cycle to improve the existing efficiency. Steam at 30bar and 250^0C is supplied at the high-pressure turbine inlet and expands still it is dry saturated at 3bar. Now the steam is taken to reheater and its temperature is again increased to 250^0C at a constant pressure reheating process. The reheated steam expands in the low-pressure turbine to a condenser pressure of 0.04bar. determine the cycle efficiency. (10)

OR

Q.6 a) Explain with a neat sketch regenerative cycle with closed feed water heater. (10)

b) In a steam power cycle, the steam supply at 25bar and dry saturated. The condenser pressure is 0.2bar. Calculate the Rankine efficiency. (10)

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	Solution and Scheme for award of marks	

AY: 2023-24

Department: Mechanical Engineering
Subject with Sub. Code: Applied Thermodynamics (BME401)
Name of Faculty: Dr. Shankar Badiger

Semester End Exam
Semester : 4th

Q.No.	Solution and Scheme	Marks

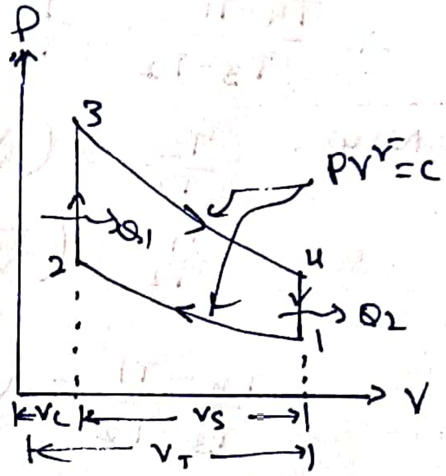
Module 1

Q.1) a) V_c = Clearance volume

V_s : Swept volume

r = compression ratio

$= V_T/V_c = \frac{V_1}{V_2}$



Let m be the fixed mass of air undergoing the cycle. — 1m

Heat supplied $= Q_1 = mc_v(T_3 - T_2)$

Heat rejected $= Q_2 = mc_v(T_1 - T_4)$

Heat rejection is -ve : $-mc_v(T_1 - T_4)$
$= mc_v(T_4 - T_1)$

$$\eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{\cancel{m}c_v(T_4 - T_1)}{\cancel{m}c_v(T_3 - T_2)} \quad \text{—(i)}$$ 3m

Process (1-2) :

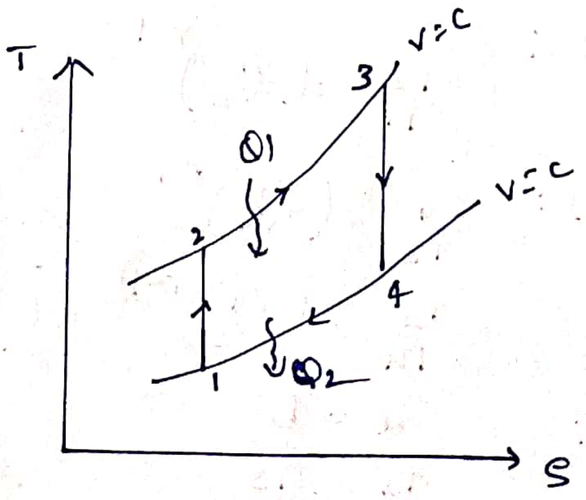
$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma - 1} \quad \text{—— (a)}$$ 1m

Process (3-4) : $\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$ (b)

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$ $\left\{ \text{Since } V_4 = V_1,\ V_3 = V_2 \right.$ 2m

$\therefore$ a = b

$$\frac{T_2}{T_1} = \frac{T_3}{T_4}$$

Q.No.	Solution and Scheme	Marks
	$\frac{T_4}{T_1} = \frac{T_3}{T_2}$ $\frac{T_4}{T_1} - 1 = \frac{T_3}{T_2} - 1$ $\frac{T_4 - T_1}{T_1} = \frac{T_3 - T_2}{T_2}$ $\therefore \frac{T_4 - T_1}{T_3 - T_2} = \frac{T_1}{T_2}$ Now. $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$ $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$ $\frac{T_4 - T_1}{T_3 - T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$ —(ii) $\therefore \eta = 1 - \left(\frac{V_2}{V_1}\right)^{\gamma-1}$ $= 1 - \left(\frac{1}{V_1/V_2}\right)^{\gamma-1}$ $= 1 - \frac{1}{r_c^{\gamma-1}}$ //	1m
b)		1m

Q.No.	Solution and Scheme	Marks
	$r_c = 8 = V_1/V_2$	
	$T_1 = 300K$	
	$P_1 = 102 kN/m^2$	
	$T_3 = T_{max} = 1900K$	
	i) $Q_1 = m C_v (T_3 - T_2)$	
	Consider (1-2):	
	Applying PVT relation.	
	$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$	
	$T_2 = T_1 (r_c)^{\gamma-1} = 300(8)^{1.4-1} = 689.2K$	
	$\therefore Q_1 = 1 \times 0.718(1900 - 689.2)$	3m
	$= 867.88 kJ/kg.$	
	ii) Net work.	
	$W_{net} = Q_1 - Q_2$	
	$Q_2 = m C_v (T_1 - T_4)$	
	$= -m C_v (T_1 - T_4)$	
	$= m C_v (T_4 - T_1)$	
	To get T_4,	
	$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$	
	$T_4 = T_3 \left(\frac{V_3}{V_4}\right)^{\gamma-1} = T_3 \left(\frac{V_2}{V_1}\right)^{\gamma-1}$	
	$= 1900 \left(\frac{1}{8}\right)^{0.4}$	
	$= 827K$	
	$\therefore Q_2 = 0.718(827 - 300)$	3m
	$= 378.38 kJ/kg.$	

Q.No.	Solution and Scheme	Marks
	$\therefore W_{net} = Q_1 - Q_2 = 489.48$ kJ/kg.	
	iii) Thermal efficiency:	
	$\eta_{th} = \dfrac{\text{net work done}}{\text{Heat supplied}}$	
	$= \dfrac{489.49}{867.88}$	
	$= 0.56$	
	$= 56\%$.	
	OR.	
	$\eta = 1 - \dfrac{1}{r_c^{\gamma-1}}$	
	$= 1 - \dfrac{1}{8^{1.4-1}}$	
	$= 0.56$	
	$= 56\%$.	3m
	OR	
Q.2) a)	1) Willan's line method 2) From IP & BP 3) Motoring test 4) Morse test 5) Retardation test.	2m

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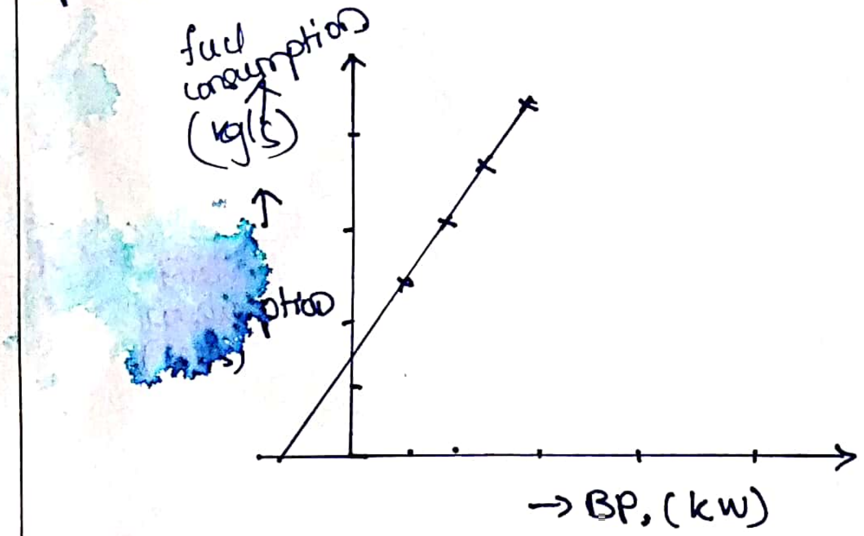
Q.No.	Solution and Scheme	Marks
	i) Willan's line method	4m

The method is known as fuel rate extrapolation method. In this method a graph of fuel consumption versus brake power is drawn & it is extrapolated on the -ve axis of brake power. The intercept of -ve axis is taken as the friction power of the engine at that speed.

