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MECHANICAL
ENGINEERING

THERMAL ENGINEERING

Volume - 1 : Study Material with Classroom Practice Questions

Thermal Engineering

Solutions for Volume – I _ Classroom Practice Questions

Chapter- 1
Basic Concepts

01. Ans: (d)

Sol: $\frac{dT}{T}-\frac{V}{T}dP$

$$= \frac{1}{T}dT-\frac{V}{T}dP \qquad \left(PV = RT, \frac{V}{T}=\frac{R}{P}\right)$$

$$= \frac{1}{T}dT-\frac{R}{P}dP$$

$$= MdT + NdP$$

$$M=\frac{1}{T}; N=-\frac{R}{P}$$

$$\frac{\partial M}{\partial P}=0; \frac{\partial N}{\partial T}=0$$

$\therefore \frac{\partial M}{\partial P}=\frac{\partial N}{\partial T}$ hence it is a property

02. Ans: (a)

Sol:

Volume	→	Extensive property
Density	→	Intensive Property
Pressure	→	Point function
Work	→	Path function
Energy	→	Point function

03. Ans: (b)

Sol: A real gas obeys perfect gas law at very high temperature and low pressure.

04. Ans: (b)

Sol: $F + P = C + 2$

No. of components, $C = 2$

No. of phases, $P = 2$

$\therefore F + 2 = 2 + 2$

$\Rightarrow F = 2$

05. Ans: (d)

Sol: When molecular momentum of system becomes zero, the pressure reaches its absolute zero values.

06. Ans: (b)

Sol: Final equilibrium temperature can be calculated by using conservation of energy i.e., first law of thermodynamics.

07. Ans: (b)

Sol: Mole fraction of $N_2 = \frac{n_{N_2}}{\text{Total no. of moles}}$

$$0.3 = \frac{n_{N_2}}{1}$$

$$n_{N_2} = 0.3$$

$$m_{N_2} = n_{N_2} \times \text{molecular weight}$$

$$= 0.3 \times 28 = 8.4 \text{ kg}$$

Mass fraction of $N_2 = \frac{m_{N_2}}{\text{Total mass}}$

$$= \frac{8.4}{36} = 0.233$$

08. Ans: (d)

Sol: $m_{N_2} = n_{N_2} \times (\text{molar weight}) = 2 \times 28$

$= 56\text{ kg}$

$m_{Co_2} = n_{Co_2} \times (\text{molecular weight}) = 6 \times 44$

$= 264\text{ kg}$

$m_{N_2} + m_{Co_2} = 320\text{ kg}$

$$\text{Mass fraction} = \frac{m_{Co_2}}{m_{Co_2} + m_{N_2}}$$

$$= \frac{264}{320} = 0.825$$

09. Ans: (a)

Sol: $m_{N_2} = n_{N_2} \times (\text{molar weight})$

$= 2 \times 28 = 56\text{ kg}$

$m_{CO_2} = n_{Co_2} \times (\text{molecular weight})$

$= 4 \times 44 = 176\text{ kg}$

$$R_{N_2} = \frac{\overline{R}}{\text{Molecular weight}} = \frac{8.314}{28}$$

$= 0.2969\text{ kJ/kg.K}$

$$R_{CO_2} = \frac{\overline{R}}{\text{molecular weight}} = \frac{8.31}{44}$$

$= 0.1889\text{ Kj/kg.K}$

$$R_{\text{mixure}} = \frac{m_{N_2} \times R_{N_2} + m_{CO_2} \times R_{CO_2}}{m_{N_2} + m_{CO_2}}$$

$$= \frac{56 \times 0.2969 + 176 \times 0.1889}{56 + 176}$$

$= 0.215\text{ kJ/kg.K}$

10. Ans: (b)

Sol: **For N_2** **For CO_2**

$n_1 = 3$ $n_2 = 7$

$P_1 = 600\text{ kPa}$ $P_2 = 200\text{ kPa}$

$n = n_1 + n_2 = 10$

$P_f = 300\text{ kPa}$

$$P_{N_2} = \left(\frac{n_1}{n_1 + n_2}\right) P_f = \left(\frac{3}{10}\right) \times 300$$

$= 90\text{ kPa}$

11. Ans: (d)

Sol: $V = 80\text{ L}$

$n = n_{N_2} + n_{CO_2}$

$$= \frac{5}{28} + \frac{5}{44}$$

$PV = n\overline{R}\,T$

$$\frac{P}{\overline{R}T} = \frac{n}{V} = \frac{\left(\frac{5}{28} + \frac{5}{44}\right)}{80}$$

$P_1V_1 = n_1\overline{R}\,T$

$$\frac{P}{\overline{R}\,T} = \frac{n_1}{V_1} = \frac{\left(\frac{5}{28}\right)}{V_1} = \frac{\left(\frac{5}{28} + \frac{5}{44}\right)}{80}$$

$\Rightarrow V_1 = 48.88\text{ L}$

12. Ans: (b)

Sol: **For Argon:**

$m = 3\text{ kgs}$

Molar weight = 40

$$\gamma = \frac{5}{3}\ (\text{monoatomic})$$

$$(C_V)_{Ar} = \frac{\overline{R}}{M(\gamma-1)} = \frac{8.314}{40\left(\frac{5}{3}-1\right)}$$

$$= 0.311 \text{ kJ/kg.K}$$

For CO_2:

m = 6 kgs, Molar weight = 44 , $\gamma = \frac{4}{3}$

$$(C_V)_{CO_2} = \frac{\overline{R}}{M(\gamma-1)} = \frac{8.314}{44\left(\frac{4}{3}-1\right)}$$

$$= 0.566 \text{ kJ/ kg.K}$$

$$(C_V)_{mix} = \frac{m_{Ar}\times(C_V)_{Ar} + m_{CO_2}\times(C_V)_{CO_2}}{m_{Ar}+m_{CO_2}}$$

$$= \frac{(3\times0.31)+(6\times0.566)}{3+6}$$

$$= 0.4806 \text{ kJ/kgK}$$

$$Q_S = m\times(C_V)_{mix}\times(\Delta T)$$

$$= (3+6)\times0.4806\times(350-250)$$

$$= 432.6 \text{ kJ}$$

13. Ans: (b)

Sol: $P_1 = 1.2$ MPa, $P_2 = 0.2$ MPa

He = 30%, Ar = 70%

Adiabatic process, $\gamma = \frac{5}{3}$ (monatomic)

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

$$T_2 = 673\times\left(\frac{0.2}{1.2}\right)^{\frac{\frac{5}{3}-1}{\frac{5}{3}}} = 328.7 \text{ K} = 55.7^0 \text{ C}$$

14. Ans: (d)

Sol: For He: $n_1 = 3$, $\gamma = \frac{5}{3}$

$$(C_P)_{He} = \frac{\gamma\overline{R}}{(\gamma-1)} = \frac{\frac{5}{3}\times8.314}{\left(\frac{5}{3}-1\right)} = 20.78 \text{ kJ/kg.K}$$

For Ar:

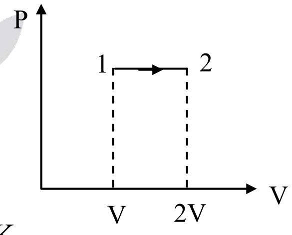
$n_2 = 7$, $\gamma = \frac{5}{3}$

$$(C_P)_{Ar} = \frac{\gamma\overline{R}}{(\gamma-1)} = \frac{\frac{5}{3}\times8.314}{\left(\frac{5}{3}-1\right)} = 20.78 \text{ kJ/kg.K}$$

$$(C_P)_{Mix} = \frac{n_{He}(C_P)_{He} + m_{Ar}(C_P)_{Ar}}{n_{He}+n_{Ar}}$$

$$= \frac{3\times20.79+7\times20.79}{3+7}$$

$$= 20.79 \text{ kJ/kg.K}$$



$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$T_2 = \frac{V_2}{V_1}\times T_1$$

$$= 2\times323 = 646 \text{ K}$$

$$Q_S = n\times(C_P)_{mix}\times(\Delta T)$$

$$= (3+7)\times20.79\times(646-323) = 67 \text{ MJ}$$

15. Ans: 2.67 cm of Hg

Sol: At ground

Balloon volume, $V_1 = \frac{4}{3}\pi r^3$

$P_1 = 72$ cm of Hg.

In the air, R = 3r

Balloon volume, $V_2 = 27\times\frac{4}{3}\pi r^3$

Temperature constant ⇒ Isothermal

⇒ **Process $P_1 V_1 = P_2 V_2$**

⇒ $P_2 = 72\ r^3/27r^3 = 2.67$ cm of Hg

16. Ans: $P_1 > P_2$

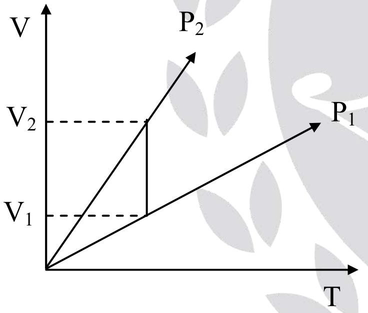
Sol: For isothermal process: T = c

$\Rightarrow P_1V_1 = P_2V_2$

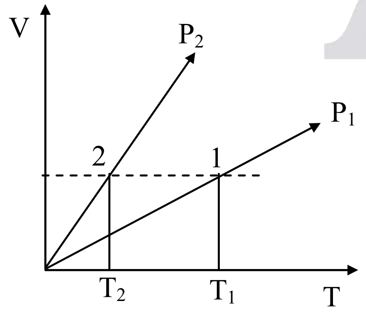
$$P_2 = P_1\left(\frac{V_1}{V_2}\right)$$

As per fig we can say $T_1 > T_2$

$\Rightarrow P_1 > P_2 ....\left(\frac{V_1}{V_2} < 1\right)$



(2) **For isochoric** : V = C



$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$T_1 > T_2$

$$\therefore P_2 = \left(\frac{T_2}{T_1}\right)P_1$$

$\therefore\ P_2 < P_1$

17. Ans: (d)

Sol: LFP = Lower fixed point

UFP = upper fixed point

$$\frac{C - LFP}{UFP - LFP} = \frac{0 - 300}{100 - 300}$$

$$\frac{C - 0}{100 - 0} = \frac{0 - 300}{100 - 300}$$

C = 150°C

18. Ans: 26.77°C

Sol: $t_A = a + bt_B + ct_B^2$

$t_A = 0°C$; $t_B = 0°C$

$t_A = 100°C$; $t_B = 100°C$

$t_A = 51°C$; $t_B = 50°C$

$0 = a + b \times 0 + c \times 0$

$\therefore\ a = 0$

$100 = 100b + 10^4\ c \times 1$

$\underline{51 = 50\ b + 2500\ c \times 2}$

$102 = 100\ b + 5000\ c$

$\underline{\_100 = \_100b + 10000\ c}$

$-\ 5000\ c = 2$

$$c = \frac{-2}{5000} = -4\times10^{-4}$$

$50\ b + 2500\ c = 51$

$50b + 2500 \times (-4\times10^{-4}) = 51$

$50\ b = 51 + 1$

$b = \dfrac{52}{50} = 1.04$

$\therefore\ t_A = 1.04\, t_B - 4 \times 10^{-4} t_B^2$

$t_B = 26°C$

$t_A = 1.04 \times 26 - 4 \times 10^{-4} \times 26^2$

$= 27.04 - 0.2704$

$= 26.77°C$

Unless the constructional features of thermometer are given it is difficult to say which thermometer is correct.

19. **Ans: 21.6°C**

Sol: Given relation $t = a\,ln(K) + b$

K is 1.83 at ice point $\Rightarrow t = 0°C$

K is 6.78 at steam point $\Rightarrow t = 100°C$

As per given relation, $t = a\ ln(K) + b$

By condition 1 $\Rightarrow 0 = a\ ln\ (1.83) + b$

$0 = 0.60\ a + b$

By condition 2 $\Rightarrow 100 = a\,ln\ (6.78) + b$

$100 = a\ 1.914 + b \Rightarrow a = 76.10$

$b = -45.66$

$\Rightarrow$ By putting value of a & b

$t = 76.10\ ln\ K - 45.66$

(K = 2.42 given)

$\Rightarrow t = 21.6°C$

20. **Ans: 550°N, –50°C**

Sol: Freezing point of ice = 0°C = 100° N

Boiling point = 100°C = 400°N

Let new scale be given as

$N = a\,t + b$

$100 = a\,(0) + b$

$\therefore\ b = 100$

$400 = 100\,a + b$

$\therefore\ a = 3$

when t = 150°C

$N = 3(150) + 100$

$N = 550°\ N$

The new scale N and Celsius will be same if

$t = 3\,t + 100$

$-2t = 100$

$\therefore\ \ t = -50°C$

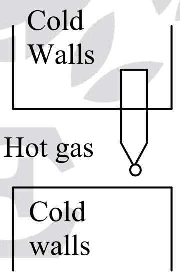
21. **Ans: (c)**

22. **Ans: (c)**

Sol: Assertion is true

Reason is false.

Reason is not the correct explanation, in this the tip of thermometer has only contact with Hot gases; it has no contact with cold walls.



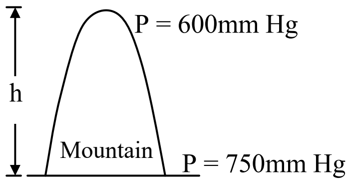
23. **Ans: (a)**

Sol: Given

$\rho = 1 kg/m^3$

$g = 10\ m/s^2$

$dP = \dfrac{\rho g dh}{g_C}$



$$dh = \frac{dP\, g_C}{\rho g}$$

$$= \frac{(750-600)(1)\times(133.33\,\text{Pa})}{1\times 10}$$

dh = 2000 m

24. Ans: (a)

Sol: Characteristic gas constant,

$$R = \frac{\overline{R}}{M}$$

where, $\overline{R}$ = Universal gas constant

M = Molecular weight

Also, $M_{H_2} < M_{N_2} < M_{Air} < M_{CO_2}$

$\therefore \quad R_{H_2} > R_{N_2} > R_{Air} > R_{CO_2}$

25. Ans: (a)

Sol: For reversibility dP = 0, dT = 0. All processes should be quasi-static which implies extremely slow, friction should not be present.

26. Ans: (d)

Sol: At T = *l*, P = 0

According to Ideal gas equation,

$Pv = mRT$

$P = C\,T$

At T = 0 K,

$P = 0$

So, P = 0 at T = *l*, and T = 0 K

$\therefore \quad l = 0\text{ K} = -273.15°\text{C}$

27. Ans: (c)

Sol:

- Boiler, turbine, condensor and pump are open systems. Since both mass and energy crosses the boundary.
- Overall plant is an closed system, as only energy crosses the boundary.

