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4th. A.

 17ME43

Fourth Semester B.E. Degree Examination, Aug./Sept. 2020
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 thermodynamic data hand book is permitted.*

Module-1

1 a. State any 2 assumptions for Air Standard Cycle and obtain air standard efficiency expression for diesel cycle. **(10 Marks)**

b. An air standard limited pressure cycle has a compression ratio of 15 and compression begins at 0.1 MPa, 40°C. The maximum pressure is limited to 6 MPa and the heat added is 1.675 MJ/kg. Compute (i) The heat supplied at constant volume per kg of air (ii) The heat supplied at constant pressure per kg of air (iii) The cycle efficiency (iv) The cut-off ratio (v) The M.E.P of the cycle. **(10 Marks)**

OR

2 a. With the help of line diagram and T-S diagram, explain intercooling and reheating in gas turbine cycles. **(10 Marks)**

b. A gas turbine working on Brayton cycle receives air at 1 bar and 27°C. The air is compresed adiabatically to 6.2 bar with efficiency of the compressor being 88%. The fuel has a heating value of 44180 kJ/kg and the fuel air ratio is 0.017 kg fuel/kg air. The efficiency of the turbine is 90%. Calculate (i) Compressor work (ii) Turbine work and (iii) Thermal efficiency. **(10 Marks)**

Module-2

3 a. Explain the types of feed water heater using flow and T-S diagram. **(10 Marks)**

b. A turbine is supplied with steam at a pressure of 32 bar and temperature of 410°C. The steam then expands isentropically to a pressure of 0.08 bar. Find the dryness fraction at the end of expansion and thermal efficiency of the cycle.
If the steam is reheated at 5.5 bar to a temperature of 400°C and then expanded isentropically to a pressure of 0.08 bar, what will be the dryness fraction and thermal efficiency of the cycle. **(10 Marks)**

OR

4 a. Discuss the effect of condenser pressure and Boiler pressure in Rankine cycle. **(08 Marks)**

b. Write any two desirable characteristics of the working fluid used in vapour power cycle. **(02 Marks)**

c. A 40 MW steam power plant working on Rankine cycle operates between boiler pressure of 4 MPa and condenser pressure of 10 KPa. The steam leaves the boiler and enters the steam turbine at 400°C. The isentropic efficiency of the steam turbine is 85%.
Determine (i) The cycle efficiency (ii) The quality of exhaust steam from the turbine and (iii) the steam flow rate in kg per hour. Consider pumpwork. **(10 Marks)**

Module-3

5 a. Define stoichimetric air, actual air, excess air and combustion efficiency. **(08 Marks)**

b. Calculate the air-fuel ratio for burning of propane (C_3H_8) with 130 percent theoretical air. **(08 Marks)**

c. Explain Detonation in SI engine. **(04 Marks)**

OR

6 a. With P-θ diagram, explain the stages of combustion in SI engine. **(08 Marks)**

b. In a test on a 3-cylinder, 4-stroke IC engine with 22 cm bore and 26 cm stroke, the following were the observations during a trail period of one hour.
Fuel consumption = 8 kg, Calorific value = 45000 kJ/kg
Total revolutions of the Crankshaft = 12000
Mean effective pressure = 6 bar
Net load on brake = 1.5 kN
Brake drum diameter = 1.8 m, Rope diameter = 3 cm
Mass of cooling water = 550 kg
Inlet temperature of water = 27°C
Exit temperature of water = 55°C
Air consumed = 300 kg, Ambient temperature = 30°C
Exhaust gas temperature = 310°C
Specific heat of gases = 1.1 kJ/kg K
Calculate (i) Indicated and brake power (ii) Mechanical efficiency
(iii) Indicated thermal efficiency
Also draw a heat balance sheet on minute and percent basis. **(12 Marks)**

Module-4

7 a. Explain any two factors affecting the performance of a simple vapour compression system. **(06 Marks)**

b. With a neat sketch, explain steam jet refrigeration. **(06 Marks)**

c. A simple vapour compression plant produces 5 tonnes of refrigeration. The enthalpies of the working fluid at inlet to the compressor, at exit of compressor and at exit from the condenser are 183.19 KJ/kg, 209.41 KJ/kg and 74.59 KJ/kg respectively. Estimate (i) The refrigerant flow rate (ii) COP of the plant (iii) Power required to drive the compressor and (iv) the rate of heat rejection in the condenser. Assume that vapour is dry saturated at the end of compression. **(08 Marks)**

OR

8 a. Explain the following: (i) Adiabatic mixing of air (ii) Heating and Humidification (iii) Cooling and dehumidification. **(12 Marks)**

b. The dry and the wet bulb temperature of atmosphere air at 1 atm (101.325 KPa) pressure are measured with a sling psychrometer and determined to be 25 and 15°C respectively. Determine (i) Specific humidity (ii) Relative humidity (iii) The enthalpy of air (iv) DPT. Use properties of table only. **(08 Marks)**

Module-5

9 a. Derive an expression for workdone with clearance volume. **(08 Marks)**

b. A single acting air compressor has a cylinder bore of 15 cm and a piston stroke of 25 cm. The crank speed is 600 rpm. Air taken from atmosphere (1 bar and 27°C) is delivered at 11 bar. Assuming that both the compression and expansion processes are according to the law $PV^{1.25}$ = constant and the clearance is 5%. Determine (i) Power required to drive the compressor, assuming mechanical efficiency as 80% (ii) The time required to deliver 1 m^3 of air as measured at compressor outlet conditions, (iii) Volumetric efficiency. **(12 Marks)**

OR

10 a. Explain the shapes of nozzle. **(06 Marks)**

b. In a 2-stage air compressor, the work output is found to be 350 KJ/kg of air. It is used to compress 1 kg of free air from 1 bar pressure and 32°C initial temperature. The value of n = 1.3 and R = 0.287 KJ/kgK. Find the intermediate pressure. **(06 Marks)**

c. Obtain an expression for volumetric efficiency of compressor. **(08 Marks)**

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Applied Thermodynamics

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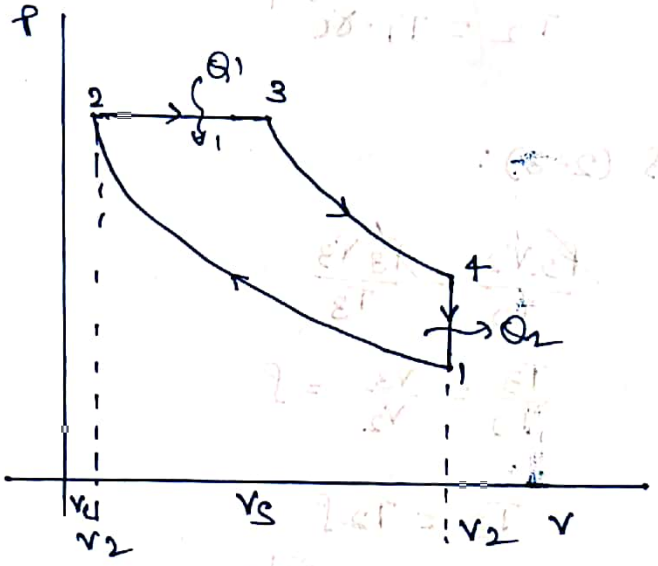
Q.1.

a) Assumptions :.

1) working fluid is air.

2) All the process are internally reversible.

Air standard efficiency of diesel cycle.



let

r_c = compression ratio = $\frac{V_1}{V_2}$

r_e = expansion ratio = $\frac{V_4}{V_3}$

ρ = cut off ratio = $\frac{V_3}{V_2}$

Heat supplied, $Q_1 = mC_p(T_3 - T_2)$

Heat rejected, $Q_2 = -mC_v(T_1 - T_4)$

$= mC_v(T_4 - T_1)$

$$\eta_{air} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

$$= 1 - \frac{\cancel{m} c_v (T_4 - T_1)}{\cancel{m} c_p (T_3 - T_2)}$$

$$= 1 - \frac{(T_4 - T_1)}{\gamma (T_3 - T_2)} \quad \text{——— (i)}$$

Express all temperature in terms of T_1

a) $T_1 = T_1$

b) Process (1-2):

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma - 1}$$

$$T_2 = T_1 \cdot r_c^{\gamma - 1}$$

c) Process (2-3):

$$\frac{\cancel{P_2} V_2}{T_2} = \frac{\cancel{P_3} V_3}{T_3}$$

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = \rho$$

$$T_3 = T_2 \rho$$

$$= T_1 \cdot r_c^{\gamma - 1} \cdot \rho$$

d) Process (3-4):

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

$$= \left(\frac{V_3}{V_2} \times \frac{V_2}{V_1}\right)^{\gamma - 1}$$

$$= \left(\frac{\rho}{r_c}\right)^{\gamma - 1}$$

$$\therefore T_4 = T_3 \left(\frac{\rho}{r_c}\right)^{\gamma-1}$$

$$= \frac{T_1 \cdot r_c^{\gamma-1} \cdot \rho \cdot \rho^{\gamma-1}}{r_c^{\gamma-1}}$$

$$T_4 = T_1 \cdot \rho^{\gamma}$$

$\therefore$ Substituting in equation (i)

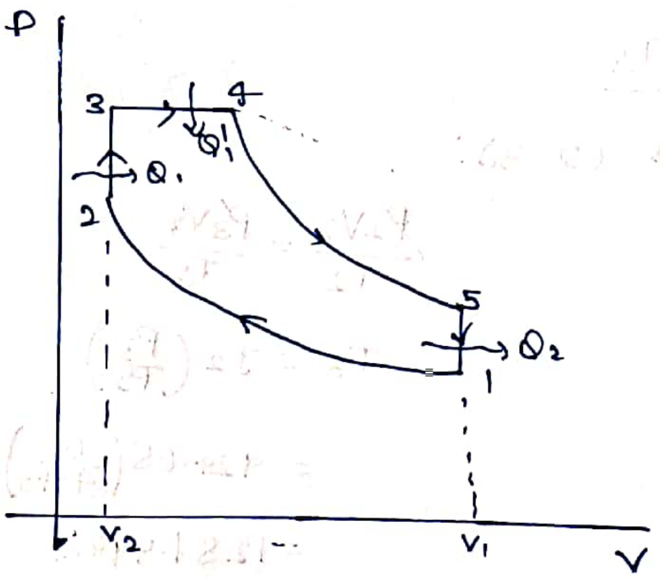
$$\eta = 1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)}$$

$$= 1 - \frac{[T_1 \cdot \rho^{\gamma} - T_1]}{\gamma\left[T_1 \cdot r_c^{\gamma-1} \cdot \rho - T_1 \cdot r_c^{\gamma-1}\right]}$$

$$= 1 - \frac{T_1(\rho^{\gamma} - 1)}{\gamma \cdot T_1 r_c^{\gamma-1}(\rho - 1)}$$

$$\eta_D = 1 - \frac{1}{\gamma \cdot r_c^{\gamma-1}} \cdot \frac{(\rho^{\gamma} - 1)}{(\rho - 1)} \quad (4)$$

b)