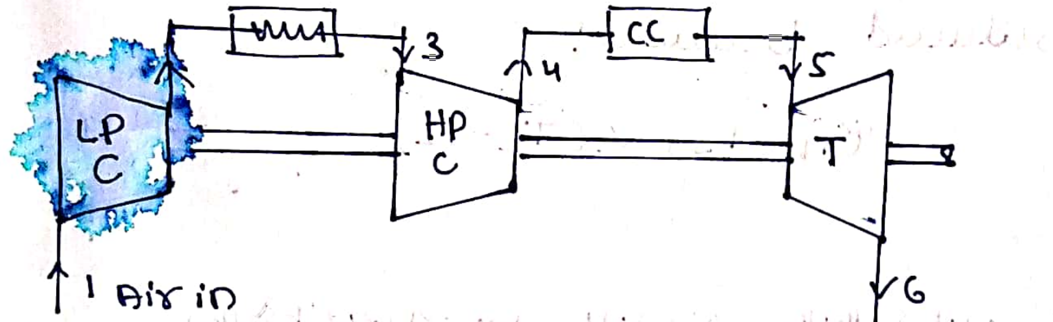
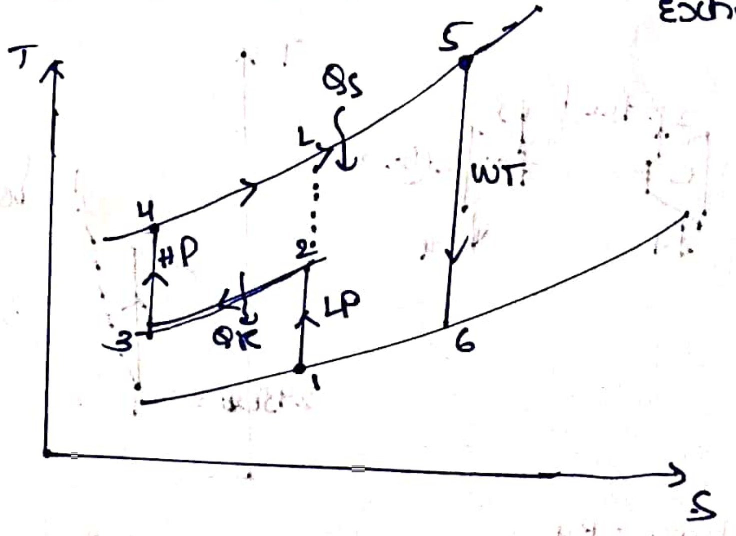


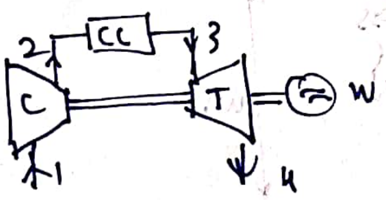
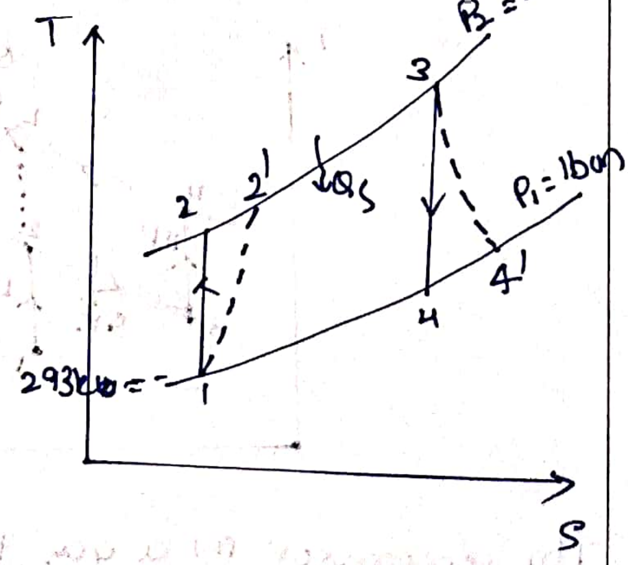
The relation between the fuel consumption & brake power is linear when speed of the engine is held constant & this permits extrapolation.

Further, when the engine does not develop power, i.e., BP = 0, it consumes a certain amount of fuel. This energy in the fuel would be spent in overcoming the friction.

Q.No.	Solution and Scheme	Marks
	2) Motoring test:	4m
	→ Engine is first run up to desired speed by its own power & allow to run at a given speed & load conditions for some time.	
	→ The power of the engine during the period is absorbed by a swinging field type electric dynamometer.	
	→ The fuel supply is then cut off & by suitable electric switching device the dynamometer is converted to run as a motor to drive for motor the engine at the same speed at which it was previously running.	
	→ The power supply to the motor is measured which is the measure of the frictional power of the engine. During the motoring test, the water supply is also cut off so that actual operating temperature are maintained.	
Q.2) b)	$n = 6$, Four stroke engine. $IP = 60kW$ $P_m = 7bar = 7\times10^2 \ kN/m^2$ $D = 70mm = 0.07m$ $L = 100mm = 0.1m$ $N = 3700rpm$ (Actual) i) no. of misfire = ? ii) IP actual = ?	

Q.No.	Solution and Scheme	Marks
	i) $IP = \frac{P_m L A N}{60 \times 2} \times n$; $A = \frac{\pi}{4} D^2 = \frac{\pi}{4}(0.07)^2 = 0.0038 m^2$	
	$= \frac{7 \times 10^2 \times 0.1 \times 0.0038}{60 \times 2} \times 6$	4m
	$\therefore (N)_{th} = 4454.48 rpm$	
	Hence theoretical explosions/min $= \frac{N}{2} = \frac{4454.48}{2}$	
	$= 2227.24$	1m
	But actual explosions/min $= \frac{N_{act}}{2} = \frac{3700}{2}$	
	$= 1850.$	
	Hence no. of misfires $= 2227.24 - 1850$	
	$= 377.24$	
	$\simeq 377$	1m
	ii) Actual indicated power:	
	$IP = \frac{P_m L A N}{60 \times 2} \times n$	
	$= \frac{7 \times 10^2 \times 0.1 \times 0.0038 \times 3700}{60 \times 2} \times 6$	3m
	$= 49.84 kW$	

Q.No.	Solution and Scheme	Marks
	Module - 2	
Q.3) a)	Applications of GT: → Aviation → Oil and gas industry → Marine propulsion / ship propulsion → Electric power generation → For turbojet & turbo propeller engines.	3m.
	Intercooling method:	
		3m.
		