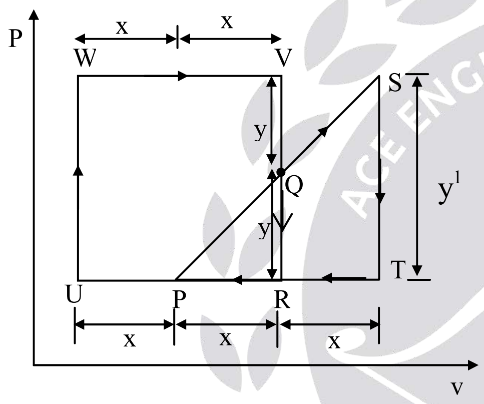
Chapter- 2
Work and Heat

01. Ans: (c)

Sol: Heat engine cycles as shown in fig

VQ = QR, PQ = QS,

UP = PR = RT



Work interaction for 'WVUR'= 48Nm

Area WVUR = 2x ×2y = 48

$\Rightarrow xy = 12$

From similar Δ^{les} PQR and PST

$$\frac{QR}{PR} = \frac{ST}{PT}$$

$$\frac{y}{x} = \frac{y^1}{2x} \Rightarrow y^1 = 2y$$

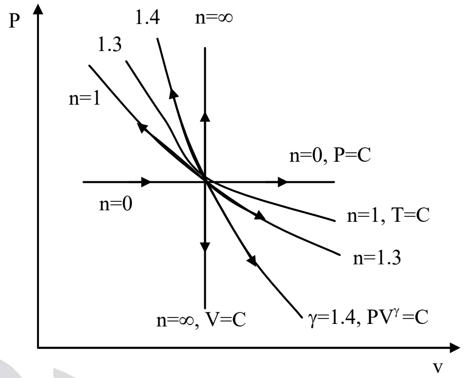
Work interaction for Δ^{le} 'PST'

$$\frac{1}{2}(2x)y^1 = \frac{1}{2}(2x)(2y) = 2xy$$

$$= 2 \times 12 = 24 \text{ Nm}$$

02. Ans: (d)

Sol:



03. Ans: (b)

Sol:

Process	**1**	**2**	**3**	**4**
dQ(kJ)	300	0	–100	0
dW(kJ)	300	250	–100	–250

Heat supplied Q_S = 300 kJ

Work of expansion, $W_E = 300 + 250 = 550$ kJ

Work of compression, $W_C = 100+250 = 350$ kJ

$W_{net} = W_E - W_C = 550 - 350 = 200$ kJ

$$\eta_{thermal} = \frac{W_{net}}{\text{Heat supplied}} = 0.67$$

$$\text{Work ratio} = \frac{W_{net}}{W_E} = \frac{200}{550} = 0.36$$

04. Ans: (c)

Sol: (A) W.D in polytropic process

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

(B) W.D in steady flow process $= -\int v\,dP$

(C) Heat transfer in reversible adiabatic process = zero

(D) W.D in an isentropic process

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

05. Ans: (d)

Sol: Given

For isothermal process

$$P_1V_1 = P_2V_2$$

$$\Rightarrow P_1V_1 = \frac{P_1}{10}\times 0.55$$

$$\Rightarrow V_1 = 0.055\ m^3$$

For adiabatic process

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

$$\Rightarrow P_1 V_1^{1.4} = \frac{P_1}{10}\times V_2^{1.4}$$

$$\Rightarrow V_2^{1.4} = 10\times(0.055)^{1.4} \Rightarrow V_2 = 0.284\ m^3$$

06. Ans: (b)

Sol:

- Adiabatic → $n = \frac{c_p}{c_v}$
- Isothermal → $n = 1$
- Constant pressure → $n = 0$
- Constant volume → $n = \infty$

07. Ans: (d)

Sol: No. of degrees of freedom in diatomic molecule = 5

No. of degrees of freedom in monoatomic molecule = 3

No. of degrees of freedom in Triatomic molecule = 6 or 7

08. Ans: (a)

Sol: The slope of log P – log V graph for a gas for isothermal change is m_1 & for adiabatic changes are m_2 if gas is diatomic gas

For isothermal process, PV = C

$$\log(P) + \log(V) = \log(C)$$

$$\log(P) = \log(C) - \log(V)$$

Compare it with y = C + mx

$$m_1 = -1$$

For adiabatic process

$$PV^{\gamma} = C$$

$$\Rightarrow \log P + \gamma \log V = \log C$$

$$\Rightarrow \log(V) = \log C - \gamma \log V$$

Compare with y = C + mx

$$m_2 = -\gamma$$

$$\Rightarrow m_1 < m_2$$

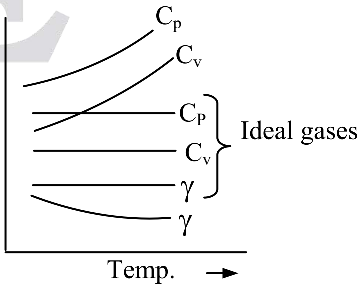
09. Ans: (d)

Sol: The ratio of C_p/C_v for a gas with n degrees of freedom is equal to $1+\frac{2}{n}$

10. Ans: (c)

Sol: C_p ; C_V ; γ ; values are constant for ideal gases

C_p ; C_v values increase with temperature for Real gases.



Where as "γ" value decreases with temperature.

11. Ans: (b)

Sol: $P = 320W$

In 30 days the refrigeration runs is

$$= 30 \times \frac{1}{4} = 7.5 \text{ days}$$

So total consumption of a month in Watt-hr is

$$= 320 \times 7.5 \times 24 = 57600 \text{ W-hr}$$

$$= 57.6 \text{ kWhr}$$

So the electricity cost per month

$$= 57.6 \times 0.09 = \$\ 5.184$$

12. Ans: (a)

Sol: $m_1 = 6\text{kg}$; $P_1 = 3\,\text{atm}$

$T_1 = 40°C = 313K$, $P_2 = 2.2$ atm

$$P_1V_1 = m_1RT_1$$

$$P_2V_2 = m_2RT_2$$

As the tank is rigid, the volume is constant

$$\Rightarrow \frac{P_1}{P_2} = \frac{m_1T_1}{m_2T_2}$$

$$\Rightarrow T_2 = \frac{m_1 \times P_2 \times T_1}{P_1}$$

$$\Rightarrow T_2 = \frac{6 \times 2.2 \times 313}{3 \times 3} = 460 \text{ K} = 187°C$$

13. Ans: (d)

Sol: Work done = Area enclosed in Pv diagram

W = Area of ΔADC + Area of ΔABC

$$\text{Area of } \Delta ADC = \frac{1}{2} \times (6-2) \times (4-1)$$

$$= 6 \text{ bar–m}^3 = 600 \text{ kN-m}$$

$$\text{Area of } \Delta ABC = \frac{1}{2} \times (6-2) \times (6-4)$$

$$= 400 \text{ kN-m}$$

$$\therefore W = (600 + 400) \text{ kN-m} = 1000 \text{ kN-m}$$

14. Ans: (d) &

15. Ans: (c)

Sol: $P_1 = 100 + 101.325 = 201.325$ kPa

$T_1 = 288$ K ,

$V_1 = 2500$ C.C

$$m = \frac{P_1V_1}{RT_1} = \frac{201.325 \times 10^3 \times 2500 \times 10^{-6}}{287 \times 288}$$

$$= 6.089 \times 10^{-3}\ kg$$

As volume is constant, $dW = 0$

$$\therefore dQ = dU = m\,C_V\,dT$$

$$= 6.089 \times 10^{-3} \times 0.718 \times 10^3 (15-5)$$

$$= 43.7 \text{ J}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$P_2 = \text{Pressure on day of play} = P_1 \times \frac{T_2}{T_1}$$

$$= 201.325 \times \frac{278}{288}$$

$$= 194.33 \text{ kPa (absolute)}$$

Gauge pressure on day of play

$$= 194.33 - 101.325$$

$$= 93 \text{ kPa} = 0.93 \text{ bar}$$

P_1 = Pressure to which it must be inflated

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{P_1}{288} = \frac{201.325}{278}$$

$$P_1 = 201.325 \times \frac{288}{278} = 208.56\,\text{kPa.}$$

Gauge pressure to which it must be inflated on previous day

$$= 208.56 - 101.3$$

$$= 107.24\text{ kPa} = 1.07\text{ bar}$$

16. Ans: (a)

Sol: Work done in isothermal process

$$= P_1V_1\,\ell n\frac{V_2}{V_1}$$

$$= 500 \times 0.8 \times \ell n\left(\frac{0.1}{0.8}\right) = -831.77\,\text{kJ}$$

17. Ans: 251.62 kJ

Sol: $m = 1.5$ kg, $P_1 = 0.1$ MPa,

$\rho_1 = 1.16$ kg/m^3, $P_2 = 0.7$ MPa

$$W = P_1V_1\;\ell n\left(\frac{V_2}{V_1}\right) = P_1V_1\ell n\left(\frac{P_2}{P_1}\right)$$

$$V_1 = \frac{m}{\rho_1} = 1.293\,\text{m}^3$$

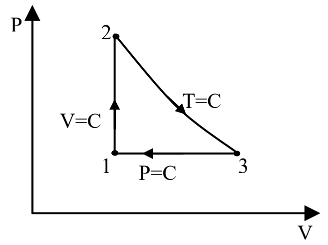
$$W = 0.1 \times 1000 \times 1.293 \times \ell n\left(\frac{0.1}{0.7}\right)$$

$$= -251.62\text{ kJ}$$

$\therefore$ Work done by piston is 251.62 kJ

18. Ans: 130.16 kJ/kg

Sol:



1 – 2 Process

$T_1 = 350$ K

$$\frac{T_2}{T_1} = 3 = \frac{P_2}{P_1}$$

$T_2 = 3 \times 350 = 1050$ K

$_1w_2 = 0$

2 – 3 Process

$$_2Q_3 = {}_2w_3 = RT_2\,\ell n\frac{P_2}{P_3}$$

$$= RT_2\,\ell n 3$$

$$= R(1050\,\ell n 3) = 1153.54R\,\frac{\text{kJ}}{\text{kg}}$$

1 – 3 Process

$P = C$

$$\frac{V_3}{T_3} = \frac{V_1}{T_1};\ \frac{V_3}{V_1} = \frac{T_3}{T_1} = \frac{T_2}{T_1} = 3$$

As $T_3 = T_2$

$$_3w_3 = P(V_1 - V_3) = RT_3\left(\frac{T_1}{T_3} - 1\right)$$

$$= 1050R\left(\frac{1}{3} - 1\right)$$

$$= -700\text{ R kJ/kg}$$

$$w_{net} = {}_1w_2 + {}_2w_3 + {}_3w_1$$

$$= 0 + 1153.54\text{ R} - 700\text{ R}$$

$$= 453.54\text{ R kJ/kg}$$

$$= 453.54 \times 0.287 = 130.16\text{ kJ/kg}$$

19. Ans: 2356.2 kJ/kg

Sol: $(1\text{cm})_x = 300$ kPa

$(1\text{ cm})_y = 0.1\ \text{m}^3/\text{kg}$

$1\ \text{cm}^2$ Area $= (1\text{cm})_x \times (1\text{cm})_y$

$= 300 \times 0.1 = 30$ kJ/kg

Area on P-V diagram $= A = \frac{\pi}{4}D^2$

$= \frac{\pi}{4} \times 10^2$

$= 78.5\ \text{cm}^2$

Net work $= 78.5\ \text{cm}^2$

$= 78.5 \times 30 = 2355$ kJ/kg

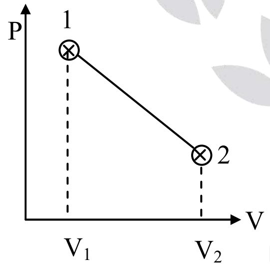
20. Ans: 29.7 kJ

Sol: $A = 0.12\ \text{m}^2$

$P_1 = 1.5$ MPa $= 1500$ kPa

$P_2 = 0.15$ MPa $= 150$ kPa

$l = 0.3$ m



$${}_1W_2 = \frac{1}{2}(P_1 + P_2)V_s,\ V_s = V_2 - V_1$$

$$\Rightarrow {}_1W_2 = \frac{1}{2} \times (1500 + 150) \times (0.036)$$

$(\because V_s = Al = 0.12 \times 0.3 = 0.036\ \text{m}^3)$

$\Rightarrow {}_1W_2 = 29.7$ kJ

21. Ans: 1742 kJ

Sol: Given $\left[P + \frac{a}{V^2}\right](V - b) = mRT$

$$P + \frac{a}{V^2} = \frac{mRT}{(V-b)}$$

$$P = \frac{mRT}{(V-b)} - \frac{a}{V^2}$$

$$W.D = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2}\left[\frac{mRT}{(V-b)} - \frac{a}{V^2}\right]dV$$

$$W.D = mRT\,\ell n[V-b]_{V_1}^{V_2} - a\left[\frac{V^{-2+1}}{-2+1}\right]_{V_1}^{V_2}$$

$$W.D = mRT\ell n\left(\frac{V_2 - b}{V_1 - b}\right) + a\left[\frac{1}{V_2} - \frac{1}{V_1}\right]$$

$m = 10$ kg, $V_1 = 1\ \text{m}^3$,

$V_2 = 10\ \text{m}^3$, $T = 293$ K,

$a = 15.7 \times 10^4\ \text{Nm}^4 = 157\ \text{kNm}^4$

$b = 1.07 \times 10^{-2}$, $R = 0.278$ kJ/kg.K

$$W.D = (10)(0.278)(293)\ ln\left(\frac{10 - (1.07 \times 10^{-2})}{1 - (1.07 \times 10^{-2})}\right) + 157\left[\frac{1}{10} - 1\right]$$

W.D = 1742.14 kJ

22. Ans: 686.62 kJ

Sol: $P \propto D^2$

$P_1 = KD_1^2$

$P_2 = KD_2^2$

$P_1 = 100$ kPa, $D_1 = 1$ m

$\therefore K = 100\ \text{kPa/m}^2$

$P_2 = 350$ kPa,

$D_2 = ?$

$$\frac{P_1}{P_2} = \frac{D_1^2}{D_2^2}$$

$$D_2 = D_1\sqrt{\frac{P_2}{P_1}}$$

$$= 1\sqrt{\frac{350}{100}} = 1.8708\,\text{m}$$

Volume of balloon

$$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi \times \left(\frac{D}{2}\right)^3$$

$$= \frac{4}{3}\times\pi\times\frac{D^3}{8}$$

$$V = \frac{\pi}{6}D^3$$

$$dV = 3\times\frac{\pi}{6}D^2 dD$$

$$= \frac{\pi}{2}D^2 dD$$

$${}_1W_2 = \int_{D_1}^{D_2} PdV = \int_{D_1}^{D_2} KD^2 \times \frac{\pi}{2}D^2 dD$$

$$= \int_{D_1}^{D_2} \frac{K}{2}\pi D^4 dD$$

$$= \int_{1}^{1.8708} \frac{100}{2}\times\pi\times D^4 dD$$

$$= 50\pi\frac{D^5}{5}\Bigg|_1^{1.8708}$$

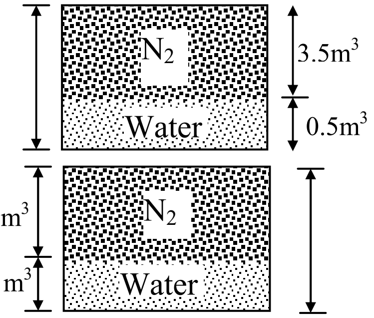
$${}_1w_2 = 10\pi\left[1.8708^5 - 1^5\right]$$

$$= 10\pi\left[22.9159 - 1\right] = 688.16\,\text{kJ}$$

23. Ans: 116.67 kPa, 54.42 kJ

Sol: Given, $m_w = 500$ kg

Total tank volume, V= 4 m^3



$P_1 = 100$ kPa

$m_w = 500$ kg, $\rho_w = 1000$ kg/m^3

For state-1, $V = \frac{500}{1000} = 0.5\,m^3$

For state-2, $m_w = 1000$ kg, V = 1 m^3

For state 1 'N_2':