$r_c = \frac{V_1}{V_2} = 15$

$P_1 = 0.1 \times 10^6 \ N/m^2$

$T_1 = 313k$

$P_3 = P_4 = P_{max.} = 6 \times 10^6 \ N/m^2 = 6 \times 10^3 \ kN/m^2$

$Q_1 + Q_2 = 1.675 \times 10^3 \ kJ/kg.$

$Q_1 = Q_{23} = m C_v (T_3 - T_2)$

consider a process (1-2)

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma - 1}$$

$$T_2 = T_1 (r_c)^{\gamma - 1}$$

$$= 313 (15)^{1.4-1}$$

$$= 924.65 k.$$

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

$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$= 0.1 (15)^{1.4}$$

$$= 4.43 \ MPa.$$

to find T_3

Process (2-3):

$$\frac{P_2 V_2}{T_2} = \frac{P_3 V_3}{T_3}$$

$$T_3 = T_2 \left(\frac{P_3}{P_2}\right)$$

$$= 924.65 \left(\frac{6}{4.43}\right)$$

$$= 1251.99 k.$$

$Q_1 = Q_{23} = m \cdot C_v (T_3 - T_2)$

$= 1 \times 0.718 (1251.99 - 924.65)$

$= 235.03$ kJ/kg.

ii) Heat supplied at constant pressure: (3-4)

$Q_{total} = Q_1 + Q_1'$

$1.67 \times 10^3 = 235.03 + Q_1'$

$\therefore Q_1' = 1434.96$ kJ/kg.

iii) cycle efficiency:

$WD = Q_{total} - Q_2$

$Q_2 = m\, C_v (T_5 - T_1)$

to find T_5.

consider a process (4-5) adiabatic.

$$\frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1}$$

$$T_5 = T_4 \left(\frac{V_4}{V_3} \times \frac{V_3}{V_5}\right)^{\gamma-1} = \left(\frac{V_4}{V_3} \times \frac{V_2}{V_1}\right)^{\gamma-1}$$

$$= T_4 \left(\frac{\rho}{r_c}\right)^{\gamma-1}$$

to find ρ.

$$\rho = \frac{T_4}{T_3}$$

to find T_4.

$Q_1' = mcp(T_4 - T_3)$

$1434.96 = 1 \times 1.005 (T_4 - 1251.99)$

$\therefore T_4 = 2679.8K.$

$\therefore \rho = \frac{T_4}{T_3} = \frac{2679.8}{1251.99} = 2.14$

$\therefore T_5 = T_4 \left(\frac{\rho}{r_c}\right)^{\gamma - 1} = 2679.8 \left(\frac{2.14}{15}\right)^{1.4-1}$

$= 1229.79. K$

$\therefore Q_2 = m \cdot cv (T_5 - T_1)$

$= 1 \times 0.718 (1229.79 - 313)$

$= 658.25 \ kJ/kg.$

$WD = Q_{total} - Q_2$

$= 1.67 \times 10^3 - 658.25 = 1011.7 kJ/kg.$

$\therefore \eta = \frac{Q_{total} - Q_2}{Q_{total}}$

$= \frac{1.67 \times 10^3 - 658.25}{1.67 \times 10^3}$

$= 60.58\%.$

iv) $\rho = 2.14.$

v) $mep = \frac{W_{net}}{(V_1 - V_2)}$

$P_1V_1 = mRT_1$

$V_1 = \frac{mRT_1}{P_1}$

$= \frac{0.287 \times 313}{0.1 \times 10^3}$

$= 0.89 \ m^3/kg.$

$\frac{V_1}{V_2} = 15$

$V_2 = 0.059.$

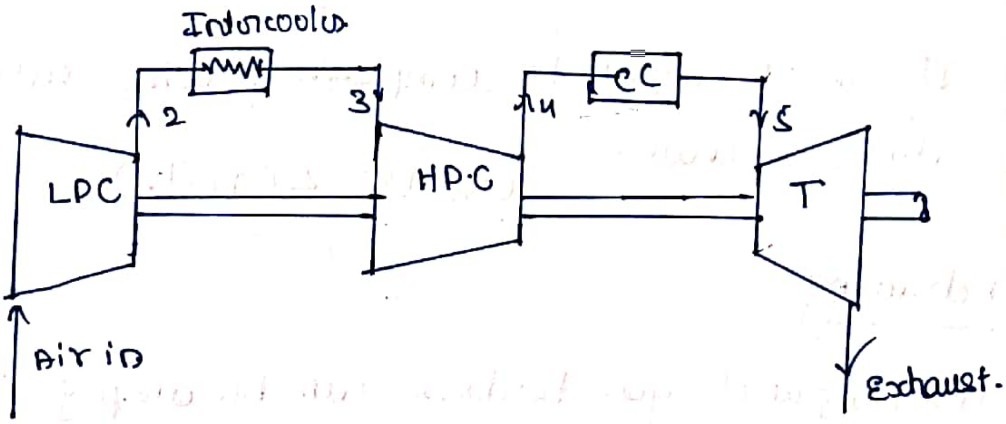
$\therefore \quad mep = \frac{1011.7}{0.89 - 0.059}$

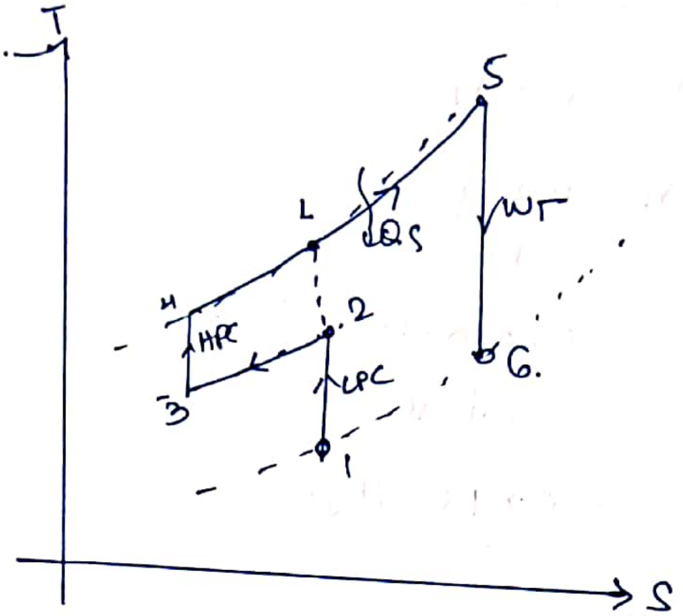
$= 1217.93 \ kN/m^2$

OR

Q2.

a) Intercooling and reheating





The compressor in a gas turbine cycle utilizes the major percentage of power developed by the gas turbine. The work required by the compressor can be reduced by compressing the air in two stages. & by incorpating intercooler between the two as shown.

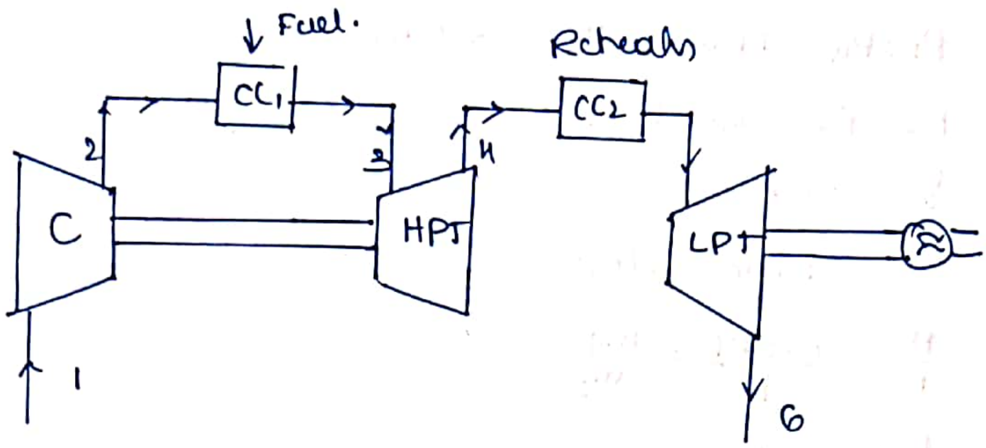
work input with intercooler $= mc_p(T_2-T_1) + mc_p(T_4-T_3)$

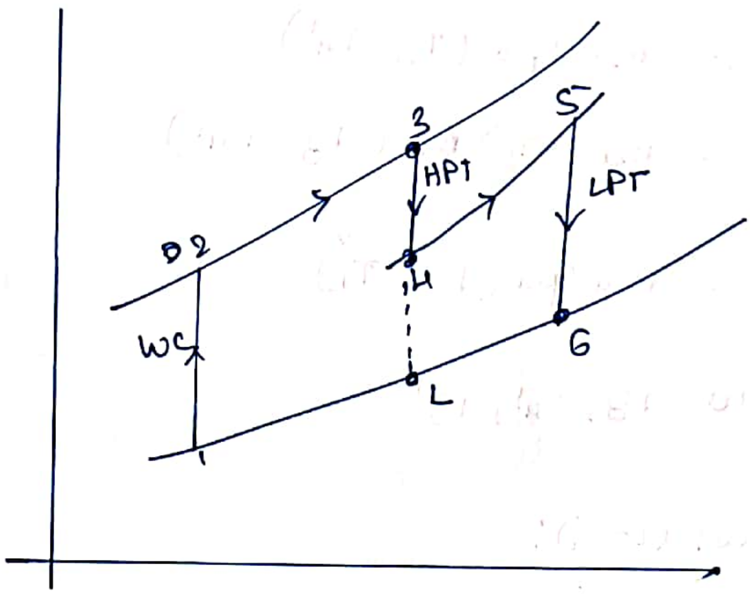
" " without intercooler $= mc_p(T_2-T_1) + m\,c_p(T_L-T_2)$

The work input to compressor with intercooler reduces because $(T_4-T_3) < (T_L-T_2)$.