	The compressor in a gas turbine cycle utilises the major percentage of power developed by	

Q.No.	Solution and Scheme	Marks
	the gas turbine. The work required by the compression can be reduced by compressing the air in two stages & by operating intercooler between the two as shown in fig.	
	work input to the compressor with intercooler	
	$= m c_p (T_2 - T_1) + m c_p (T_4 - T_3)$	
	work input without intercooler	
	$= m c_p (T_2 - T_1) + m c_p (T_L - T_2)$	
	The work input to compressor with intercooler is reduced because:	
	$(T_4 - T_3) < (T_L - T_2)$	4m
3. b)	$c_p = 1.k J/kgk$, $\gamma = 1.4$, $C_v = 41800\ kJ/kg$.	
	 	2m
	$P_1 = 1 bar = P_4$	
	$T_1 = 293k$	
	$P_2 = 4 bar = P_3$	

Q.No.	Solution and Scheme	Marks
	$\eta_c = 80\%$, $\eta_t = 85\%$	
	$\frac{A}{F} = \frac{90}{1}$, $m_a = 3 kg/s$.	
	i) $P = \dot{m} \times W_{Dnet}$.	
	$W_{Dnet} = W_T - W_C$	
	$W_T = m_g \times c_p (T_3 - T_4')$	
	$W_c = m_a \times c_p (T_2' - T_1)$	
	Calculate all temperature:	
	Heat supplied by fuel = Heat carried away by burning gas.	
	$\dot{m}_f \times C_V = m_g \times C_{pg} (T_3 - T_2')$	
	$C_V = \frac{(m_f + m_a)}{m_f} \times c_p (T_3 - T_2')$	
	$C_V = \left(1 + \frac{m_a}{m_f}\right) c_p (T_3 - T_2')$ —(i)	2m
	Consider (1-2)	
	$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}$	
	$T_2 = T_1 \left(\frac{4}{1}\right)^{\frac{1.4-1}{1.4}} = 435.4 k$.	
	$\therefore \eta_c = \frac{\text{Theoretical}}{\text{Actual compression}} = \frac{T_2 - T_1}{T_2' - T_1}$	
	$0.8 = \frac{435.4 - 293}{T_2' - 293}$	

Q.No.	Solution and Scheme	Marks

$$T_2' = 471k.$$

$$\therefore \; CV = \left(1 + \frac{ma}{mf}\right) \times cp \, (T_3 - T_2')$$

$$41800 = (1+90) \times 1 \times (T_3 - 471)$$

$$T_3 = 930k.$$

Again, consider (3-4)

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\gamma-1/\gamma}$$

$$T_4 = 930\left(\frac{1}{4}\right)^{\frac{1.4-1}{1.4}} = 624.9k.$$

$$\therefore \eta_T = \frac{\text{actual}}{\text{Ideal}} = \frac{T_3 - T_4'}{T_3 - T_4}$$

$$0.85 = \frac{930 - T_4'}{930 - 824.9}$$

$$T_4' = 670.6k.$$ 2m

$$W_T = mg \times cpg \times (T_3 - T_4')$$

$$mg = ma + mf$$

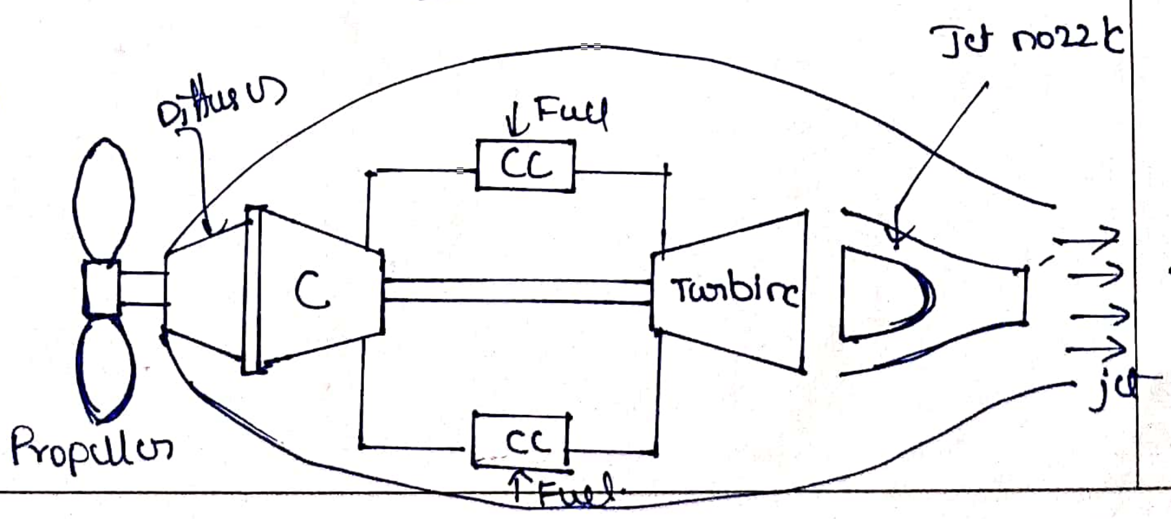
$$= \frac{ma}{ma} + \frac{mf}{ma}$$ — for 1kg of air

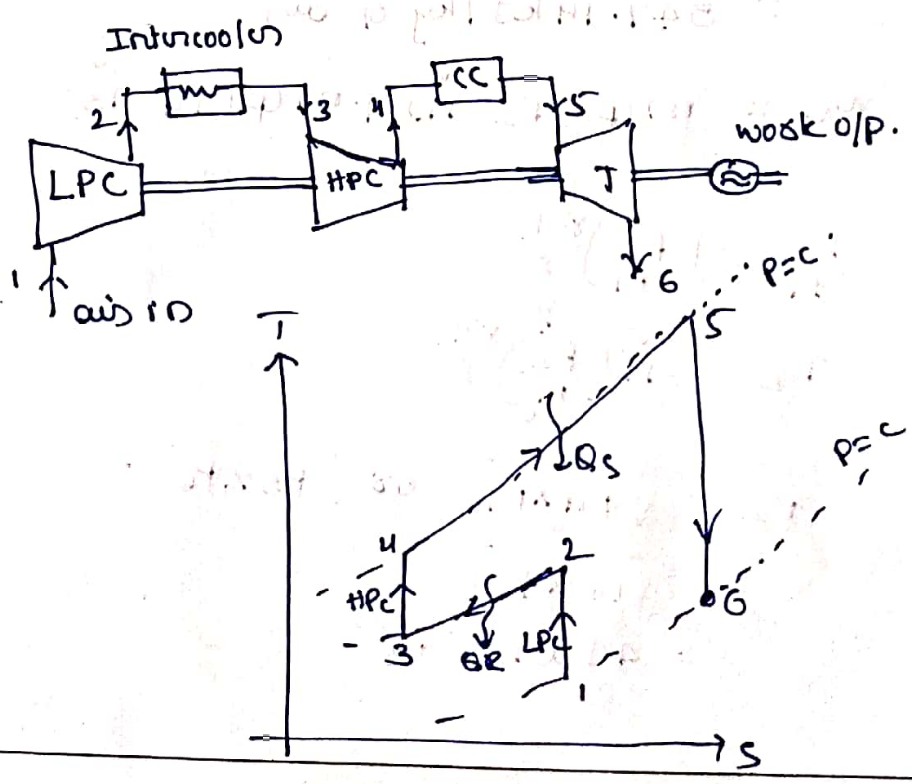
$$= 1 + \frac{mf}{ma}$$

$$= 1 + \frac{1}{90}$$

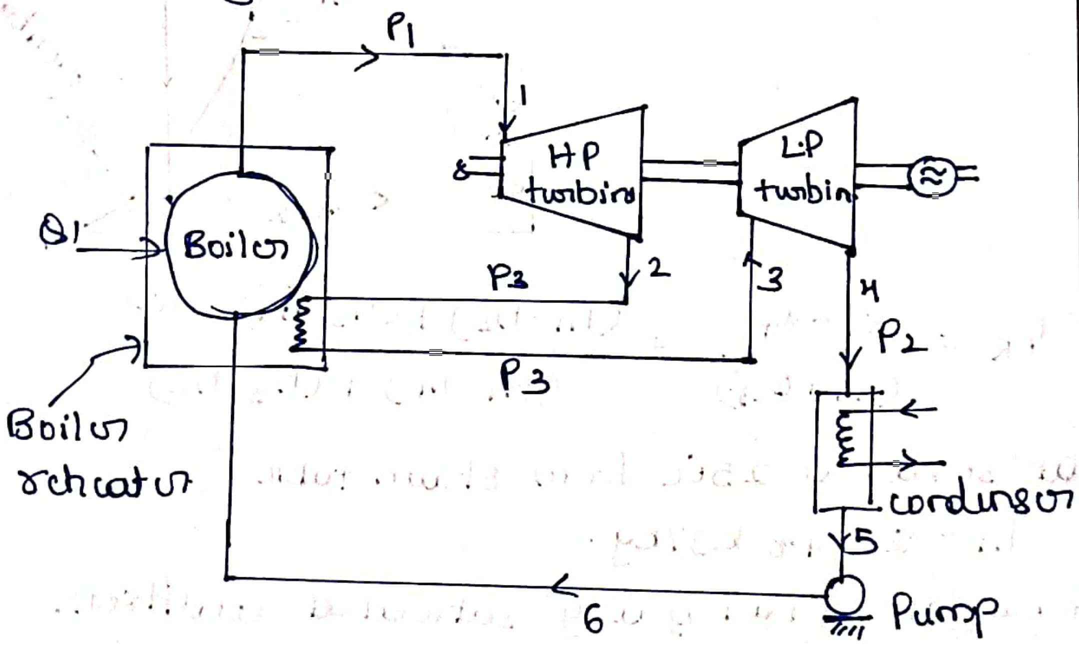
for 1kg of air $(1/90)^{th}$ of fuel is burned.