$P_1 = 100$ kPa

V_1 = Total volume – vol. of water

= 4 – 0.5 = 3.5 m^3

For state 2 ('N_2'):

V_2 = Total volume – vol. of water

= 4 –1 = 3 m^3

Condition: Isothermal process

⇒ From eq^n $P_1V_1 = P_2V_2$

$$\Rightarrow P_2 = \frac{P_1V_1}{V_2} = \frac{100\times 3.5}{3}$$

⇒ $P_2 = 116.67$ kPa

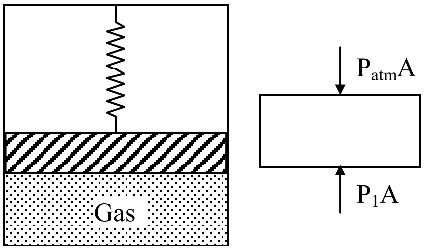
$${}_1W_2 = P_1V_1 \ln\left(\frac{V_2}{V_1}\right) = 100 \times 3.53 \times \ln\left(\frac{3}{3.5}\right)$$

⇒ W = –54.42 kJ

Here '–ve' sign indicates compression of N_2 so system volume decreases

24. Ans: 320 kPa, 13 kJ

Sol:



$V_1 = 0.05\ m^3$, $P_1 = 200$ kPa,

$A_p = 0.25\ m^2$,

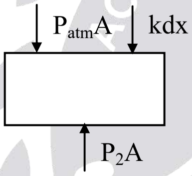
Spring constant, k = 150 kN/m

$V_2 = 2V_1 = 2 \times 0.05 = 0.1\ m^3$

$$dx = \frac{V_2 - V_1}{A} = \frac{0.1 - 0.05}{0.25} = 0.2\,m$$

$P_1A = P_{atm}A$

$P_1 = P_{atm}$



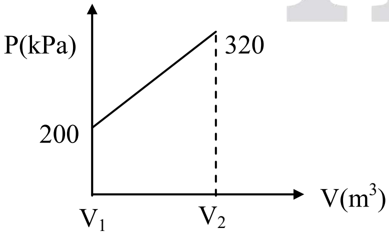
Final force = Initial force + spring force

$P_2A = P_1A + kdx$

$$P_2 = P_1 + k.\frac{dx}{A}$$

$$= 200 + 150 \times \frac{(0.2)}{0.25}$$

$= 200 + 120 = 320$ kPa



$$\text{Work done} = \frac{1}{2}(320 + 200) \times 0.05 = 13kJ$$

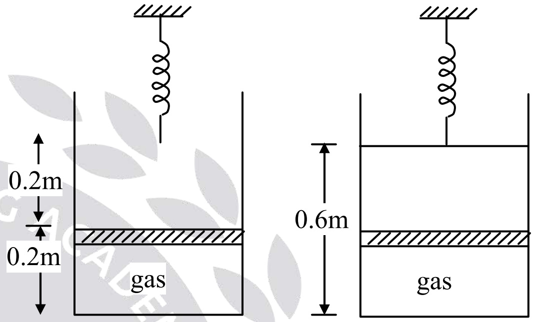
25. Ans: 2.5 kJ

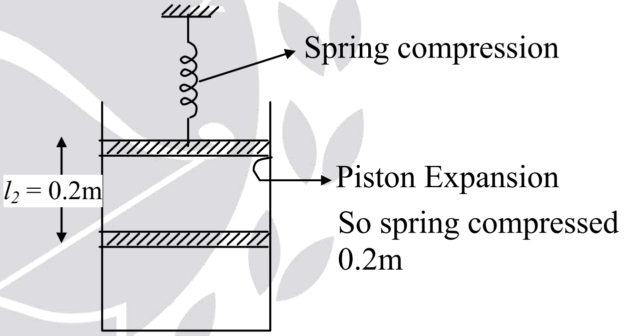
Sol: Given $P_a = 0.1$ MPa = 100 kPa

$V_1 = 0.01 m^3$; $A_1 = 0.05\ m^3$

$$\Rightarrow l_1 = \frac{V_1}{A_1} = \frac{0.01}{0.05} \Rightarrow l_1 = 0.2\ m$$

$V_2 = 3V_1$





Find: Total W.D

Here rigid cylinder so area will be same

$Al_2 = 3\ Al_1$

$l_2 = 3l_1$

$\Rightarrow$ $l_2 = 0.6$ m

$\Rightarrow$ $V_2 = 0.03\ m^3$

Total work = [work of gas + (work of spring due to expansion by heating)]

(Due to expansion of piston, spring is compressed)

$$= PdV + \frac{1}{2}Kx^2$$

$$= P(V_2 - V_1) + \frac{1}{2}(25)(0.2)^2$$

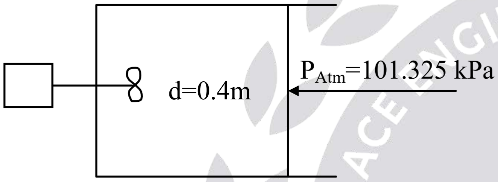
[∵ constant pressure process]

$$= 100\,(0.03 - 0.01) + \frac{1}{2}(0.2)^2(25)$$

Total work = 2.5 kJ

26. Ans: 0.79 N-m, 6.95 W

Sol:



d = 0.4 m , time = 600 sec

W = 2 kJ , l = 0.485 m, N = 840 rpm

W_{Net} = Piston expansion work – $W_{Stirrer}$

$$2 = PdV - W_s$$

$$2 = (101.325)\,Al - W_S$$

$$2 = (101.325)\left(\frac{\pi}{4}(0.4)^2 \times 0.485\right) - W_S$$

W_S = 4.175 kJ

$$\Rightarrow \text{Power} = \frac{W_S}{\text{Time}} = \frac{4.175}{600}$$

$$= 6.95 \times 10^{-3}\ \text{kW} = 6.95\ \text{W}$$

$$\text{Now, } P_S = \frac{2\pi NT}{60}$$

$$T = \frac{60P_S}{2\pi N} = \frac{60(6.95)}{2 \times 3.14 \times 840}$$

$\Rightarrow$ T = 0.079 Nm

27. Ans: (d)

Sol:

- Electrical work crosses the boundary A and hence it is work transfer.
- Across boundary B heat transfer is there.

28. Ans: (a)

Sol: $c_p = \left(\frac{dh}{dT}\right)_{p=c}$

$c_v = \left(\frac{du}{dT}\right)_{v=c}$,

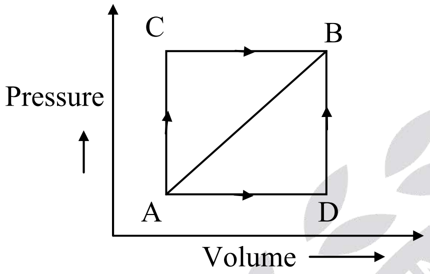
h > u

Therefore, $c_p > c_v$

Chapter- 3
First Law of Thermodynamics

01. Ans: (c)

Sol:



Along A – B – C:

$Q_{A-B} - W_{A\text{-}B} = U_{A-B}$

$180 - 130 = U_B - U_A$

$U_B - U_A = 50$ kJ

Along A – D – B:

$Q_{A-B} - W_{A\text{-}B} = U_{A-B}$

$Q_{A-B} = 50 + 40 = 90$ kJ

02. Ans: –200 kJ

Sol: For 1–2 process

${}_1Q_2 - {}_1W_2 = {}_1U_2$

$\Rightarrow 100 - 100 = U_2 - U_1$

$\Rightarrow U_2 = U_1$

For 2–3 process

${}_2Q_3 - {}_2W_3 = {}_2U_3$

$\Rightarrow -150 - {}_2W_3 = U_3 - U_2 = U_3 - U_1 = 200$

${}_2W_3 = -350$ kJ

For 3 – 4 process

${}_3Q_4 - {}_3W_4 = {}_3U_4$

${}_3U_4 = (U_4 - U_3) = (U_4 - U_1) - (U_3 - U_1)$

$= -(U_1 - U_4) - (U_3 - U_1)$

$= -50 - 200 = -250$

${}_3Q_4 = {}_3U_4 - 250$ ……… (1)

For 4 – 1 Process

${}_4Q_1 - {}_4W_1 = {}_4U_1 = U_1 - U_4$

${}_4Q_1 - 300 = 50$

${}_4Q_1 = 350$ kJ

$\sum Q = {}_1Q_2 + {}_2Q_3 - {}_3Q_4 + {}_4Q_1$

$= 100 - 150 - 500 + 350 = -200$ kJ

$(\because \sum Q = \sum W)$

$\sum W = 100 - 350 - 250 + 300 = -200$ kJ

03. Ans: (c)

Sol: (a) $dW = 0$ (Rigid)

$dQ = -ve$

$dU = -ve$

$dQ - dW = dU$

$dU = -ve$

(b) $dQ = 0$ (Insulated)

$dW = +ve$ (Expansion)

$\therefore dQ - dW = dU$

$0 - dW = dU$

$dU = -ve$

(c) $dW = 0$ (Free expansion)

$dQ = 0$ (Insulated)

$\Rightarrow dU = 0$

(d) $dW = -ve$

$dQ = 0$ (Adiabatic)

$dU = +ve$

04. Ans: (e)

Sol: $m = 60$ kg , $P = 200$ kPa

$T = 25°C$, $\frac{dQ}{dt} = 0.8$ kW

$t = 30$ min $= 1800$ sec

Well sealed = control mass

(Non flow process)

$$dQ - dW = dU$$

$$\frac{dQ}{dt}\times t - \frac{dW}{dt}\times t = mC_v dT$$

$$1800[0.8 - (-0.12)] = 60(0.718)(T - 25)$$

$$T = 63.4^0C$$

05. Ans (d)

Sol: $Q = 2000$ W

$t = 15$ min $= 900$ sec

$m = 75$ kg

Well sealed = control mass (Non flow process)

$$dQ - dW = dU$$

$$\frac{dQ}{dt}\times t - \frac{dW}{dt}\times t = mC_v dT$$

$$t\left(\frac{dQ}{dt} - \frac{dW}{dt}\right) = mC_V dT$$

$$900\,[0-(-2)] = 75(0.718)dT$$

$$dT = 33.42°C$$

06. Ans: (c)

Sol: $P_1 = -0.25$ kW (– ve sign indicates it is a power consuming device)

$P_2 = -\,0.12$ kW

$P_3 = -1$ kW

$P_4 = -\,0.05$ kW

Temperature = constant

(Isothermal process)

$dQ = dW \quad (\because dU = 0)$

$dQ = -(0.25 + 0.12 + 1 + 0.05) \times 3600$

$= -5112$ kJ/hr

07. (i) Ans: (b), (ii) Ans: (c)

Sol:

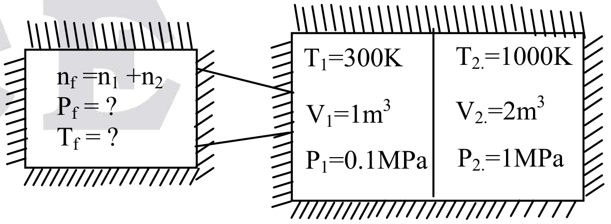
(ii) Ideal gas stored in Rigid insulated Tank. Total volume of Tank $V_f = 3m^3$

State : 1

Tank has two compartments.

State : 2

Partition between two compartments Ruptured



$$PV = mRT$$

$$\Rightarrow PV = m\frac{\overline{R}T}{M}\left(\because R = \overline{R}/M\right)$$

$$\Rightarrow PV = n\overline{R}T\left(\because n = \frac{m}{M}\right)$$

By equation $PV = n\bar{R}T$

$$= P_1V_1 = n_1\bar{R}T_1$$

$$\Rightarrow n_1 = \frac{P_1V_1}{\bar{R}T_1} = \frac{0.1MPa \times 1m^3}{8.314 \times 300K}$$

$$= \frac{0.1 \times 10^3 kPa \times 1m^3}{8.314 \times 300}$$

$$\Rightarrow n_1 = 0.040 \text{ moles}$$

For $n_2 = \frac{P_2V_2}{\bar{R}T_2} = \frac{1\times10^3 \times 2}{8.314 \times 1000}$

$$= 0.24 \text{ Moles}$$

$$n_f = n_1 + n_2 = 0.04 + 0.24 = 0.28 \text{ Moles}$$

$$V_f = V_1 + V_2 = 3m^3$$

Here rigid & Insulated tank given

$\Rightarrow dQ = 0, \quad dW = 0$

$(\because \text{Rigid} \Rightarrow V = C \Rightarrow dW = 0)$

$\Rightarrow$ By 1st law

$$dQ - dW = dU = C_VdT = 0$$

Here $dU_1 + dU_2 = 0$

$$\Rightarrow n_1C_VdT + n_2C_VdT = 0$$

$$\Rightarrow n_1C_V(T_f - T_1) + n_2C_v(T_f - T_2) = 0$$

$$0.040C_V(T_f - 300) + 0.24C_V(T_f - 1000) = 0$$

$$\Rightarrow C_V(0.28T_f - 241.2) = 0$$

$$\Rightarrow T_f \approx 900K$$

Again

$$\Rightarrow P_fV_f = n_f\bar{R}\,T_f$$

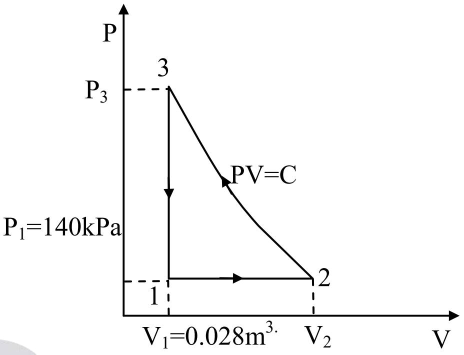
$$\Rightarrow P_f = \frac{n_f\bar{R}T_f}{V_f} = \frac{0.28(8.314)(900)}{3}$$

$$= 700 \text{ kPa}$$

$$\Rightarrow P_f = 0.7MPa$$

08. (i) Ans: (c) , (ii) Ans: (b) , (iii) Ans: (b)

Sol:



Given

Process 1→ 2: (P = C),

$P_1 = 1.4$ bar,

$V_1 = 0.028\ m^3$,

$W_{1-2} = 10.5kJ$

Process 2 – 3: (PV = C),

$U_3 = U_2$

Process 3 – 1: (V = C),

$U_1 - U_3 = -26.4$ kJ

Process 1 – 2: (Constant pressure)

$\Rightarrow Q_{1-2} - W_{1-2} = U_{1-2}$

Given ${}_1W_2 = 10.5kJ = P(V_2 - V_1)$

$W_{1-2} = P_1(V_2 - V_1)$

$\Rightarrow 10.5 = 140(V_2 - 0.028)$

$\Rightarrow V_2 = 0.103m^3$

$U_3 = U_2$ & $U_1 - U_3 = -26.4kJ$

$\Rightarrow U_1 - U_2 = -26.4kJ$

$\Rightarrow U_2 - U_1 = 26.4$ kJ.