Reheating

The output of gas turbine can be amply improved by expanding the gases in two stages with a reheater between two turbines. The high pressure (HP) turbine drives the compressor & LP turbine provides useful power output.





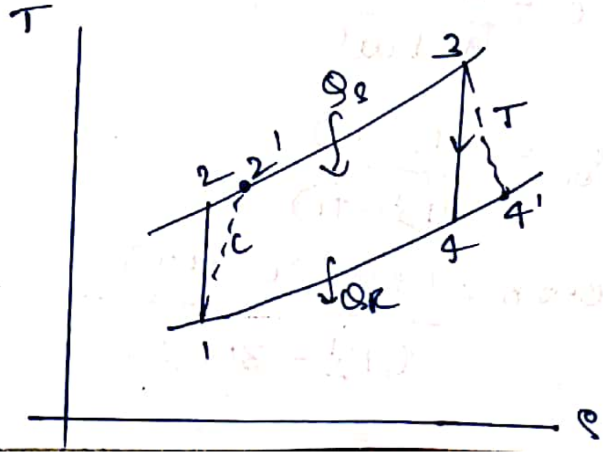
Net work of LP turbine with intercooler

$= m\, c_{pg} (T_5 - T_6)$

without reheating $= m\, c_{pg} (T_4 - T_L)$

With reheating, the work output by LP turbine increase because $(T_5 - T_6) > (T_4 - T_L)$.

b)



$P_1 = P_4 = 1\,bar, \quad T_1 = 300k.$

$P_2 = P_3 = 6.2\,bar.$

$\eta_c = 0.88$

$C_V = 44180\,kJ/kg.$

$\frac{A}{F} = \frac{0.017}{1} = \frac{m_a}{m_f}$

$\eta_T = 0.9$

$W_T = (m_g) C_{pg} (T_3 - T_4')$

$= (m_a + m_f) C_p (T_3 - T_4')$

$W_c = m_a C_{pa} (T_2' - T_1).$ ✓

To find T_3, T_4', T_2'

Consider (1-2):

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= 300 \left(\frac{6.2}{1}\right)^{\frac{1.4-1}{1.4}}$$

$$T_2 = 505.26k.$$

$$\therefore \quad \eta_c = \frac{\text{theoretical}}{\text{Actual}}$$

$$\eta_c = \frac{(T_2 - T_1)}{(T_2' - T_1)}$$

$$0.88 = \frac{(505.26 - 300)}{(T_2' - 300)}$$

$\therefore T_2' = 533.25\,k.$

to find T_3 :

Heat supplied = Heat carried away by gases

$$m_f \times CV_f = (m_g)(cp_g)(T_3 - T_2')$$

$$= (m_a + m_f)\, C_p\, (T_3 - T_2')$$

$$0.017 \times 44180 = (1 + 0.017) \times 1.005\, (T_3 - 533.25)$$

$$T_3 = 1268\,k.$$

$\therefore$ from (3-4) :

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

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

$$= 1268 \left(\frac{1}{6.2}\right)^{\frac{1.4-1}{1.4}}$$

$$= 752.8\,k.$$

to find T_4'

$$\eta_T = \frac{\text{Actual}}{\text{theoretical}} = \frac{(T_3 - T_4')}{(T_3 - T_4)}$$

$$0.9 = \frac{1268 - T_4'}{1268 - 752.8}$$

$$T_4' = 804.32\,k.$$

$$\therefore W_T = (m_a + m_f) \times cp\, (T_3 - T_4')$$

$$= (1 + 0.017) \times 1.005\, (1268 - 804.32)$$

$$= 473.92\,kJ$$

$$W_C = m_a \cdot c_p \cdot (T_2' - T_1)$$

$$= 1 \times 1.005 \times (533.25 - 300)$$

$$= 234.4 \text{ kJ.}$$

Note: cp of gas is not given ∴ take cp = 1.005 kJ/kgK (cp of air).

$$\eta = \frac{W_T - W_C}{Q_S}$$

$$= \frac{473.92 - 234.4}{Q_S}$$

$$Q_S = (m_a + m_f) \cdot c_p \, (T_3 - T_2')$$

$$= (1 + 0.017)(1.005)(1268 - 533.25)$$

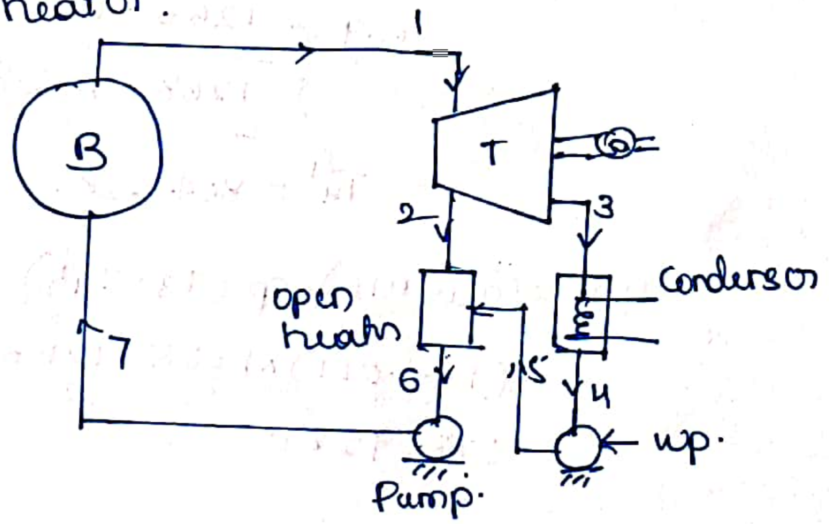
$$= 750.97.$$

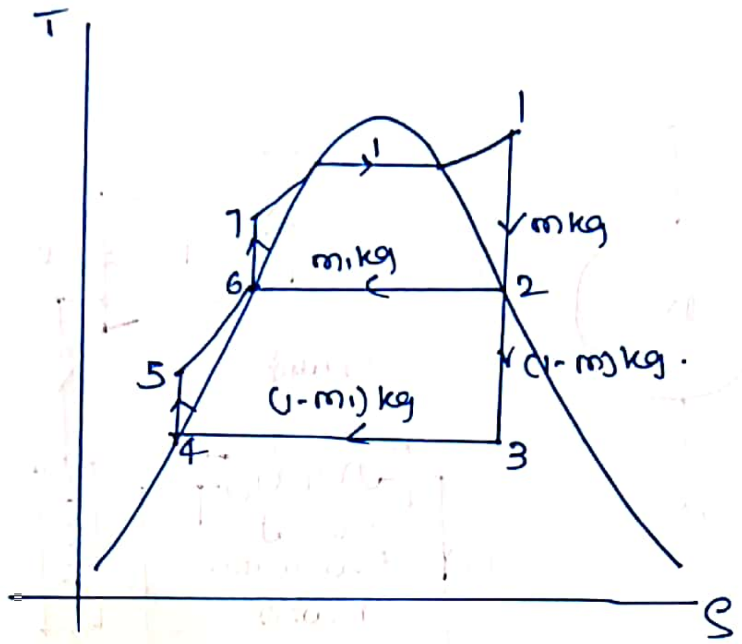
$$\therefore \eta = 0.318$$

$$= 31.8\%.$$

Q3.

a) Feed water heater:

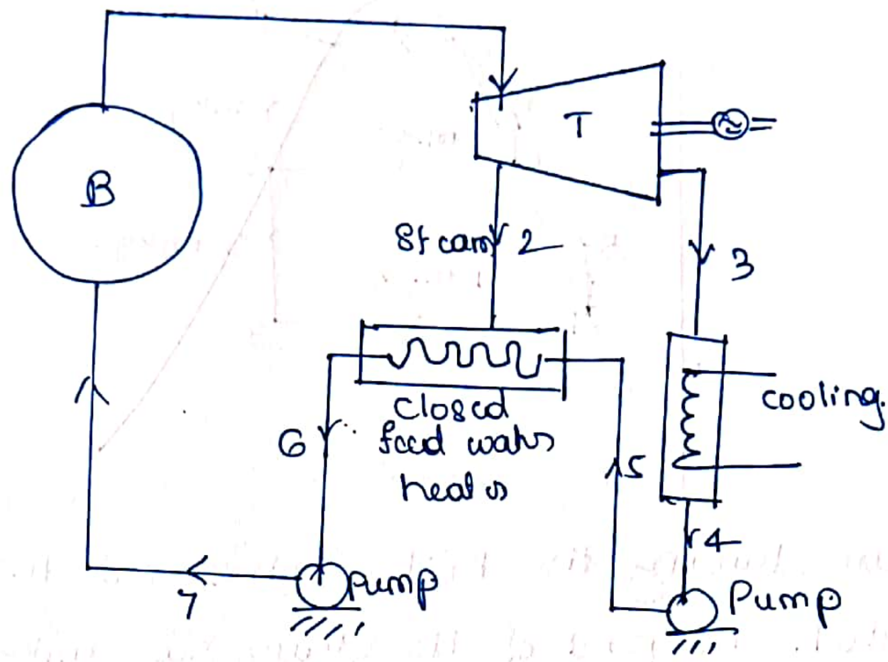




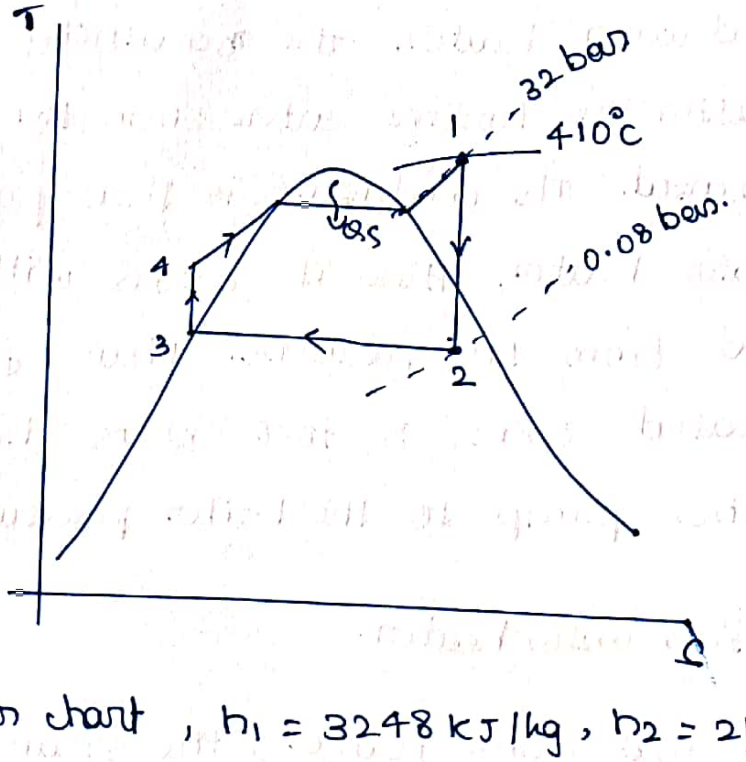
The steam leaving the boiler enters into the turbine at state 1. The part of the steam say m_1 kg, is expanded to state 2 only & this steam enters the feed water heater. the remaining $(1-m_1)$ kg of steam after the turbine enters into the condenser & is condensed. The condensate is then pumped to the feed water heater. Here it mixes with the steam extracted from the turbine. Thus feed water gets heated from 5 to 6 & is then pumped by another pump to the boiler pressure.

Closed feed water heater.

In closed feed water heater, the steam and feed water kept separate, & not allowed to mix together in water heater. The feed water is made to flow through the tubes. The extracted steam from turbine is passed around the tubes & transfers heat to the feed water.



b)



from mollier chart, $h_1 = 3248\ kJ/kg$, $h_2 = 2168\ kJ/kg$.

To find dryness fraction at end of expansion, (x_2):

at point, the dryness fraction $x_2 = 0.83$.

$$\eta_{th} = \frac{WD}{QS} = \frac{h_1 - h_2}{h_1 - h_4}$$

Pump work is negligible:

from steam table, at =0.08 bar, $h_3 = h_f = h_4 = 173.9$ kJ/kg.

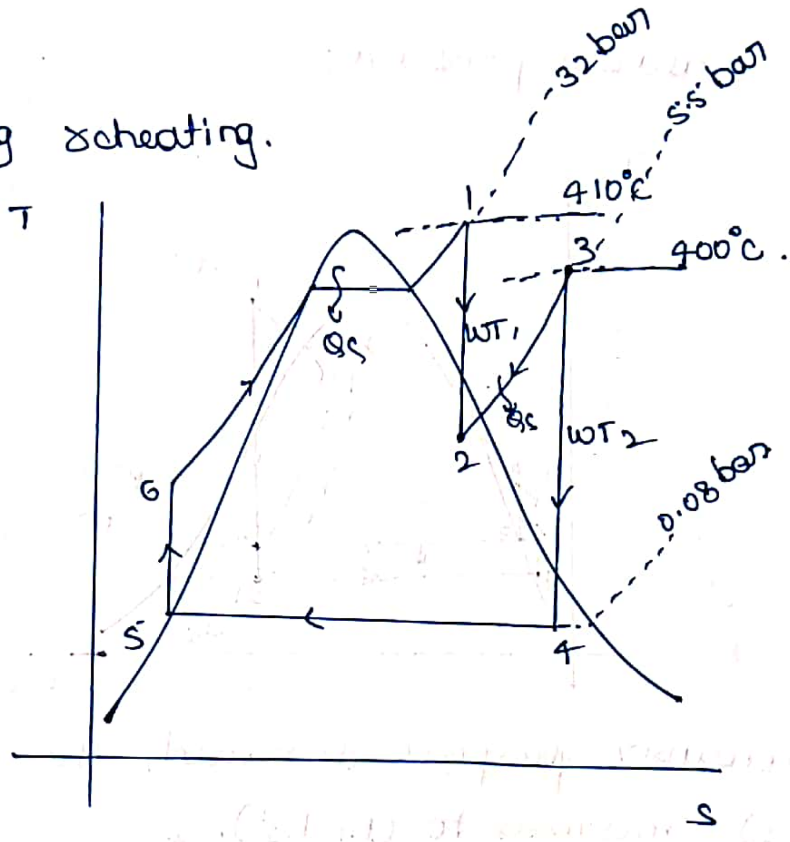
$$\therefore \eta_{th} = \frac{3245 - 2168}{3248 - 173.9}$$

$$= 0.351$$

$$= 35.13\%$$

Case 2:

Considering reheating.



η_{th} =

from mollier chart, $h_1 = 3248$ kJ/kg, $h_2 = 2826$ kJ/kg.
$h_3 = 3274$ kJ/kg, $h_4 = 2426$ kJ/kg.

$x_4 = 0.935$

$$\eta_{th} = \frac{(WT_1 + WT_2)}{(h_1 - h_6) + (h_3 - h_2)}$$

$h_6 = h_5$ at 0.08 bar = 173.9 kJ/kg.

$$\therefore \eta_{th} = \frac{(3248 - 2826) + (3274 - 2426)}{(3248 - 173.9) + (3274 - 2826)}$$

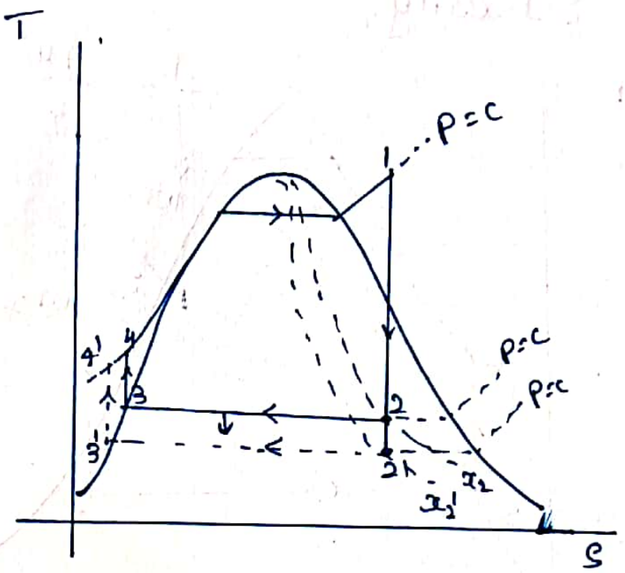
$= 0.36$

$= 36\%$.

OR

Q4.

a) Effect of condenser pressure:



→ If condenser pressure decreased, the turbine work $(h_1 - h_2)$ increases to $(h_1 - h_2')$.

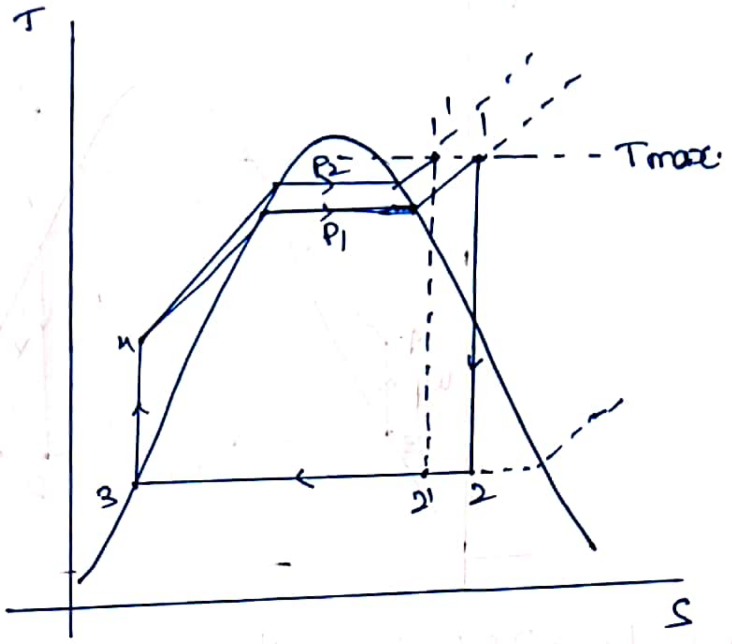
→ Thus increase the cycle efficiency.

→ But at the end of expansion, the moisture content increases from x_2 to x_2'. This effects on turbine blades.

→ condenser load increase.

→ Pump work increase.

Boiler pressure



→ When max temperature is fixed, the pressure increases from P_1 to P_2 in the boiler

→ The mean temperature of heat addition increases.

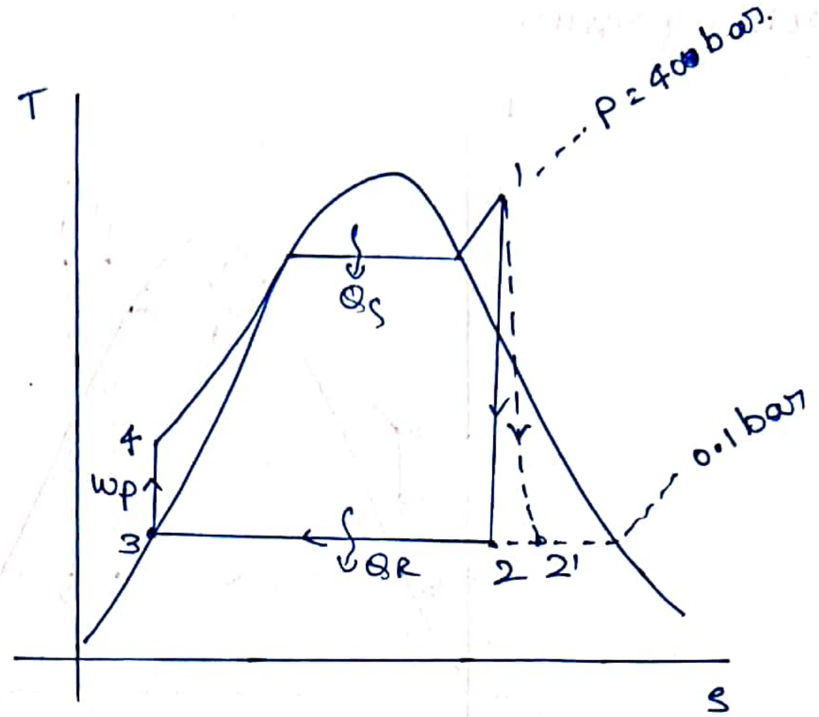
→ But when when turbine inlet pressure increases from P_1 to P_2, ideal expansion line (1 to 2) shifts to left & the moisture content increases, water particles along with vapour coming out of nozzle with high velocity strikes the blades & erode their surfaces & life of the blade decreases.

b) 1) The fluid should have high critical temperature.