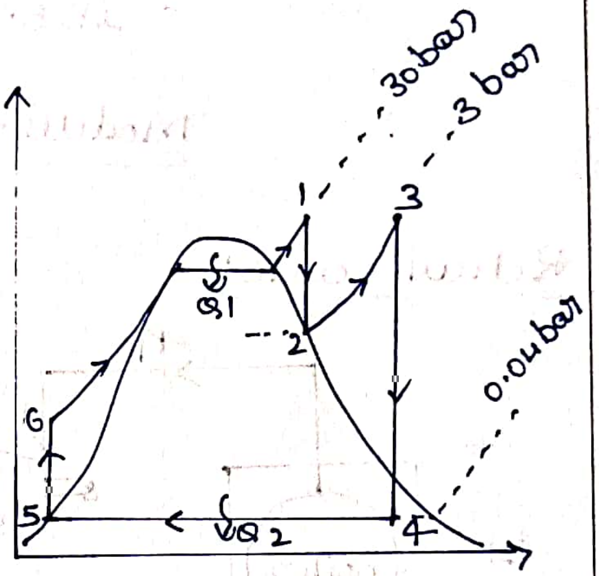
or $\therefore \frac{A}{F} = \frac{90}{1}$; $\frac{ma}{mf} = \frac{1}{(1/90)}$

Q.No.	Solution and Scheme	Marks
	$m_g = m_a + m_f$ $= 1 + \frac{1}{90}$ $= \frac{90+1}{90}$ $= \frac{91}{90}$	2m
	$w_T = m_g c_p (T_3 - T_4')$ $= \frac{91}{90} \times 1 \times (930 - 670.6)$ $= 262.28$ kJ/kg of air $w_C = m_a \times c_{pa} (T_2' - T_1)$ $= 1 \times 1 \times (471 - 293)$ $= 178$ kJ/kg of air $w_{net} = w_T - w_C = 262.28 - 178 = 84.28$ kJ/kg of air.	
	$\therefore$ Power $= m \times w_{net}$ $= 3 \times 84.28 = 252.8$ kW	2m.
	OR	
Q.4) a)		4m

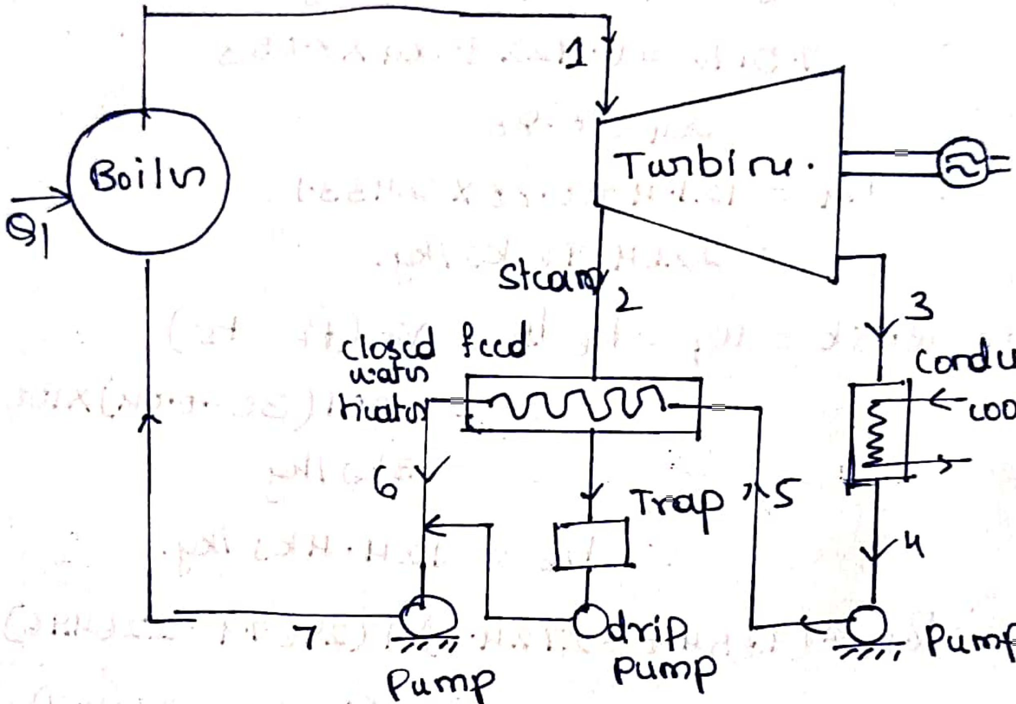
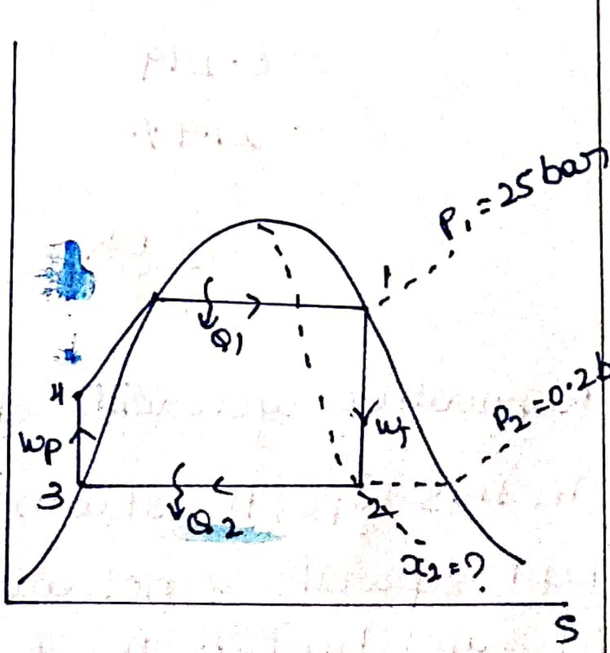
Q.No.	Solution and Scheme	Marks
	This is employed in aircraft. Here the expansion of gases takes place partly in turbine (80%) & partly (20%) in the nozzle. The power developed by the turbine is consumed in running the compressor & the propeller. The propeller & jet produced by the nozzle give forward motion to the aircraft. The turbo-prop entails the advantages of turbo-prop is improved by providing the diffuser befor the compressor as shown. The pressure raise takes place due to conversion of kinetic energy of the incoming air into pressure energy by the diffuser. This is called "ram effect".	6m
4. b)		2m

Q.No.	Solution and Scheme	Marks
	$T_1 = 300k = T_3$ $T_5 = 1000k$ $P_1 = 1bar = P_6$ $P_5 = 16\ bar = P_4$ $C_p = 1kJ/kgK.$ For perfect intercooler: $T_1 = T_3,\quad T_2 = T_4$ Net power $= \dot{m}(W_T - W_C)$ $W_T = \dot{m}C_p(T_5 - T_6)$ $\frac{T_6}{T_5} = \left(\frac{P_6}{P_5}\right)^{\frac{\gamma-1}{\gamma}}$ $T_6 = 1000\left(\frac{1}{16}\right)^{\frac{1.4-1}{1.4}} = 452.86K.$	2m
	$W_T = \dot{m}C_p(T_5 - T_6)$ $= 1\times 1(1000 - 452.86)$ $= 547.14\ kJ/kg$ of air	1m
	$W_C = \dot{m}C_p(T_2 - T_1) + \dot{m}C_p(T_4 - T_3)$ $=$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$? $T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$ $P_2 = \sqrt{P_4\times P_1}$ or $\sqrt{P_5\times P_6}$ $= \sqrt{16\times 1}$ $= 4\ bar = P_3$	2m