$\Rightarrow {}_1Q_2 = {}_1U_2 + {}_1W_2$

$\Rightarrow {}_1Q_2 = 26.4 + 10.5$

$\Rightarrow {}_1Q_2 = 36.9$ kJ

Process 2 – 3:(Isothermal Process)

⇒ $Q_{2\text{-}3} - W_{2\text{-}3} = U_{2\text{-}3}$

Hence T = C ⇒ ${}_2U_3 = 0$

$$\Rightarrow Q_{2\text{-}3} = W_{2\text{-}3} = P_2V_2\ln\frac{V_3}{V_2}$$

$$= 140\times0.103\ln\left(\frac{0.028}{0.103}\right)$$

⇒ ${}_2W_3 = -18.79$ kJ

Process 3 – 1:(constant volume)

${}_3W_1 = 0$

⇒ $dQ - dW = dU$

⇒ ${}_3Q_1 = {}_3U_1 = -26.4$

⇒ ${}_3Q_1 = -26.4$ kJ

For checking answer

$\Sigma Q = {}_1Q_2 + {}_2Q_2 + {}_3Q_1$

$\Sigma Q = -8.28$ kJ

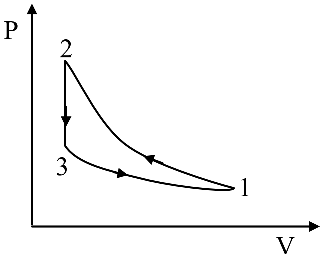
$\Sigma W = {}_1W_2 + {}_2W_3 + {}_3W_1$

⇒ $\Sigma W = -8.28$kJ

⇒ $\Sigma Q = \Sigma W$ (First law proved)

09. Ans: 74 kJ, 22 kJ

Sol:



$U_1 = 512$ kJ, $P_1 = 1$ bar, $P_2 = 2$ bar

$U_2 = 690$ kJ, $V_1 = 1.5\ m^3$

Process 1-2:

$\delta Q_{1\text{-}2} = dU + \delta W_{1\text{-}2}$

$$= U_2 - U_1 + P_1V_1\ \ell n\left(\frac{V_2}{V_1}\right)$$

$$= 690 - 512 + 100\times1.5\,\ell n\left(\frac{P_1}{P_2}\right)$$

$$= 178 + 150\,\ell n\left(\frac{1}{2}\right)$$

$\delta Q_{1\text{-}2} = 74.02$ kJ

Process 2-3 :

$\delta Q = dU + \delta W$

$-150 = U_3 - U_2$

$-150 = U_3 - 690$

$U_3 = 540$ kJ

Process 3-1 :

$\delta Q = dU + \delta W$

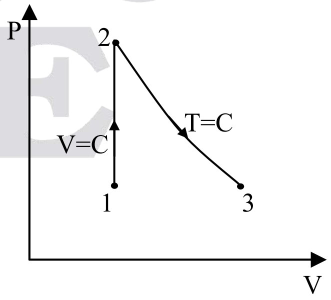
$= U_1 - U_3 + 50$

$= 512 - 540 + 50$

$Q_{3\text{-}1} = 22$ kJ

10. Ans: 69.3 kJ, 131.831 kJ

Sol:



Air :

$P_1 = 100$ kPa

$T_1 = 300$ K

$V_1 = 0.75\ m^3$

$T_2 = 400$ K

1 – 2 Process V = C

$$\frac{P_1}{T_1}=\frac{P_2}{T_2}$$

$$P_2=\frac{T_2}{T_1}\times P_1=\frac{400}{300}\times 100=133.33\text{kPa}$$

$T_3 = 400$ K $= T_2$

$V_3 = 1.5\ m^3$

${}_1W_2 = 0\ (\because\ V = C)$

$$m=\frac{P_1V_1}{RT_1}=\frac{100\times 0.75}{0.287\times 300}=0.871\text{kg}$$

${}_1Q_2 = mc_v(T_2–T_1)$

$= 0.871 \times 0.718\ (400–300)=62.54$ kJ

2 – 3 Process T = C

$P_2V_2 = P_3V_3$

$$P_3=P_2\times\frac{V_2}{V_3}=133.33\times\frac{0.75}{1.5}=66.67\,\text{kPa}$$

$${}_2W_3={}_2Q_3=P_2V_2\ell n\frac{V_3}{V_2}$$

$$=133.33\times 0.75\ell n\frac{1.5}{0.75}=69.313\text{kJ}$$

${}_1W_3 = {}_1W_2 + {}_2W_3 = 0 + 69.313 = 69.313$ kJ

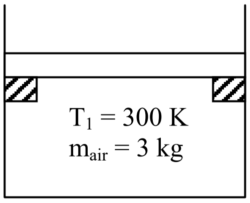
${}_1Q_3 = {}_1Q_2 + {}_2Q_3$

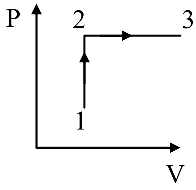
$= 62.54 + 69.313 = 131.853$ kJ

11. Ans: 516 kJ, 2454.6 kJ

Sol: $m_{air} = 3$ kg, $P_1 = 200$ kPa,

$T_1 = 27°C = 300$ K, $P_2 = 400$ kPa





1 – 2 (V = C)

$$\frac{200}{300}=\frac{400}{T_2}$$

$T_2 = 600$ K

$P_1V_1 = mRT_1$

$$V_1=\frac{3\times 0.287\times 300}{200}=1.2915\,m^3$$

$V_1 = V_2 = 1.2915\ m^3$,

$V_3 = 2V_2 = 2.583\ m^3$

2 – 3 (P = C)

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

$$2=\frac{T_3}{600}$$

$T_3 = 1200$ K

Work done $= 0 + P \times (V_3–V_2)$

$= 400 \times 1.2915 = 516.6$ kJ

${}_1Q_2 = mc_v\ (T_2–T_1)$

$= 3 \times 0.717 \times (600–30)$

$= 645.3$ kJ

${}_2Q_3 = {}_2W_3 + {}_2U_3 = m\ c_p(T_3–T_2)$

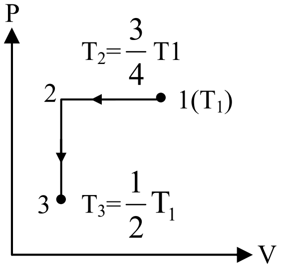
$= 3 \times 1.005\ (1200–600)$

$= 1809$ kJ

Total heat transfer $= 645.3 + 1809 = 2454.3$

12. (i) Ans: (d) , (ii) Ans: (a) , (iii) Ans: (d)

Sol:



Process 1 – 2: (P = C)

$$\frac{V_1}{T_1}=\frac{V_2}{T_2}$$

$$\therefore \frac{V_2}{V_1}=\frac{T_2}{T_1}=\frac{\frac{3}{4}T_1}{T_1}=\frac{3}{4}=0.75$$

$${}_1Q_2 - {}_1W_2 = {}_1U_2$$

$${}_1Q_2 - P(V_2 - V_1) = (U_2 - U_1)$$

$$\therefore {}_1Q_2 = C_V(T_2 - T_1) + P(V_2 - V_1)$$

$$= C_VT_1\left(\frac{T_2}{T_1}-1\right)+PV_1\left(\frac{V_2}{V_1}-1\right)$$

$$= C_VT_1\left(\frac{3}{4}-1\right)+PV_1\left(\frac{3}{4}-1\right)$$

$$= -\frac{1}{4}\left(C_VT_1+PV_1\right)$$

$$= -\frac{1}{4}\left(C_VT_1+RT_1\right)$$

$$= \frac{-1}{4}T_1\left(R+C_V\right) = \frac{-1}{4}T_1C_P = \frac{C_PT_1}{4}$$

Process 1 – 2:

$${}_1W_2 = P(V_2 - V_1)$$

$$= PV_1\left(\frac{V_2}{V_1}-1\right)=\frac{-RT_1}{4}$$

Process 2 – 3: (V = Constant)

$${}_2W_3 = 0$$

$${}_2Q_3 = {}_2U_3 = U_3 - U_2$$

$$= C_V(T_3 - T_2)$$

$$= C_V\left(\frac{T_1}{2}-\frac{3T_1}{4}\right)$$

$$= -C_VT_1\left(\frac{1}{4}\right)$$

$$= \frac{-C_VT_1}{4}$$

$${}_1Q_3 = {}_1Q_2 + {}_2Q_3$$

$$= \frac{-C_PT_1}{4}+\frac{-C_VT_1}{4}$$

$$= \frac{-T_1}{4}\left(C_P+C_V\right) = (C_V + C_P)\frac{T_1}{4}$$

13. (i) Ans: (c), (ii) Ans: (c), (iii) Ans: (b)

Sol:

m = 1.5 kg

P_1 = 1000 kPa

P_2 = 200 kPa

$V_1 = 0.2\text{m}^3$

$V_2 = 1.2\text{ m}^3$

P = a + bV

u = 1.5Pv – 85

1000 = a + 0.2b ……… (i)

200 = a + 1.2b …….. (ii)

By solving

b = – 800

a = 1160

P = 1160 – 800V

(ii) $${}_1W_2 = \int_{V_1}^{V_2}PdV=\int_{v_1}^{v_2}(1160-800V)dV$$

$$= \int_{0.2}^{1.2}(1160-800V)dV$$

$$= 1160(1.2-0.2)-400(1.2^2 - 0.2^2)$$

$$= 600\text{ kJ}$$

(iii) u = (1.5 Pv – 85) kJ/kg

$$= (1.5P\frac{V}{m} - 85)\text{ kJ/kg}$$

$$= 1.5P\frac{V}{m} - 85$$

$$= 1.5P\frac{V}{1.5} - 85$$

$$= (Pv - 85)\ \text{kJ/kg}$$

$$u_1 = P_1V_1 - 85 \quad = 1000 \times 0.2 - 85$$

$$= 115\ \text{kJ/kg}$$

$$u_2 = P_2V_2 - 85 \quad = 200 \times 1.2 - 85$$

$$= 155\ \text{kJ/kg}$$

$$u_2 - u_1 = 40\ \text{kJ/kg}$$

$$dU = m(u_2 - u_1)$$

$$= 1.5 \times 40 = 60\ \text{kJ}$$

$$dQ - dW = dU$$

$$dQ = 60 + 600 = 660\ \text{kJ}$$

$$u = Pv - 85$$

$$= (a + bv)v - 85$$

$$= av + bv^2 - 85 = f(v)$$

For Maximum internal energy

$$\frac{du}{dv} = 0$$

$$\Rightarrow a + 2bV = 0$$

$$\Rightarrow V = \frac{-a}{2b} = \frac{-1160}{-2\times 800}\ \text{m}^3 = 0.725\text{m}^3$$

$$u_{max} = (1160\times 0.725) - (800 \times 0.725^2) - 85$$

$$= 335.5\ \text{kJ/kg}$$

$$U_{max} = \dot{m} \times u_{max}$$

$$= 1.5 \times 335.5$$

$$= 503.25\ \text{kJ}$$

14. Ans: (a)

Sol: n = 1 mole

$C_V = 20.785$ J/mol K

$T_1 = 300$ K

P = 50 W

t = 120 sec

dQ = 0 (Insulated non flow process)

$$dQ - dW = dU$$

$$0 - (-P \times t) = nC_VdT$$

$$50 \times 120 = 1\times 20.785\times(T_2 - 300)$$

$$T_2 = 588\ \text{K}$$

For Ideal gas, $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$$\therefore\ P_2 = \frac{T_2}{T_1}\times\frac{V_1}{V_2}\times P_1$$

$$= \frac{588}{300}\times 100$$

$$P_2 = 196\ \text{kPa} = 0.196\ \text{MPa}$$

15. Ans: (b)

Sol:

For process 1 – 2 : (P = C)

$$\Rightarrow {}_1W_2 = P_1(V_2 - V_1)$$

$$\Rightarrow {}_1W_2 = 100 \times (0.3 - 0.003)$$

$$\Rightarrow {}_1W_2 = 29.7\text{kJ}$$

By Ist law

$${}_1Q_2 - {}^1W_2 = E_2 - E_1$$

$$\Rightarrow\ 0 - 29.7 = E_2 - E_1$$

$$(\because\ {}_1Q_2 = 0)$$

$$-29.7 = E_2 - 0$$

$$E_2 = -29.7\ \text{kJ}$$

By Process 2 – 3

$$ {}_2Q_3 - {}_2W_3 = {}_2E_3 = E_3 - E_2 $$

$$ {}_2Q_3 - P(V_3 - V_2) = E_3 - E_2 $$

$$ -105 - 100(0.06 - 0.3) = E_3 - (-29.7) $$

$$ E_3 = -110.7 \text{ kJ} $$

16. (i) Ans: (a) , (ii) Ans: (b)

Sol: $C_P = 2.093 + \dfrac{41.87}{t+100} \, J/{}^0C$

P = 1 atm

$V_1 = 2000 \text{ cm}^3$ $\quad T_1 = 0°C$

$V_2 = 2400 \text{ cm}^3$ $\quad T_2 = 100°C$

Here C_P = J/°C form it should always in J/kg °C form

So C_P × kg = J/°C

⇒ Sp. Heat × mass = Heat capacity

$$ dQ = \int_{T1}^{T2} C_P dt = \int_{0^0C}^{100^0C} \left[2.093 + \frac{41.87}{t+100} \right] dt $$

$$ = [2.093t]_0^{100} + 41.87\, ln[t+100]_0^{100} $$

$$ = [2.093(100)] + [41.87\, ln(200) - 41.87\, ln(100)] $$

$$ = 209.3 + [2218 - 192.81] $$

(i) dQ = 238.32J

Here constant pressure is given

$$ \Rightarrow {}_1W_2 = P_1(V_2 - V_1) = P_{atm}(V_2 - V_1) $$

$$ = 101325(2400 - 2000) \times 10^{-6} $$

$$ {}_1W_2 = 40.53J $$

$$ \Rightarrow dQ - dW = dU $$

$$ \Rightarrow dU = 238.32 - 40.53 $$

$$ dU = 197.79J $$

17. (i) Ans: (a), (ii) Ans: (b) , (iii) Ans: (a)

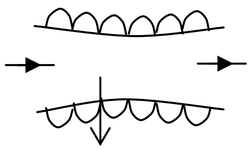
Sol: $h_1 = 3000$ kJ/kg , $\quad h_2 = 2762$ kJ/kg

$V_1 = 60$ m/s , $\quad V_2 = ?$

$A_1 = 0.1 \text{ m}^2$,

$v_2 = 0.498 \text{ m}^3/\text{kg}$

$v_1 = 0.187 \text{ m}^3/\text{kg}$



$$ \frac{dQ}{dt} = 0 $$

Applying steady flow energy equation

$$ h_1 + \frac{V_1^2}{2000} + \frac{dQ}{dt} = h_2 + \frac{V_2^2}{2000} + \frac{dW}{dt} $$

$$ \Rightarrow 3000 + \frac{(60)^2}{2000} = (2762) + \frac{V_2^2}{2000} $$

$$ \Rightarrow V_2 = 692.5 \text{ m./s} $$

$$ \Rightarrow \dot{m} = \frac{A_1V_1}{v_1} = \frac{A_2V_2}{v_2} $$

$$ \Rightarrow \dot{m} = \frac{(0.1)(60)}{0.187} \Rightarrow m = 32.08 \frac{kg}{sec} $$

Find, $A_2 = ?$

$$ \Rightarrow \dot{m} = \frac{A_2V_2}{v_2} \Rightarrow A_2 = \frac{mV_2}{v_2} $$

$$ \Rightarrow A_2 = \frac{32.08 \times (0.498)}{692.5} $$

$$ \Rightarrow A_2 = 0.023 \text{ m}^2 $$

18. Ans: (a)

Sol: Given:

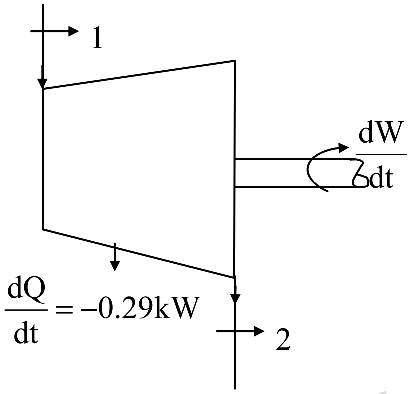
$P_1 = 1.2$ MPa, $\quad P_2 = 20$ kPa , $\quad T_1 = 188°C$,

$h_1 = 2785$ kJ/kg, $h_2 = 2512$ kJ/kg

$V_1 = 33.33$ m/s, $V_2 = 100$ m/sec.