2) The saturation pressure at the temperature of heat rejection should be above atmospheric pressure so as to avoid the necessity of maintaining vacuum in the condenser.

3) The specific heat of the liquid should be small.

c)



At 40 bar $t_s = 250.33°C$, which is less than the given temperature 400°C. Hence the steam is superheated.

at 40 bar & 400°C. From superheated table

$h_1 = 3215.7\ kJ/kg$, $S_{g1} = 6.773\ kJ/kgK$.

at 0.1 bar. $v_3 = v_f = 0.00101\ m^3/kg$

$h_{f2} = 191.8\ kJ/kg$.

$S_{fg2} = 7.501\ kJ/kg$

$S_{f2} = 0.6493\ kJ/kgK$.

$\therefore\ W_T = h_1 - h_2$

$h_2 = h_{f2} + x_2 h_{fg2}$.

to find x_2,

$S_1 = S_2$

$S_1 = S_2 = S_{f2} + x_2 S_{fg2}$

$6.7733 = 0.649 + x_2(7.501)$

$\therefore\ x_2 = 0.816$.

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$\therefore h_2 = 191.8 + 0.816(2392.9)$

$= 2144.4 \text{ kJ/kg.}$

Turbine. $\eta_T = \dfrac{h_1 - h_2'}{h_1 - h_2}$

$\therefore h_1 - h_2' = \eta(h_1 - h_2)$

actual: $W_T = 0.85(3215.7 - 2144.4)$

$= 910.6 \text{ kJ/kg.}$

To find pump work,

$w_p = (h_4 - h_3) = v_f \cdot (P_b - P_c)$

$= 0.00101(40 - 0.1) \times 10^2$

$= 4.03 \text{ kJ/kg.}$

$\therefore 4.03 = h_4 - 191.8$

$\therefore h_4 = 195.83 \text{ kJ/kg.}$

$\therefore \eta_R = \dfrac{W_T - W_P}{Q_S}$

$Q_S = (h_1 - h_4)$

$= (3215.7 - 195.83)$

$= 3019.87 \text{ kJ/kg.}$

$\therefore \eta_R = \dfrac{910.6 - 4.03}{3019.87}$

$= 0.30$

$= 30\%.$

To find quality of steam from the turbine (x_2')

$$h_2' = h_{f2} + x_2' h_{fg2}'$$

$$= 191.8 + x_2'(2392.9)$$

to find h_2':

$$\eta_t = \frac{h_1 - h_2'}{h_1 - h_2}$$

$$0.85 = \frac{3215.7 - h_2'}{3215.7 - 2144.4}$$

$$\therefore h_2' = 2305 \text{ kJ/kg.}$$

$$\therefore 2305 = 191.8 + x_2'(2392.9)$$

$$x_2' = 0.883$$

$$= 88.3\%$$

To find steam flow rate,

$$P = m'(W_T - W_P)$$

$$40 \times 10^3 = m'(910.6 - 4.08)$$

$$m' = 44.12 \text{ kg/s.}$$

Q.5.

a) Stoichiometric air -

The minimum amount of air required for complete combustion of a fuel is known as theoretical air.

Actual air -

The mass of air supplied per kg of fuel in a given combustion process. It may be less than, equal or greater than the theoretical air.

Excess air -

complete combustion of a fuel may not be ensured if only minimum air is supplied. To ensure the complete combustion, excess air is supplied. The air which is greater than theoretical air.

Combustion efficiency -

It is a measure of how much of the energy available in the fuel is released & utilized.

$$\eta_{comb.} = \frac{\text{Theoretical A/F ratio for a given temperature rise}}{\text{Actual A/F ratio for the same temperature rise}}$$

b)

$$C_3H_8 + a(O_2 + 3.76N_2) \rightarrow bCO_2 + dN_2 + eH_2O$$

balancing.

C:

$$3\times1 = b\times1$$

$$b = 3.$$

H_2 :

$$8\times1 = e\times2$$

$$\therefore e = 8/2 = 4.$$

O_2 :

$$a\times2 = b\times2 + e\times1$$

$$\therefore a = 5.$$

N_2 :

$$a\,3.76\times2 = d\times2$$

$$d = 18.8$$

$$\therefore C_3H_8 + 5(O_2 + 3.76N_2) \rightarrow 3CO_2 + 18.8N_2 + 4H_2O$$

To find A/F ratio :

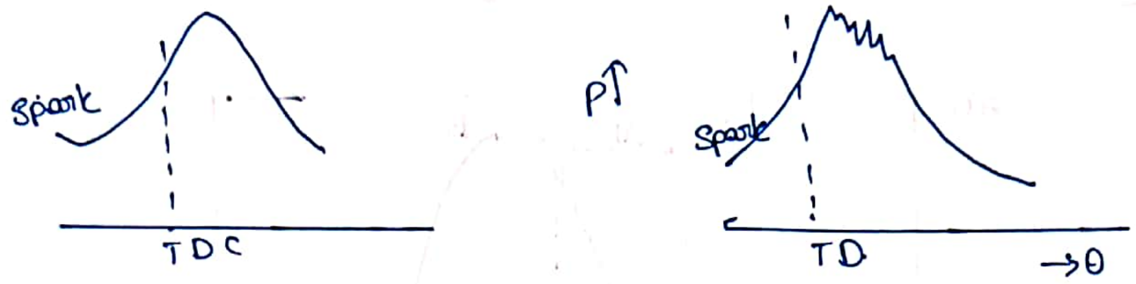
$$\frac{\text{mass of air}}{\text{mass of fuel}} = \frac{5(O_2 + 3.76N_2)}{3(12) + 8\times1.}$$

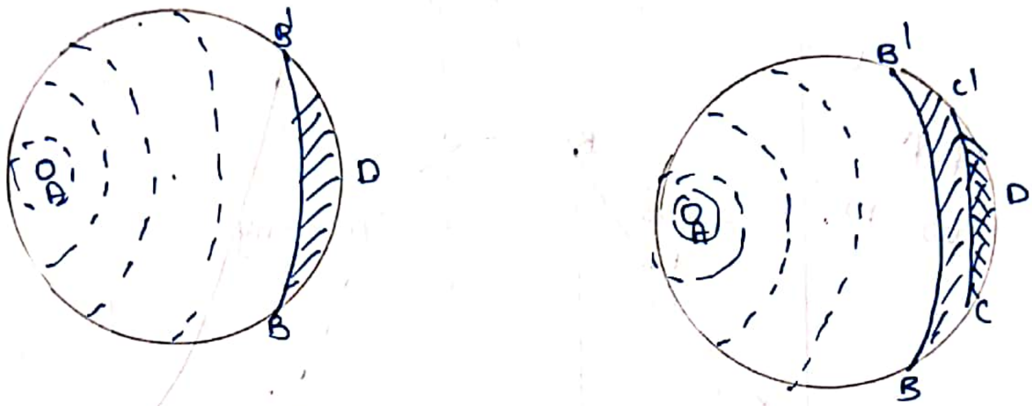
$$= 20.28.\ \frac{686.4}{44}$$

For 130% theoretical air = $\frac{13(686.4)}{44}$

$$= 20.28.$$

c) Explain detonation in SI engine:

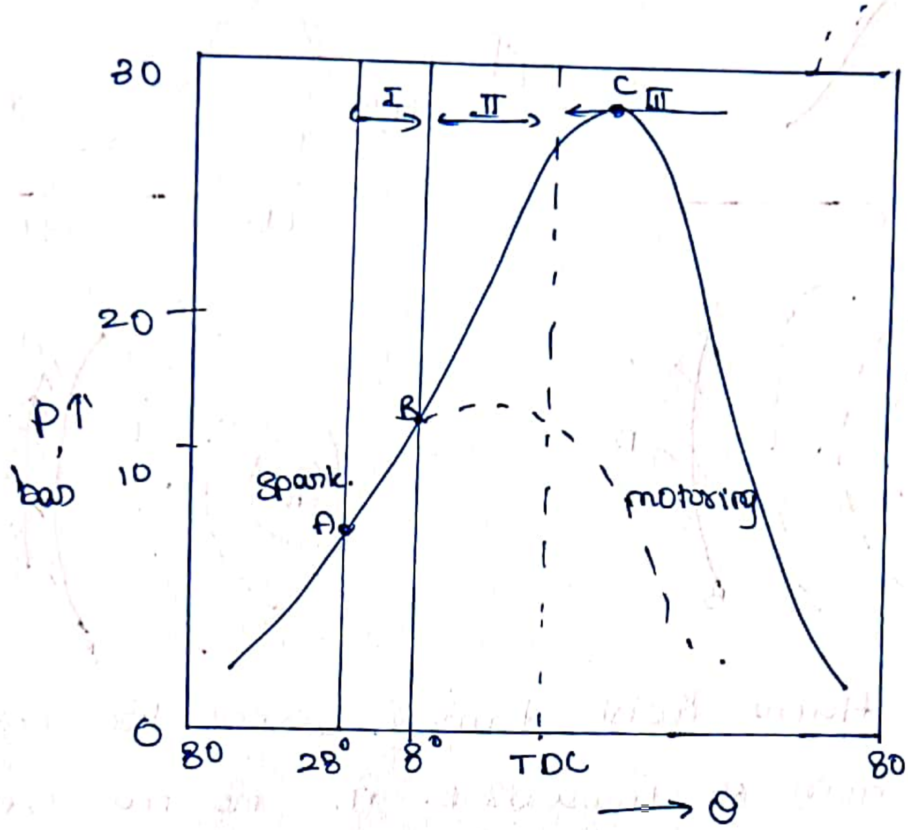




A normal flame front travels across the combustion chamber from A towards D. in normal combustion. If, however, the flame front is able to proceed only as far as, say CC', during the ignition delay period, then the remaining portion of the unburned charge CC'D will auto-ignite & cause extreme pressure fluctuations. This causes severe pressure wave which strike the cylinder wall & sets it vibrating, giving rise to a characteristic high pitched metallic sound. called detonation.