Q.No.	Solution and Scheme	Marks
	$\therefore T_2 = 300\left(\frac{4}{1}\right)^{0.4/1.4} = 445.8k$	
	$W_C = 1\times1[(445.8-300)+(445.8-300)]$	
	$= 291.6 \text{ kJ/kg}.$	2m
	$P = \dot{m}\times w_{net} = \dot{m}(w_T - w_C)$	
	$= 1(547.14 - 291.6)$	
	$= 255.5 \text{ kJ/s}$ or kW.	1m
	Module - 3	
Q.5) a)	Reheat cycle:-	
		4m
	In reheat cycle, expansion of steam from initial state 1 to the condenser pressure is carried out in two or more steps, depending upon number of reheat used.	6m
	In first step, steam expands in high pressure turbine from initial state to approximately	

Q.No.	Solution and Scheme	Marks
	the saturated vapour line (1-2). The steam is then superheated at a constant pressure in a boiler (2-3) & the remaining expansion (3-4) is carried out in a low pressure (LP) turbine.	
5.b)	$P_1 = 30$ bar, $T_1 = 250°C$ $P_2 = 3$ bar, $T_3 = 100°C$ $P_4 = 0.04$ bar	
		2m
	$\eta_R = \frac{W_T - W_P}{(Q_1 + Q_{23})} = \frac{(h_1 - h_2) + (h_3 - h_4) - W_P}{(h_1 - h_6) + (h_3 - h_2)}$	
	at 30 bar & 250°C from steam table $h_1 = 2854.8$ kJ/kg.	1m
	now at 3 bar & dry saturated condition, $h_2 = h_g = 2724.7$ kJ/kg	
	at 3 bar & 250°C $h_3 = 2967.9$ kJ/kg $S_3 = 7.5176$ kJ/kgK	1m
	at 0.04 bar $v_5 = v_f = 0.001$ m3/kg	

Q.No.	Solution and Scheme	Marks
	$h_{f4} = 121.4\,kJ/kg$, $h_{fg4} = 2433.1\,kJ/kg$.	1m
	$s_{f4} = 0.422\,kJ/kgK$, $s_{fg4} = 8.053\,kJ/kgK$.	
	$\therefore h_4 = h_{f4} + x_4 \times h_{fg4}$	
	Equating entropy :	
	$s_3 = s_4 = s_{f4} + x_4 s_{fg4}$	
	$7.5176 = 0.422 + x_4 \times 8.053$	2m
	$x_4 = 0.88$	
	$\therefore h_4 = 121.4 + 0.88 \times 2433.1$	
	$= 2264.96\,kJ/kg$.	1m
	Pump work $= w_p = h_6 - h_5 = v_5 (P_6 - P_5)$	
	$= 0.001(30 - 0.04) \times 100$	
	$= 3\,kJ/kg$	
	$\therefore h_6 = 124.4\,kJ/kg$.	1m
	$\therefore \eta_R = \dfrac{(2854.8 - 2724.7) + (2967.9 - 2264.96) - 3}{(2854.8 - 124.4) + (2967.9 - 2724.7)}$	
	$= 0.279$	1m
	$= 27.9\%$	
	OR	
Q.6) a)	Regenerative cycle with closed feed water heater.	5m
	In this type, the steam & feed water are kept separate & not allowed to mix together in water heater. The feed water is made to	

Q.No.	Solution and Scheme	Marks
	flow through the tubes. The extracted steam from turbine is passed around the tubes & transfers heat to the feed water. Thus the condensed steam may be pumped back to the feed water line. 	5m
6.b)	$P_1 = 25$ bar $P_2 = 0.2$ bar $\dot{m} = 10$ kg/s $x_2 = ?$ $w_T = ?$ $w_P = ?$ $\eta_R = ?$ 	1m