$Z_2 = 0$ m , $\quad Z_1 = 3$ m ,

$\dot{m} = 0.42$ kg/sec



Applying steady flow energy equations

$$\dot{m}\left[h_1+\frac{Z_1 g}{1000}+\frac{V_1^2}{2000}\right]+\frac{dQ}{dt}$$

$$=\dot{m}\left[h_2+\frac{V_2^2}{2000}+\frac{Z_2 g}{1000}\right]+\frac{dW}{dt}$$

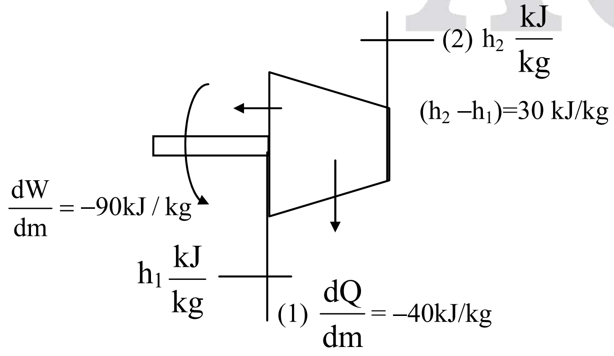
$$\Rightarrow 0.42\left[2785+\frac{3(9.81)}{1000}+\frac{(33.33)^2}{2000}\right]-0.29$$

$$=0.42\left[2512+\frac{(100)^2}{2000}+0\right]+\frac{dW}{dt}$$

$$\Rightarrow \frac{dW}{dt}=112.51\ \text{kW}$$

19. Ans: (a)

Sol:



$dW = -90$ kN.m/kg $= -90$ kJ/kg

$(h_2 - h_1) = 30$ kJ/kg.

$$\frac{dQ}{dm} = -\ 40\text{kJ/kg}$$

Heat rejected ⇒ dQ = '−Ve'

According to Steady flow energy equation,

$$h_1+\left(\frac{dQ}{dm}\right)_{air}+\left(\frac{dQ}{dm}\right)_{w}=h_2+\left(\frac{dW}{dm}\right)$$

$$\left(\frac{dQ}{dm}\right)_{air}=(h_2-h_1)+\frac{dW}{dm}-\left(\frac{dQ}{dm}\right)_{w}$$

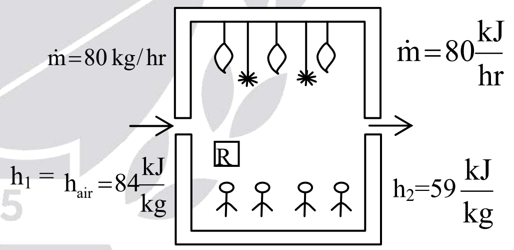
$$= 30 - 90 - (-40)$$

$$= -\ 20\text{kJ}$$

(−ve sign indicates heat is rejected from the system)

20. Ans: (b)

Sol:



$$\left(\frac{dW}{dt}\right)_{fans} = 0.18\times 2 = -0.36\ \text{kW}$$

$$\left(\frac{dW}{dt}\right)_{Bulb} = 3 \times 0.1 = -0.3\ \text{kW}$$

$$\left(\frac{dW}{dt}\right)_{Total} = -\ 0.36 + (-\ 0.3) = -0.66\ \text{kW}$$

$\dot{m}_{\text{air enter}} = 80$ kg/hr.

$h_1 = 84$ kJ/kg

$h_2 = 59$ kJ/kg

$$\left(\frac{dQ}{dt}\right)_{person} = 630\times 4 = 2520\,kJ/hr$$

$$\left(\frac{dQ}{dT}\right)_{R\,cooler} = ?$$

By steady flow energy equation

$$\dot{m}_1 h_1 + \left(\frac{dQ}{dt}\right)_{person} + \left(\frac{dQ}{dt}\right)_{RCooler} = \dot{m}_2 h_2 + \left(\frac{dW}{dt}\right)_{fan} + \left(\frac{dW}{dt}\right)_{bulb}$$

$$\frac{80\times 84}{3600} + \frac{2520}{3600} + \left(\frac{dQ}{dt}\right)_{RCooler} = \frac{80\times 59}{3600} + (-0.66)$$

$$\Rightarrow \left(\frac{dQ}{dt}\right)_{RC} = -1.91\,kW$$

Heat is removed from a cooler is 1.91 kW

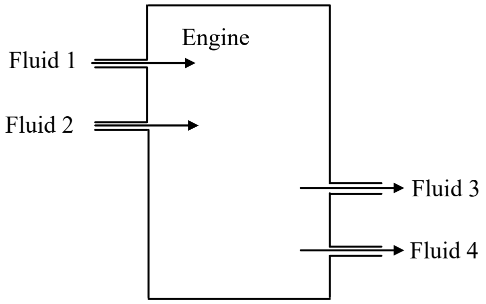
21. (i) Ans: (a), (ii) Ans: (a)

Sol: $\dot{m}_1 = 0.01 kg/sec$ $h_1 = 2952$ kJ/kg

$\dot{m}_2 = 0.1 kg/sec$ $h_2 = 2569$ kJ/kg.K

$\dot{m}_3 = 0.001 kg/sec$ $h_3 = 420$ kJ/kg

$V_1 = 20 m/sec$ $V_2 = 120 m/sec$



1) Mass balance :

Mass entering/sec = mass leaving/sec

$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3 + \dot{m}_4$$

$$\Rightarrow \quad \dot{m}_4 = 0.109 \text{ kg/sec}$$

(2) Energy balance

$$\dot{m}_1\left[h_1 + \frac{V_1^2}{2000}\right] + \dot{m}_2\left[h_2 + \frac{V_2^2}{2000}\right] + \frac{dQ}{dt} = \dot{m}_3 h_3 + \dot{m}_4 h_4 + \frac{dW}{dt}$$

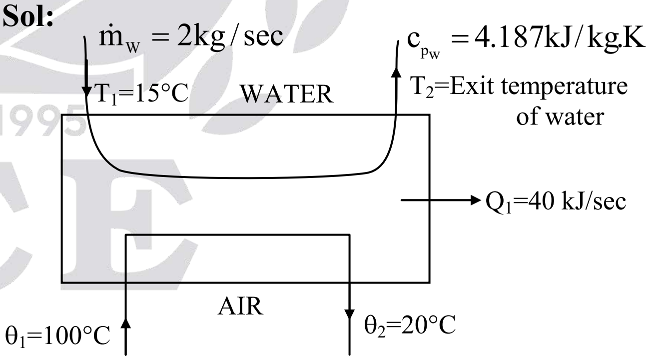
Here $\frac{dQ}{dt} = 0$

$$0.01\left[2952 + \frac{(20)^2}{2000}\right] + 0.1\left[2569 + \frac{(120)^2}{2000}\right] = (0.001\times 420) + (0.109\times h_4) + 25$$

$\Rightarrow h_4 = 2401$ kJ/kg

22. Ans: (c)

Sol:



$\dot{m}_a = 3 kg/sec$,

$c_{p_a} = 1.005 kJ/kg.K$

Heat lost to surrounding = Q_1 = 40 kW

Heat lost by air = Heat gained by water + heat lost to surroundings

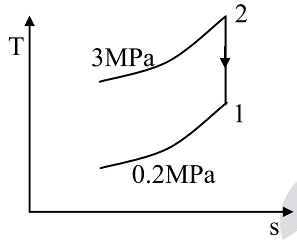
$$\dot{m}_a c_{p_a}\left(\theta_1-\theta_2\right)=\dot{m}_w c_{p_w}\left(T_2-T_1\right)+\theta_1$$

$$3\times1.005[100-20] = 2\times4.187(T_2-15)+40$$

$$T_2 = 15+\frac{241.2-40}{2\times4.187} = 39.02°C$$

23. Ans: (d)

Sol:



$T_1 = 1023$ K

Argon is a monoatomic gas, $\gamma_{Ar} = \frac{5}{3}$

Molecular weight of Argon, M = 40

$$C_{P_{Ar}} = \frac{\gamma\overline{R}}{M(\gamma-1)}$$

$$= \frac{\frac{5}{3}\times(8.314)}{40\times\left(\frac{5}{3}-1\right)} = 0.5196 \text{ kJ/kg.K}$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 1023\left(\frac{0.2}{3}\right)^{0.4}$$

$$= 346.28 \text{ K} = 73.28°C$$

$$\text{Power (kW)} = \dot{m}C_{P_{Ar}}(T_1-T_2)$$

$$= 5\times0.5196\times(1023-346.28)$$

$$= \frac{1758.1}{1000} = 1.758 \text{ MW}$$

24. Ans: (b)

Sol: 'He' is monoatomic gas, $\gamma = \frac{5}{3}$, M = 4,

$$(C_P)_{Ar} = \frac{\gamma\overline{R}}{M(\gamma-1)} = \frac{\frac{5}{3}\times(8.314)}{40\times\left(\frac{5}{3}-1\right)} = 0.5196 \text{ kJ/kgK}$$

$$(C_P)_{He} = \frac{\gamma\overline{R}}{M(\gamma-1)} = \frac{\frac{5}{3}\times(8.314)}{4\times\left(\frac{5}{3}-1\right)} = 5.196 \text{ kJ/kgK}$$

$$\gamma_{mixture} = \frac{5}{3}$$

$$C_{P\,mix} = 0.5(C_P)_{He} + 0.5(C_P)_{Ar}$$

$$= 0.5\times0.519 + 0.5\times5.19 = 2.857 \text{ kJ/kg.K}$$

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

$$= 1200\left(\frac{100}{1000}\right)^{0.4} = 477.72 \text{ K}$$

$$\text{Power (kW)} = \dot{m}_a\times C_{P\,mix}\times(T_1-T_2)$$

$$= 0.3\times2.857\times(1200-477.72)$$

$$= 619.05 \text{ kW}$$

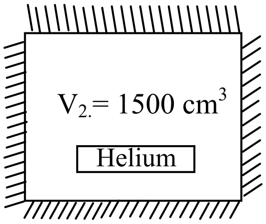
25. Ans: (a)

Sol: $V_c = V_1 = 15\text{ cm}^3$

$V_{CO} = V_2 = 1500\text{ cm}^3$

$P_1 = P_{He} = 20$ atm

$T_1 = 40°C$



⇒ dW = 0 (Free expansion)

dQ = 0 (due to insulation)

By 1st law $dU = dQ - dW$

$$\Rightarrow dU = 0 = C_V dT = 0$$

$$\Rightarrow dT = 0 \Rightarrow T = \text{constant}$$

Temperature = constant (Isothermal)

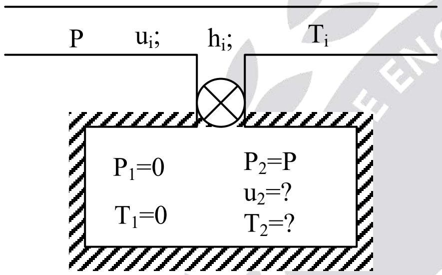
$$\Rightarrow P_1V_1 = P_2V_2$$

$$\Rightarrow 20\times 15 = P_2\times 1500$$

$$\Rightarrow P_2 = 0.2\,\text{atm}$$

26.

Sol:



Insulated $Q = 0$

Evacuated $m_1 = 0$

$$Q = m_2u_2 - m_1u_1 - (m_2 - m_1)h$$

$$m_2u_2 = m_2h_i$$

Final internal energy = $u_2 = h_i$

$$c_v\,T_2 = c_pT_i$$

Final temperature = $T_2 = \dfrac{c_p}{c_v}T_i = \gamma T_i$

27. Ans: (a)

Sol: From 1st law of thermodynamics

$$Q - W = \Delta U$$

$$30 - W = -25$$

$$\Rightarrow \quad W = 55\text{ kJ}$$

28. Ans: (d)

Sol:

- When we remove weights from the piston very slowly the pressure decreases
- Wheat heat is transferred (reversibly) the volume increases.
- Thus, the product of pressure and volume remains constant and hence it is an reversible isothermal expansion.

29. Ans: (a)

Sol: By using S.F.E.E

$$h_1 + \frac{V_1^2}{2000} + \frac{dQ}{dm} = h_2 + \frac{V_2^2}{2000} + \frac{dW}{dm}$$

$$1.005\times 500 + \frac{150^2}{2000} + 0 = 1.005\times 510 + \frac{V_2^2}{2000}$$

$\Rightarrow V_2 = 49$ m/s

Thus, the passage acts as a diffuser with velocity of exit approximately as 49 m/s.

30. Ans: (d)

Sol: From first law of thermodynamics.

$\delta Q - \delta W = dU$, which is point function.

31. Ans: (c)

Sol: Taking gas to be our system and room boundary to be our system boundary and applying first law of thermodynamics

$$Q - W = \Delta U$$

$$\Delta U = 0$$

$$T_i = T_f$$

Thus, at the end of process both enthalpy and internal energy remains constant.