Q6.

a) Stages of combustion in SI engine:



I. Ignition lag.

→ Growth & development of a semipropagating nucleus of flame called ignition lag.

→ It is a chemical process depends upon the nature of fuel, upon both tempr. & pressure.

II. Propagation of flame.

→ Spread of flame throughout the combustion chamber.

→ This stage is mechanical, pure & simple.

→ Point 'A' is a passage of spark, B the point at which first pressure rise can be detected & C is attainment of peak pressure.

→ The point c marks the completion of the flame travel.

→ After burning take place during expansion. Theoretically it is expected that the fuel droplets will burn during expansion also.

Ignition lag depends upon.

Fuel, mixture ratio, CR, initial temperature & pressure., electrode gap & turbulence.

b) $n = 3$,

4 strokes

$D = 22cm = 0.22m$

$L = 26cm = 0.26m$.

$m_f = 8kg/hr. = 2.22 \times 10^{-3} kg/s$.

$CV = 45000 KJ/kg$.

$N = 12000/hr = 200 rpm$.

$P_m = 6 bar$.

$W = 1.5 KN = 1.5 \times 10^3 N$.

$D_{drum} = 1.8m$

$d_{rope} = 3cm = 0.03m$.

$m_w = 550 kg/hr = 9.167 kg/min$.

$T_{win} = 27°C$.

$T_{out} = 55°C$

$m_a = 300 kg/hr = 5 kg/min$.

$$IP = \frac{P_m L A N}{60 \times 2} \times n$$

$$= \frac{6\times10^2 \times 0.26 \times \left(\frac{\pi}{4}\times0.22^2\right)\times200 \times 3}{60\times2}$$

$$= 29.65 \text{ kw.}$$

$$BP = \frac{2\pi NT}{60}$$

$$= \frac{2\times\pi \times 200\times 1500\times0.915}{60\times1000}$$

$$= 28.74 \text{ kw.}$$

$$T = W \times R.$$

$$R = \frac{D_{drum} + d_{rope}}{2}$$

$$= \frac{1.8 + 0.03}{2}$$

$$= 0.915 \text{ m.}$$

$$\eta_{mech.} = \frac{BP}{IP} = \frac{28.74}{29.65} = 0.96 = 96.93\%$$

$$\eta_{itc} = \frac{IP}{m_f \times CV.}$$

$$= \frac{29.65}{2.22\times10^{-3} \times 45000}$$

$$= 29.68\%$$

Heat balance sheet

I. Heat from fuel $= m_f \times CV$

$= 0.133 \times 45000$

$= 5985$ KJ/min.

II.

→ Heat to BP = 28.74 kJ/s × 60 = 1724.4 kJ/min.

→ Heat carried away by cooling water

$= m_w c_{pw} (T_o - T_i)$

$= 9.167 \times 4.187 (55 - 27)$

$= 1074.7$ kJ/min.

→ Heat to exhaust gases $= m_{eg} \cdot c_{peg} (T_g - T_a)$

~~= 9.167 × 4.187 (~~

$= (m_a + m_f) c_{pg} (T_g - T_a)$

$= (5 + 0.133) 1.1 (310 - 30)$

$= 1580.96$ kJ/min.

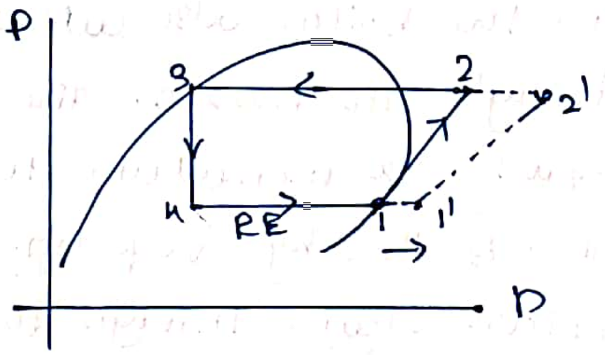
→ Heat lose due to friction = IP − BP

$= 29.65 - 28.74$

$= 0.91$ kW.

Q7. a) Factors affecting the performance of vapour compression refrigeration system.

- i) Effect of suction vapour superheat.



→ Increases refrigeration effect

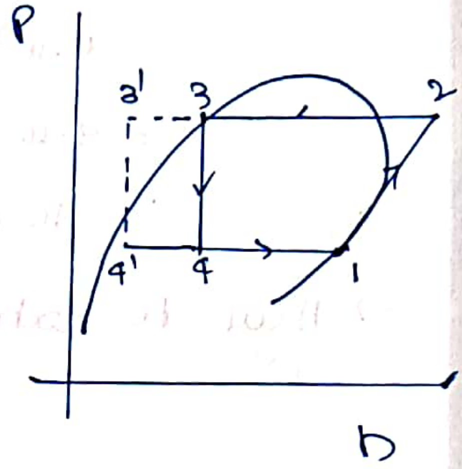
→ Increase in specific work.

→ Increase in condenser load.

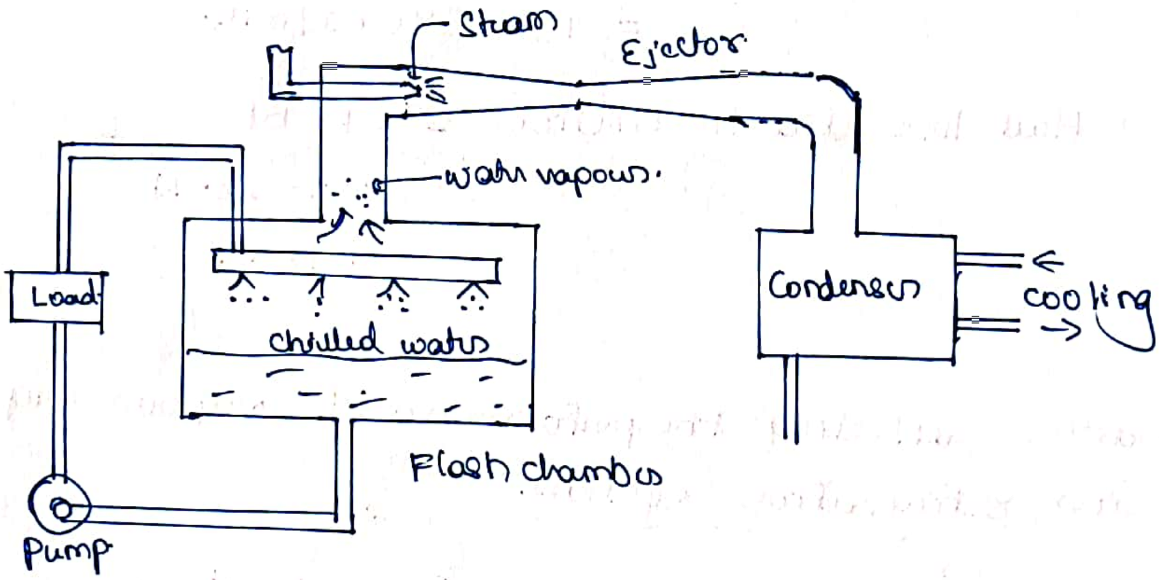
ii) Effect of sub-cooling:

→ Refrigerant temperature reduces from T_3 to T_3' & reduces flashing of the liquid during expansion.

→ Increase RE from $(h_1 - h_4)$ to $(h_1 - h_{4'})$



b) Steam jet refrigeration



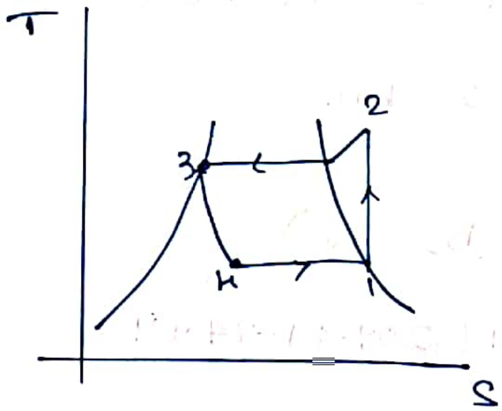
→ Steam from the boiler also called motive steam expands through the nozzle. The high velocity vapour imparts the momentum to the vapour the flash chamber & thereby vapour moves along with the motive steam through the ejector.

→ The vapour mixture is then finally compressed in the ejector to the condenser pressure where circulating water causes its condensation.

→ The chilled water of the flash chamber is pumped through the load. The warmed up water due to heat extraction from the load is sprayed into the flash chamber.

→ Cooling is caused as a result of vapourization.

c.)



$h_1 = 183.19\,kJ/kg$

$h_2 = 209.41\,kJ/kg$

$h_3 = h_4 = 74.59\,kJ/kg$.