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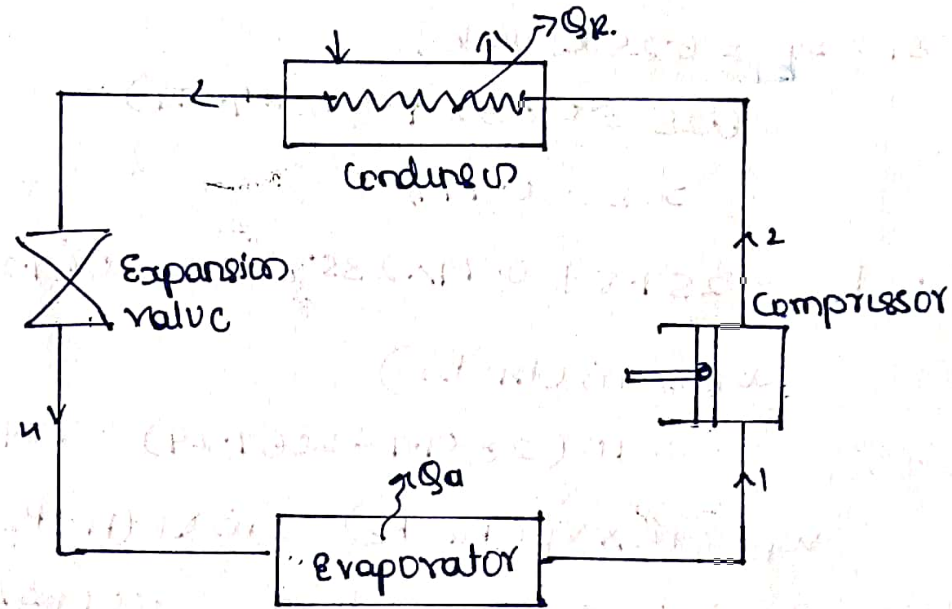
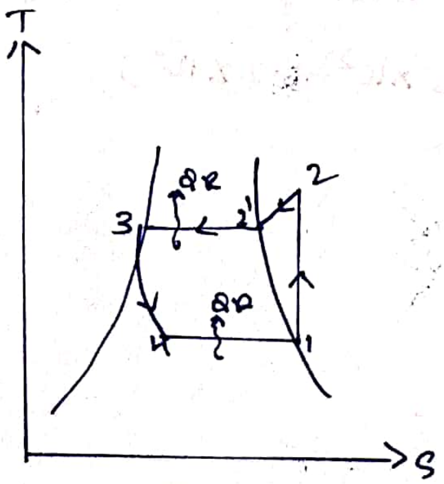
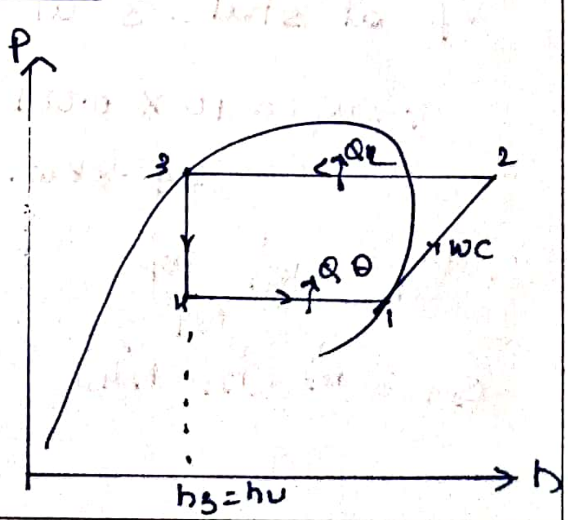
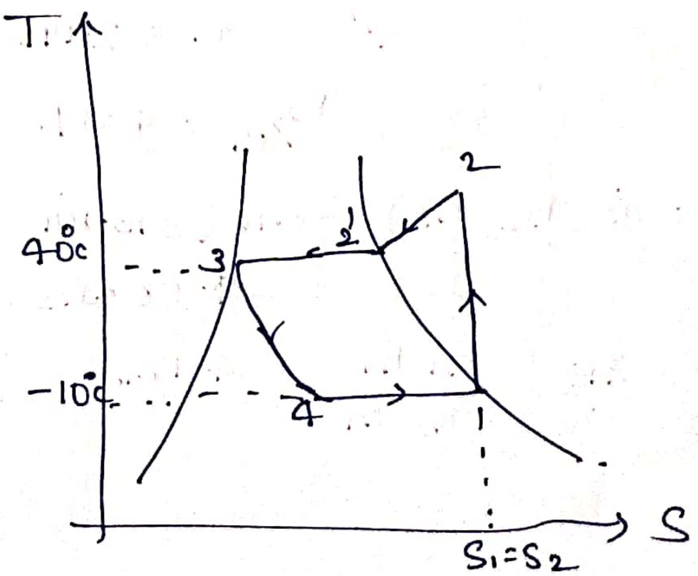
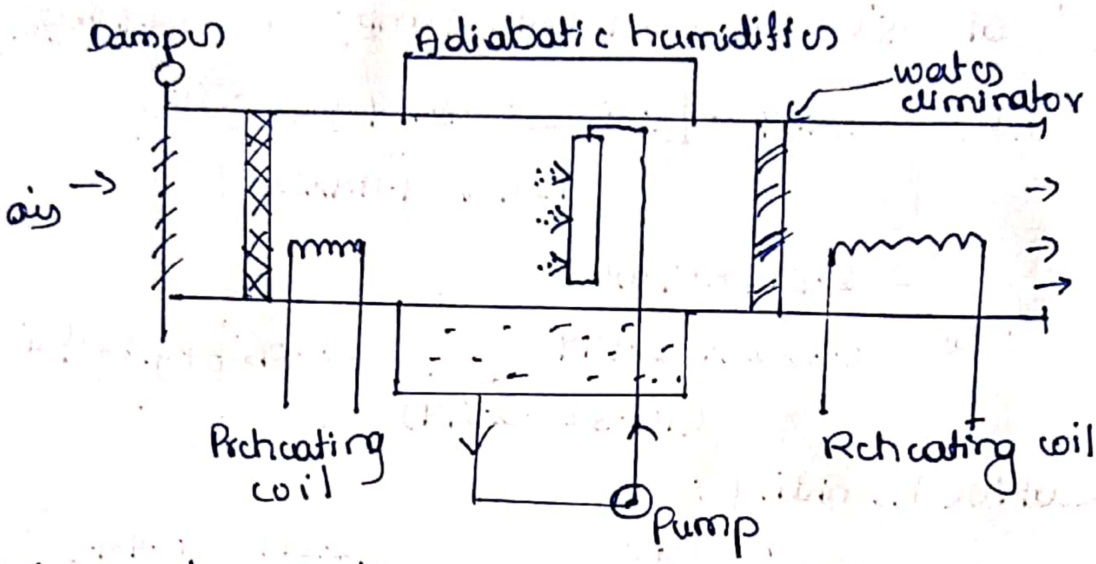
Q.No.	Solution and Scheme	Marks
	$\eta_R = \dfrac{W_T - W_P}{Q_1}$	
	$h_1 = h_g$ at 25 bar from table $= 2801 kJ/kg$	
	$S_1 = S_g$ " " $= 6.25 kJ/kg$	
	$h_2 = h_{f_2} + x_2 h_{fg_2}$.	
	at 0.2 bar, $h_{f_2} = 251.5 kJ/kg$. $S_{f_2} = 0.83 kJ/kgK$	
	$h_{fg_2} = 2358.4 kJ/kg$, $S_{fg_2} = 7.07 kJ/kgK$.	
	$S_1 = S_2 = S_{f_2} + x_2 S_{fg_2}$	
	$S_1 = S_g = 6.25 kJ/kg.K$,	
	$6.25 = 0.832 + (x_2 \times 7.077)$	
	$x_2 = 0.77$,	3m
	$\therefore h_2 = 251.5 + 0.77 \times 2358.4 = 2067.29 kJ/kg$	
	$W_T = \dot{m}(h_1 - h_2)$	
	$= 10(2801.7 - 2067.29) = 7345 kJ/s$.	2m
	$W_P = \dot{m} \times V_f (P_4 - P_3) = \dot{m} V_f (P_1 - P_2)$	
	V_f at state 3 at 0.2 bar $= 0.001 m^3/kg$	
	$\therefore W_P = 10 \times 0.001 (25 \times 10^2 - 0.2 \times 10^2)$	
	$= 24.8 kW$.	2m
	$\therefore \eta_R = \dfrac{W_T - W_P}{Q_1}$	
	$Q_1 = \dot{m}(h_1 - h_4)$	

Q.No.	Solution and Scheme	Marks
	$h_3 = h_f$ at 0.2 bar $= 251.5$ kJ/kg	
	$\therefore \quad 24.8 = 10 \times (h_4 - 251.5)$	
	$h_4 = 253.98$ kJ/kg	
	$\therefore Q_1 = 10(2801 - 253.98) = 25470.2$ kJ/s	
	$\therefore \eta_R = \frac{7345 - 24.8}{25470.2} = 0.287 = 28\%$	2m
	Module-4	
Q.7) a)		
	 	

Q.No.	Solution and Scheme	Marks
	→ The vapour coming from the evaporator is compressed into the compressor to the high pressure (1-2).	
	→ Thus the high pressure, high temperature vapour is delivered to the condenser, where it is cooled.	
	→ The high pressure refrignant is thus expanded into the expansion valve & due to the expansion its temperature decreases & becomes liquid refrigrant.	
	→ The liquid refrignant is passed through the evaporator where it absorbs all heat from the objects being cooled. By absorbing heat, liquid refrignant becomes vapour & is again delivered to the compressor to repeat the cycle.	
b)		1m

Q.No.	Solution and Scheme	Marks
	from table	
	$h_1 = h_g = 347.13\ kJ/kg$	
	$h_2' = h_g = 367.14\ kJ/kg$	
	$h_3 = h_f = 238.53\ kJ/kg = h_4.$	
	$h_2 = h_2' + c_{pv}(T_2 - T_2')$	
	$s_1 = s_2$ $s_1 = s_g = 1.55\ kJ/kgK$	
	$S_2 = S_2' + c_{pv} \ln\left(\frac{T_2}{T_2'}\right)$	
	$1.559 = 1.54 + 0.78 \times \ln\left(\frac{T_2}{40+273}\right)$	
	$T_2 = 48.08^\circ C.$	2m
	$\therefore h_2 = 373.44\ kJ/kg.$	1m
	i) $RC = \dot{m} \times RE$	
	$5 \times 3.5 = \dot{m}(h_1 - h_4) = \dot{m}(347.13 - 238.53)$	
	$\dot{m} = 0.16\ kg/s.$	1m
	ii) $T_2 = 48.08^\circ C.$	1m
	iii) from table at $40^\circ c = P_2 = 9.6\ bar$	
	$-10^\circ c = P_1 = 2.193\ bar$	
	$P_2/P_1 = 4.39.$	1m
	iv) $Q_R = \dot{m}(h_2 - h_3) = 0.16(373.44 - 238.53)$	
	$= 21.58\ kJ/s.$	1m
	v) $COP = \frac{RE}{W_c} = \frac{h_1 - h_4}{h_2 - h_1} = 4.12$	1m