32. Ans: (b)

Sol: By first law of thermodynamics

$$Q - W = \Delta U$$

$$Q - W = 30 \quad \text{-----(i)}$$

By seeing the options, option A satisfies the equation(i)

33. Ans: (a)

Sol: **Process J - K :**

$W = 0$ [$\because$ $\Delta V = 0$]

$\Delta U < 0$ [$\because$ temperature decreases]

From first law of thermodynamics

$Q - W = \Delta U$

$Q = \Delta U$

$Q < 0$

Process K - L :

W is positive

As volume increases, temperature increases

$\Rightarrow \Delta U > 0$

From first law of thermodynamics

$Q - W = \Delta U$

$Q = W + \Delta U$ = positive

Process L - M :

$\Delta V = 0$

$\Rightarrow W = 0$

Process M - L :

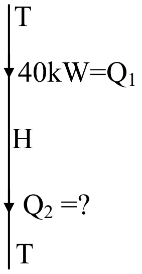
ΔV is negative $\Rightarrow W < 0$

Chapter- 4
Second Law of Thermodynamics

01. Ans: (b)

02. Ans: (c)

Sol: Given: H.E



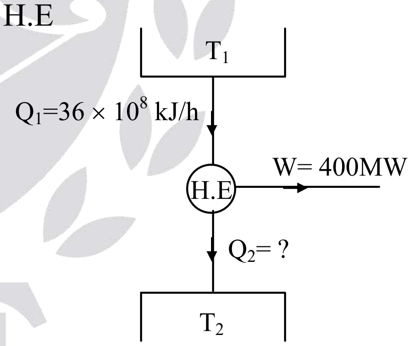
$$\eta_{H.E} = \frac{T_1 - T_2}{T_1} = \frac{Q_1 - Q_2}{Q_1}$$

$$\Rightarrow \frac{1200 - 300}{1200} = \frac{40 - Q_2}{40}$$

$$\Rightarrow Q_2 = 10\text{ kW}$$

03. Ans: (c)

Sol: *Given:* Electric power generating station means H.E



$$\eta_{H.E} = \frac{Q_1 - Q_2}{Q_1} = \frac{W}{Q_1}$$

$$\Rightarrow Q_2 = Q_1 - W$$

$$Q_2 = 36\times10^8 \frac{KJ}{h} - 400MW$$

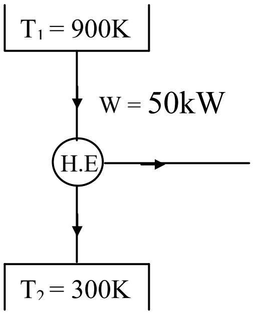
$$= \frac{36\times10^8}{1000\times3600}(MW) - 400MW$$

$$= 1000\,MW - 400MW$$

$$Q_2 = 600MW$$

04. Ans: (b)

Sol:



$$\eta = \frac{\text{Power(kW)}}{Q_S(\text{kW})} = \frac{W(\text{kW})}{\dot{m}_f\left(\frac{\text{kg}}{\text{sec}}\right) \times C.V\left(\frac{\text{kJ}}{\text{kg}}\right)}$$

$$= \frac{50}{\frac{3}{3600} \times 75000} = 0.8$$

$$\eta_C = \frac{T_1 - T_2}{T_1} = \frac{627 - 27}{900} = 0.67$$

$\eta > \eta_c \Rightarrow$ Not possible

05. Ans: (b)

Sol: $(\text{COP})_R = \frac{1 - \eta_E}{\eta_E} = \frac{1 - 0.75}{0.75} = 0.33$

06. Ans: (a)

Sol: Assertion is true

Reason is true and reason is the correct explanation.

07. Ans: (a)

Sol: PMM I → A machine which can supply mechanical work continuously without consumption of any energy. So, statement (2) is wrong.

After eliminating statement (2) only one option is available i.e., option (a).

08. Ans: (c)

Sol: ${}_1Q_2 = {}_1W_2 + {}_1U_2$

$$= \frac{P_1V_1 - P_2V_2}{n - 1} + C_V[T_2 - T_1]$$

$$= \frac{R}{n-1}[T_1 - T_2] + \frac{R}{\gamma - 1}[T_2 - T_1]$$

$$= \frac{R}{n-1}[T_1 - T_2] - \frac{R}{\gamma - 1}[T_1 - T_2]$$

$$= R[T_1 - T_2]\left[\frac{1}{n-1} - \frac{1}{\gamma - 1}\right]$$

$$= R[T_1 - T_2]\left[\frac{(\gamma - 1) - (n - 1)}{(n-1)(\gamma - 1)}\right]$$

$$= \frac{\gamma - n}{(n-1)(\gamma-1)}[R(T_1 - T_2)]$$

$$= \frac{(\gamma - n)}{(\gamma - 1)} \times \frac{R(T_1 - T_2)}{(n-1)}$$

$$= \left(\frac{\gamma - n}{(\gamma - 1)}\right)(W)$$

= Heat transfer for polytropic process

09. Ans: (d)

Sol: $\eta_1 = \frac{W}{Q_1} = \frac{8.2}{\left(\frac{1500}{60}\right)} = 0.328$

$$\eta_2 = \frac{W}{Q_2} = \frac{8.75}{\left(\frac{1600}{60}\right)} = 0.328$$

$$\eta_3 = \frac{W}{Q_3} = \frac{9.3}{\left(\frac{1700}{60}\right)} = 0.328$$

$$\eta_4 = \frac{W}{Q_4} = \frac{9.85}{\left(\frac{1800}{60}\right)} = 0.328$$

$$\eta = \frac{W}{Q_1} \Rightarrow W = \eta \times Q_1$$

$$W = 0.328 \times \frac{2000}{60}(\text{kJ/sec}) = 10.94\text{kJ/sec}$$

10. Ans: (a)

Sol: $\text{COP} = \frac{\text{NRE(kW)}}{W_C\text{(kW)}}$

$$3.1 = \frac{10}{3600} \times \frac{4.187 \times 10^3 \times (23-6)}{W_C}$$

W_C = 197 W

11. Ans: (a)

Sol: COP = 3.2 , m = 1200 kg , P = 5 kW

$$\text{COP} = \frac{\text{NRE(kW)}}{W_C\text{(kW)}}$$

$$= \frac{m_a \times C_{va} \times (\Delta T)_a}{W_C\text{(kJ)}}$$

$$\Rightarrow 3.2 = \frac{1200(0.718)(22-7)}{W_C}$$

W_C = 4169kJ

$$\Rightarrow \text{Time} = \frac{W_C\text{(kJ)}}{W_C\text{(kW)}}$$

$$= \frac{4169\text{(kJ)}}{5\text{(kJ/sec)}} = \frac{834}{60} = 13.5\,\text{min}$$

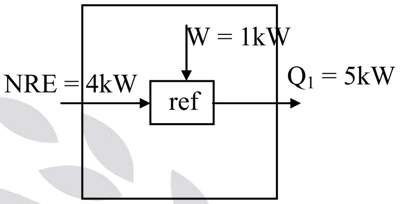
12. Ans: (d)

Sol: $\text{COP} = \frac{\text{NRE}}{W_C} = \frac{\text{NRE}}{680\text{kWhr}} = \frac{\text{NRE}}{680 \times 3600}$

$\Rightarrow$ NRE = 680 × 3600 × 1.4 = 3427 MJ/yr

13. Ans: (d)

Sol:



$Q_2 = Q_1 - W = 1\text{kW}$

Net effect = $Q_1 - Q_2$

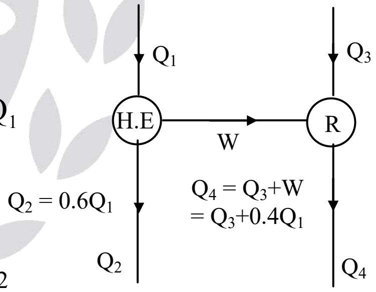
= 5 – 4 = 1 kW (heating)

14. Ans: (d)

Sol: Given

$\eta_E = 0.4$

$Q_2 + Q_4 = 3Q_1$



$$\eta_E = \frac{Q_1 - Q_2}{Q_1}$$

$\Rightarrow 0.4Q_1 = Q_1 - Q_2 = W$

$\Rightarrow Q_2 = 0.6Q_1$

$Q_2 + Q_4 = 3Q_1$

$\Rightarrow 0.6Q_1 + Q_4 = 3Q_1$

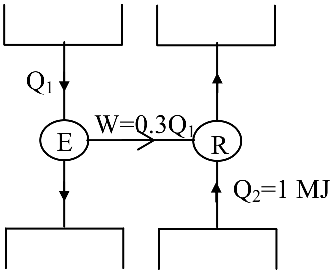
$\Rightarrow Q_4 = 2.4Q_1$

$Q_3 = Q_4 - W = 2.4Q_1 - 0.4Q_1 = 2Q_1$

$$(\text{COP})_R = \frac{Q_3}{W} = \frac{2Q_1}{0.4Q_1} = 5$$

15. Ans: 0.667 MJ

Sol:



$$\eta = \frac{W}{Q_1}$$

$$0.3 = \frac{W}{Q_1}$$

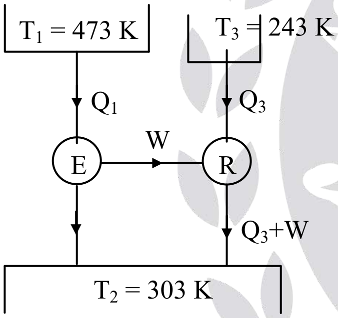
$$W = 0.3Q_1$$

$$(COP)_R = 5 = \frac{Q_2}{W}$$

$$\Rightarrow Q_1 = \frac{1\,MJ}{5\times 0.3} = 0.667\,MJ$$

16. Ans: 0.68

Sol:



$$\eta_E = \frac{T_1 - T_2}{T_1} = \frac{W}{Q_1}$$

$$\frac{473-303}{473} = \frac{W}{Q_1} \Rightarrow W = 0.359Q_1$$

$$(COP)_R = \frac{T_3}{T_2 - T_3} = \frac{Q_3}{W}$$

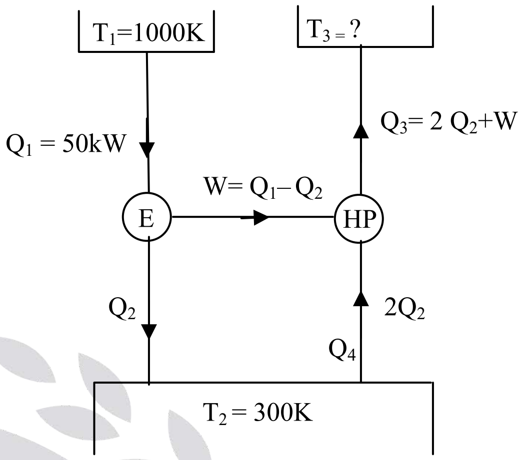
$$\frac{243}{303-243} = \frac{Q_3}{0.359Q_1}$$

$$\Rightarrow \frac{Q_3}{Q_1} = 1.45$$

$$\frac{Q_1}{Q_3} = 0.68$$

17. Ans: 86 kW

Sol:



$$\eta_E = 0.4\times\eta_{Carnot}$$

$$0.4\times\frac{T_1 - T_2}{T_1} = \frac{W}{Q_1}$$

$$0.4\times\frac{(1000-300)}{1000} = \frac{W}{Q_1}$$

$$\therefore\ W = 0.28Q_1$$

$$Q_2 = Q_1 - W$$

$$= Q_1 - 0.28Q_1 = 0.72Q_1$$

$$Q_2 = 0.72Q_1$$

$$Q_3 = 2Q_2 + W$$

$$= 1.44Q_1 + 0.28Q_1$$

$$Q_3 = 1.72Q_1$$

$$\frac{1.72Q_1}{0.28Q_1} = 0.5\left(\frac{T_3}{T_3 - 300}\right)$$

$$T_3 = 326\ K$$

If $Q_1 = 50$ kW

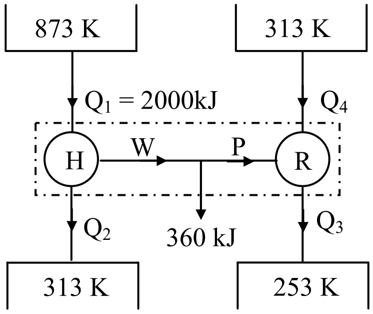
$$Q_3 = 2Q_2 + W$$

$$= 2\times 0.72Q_1 + 0.28Q_1$$

$$= 1.72\times 50 = 86\ kW$$

18.

Sol:



(a) Efficiency of heat engine

$$(\eta) = 1 - \frac{313}{873} = \frac{W}{2000}$$

W = 1283.93 kJ

P = W – 360 = 922.932 kJ

$$(COP)_R = \frac{253}{313-253} = \frac{Q_3}{P}$$

Q_3 = 3891.69 kJ

Energy balance :

$Q_1 + Q_3 = Q_4 + Q_2 + 360$

$Q_2 + Q_4 = Q_1 + Q_3 - 360$

$= 2000 + 1283.93 - 360$

= 5531.69 kJ

(b) $\eta = 0.4 \times (\eta)_{max}$

$$= 0.4 \times \left(1 - \frac{313}{873}\right)$$

$$0.2565 = \frac{W}{2000} \Rightarrow W = 513.17 \text{ kJ}$$

P = W – 360 = 153.17 kJ

$(COP) = 0.4 \times (COP)_{max}$

$$= 0.4 \times \left(\frac{253}{313-253}\right) = \frac{Q_3}{P}$$

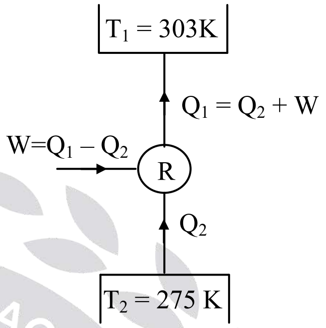
$Q_3 = 1.68 \times 153.17 = 258.34$ kJ

$Q_2 + Q_4 = 2000 + 258.34 - 360$

= 1848.34 kJ

19. Ans: 15.168

Sol:



$Q_2 = 20 \times 420 = 8400$ kJ/day

$$(COP)_{actual} = 0.15(COP)_{max}$$

$$= 0.15 \times \frac{T_2}{T_1 - T_2} = \frac{Q_2}{W}$$

$$\Rightarrow 0.15 \times \frac{275}{303-275} = \frac{8400}{W}$$

$\Rightarrow$ W = 5701 kJ

$$1 \text{ kW hr} = 3600 \text{ kJ} = \frac{5701}{3600} = 1.58 \text{ kW hr / day}$$

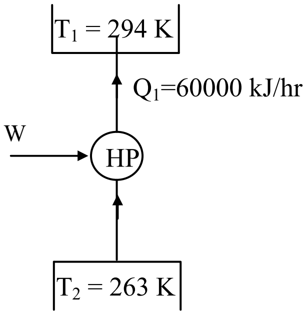
Electricity bill

= No. of unit/day × No. of days × cost/kWhr

$= 1.58 \times 30 \times 0.32 = 15.168$/-

20. Ans: 6326.5 kJ/hr

Sol:



$$(COP)_{H.P} = \frac{Q_1}{W} = \frac{T_1}{T_1 - T_2}$$

$$\Rightarrow \frac{60,000}{W} = \frac{294}{294 - 263}$$

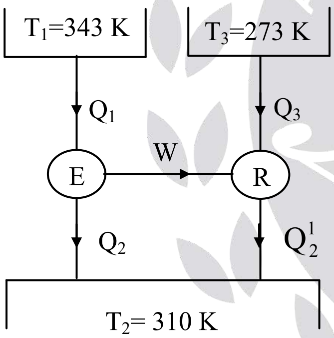
$$W = 6326.5 \text{ kJ/hr}$$

$$\frac{W_{HP}}{W_{EH}} = \frac{6326.5}{60,000} = 0.1054$$

With heat pump, initial investment is high but running cost is less. With electrical heater the initial investment is less but running cost is high.

21.