$RC = 5\,tons = 5 \times 3.5\,kJ/s$.

i) $\dot{m} = ?$

$RC = \dot{m} \times RE$

$5 \times 3.5 = \dot{m}(h_1 - h_4)$

$= \dot{m}(183.19 - 74.59)$

$\therefore \dot{m} = 0.161\,kg/s$.

ii) $COP = \frac{RE}{W_c} = \frac{\cancel{m}(h_1 - h_4)}{\cancel{m}(h_2 - h_1)}$

$= \frac{183.19 - 74.59}{209.41 - 183.19}$

$= 4.14$

iii) $P = m(h_2 - h_1)$

$= 0.161(209.41 - 183.19)$

$= 4.22$ kw.

iv) $Q_R = m(h_2 - h_3)$

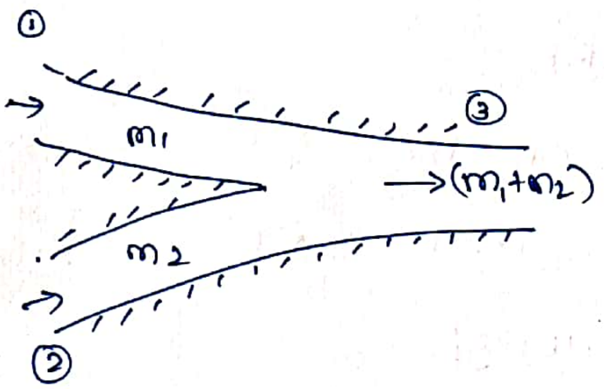
$= 0.161(209.41 - 74.59)$

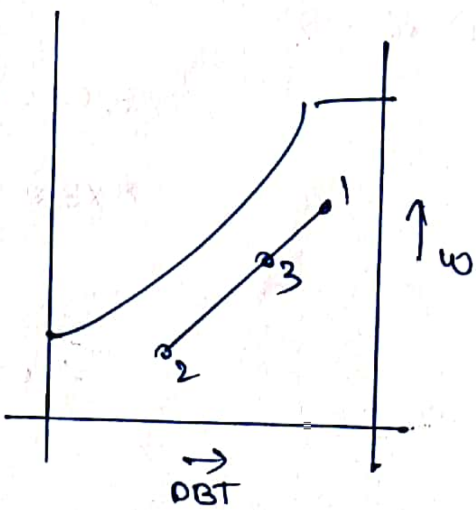
$= 21.71$ kw.

OR

Q.8.

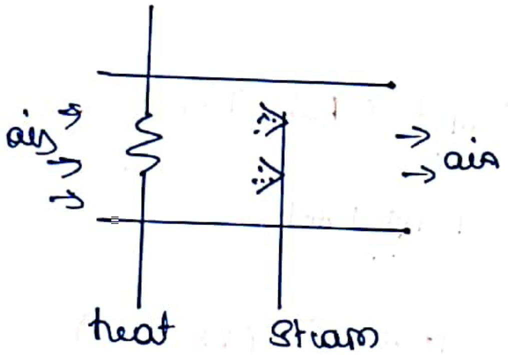
a) i) Adiabatic mixing of air

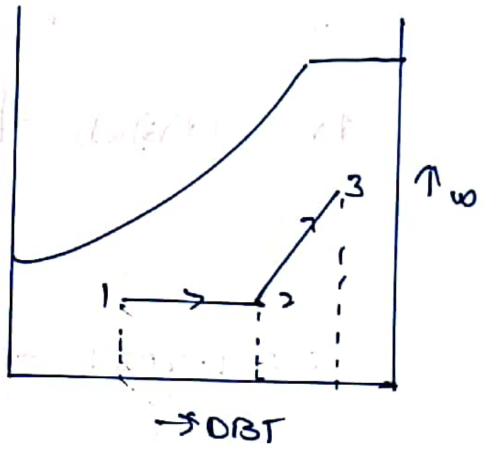




Two air stream of different Psychrometric properties are mixed together. Then the Psychrometric properties of the mixture can be calculated by balancing the enthalpies & mass of water vapours.

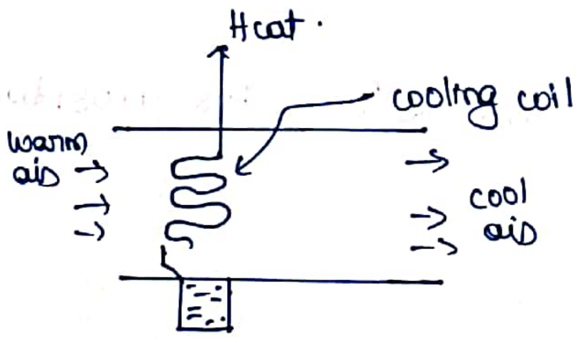
ii) Heating & humidification.

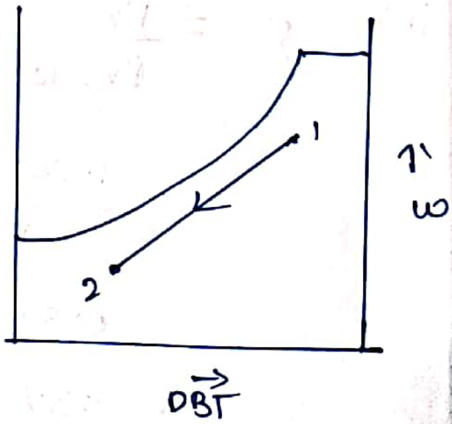




In the heating / humidifying process, the air first passes through a heat exchanger & then through the humidifier where steam is sprayed into the air stream.

iii) Cooling & dehumidification.





The removal of water vapour from air is termed as dehumidification of air. Here the air is cooled below the

DPT of air. ∴ water vapour are removed.

b) DBT = 25°C

WBT = 15°C

P = 101.325 kN/m².

i) $$\omega = 0.622 \frac{P_v}{(P_t - P_v)}$$

$$P_v = (P_{vs})_{wb} - \frac{[P_t - (P_{vs})_{wb}](T_{db} - T_{wb})}{1547 - 1.44 T_{db}}$$

$$= 1.7039 - \frac{[101.325 - 1.7039](25 - 15)}{1547 - 1.44 \times (15)}$$

$$= 1.0508 \text{ kPa.}$$

$$\therefore \omega = 0.622 \times \frac{1.0508}{(101.325 - 1.0508)}$$

$$= 0.00651 \text{ kg/kg of air.}$$

ii) $$\phi = \frac{P_v}{P_{vs} \text{ @ DBT}}$$ at 25°C = P_{vs} = 0.031 bar

$$= \frac{1.0508}{3.1}$$

$$= 0.33$$

$$= 33\%.$$

iii) $h = 1.005\,T_{db} + \omega[2500 + 1.88\,T_{db}]$

$= 1.005 \times 25 + 0.0065[2500 + 1.88(25)]$

$= 41.7$ kJ/kg.

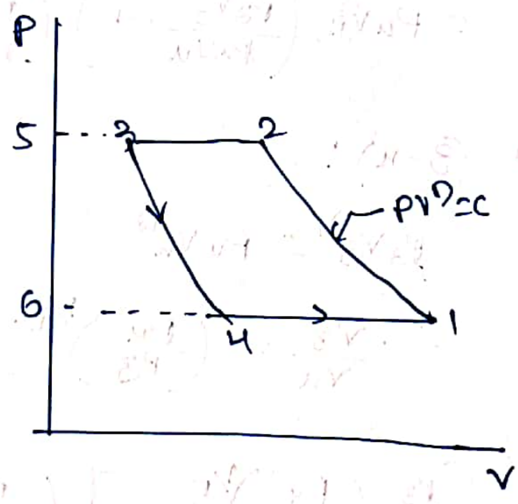
iv) DPT:

at $P_v = 1.0508$ kPa. from table,

DPT = 7.5°C.

Q.9.

a) work done with clearance volume:



WD = area (1-2-3-4-1)

WD = area (1-2-5-6-1) - area (4-3-5-6-4)

area (1-2-5-6-1) = area (2-5) + area (1-2) - area (1-6)

$= \left[(P_2V_2 - P_5V_5) + \frac{(P_2V_2 - P_1V_1)}{n-1} - (P_1V_1 - P_6V_6)\right]$

$= P_2V_2 + \frac{(P_2V_2 - P_1V_1)}{n-1} - P_1V_1$

$= (P_2V_2 - P_1V_1) + \frac{(P_2V_2 - P_1V_1)}{n-1}$

$$= (P_2V_2 - P_1V_1)\left(1 + \frac{1}{n-1}\right)$$

$$= P_1V_1\left(\frac{P_2V_2}{P_1V_1} - 1\right)\left(\frac{n}{n-1}\right)$$

$$= \frac{n}{n-1} \times P_1V_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

now:

area (4 3 5 6 4) = area (3-5) + (4-3) − (4-6).

$$= \left[P_3V_3 - P_5 \cancel{V_5}^{0}) + \frac{(P_3V_3 - P_4V_4)}{n-1}\right] - (P_4V_4 - P_6 \cancel{V_6}^{0})$$

$$= (P_3V_3 - P_4V_4)\left(1 + \frac{n}{n-1}\right)$$

$$= P_4V_4\left(\frac{P_3V_3}{P_4V_4} - 1\right)\left(\frac{n}{n-1}\right) \quad \text{—(iii)}$$

from (3-4):

$$P_3V_3^n = P_4V_4^n$$

$$\therefore \frac{V_3}{V_4} = \left(\frac{P_4}{P_3}\right)^{1/n}$$

$$\therefore = P_4V_4\left[\frac{P_3}{P_4}\left(\frac{P_4}{P_3}\right)^{1/n} - 1\right]\left(\frac{n}{n-1}\right)$$

$$= P_4V_4\left[\frac{P_3}{P_4}\left(\frac{P_3}{P_4}\right)^{-1/n} - 1\right]\left(\frac{n}{n-1}\right)$$

$$= \left(\frac{n}{n-1}\right) \times P_4V_4\left[\left(\frac{P_3}{P_4}\right)^{\frac{n-1}{n}} - 1\right] \quad \text{—(iv)}$$

Substitute (ii) & (iv) in equation (i):

$$WD = \frac{n}{n-1} \times P_1V_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] - \left(\frac{n}{n-1}\right)P_4V_4\left[\left(\frac{P_3}{P_4}\right)^{\frac{n-1}{n}} - 1\right]$$

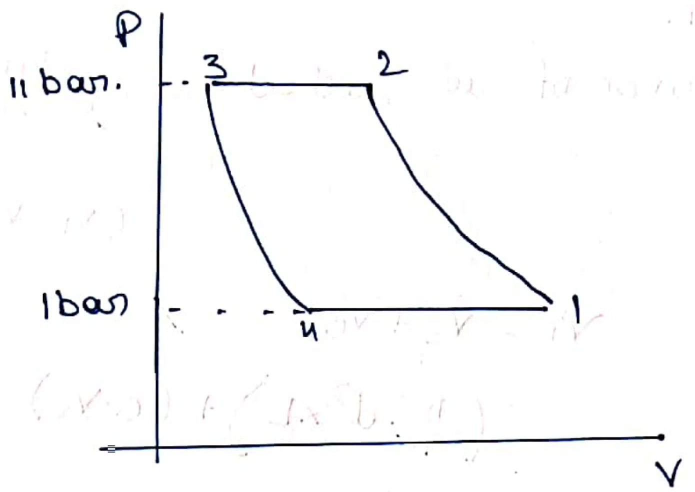
$\frac{P_3}{P_4} \to \frac{P_2}{P_1}$

$P_1 = P_4, \quad P_2 = P_3.$

$$\therefore WD = \left(\frac{n}{n-1}\right) \times P_1(V_1 - V_4)\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