Q.No.	Solution and Scheme	Marks
	OR	
Q.8) a)	winter air conditioning system:	
		5m
	The winter conditions are say 15°c & 80% RH. The required comfort conditions are 24°c & 60% RH. It is used for mild winter conditions at cities like Aurangabad, Poona etc.	5m
	The air is passed through the resistance heater which is known as preheating coil & then it is passed through the humidifier & again through second heater. In between two heaters, the water vapours are added to increase the humidity.	
b)	$T_{db} = 35°C$ $T_{wb} = 25°C$ $P_t = 101.325\ kN/m^2$ $\omega = 0.622 \times \frac{P_v}{(P_t - P_v)}$	

Q.No.	Solution and Scheme	Marks

$$P_V = (P_{VS})_{wb} - \frac{[P_t - (P_{VS})_{wb}](T_{db} - T_{wb})}{1547 - 1.44\,T_{wb}}$$

at 25°c T_{wb} = wet bulb tempr, $P_{VS} = 3.169\,kN/m^2$

$$\therefore P_V = 3.169 - \frac{[101.325 - 3.169](35-25)}{1547 - 1.44\times 25}$$

$$= 2.519\,kN/m^2.$$

$$\therefore \omega = 0.622 \times \frac{2.519}{(101.32 - 2.519)} = 0.0158\ kg/kg\ of\ air$$ 4m

Relative humidity :

$$\phi = \frac{P_V}{P_{VS}\ @\ DBT} = \frac{2.519}{5.62} = 0.44.$$ 2m

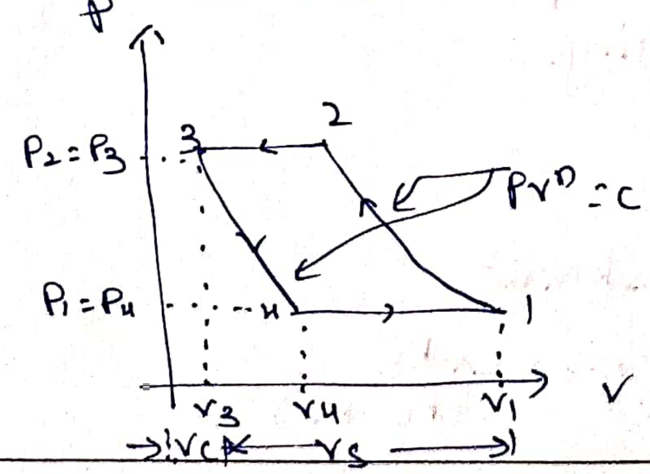
Dew point temperature at $P_V = 2.519$ from table
$= 21.5°C$ 1m

Enthalpy $h = 1.005 \times T_{db} + \omega[2500 + 1.88 \times T_{db}]$ 3m

$= 75.86\ kJ/kg.$

Module - 5

Q.9)
a)



2m

Q.No.	Solution and Scheme	Marks
	$\eta_v = \frac{V_a}{V_s} = \frac{(V_1 - V_4)}{(V_1 - V_3)}$ —— (i)	
	$= \frac{(V_1 - V_4) + V_3 - V_3}{V_3}$ Adding, subtracting $+V_3, -V_3$	
	$= \frac{V_1 - V_4 + V_3 - V_3}{V_3}$	
	$= V_1 - V_3 + V_3 - V_4 / V_3$	
	$= (V_1 - V_3) + V_c - V_4 / V_s$	
	$= (V_1 - V_3) + (V_3 - V_4) / (V_1 - V_3)$	
	$= 1 + \frac{(V_3 - V_4)}{(V_1 - V_3)}$	
	$= 1 + \frac{V_3}{(V_1 - V_3)} - \frac{V_4}{(V_1 - V_3)}$ —— (2)	4m
	Clearance, $C = V_c / V_s$ $\therefore V_c = V_3,\ V_s = V_1 - V_3$	
	$C = \frac{V_3}{V_1 - V_3}$	
	$\therefore \eta_v = 1 + C - \frac{V_4}{(V_1 - V_3)}$	
	consider (3-4): $PV^n = C$	
	$P_3 V_3^n = P_4 V_4^n$	
	$\frac{V_4}{V_3} = \left(\frac{P_3}{P_4}\right)^{1/n}$	
	$V_4 = V_3 (P_3 / P_4)^{1/n}$	
	substitute V_4 in (3)	
	$\eta_v = 1 + C - \frac{1}{(V_1 - V_3)} \times V_3 \left(\frac{P_3}{P_4}\right)^{1/n}$	4m

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Q.No.	Solution and Scheme	Marks

$$= 1 - C\left[\left(\frac{P_2}{P_1}\right)^{1/n} - 1\right]_{,,}$$

b) double acting

$V_0 = 0.25\ m^3/s$

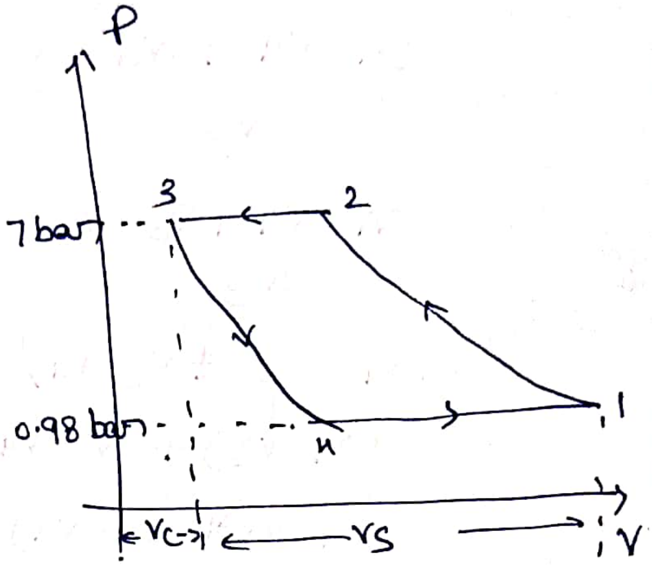
$P_0 = 1.013$ bar

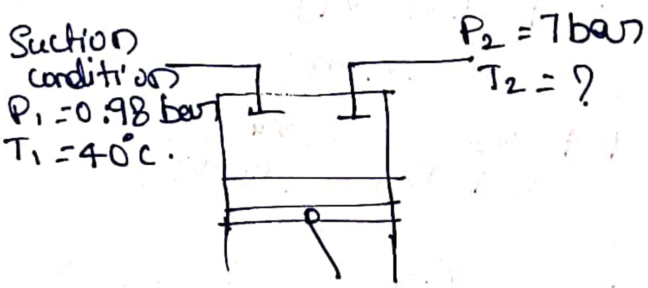
$T_0 = 27°c$

$P_2 = 7$ bar

$P_1 = 0.98$ bar

$T_1 = 40°c$.





2m

air-ambient

$P_0 = 1.013$ bar

$T_0 = 27°c$

$V_c = 4\%\ V_s$

$$C = \frac{V_c}{V_s} = 4\% = 0.04$$

$$\frac{L}{D} = \frac{1}{3}, \quad N = 300\ rpm$$

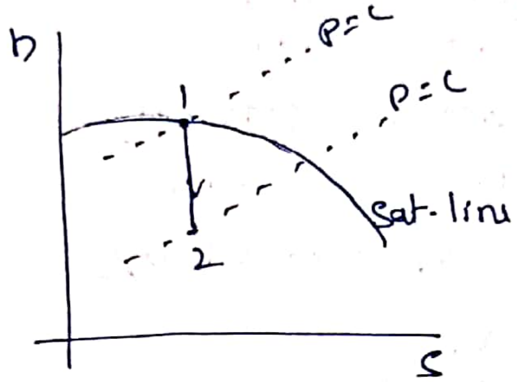
i) $$\eta_v = \frac{V_1}{V_s \times 2N}$$

$$\eta_v = 1 + C - C\left(\frac{P_2}{P_1}\right)^{1/n}$$

$$= 1 + 0.04 - 0.04\left(\frac{7}{0.98}\right)^{1/1.3} = 0.858 = 85.8\%$$

3m

Q.No.	Solution and Scheme	Marks
	Equating ambient & suction conditions	
	$\frac{P_0 V_0}{T_0} = \frac{P_1 V_1}{T_1}$	
	$\frac{1.013 \times 0.25}{300} = \frac{0.98 \times V_1}{313}$	
	$V_1 = 0.269\ m^3/s$	
	$\therefore \eta_v = \frac{V_1}{V_s \times 2N}$	
	$0.858 = \frac{0.269}{V_s \times 2 \times 300}$	
	$V_s = 0.0314\ m^3$	
	$V_s = \frac{\pi}{4} \times D^2 \times L$	
	$= \frac{\pi}{4} \times (3 \cdot L)^2 \times L$	
ii)	$\therefore L = 0.164 m$	3m
	$D = 3L = 0.493 m.$	
iii)	$WD = \frac{n}{n-1} \times P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$	
	$= \frac{1.3}{1.3-1} \times 0.98 \times 10^2 \times 0.269 \left[\left(\frac{7}{0.98} \right)^{\frac{1.3-1}{1.3}} - 1 \right]$	2m.
	$IP = 65.7 kW.$	