Sol: (a)



$$\dot{m} = \frac{1000}{3600} = 0.277 \text{ kg/s}$$

$$Q_3 = \dot{m} \times \text{latent heat} = 0.277 \times 333.43$$
$$= 92.36 \text{ kW}$$

$$\eta_E = \frac{W}{Q_1} = \frac{T_1 - T_2}{T_1}$$

$$\because W = \left(\frac{343 - 310}{343}\right) Q_1$$

$$\therefore W = 0.096\, Q_1 \text{ -----(1)}$$

$$(COP)_R = \frac{Q_3}{W} = \frac{T_3}{T_2 - T_3}$$

$$\frac{333.43 \times 10^3}{W} = \frac{273}{310 - 273}$$

$$\therefore W = 45190.147 \text{ kJ}$$

$$\dot{W} = \frac{45190.147}{3600} = 12.55 \text{ kW}$$

From (1)

$Q_1 = 130.759$ kW

$Q_2 = Q_1 - W$

$Q_2 = 118.20$ kW

$$Q_4 = Q_3 + W = \frac{333.43 \times 10^3}{3600} + W$$
$$= 92.62 + 12.55 = 105.17 \text{ kW}$$

$$\frac{Q_3}{Q_1} = \frac{92.62}{130.75} = 0.708$$

Total heat rejected to lower temperature reservoir = $Q_2 + Q_{ref}$

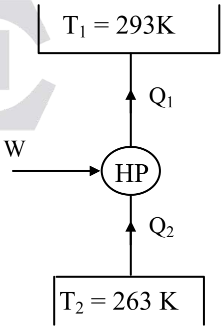
$$= 118.2 + 105.17 = 223.37 \text{ kW}$$

$$\frac{\text{Energy of freezing water}}{\text{Energy of heat engine}} = \frac{92.62}{130.759} = 0.706$$

22. Ans: 2 kW, 50°C

Sol:

(a)



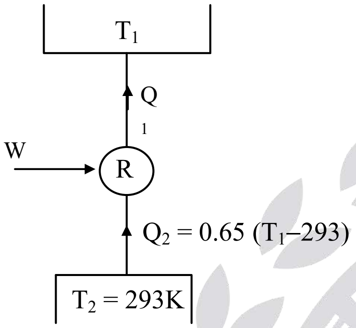
$$Q_1 = 0.65(T_1 - T_2) = 0.65(293 - 263)$$
$$= 19.5 \text{ kW}$$

$$(\text{COP})_{\text{HP}} = \frac{T_1}{T_1 - T_2} = \frac{Q_1}{W}$$

$$= \frac{293}{293 - 263} = \frac{19.5}{W}$$

$$\dot{W} = 1.99 \approx 2 \text{ kW}$$

(b)



$$Q_2 = 0.65(T_1 - T_2) = 0.65(T_1 - 293)$$

$$(\text{COP})_R = \frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$$

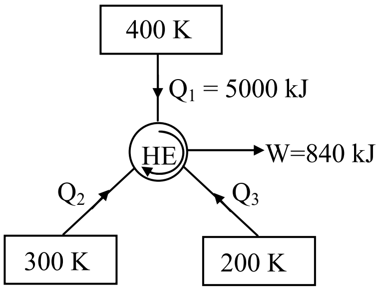
$$\Rightarrow \frac{0.65(T_1 - 293)}{1.99} = \frac{293}{T_1 - 293}$$

$$T_1 = 323 \text{ K} = 50°\text{C}$$

Up to 50°C outside temperature, the temperature of room can be maintained 20^0 C.

23.

Sol: Initial diagram:



For reversible heat engine,

$$\oint \frac{dQ}{T} = 0$$

$$\frac{5000}{400} + \frac{Q_2}{300} + \frac{Q_3}{200} = 0$$

$$\Rightarrow \frac{Q_2}{300} + \frac{Q_3}{200} = -\frac{50}{4}$$

$$\frac{2Q_2 + 3Q_3}{600} = -\frac{50}{4}$$

$$2Q_2 + 3Q_3 = -\frac{50}{4} \times 600$$

$2Q_2 + 3Q_3 = -7500$ ------(i)

Energy balance

$5000 + Q_2 + Q_3 = W$

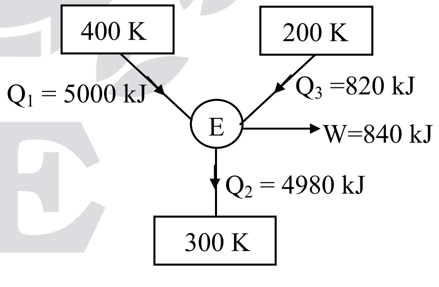
$Q_2 + Q_3 = 840 - 5000$

$Q_2 + Q_3 = -4160$ ------- (ii)

from eq.(i)

$Q_2 = -4980$ kJ , $Q_3 = 820$ kJ

Final diagram

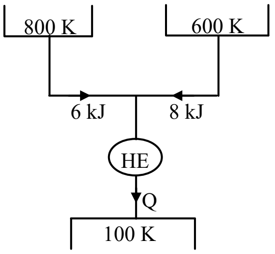


24. Ans: (d)

Sol:

For reversible engine,

$s_{gen} = 0$



dS(reservoir at 800 K) + dS(reservoir at 600K) + dS(reservoir at 100K) + dS(working fluid) = 0

$$-\frac{6}{800}-\frac{8}{600}+\frac{Q}{100}+0=0$$

$$\Rightarrow Q = 2.083 \text{ kJ}$$

$$W_{net} = 8 + 6 - 2.083 = 11.917$$

$$\eta_{th} = \frac{11.917}{8+6} = 85\%$$

25.

Sol: Efficiency of Carnot heat engine :

$$\eta = 1-\frac{T_L}{T_H}$$

$$\frac{d\eta}{dT_L} = 0-\frac{1}{T_H} = -\frac{1}{T_H} \text{ ---- (1)}$$

$$\frac{d\eta}{dT_H} = 0-\left(-\frac{T_L}{T_H^{\ 2}}\right) = \frac{T_L}{T_H^{\ 2}} \text{ ----- (2)}$$

$$\frac{d\eta}{dT_L} = -\frac{1\times T_H}{T_H\times T_H} = -\frac{T_H}{T_H^{\ 2}} \text{ ------(3)}$$

$$\frac{d\eta}{dT_H} = \frac{T_L}{T_H^{\ 2}} \text{ -----(4)}$$

∵ $T_H > T_L$, therefore, efficiency of heat engine will increase faster rate with lowering minimum temperature as compared to increasing the maximum temperature.

26. Ans: (a)

Sol: In defining the Kelvin temperature scale, the triple point of water is taken as the standard reference point.

27. Ans: (a)

Sol: Work done by a system is always less than heat supplied or else it violates second law.

28. Ans: (a)

Sol: $$\oint\frac{\delta Q}{T} = \frac{100}{1000}+\frac{50}{500}-\frac{60}{300} = 0$$

So, it is a reversible cycle.

Also, Total heat supplied = 100 + 50 = 150 kJ

Total heat rejected = 60 kJ

Work output = 150 - 60 = 90 kJ

Hence, the device is reversible heat engine.

29. Ans: (b)

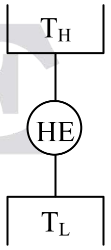
Sol: $\oint\frac{\delta Q}{T} = 0$ for reversible cycle.

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

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

30. Ans: (d)

Sol:



Let the heat engine is operating between high temperature source (T_H) and low temperature sink (T_L)

$$\eta_{max} = \frac{T_H - T_L}{T_H}$$

$$\Rightarrow \eta_{max} = 1 - \frac{T_L}{T_H} \text{ ------- (i)}$$

$$(COP)_{max} = \frac{T_L}{T_H - T_L} = \frac{\frac{T_L}{T_H}}{1 - \frac{T_L}{T_H}}$$

using eq.(i)

$$(COP)_{max} = \frac{1 - \eta_{max}}{\eta_{max}}$$

$$(COP)_{max} = \frac{1}{\eta_{max}} - 1$$

31. Ans: (a)

Sol: $COP = \frac{\text{Refrigeration heat}}{\text{Work input}}$

According to Clausius statement of second law of thermodynamics.

Clausius' Statement :

- It is impossible to construct a cyclically working device which produces no effect other than the transfer of energy as heat from a low temperature body to a high temperature body.
- Energy transfer as heat from a high temperature body to a low temperature body is a spontaneous process.
- The Clausius' statement of the second law of thermodynamics tells that this spontaneous process cannot proceed in the reverse direction.

So, if work input is zero.

$\Rightarrow COP = \infty$.

which is not possible.

Chapter- 5
Entropy

01. Ans: (c)

Sol: $C_p = \left(\frac{dh}{dT}\right)_p$

$Tds = dh - vdp$

As $P = c$, $dp = 0$

So, $Tds = dh$

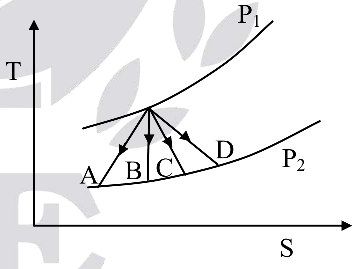
$$C_p = \left(\frac{Tds}{dT}\right)_p$$

$$C_p = T.\left(\frac{\partial s}{\partial T}\right)_p$$

02. Ans: (b)

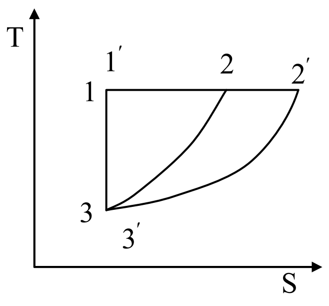
03. Ans: (a)

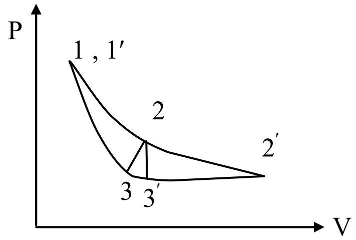
Sol:



04. Ans: (b)

Sol:





1–2, 1′–2′ → constant temperature

2 – 3 → constant volume

$2^1 - 3^1$ → constant pressure

3– 1, $3^1 - 1^1$ → Entropy constant

05. Ans: (c)

06. Ans: (c)

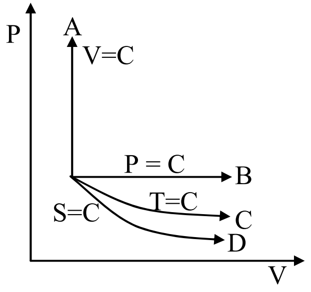
Sol: i) Temperature measurement is due to Zeroth law of thermodynamics.

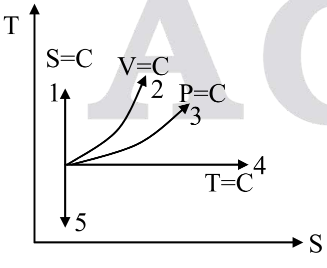
ii) Entropy is due to Second law of thermodynamics

iii) Internal Energy is due to first law of thermodynamics

07. Ans: (b)

Sol:





Slope of constant volume curve is more than that of constant pressure curve in T-S diagram. Similarly slope of adiabatic curve is more than that of isothermal curve in P-V diagram.

08. Ans: (c)

Sol: $(dS)_{system} = 0$

$(dS)_{surr} = 0$

$(dS)_{univ} = 0$

09. Ans: (c)

Sol: Tds = du + Pdv.

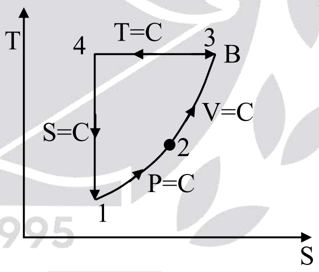
This process is valid for any process, reversible (or) irreversible, undergone by a closed system.

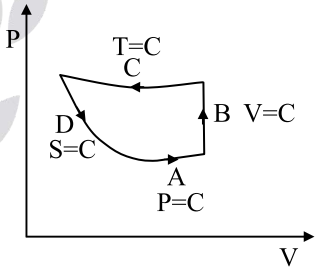
10. Ans: (c)

Sol: Area on T-S graph gives amount of heat supplied.

11. Ans: (c)

Sol:





12. Ans: (b)

Sol: Clausius inequality $\oint \frac{dQ}{T} \le 0$

$$\Rightarrow \oint \frac{dQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2} = \frac{600}{1000} - \frac{450}{300}$$

$$\oint \frac{dQ}{T} = -0.9\,\text{kJ/K} < 0$$

⇒ Irreversible cycle

$$\Rightarrow \eta = \frac{Q_1 - Q_2}{Q_1} = \frac{600 - 450}{600} = 0.25 = 25\%$$

13. Ans: (d)

Sol: Find the cycle of thermodynamic.

$T_1 = 285 + 273 = 558$ K

$T_2 = 5 + 273 = 278$ K

$$\oint \frac{dQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2}$$

$$= \frac{1000}{558} - \frac{492}{278} = 1.79 - 1.76$$

$$\oint \frac{dQ}{T} = 0.022 > 0$$

∴ It is an impossible cycle.

14. Ans: (c)

Sol: Motor power = 5 kW.