=

b)



$d = 15\,cm = 0.15\,m$

$L = 25\,cm = 0.25\,m$

$N = 600\,rpm$

$P_1 = P_4 = 1\,bar$

$T_1 = 27°C$

$P_3 = P_4 = 11\,bar$

$C = 5\% = 0.05$

$\eta_{mech} = 80\% = 0.8$

$$P = m \times WD = \left(\frac{n}{n-1}\right) \cdot mR(T_2 - T_1)$$

To find T_2 & m

from (1-2) $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$= 300\left(\frac{11}{1}\right)^{\frac{1.25-1}{1.25}}$$

$$= 484.6 k.$$

$$P_1V_1 = mRT_1$$

$$m = \frac{P_1V_1}{RT_1}$$

where V_1.

volume of air sucked = $\left(\begin{matrix}\text{volume of air}\\ \text{sucked in 1sec}\end{matrix}\right)\left(\frac{N}{60}\right)$

$$= (V_1 - V_4)\left(\frac{600}{60}\right)$$

$$V_1 = V_s + V_c$$

$$= \left(\frac{\pi}{4}.d^2 \times L\right) + (c.V_s) \quad \left\{ C = \frac{V_c}{V_s} \right.$$

$$= \left(\frac{\pi}{4} \times 0.15^2 \times 0.25\right) + 0.05 \times \left(\frac{\pi}{4} \times 0.05^2 \times 0.25\right)$$

$$= 4.637 \times 10^{-3} m^3$$

for polytropic process (3-4)

$$P_3V_3^n = P_4V_4^n$$

$$V_4 = \left(\frac{P_3}{P_4}\right)^{1/n}. V_3$$

$$= \left(\frac{11}{1}\right)^{1/1.25} \times (0.05 \times 4.417 \times 10^{-3})$$

$$= 1.503 \times 10^{-3} m^3$$

now $V_1' = (V_1 - V_4)\left(\frac{600}{60}\right)$

$= \left[(4.637\times10^{-3}) - (1.503)\times10^{-3}\right]\frac{600}{60}$

$V_1' =$ ~~1.808×10^{-3} m³~~ $0.031\ m^3$

$\therefore m = \frac{(1\times10^2)(0.031)}{0.287(300)} = 0.036\ kg/s.$

$\therefore P = \frac{1.25}{1.25-1}(0.0364)(0.287)(484.6-300)$

$= 9.64\ kW$

$\therefore \eta_{mech.} = \frac{\text{Indicated power}}{\text{actual power}}$

$0.8 = \frac{9.64}{\text{actual power}}$

$\therefore$ actual power $= 12.05\ kW.$

ii) Time required to deliver $1 m^3$ of air at compressor exit at 2,

$P_2 V_2' = m' R T_2$

$V_2' = \frac{m' R T_2}{P_2} = \frac{(0.036)(0.287)(484.6)}{11\times10^2}$

$= 4.602\times10^{-3}\ m^3/s.$

4.602×10^{-3} m^3 of air is delivered at compressor exit in 1 sec

$\therefore$ 1 m^3 of air delivery = ?

$$= \frac{1}{4.602 \times 10^{-3}}$$

$= 217$ sec.

iii) Volumetric efficiency:

$$\eta_{vol} = \frac{(v_1 - v_4)}{v_s}$$

$$= \frac{(4.637 \times 10^{-3}) - (1.503 \times 10^{-3})}{(4.417 \times 10^{-3})}$$

$= 0.709$

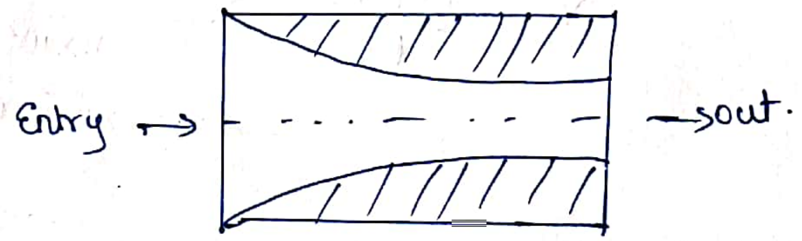
$= 70.9\%$

OR

Q.10.

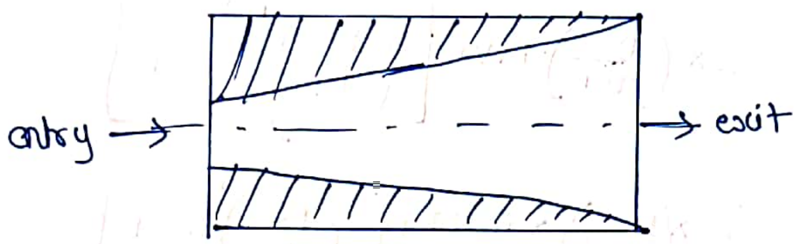
a) Shape of nozzle:

i) Convergent nozzle



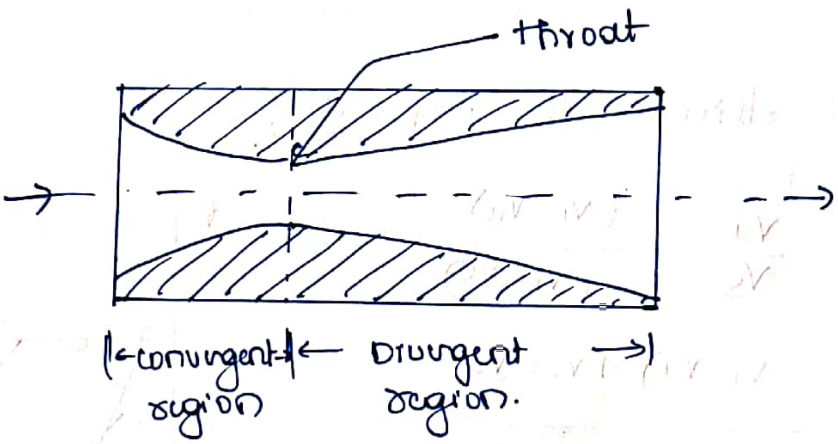
In this nozzle, the cross sectional area decreases continuously from its entrance to exit. It is used in a case where the back pressure is less than the critical pressure ratio.

2) Divergent nozzle:



The cross sectional area of the divergent nozzle increases continuously from its entrance to exit. It is used in a case where the back pressure is less than the critical pressure ratio.

3) Convergent - divergent nozzle:



The cross sectional area of nozzle first tapers to a smaller section ; being throat, & then it diverges to a large diameter. The nozzle which converges to throat & diverges afterwards is known as convergent-divergent nozzle.

b) $i = 2$ (two stage).

$WD = 350\ kJ/kg$

$m = 1kg$

$P_1 = 1\ bar$

$T_1 = 32°C$

$PV^n = PV^{1.3}$

$$WD = 2 \times \left(\frac{n}{n-1}\right) P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$= 2 \times \left(\frac{n}{n-1}\right) \times mRT_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$350 = 2 \times \frac{(1.3)}{(1.3-1)} \times (1 \times 0.287 \times 305) \left[\left(\frac{P_2}{1}\right)^{\frac{1.3-1}{1.3}} - 1\right]$$

$$350 = 758.63 \left[(P_2)^{0.23} - 1\right]$$

$$\therefore P_2 = (1.461)^{1/0.23}$$

$$= 5.2\ bar$$

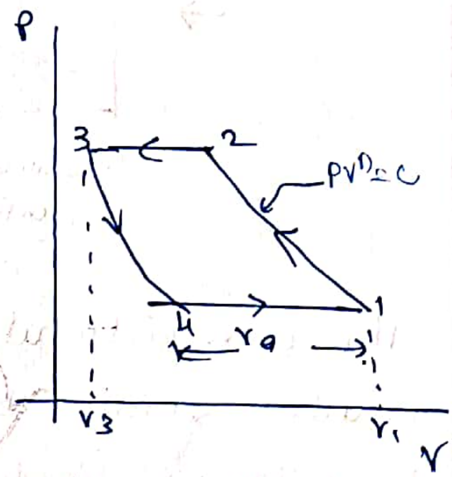
c) <u>volumetric efficiency of compressor:</u>

$$\eta_v = \frac{V_a}{V_s} = \frac{(V_1 - V_4)}{(V_1 - V_3)}$$

$$= \frac{(V_1 - V_4) + V_3 - V_3}{V_s}$$

$$= \frac{V_1 - V_4 + V_3 - V_3}{V_s}$$

$$= \frac{(V_1 - V_3) + V_c - V_4}{V_s}$$



$$= \frac{(v_1 - v_3) + (v_3 - v_4)}{(v_1 - v_3)}$$

$$= 1 + \frac{(v_3 - v_4)}{(v_1 - v_3)}$$

$$= 1 + \frac{v_3}{(v_1 - v_3)} - \frac{v_4}{(v_1 - v_3)}$$

$$= 1 + c - \frac{v_4}{(v_1 - v_3)}$$

Consider (3-4) $\quad pv^n = C$

$$P_3 v_3^n = P_4 v_4^n$$

$$\frac{v_4}{v_3} = \left(\frac{P_3}{P_4}\right)^{1/n}$$

$$v_4 = v_3 \left(\frac{P_3}{P_4}\right)^{1/n}$$

$$\therefore \eta_v = 1 + c - \frac{1}{(v_1 - v_3)} \times v_3 \left(\frac{P_3}{P_4}\right)^{1/n}$$

$$\boxed{\eta_v = 1 + c - c\left(\frac{P_3}{P_4}\right)^{1/n}}$$

—x—x—

(S.N. Badigan).

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