Q.No.	Solution and Scheme	Marks
	OR	
Q.10) a)		1m
	The gain in KE through a nozzle $= V_2^2/2$	
	W.D during Rankine cycle $= \frac{n}{(n-1)}(P_1V_1 - P_2V_2)$.	
	Heat drop = WD.	
	Since KE is equal to heat drop.	
	$\frac{V_2^2}{2} = \frac{n}{n-1}(P_1V_1 - P_2V_2)$	
	V_1 & V_2 = Specific volume. m^3/kg.	
	$\frac{V_2^2}{2} = \frac{n}{n-1} \times P_1V_1\left(1 - \frac{P_2V_2}{P_1V_1}\right)$ —(i)	
	$P_1V_1^n = P_2V_2^n = C$	
	$\frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{1/n} = \frac{P_1^{1/n}}{P_2^{1/n}} = \frac{P_2^{-1/n}}{P_1^{-1/n}}$	
	$= \left(\frac{P_2}{P_1}\right)^{-1/n}$.	
	$\therefore V_2 = V_1\left(\frac{P_2}{P_1}\right)^{-1/n}$.	2m
	Substitute $\frac{V_2}{V_1}$ in equation (i)	

Q.No.	Solution and Scheme	Marks
	$\frac{V_2^2}{2} = \frac{n}{n-1} \times P_1V_1 \left[1 - \frac{P_2}{P_1}\left(\frac{P_2}{P_1}\right)^{-1/n}\right]$	
	$= \frac{n}{n-1} \times P_1V_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]$	
	$V_2 = \sqrt{2 \times \frac{n}{n-1} \times P_1V_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$	2m.
	$Q = AV_2$	
	$\dot{m} = \rho Q$	
	$= \rho \times AV_2$	
	$= \frac{kg}{m^3} \times A \times V_2$	
	$= \frac{1}{v_2} \times A \times V_2$	
	$= \frac{AV_2}{v_2}.$	
	$= \frac{AV_2}{v_2} = \frac{A}{v_2} \times \sqrt{2 \times \frac{n}{n-1} \times P_1v_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$	
	$= \frac{A}{v_1\left(\frac{P_2}{P_1}\right)^{-1/n}} \times \sqrt{2 \times \frac{n}{n-1} \times P_1v_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$	
	$= A\sqrt{\left(\frac{P_2}{P_1}\right)^{\frac{2}{n}} \times \frac{2n}{n-1} \times \frac{P_1V_1}{v_2}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$	
	$= A\sqrt{\frac{2n}{n-1} \times \frac{P_1}{v_1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{n}} - \left(\frac{P_2}{P_1}\right)^{\frac{n+1}{n}}\right]}$ //	5m.

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Q.No.	Solution and Scheme	Marks

b)

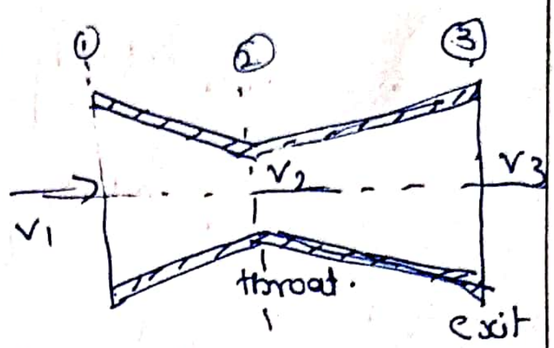
$\dot{m} = 10 \, kg/s$

$P_1 = 10 \, bar$

$T_1 = 673 \, K$

$P_3 = 1 \, bar$

$k = \eta_n = 0.92, \; n = 1.3$



i) $V_2 = 44.72\sqrt{hd_2}$

$hd_2 = (h_1 - h_2)$

or $V_2 = \sqrt{2 \times \frac{n}{n-1} \times P_1 v_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$

To calculate V_3:

$$hd_3 = h_1 - h_3 = \frac{n}{n-1} \times P_1 v_1 \left[1 - \left(\frac{P_3}{P_1}\right)^{\frac{n-1}{n}}\right]$$

$$= \frac{n}{n-1} \times mRT_1 \left[1 - \left(\frac{P_3}{P_1}\right)^{\frac{n-1}{n}}\right]$$

$$= \frac{1.3}{1.3-1} \times 1 \times 287 \times 673 \left[1 - \left(\frac{1}{10}\right)^{\frac{1.3-1}{1.3}}\right]$$

$$= 344132.78 \, J/kg$$

$$= 344.13 \, kJ/kg.$$

$\therefore V_3 = 44.72\sqrt{k \, hd_3}$

$= 44.72\sqrt{0.92 \times 344.13}$

$= 795.71 \, m/s.$ 3m

ii) $\dot{m} = \frac{A_2 V_2}{v_2 ?}$

Q.No.	Solution and Scheme	Marks
	$P_2 v_2 = \dot{m} R T_2$	
	$\therefore \quad \frac{P_2}{P_1} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$	
	$P_2 = P_1\left(\frac{2}{1.3+1}\right)^{\frac{1.3}{1.3-1}} = 5.45$ bar.	
	$P_1 v_1 = mRT_1$	
	$V_2 = \sqrt{2 \times \frac{n}{n-1} \times P_1 v_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$	
	$= \sqrt{2 \times \frac{n}{n-1} \times mRT_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]}$	
	$= \sqrt{\frac{2 \times 1.3}{1.3-1} \times 1 \times 287 \times 673 \left[1 - \left(\frac{5.45}{10}\right)^{\frac{1.3-1}{1.3}}\right]}$	
	$= 467.01$ m/s.	
	$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = 673\left(\frac{5.45}{10}\right)^{\frac{1.3-1}{1.3}} = 585.31$ k.	
	$P_2 v_2 = mRT_2$	
	$v_2 = \frac{mRT_2}{P_2} = \frac{1 \times 287 \times 585.31}{5.45 \times 10^5} = 0.308$ m³/kg.	
	$\dot{m} = \frac{A V_2}{v_2}$	
	Throat area $= A_2 = \frac{\dot{m} v_2}{V_2} = \frac{1 \times 0.308}{467.02} = 6.59 \times 10^{-4}$ m²	4m

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Q.No.	Solution and Scheme	Marks
	Exit area :	
	$\dot{m} = \frac{A_3 V_3}{v_3}$	
	$P_3 v_3 = m R T_3$	
	increase in temprature $= \frac{27.53}{r \times 1} = 27.53k$.	
	$T_3 = 396.29 + 27.53 = 423.82K$.	
	$\therefore v_3 = \frac{mRT_3}{P_3} = \frac{1 \times 287 \times 423.82}{1 \times 105}$	
	$= 1.216 m^3/kg$.	
	$\therefore A_3 = \frac{\dot{m} \times v_3}{V_3}$	
	$= \frac{1 \times 1.216}{795.71}$	
	$= 1.528 \times 10^{-3} m^2$.	3m
	—— x —— x ——	
	(Dr. Shankar. Badiger). 19/4/24	