T = 20°C = 293 K

Due to friction, there is heat between brake and shoe and heat is transferred to surroundings.

$$(dS)_{sur} = \frac{Q}{T} = \frac{\text{Power} \times \text{Time}}{T} = \frac{5 \times 3600}{293}$$

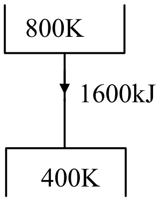
dS = 61.4 kJ/K

15. Ans: (c)

Sol: $S_{gen} = (S_2 - S_1) - \int \frac{dQ}{T}$

$$= \frac{Q}{T_2} - \frac{Q}{T_1} = \left(\frac{1600}{400} - \frac{1600}{800}\right)$$

$$= 2 \text{ kJ/K}$$



16. Ans: (b)

Sol: $m_s = 100$kg

$$(dS)_{system} = m(s_2 - s_1) = 100(0.1) = 10 \frac{kJ}{K}$$

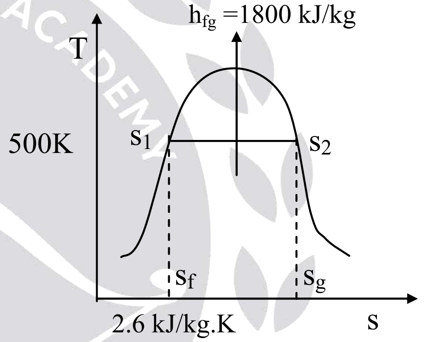
$$(dS)_{surrounding} = (S_2 - S_1) = -5 \frac{kJ}{K}$$

$(dS)_{universe} = (dS)_{sys} - (dS)_{surr} = 10 - 5$

$(dS)_{uni.} = 5$ kJ/K > 0 ⇒ irreversible process

17. Ans: (b)

Sol:



$$s_g - s_f = \frac{h_{fg}}{T_{sat}}$$

$$s_g - 2.6 = \frac{1800}{500}$$

$s_g = 6.2$ kJ/kg.K

18. Ans: (b)

Sol: T = 273 + 30 = 303 K

$d\dot{Q} = -55 \times 10^6$ W

As heat is removed at constant temperature,

$$dS = \frac{d\dot{Q}}{T} = \frac{-55}{303} = -0.18 \text{ MW/K}$$

19. Ans: (c)

20. Ans: (c)

Sol: $(dS)_{\text{Isothermal}} = mR\,ln\left(\dfrac{V_2}{V_1}\right)$

$$= mR\,ln\left(\frac{P_1}{P_2}\right)$$

21. Ans: (d)

22. Ans: (d)

Sol: $Q = \alpha T + \beta T^2$

$$dS = \int\frac{\delta Q}{T} = \int\frac{\delta\left(\alpha T + \beta T^2\right)}{T}$$

$$= \alpha\ln\frac{T_2}{T_1} + 2\beta\left(T_2 - T_1\right)$$

23. Ans: (a)

Sol: $S_{gen} = (S_2 - S_1) - \int\dfrac{dQ}{T} = \dfrac{Q}{T_2} - \dfrac{Q}{T_1}$

$$= \frac{600}{278} - \frac{600}{293} = 0.11\,W/K$$

24. Ans: (a)

Sol: $T_1 = 273+15 = 288$ K ,

$T_2 = 288.2$ K

$$(S_2 - S_1) - \int\frac{dQ}{T} = S_{gen}$$

Here $dQ = 0$

$$\therefore\ S_2 - S1 = dS = mC_p\ln\left(\frac{T_2}{T_1}\right)$$

$$= 8\times 4200\times\ln\left(\frac{288.2}{288}\right) = 23\text{ W/K}$$

25. Ans: 6.68 kJ/K

Sol: H_2O $T_1 = 0°C = 273K$

↓

H_2O $T_2 = 164.97°C = 437.97K$

↓

Steam $T_3 = 164.97°C = 437.97K$

$$(dS)_1 = \int_{T_1}^{T_2}\frac{dQ}{T} = mC_{pw}\,ln\left(\frac{T_2}{T_1}\right)$$

$$= 1\times(4.187)\,ln\left(\frac{437.97}{273}\right)$$

$(dS)_1 = 1.97$ kJ/kg.K

$$(dS)_2 = \frac{Q}{T} = \frac{m\times L.H}{T} = \frac{1\times(2066.3)}{437.97}$$

$\Rightarrow (dS)_2 = 4.71$ kJ/kg.K

$(dS)_{\text{Universe}} = (dS)_1 + (dS)_2$

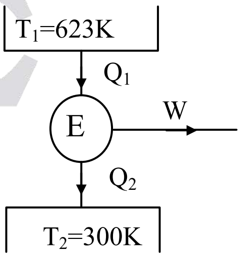
$\Rightarrow (dS)_{\text{Universe}} = 6.68$ kJ/kg.K

26.

Sol:

(a): Given Carnot cycle

$ds = 1.44$ kJ/kgK



$$\eta_{\text{Carnot}} = \frac{T_1 - T_2}{T_1} = \frac{623 - 300}{623} = 0.518$$

$$\eta = \frac{W}{Q_1}$$

$W = Q_1 \times \eta = T_1 dS \times \eta$

$W = 623 \times 1.44 \times 0.518 = 464.7$ kJ

(b) Given

Power = 20 kW

$$\text{Power (kW)} = \dot{m}_s\left(\frac{\text{kg}}{\text{sec}}\right)\times W\left(\frac{\text{kJ}}{\text{kg}}\right)$$

$$\Rightarrow \dot{m}_s = 0.043 \text{kg/sec}$$

$$= 0.043 \times 3600 \text{ kg/hr}$$

$$\dot{m}_s = 154.8 \text{ kg/hr}$$

27. Ans: –16.01 J/K

Sol: Water $T_1 = 20°C = 293$ K

↓

Water $T_2 = 0°C = 273$ K

↓

Ice $T_2 = 0°C = 273K$

↓

Ice $T_3 = -10^oC = 263K$

$m = 10$ g, $C_P = 4.2$ J/gK

$$dS_1 = mC_P \ell n\frac{T_2}{T_1} = 10 \times 4.2 \times \ell n\left(\frac{273}{293}\right)$$

$$= -2.96 \text{ J/K}$$

$$dS_2 = \frac{-m_i L_{ice}}{T_2} = \frac{-10 \times 335}{273} = -12.27 \text{ J/K}$$

$$dS_3 = mC_{P_{ice}} \ell n\frac{T_3}{T_2} = 10 \times 2.1 \ell n\left(\frac{263}{273}\right)$$

$$= -0.78 \text{J}$$

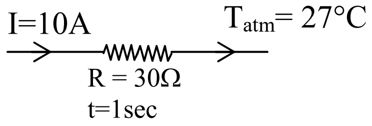
$(dS)_{system} = dS_1 + dS_2 + dS_3$

$= -2.96 - 12.27 - 0.78$

$= -16.01$ J/K

28.

Sol:



$m_w = 10$ gm, $C_{pw} = 0.9 \times 10^3$

With work transfer there is no entropy change so entropy change of resistor is equal to zero.

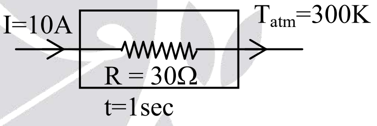
$(dS)_{Resister} = 0$

$$(ds)_{surrounding} = \frac{Q}{T_{atm}} = \frac{I^2Rt}{T_{atm}} = \frac{10^2 \times 30 \times 1}{300} = 10 \text{J/K}$$

$(dS)_{universe} = (dS)_{resistor} + (dS)_{surrounding}$

$= 10$ J/K

When it is insulated:



Heat gained by wire = work done = I^2Rt

$m_w \times C_{pw} \times (T_2 - T_{atm}) = I^2Rt$

$10 \times 10^{-3}(0.9 \times 10^3)(T_2 - 300) = 10^2 \times 30 \times 1$

$T_2 = 633$ K

$$(dS)_{wire} = \frac{dQ}{T} = m_{wire} \times C_{Pwire} \times \ell n\frac{T_2}{T_1}$$

$$= \left(10 \times 10^{-3}\right) \times \left(0.9 \times 10^3\right) \times \ell n\left(\frac{633}{300}\right)$$

$$= 6.720 \text{J/K}$$

$(dS)_{surrounding} = 0$

$(dS)_{universe} = 6.720 + 0 = 6.72$ J/K

29.

Sol: Case - 1:

Copper block

$m = 600$ g, $C_P = 150$ J/k, $T_1 = 100°C$

Lake Temperature = $8°C = T_2$

Find: $(dS)_{Universe}$

If C_P is in J/K means mass is included and it is known as heat capacity.)

$$(dS)_{\text{Cu block}} = mC_P \ln\frac{T_2}{T_1} = 150 \ln\left(\frac{281}{373}\right)$$

$$\Rightarrow (dS)_{\text{Cu block}} = -42.48 \text{ J/K}$$

$$(dS)_{H_2O} = \frac{mC_P(T_2 - T_1)}{T_2}$$

$$= 150\frac{(373-281)}{281} = 49.11 \text{ J/K}$$

$$\Rightarrow (dS)_{\text{Universe}} = (dS)_{\text{Cu block}} + (dS)_{H_20}$$

$$= -42.48 + 49.11$$

$$(dS)_{\text{Universe}} = 6.626 \text{ J/K}$$

Case – 2 :

Same block, $T_2 = 8°C = 281$ K

As it is dropped from certain height, so there is change in potential energy. Work is done by the block

Change in entropy due to work interaction = 0

$$\Rightarrow (dS)_{\text{block}} = 0$$

$$(dS)_{H_2O} = \frac{Q}{T_2} = \frac{mgh}{T_2} = \frac{0.6\times 9.81\times 100}{281}$$

$$= 2.09 \text{ J/K}$$

$$\Rightarrow (dS)_{\text{Uni}} = 2.09 \text{ J/K}$$

Case - 3

Now by joining two blocks find $(dS)_{uni}$

$T_1 = 100°C$, $T_2 = 0°C$

Heat lost by block -1 = Heat gained by block -2

$$C(T_1 - T_f) = C(T_f - T_2)$$

$$T_f = \frac{T_1 + T_2}{2} = 50^\circ C$$

$$\Rightarrow (dS)_{\text{block 1}} = C \ln\left(\frac{T_f}{T_1}\right)$$

$$= 150\ell n\left(\frac{50+273}{373}\right) = -21.58 \text{ J/K}$$

$$\Rightarrow (dS)_{\text{Block 2}} = C\,\ell n\left(\frac{T_f}{T_2}\right)$$

$$= 150 \ln\left(\frac{50+273}{273}\right) = +25.22 \text{ J/K}$$

$$\Rightarrow (dS)_{\text{Uni}} = -21.58 + 25.22$$

$$\Rightarrow (dS)_{\text{Uni}} = 3.64 \text{ J/K}$$

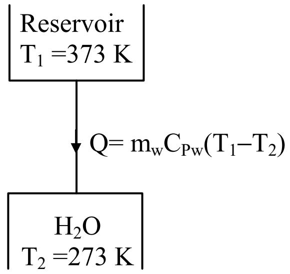
$$(dS)_{\text{Universe}} > 0$$

So it is an irreversible process.

30.

Sol:

(a)



m = 1 kg water

$$(dS)_{H_2O} = \int_{T_2}^{T_1}\frac{dQ}{T} = \int_{T_2}^{T_1} m_w C_{Pw}\frac{dT}{T}$$

$$= mC_P\, ln\left(\frac{T_1}{T_2}\right)$$

$$(dS)_{Reservoir} = -\frac{Q}{T_1} = \frac{-m_w C_{Pw}\times(T_1-T_2)}{T_1}$$

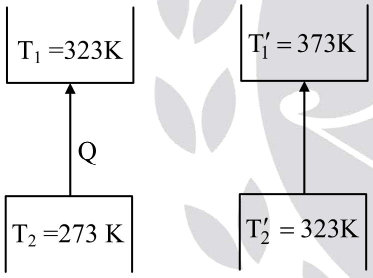
$$(dS)_{Universe} = (dS)_{H_2O} + (dS)_{surr}$$

$$= m_wC_{Pw}\left[\ln\left(\frac{T_1}{T_2}\right)-\left(\frac{T_1-T_2}{T_1}\right)\right]$$

$$= 1(4.187)\times\left[\ln\left(\frac{373}{273}\right)-\left(\frac{373-273}{373}\right)\right]$$

$(dS)_{universe} = 0.183$ kJ/kg.K

(b)



By providing one more reservoir at 323 K

1st stage, $(dS)_{universe,1st}$

$$\Rightarrow (ds)_{universe1} = m_w C_{Pw}\left[\ln\frac{T_1}{T_2}-\left(\frac{T_1-T_2}{T_1}\right)\right]$$

$$(dS)_{univ,1st\,stage} = 1\times 4.18\left[\ln\left(\frac{323}{273}\right)-\left(\frac{323-273}{323}\right)\right]$$

$$= 0.056 \text{ kJ/kg.K}$$

$$\Rightarrow (ds)_{univ,2nd\,stage}$$

$$= 1\times 4187\left[\ln\left(\frac{373}{323}\right)-\left(\frac{373-323}{373}\right)\right]$$

$$= 0.041 \text{ kJ/kg.K}$$

$$(dS)_{universe} = (dS)_{univ,\,2nd\,stage} + (dS)_{univ,\,1st\,stage}$$

$$= 0.041 + 0.056 = 0.097 \text{ kJ/kgK}$$

$(dS)_{uni} = 0.097$ kJ/kg.K

(c) From above problem, when compared to singe stage heating in a two stage heating entropy is halved. As the no. of stages of heating goes on increasing, entropy change of universe are decreasing. This way we can heat the fluid with almost no change in entropy of universe.

31.

Sol: Given $C_P = a + bT$.

$$Q = \int_1^2 dQ = \int_{T_1}^{T_2} mC_p dT = \int_{T_1}^{T_2} m(a+bT)\,dT$$

$$= \int_{T_1}^{T_2} ma\,dT + mbT\,dT$$

$$Q = a\{T_2 - T_1\} + \frac{b}{2}\left[T_2^2 - T_1^2\right]$$

$$\int_{S_1}^{S_2} dS = \int_{T_1}^{T_2} mC_P\frac{dT}{T}$$

$$\Rightarrow dS = (S_2 - S_1) = \int_{T_1}^{T_2} m(a+bT)\frac{dT}{T}$$

$$\Rightarrow (S_2\text{-}S_1) = am\, ln\left[\frac{T_2}{T_1}\right] + bm\left[T_2 - T_1\right]$$

$C_P = a + bT$

$25.2\times10^3 = a + b\times500$ ……….. (1)

$30.1\times10^3 = a + b\times1200$ ……….. (2)

By solving

$a = 21700$, $b = 7$

$$Q = 21{,}700(1200-500)+\frac{7}{2}(1200^2-500^2)$$

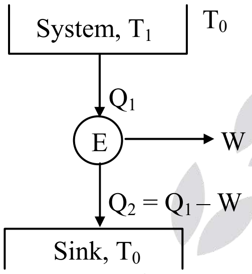
$$= 19355\ \text{J}$$

$$dS = 21700\left(\frac{1200}{500}\right)+7(1200-500)$$

$$= 2897.6716\ \text{J/K}$$

32.

Sol:



For maximum work done condition the engine has to be reversible and for the condition of reversibility entropy change of universe is zero.

$$(dS)_{\text{system}} = \int_{T_1}^{T_0}\frac{dQ}{T}$$

$$\int_{T_1}^{T_0}\frac{C_v dT}{T} = C_v \ell n\left(\frac{T_0}{T_1}\right)$$

$$(dS)_{\text{surrounding}} = \frac{Q_1 - W}{T_0} = \frac{C_v(T_1 - T_0) - W}{T_0}$$

$$(dS)_{\text{univ}} = (dS)_{\text{system}} + (dS)_{\text{sink}} = 0$$

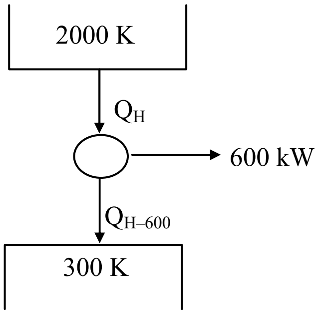
$$C_v \ell n\left(\frac{T_0}{T_1}\right) + \frac{C_v(T_1 - T_0) - W}{T_0} = 0$$

$$W = C_v(T_1 - T_0) + T_0\, C_v\ \ell n\left(\frac{T_0}{T_1}\right)$$

$$= C_v\left((T_1 - T_0) + T_0\ \ell n\left(\frac{T_0}{T_1}\right)\right)$$

33. Ans: (c)

Sol:



$$W_{\text{output}} = \left(\frac{T_H - T_L}{T_H}\right)\times Q_H$$

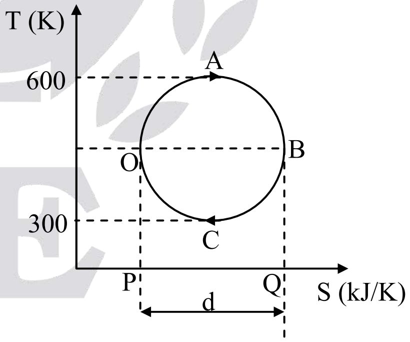
$$\left(\frac{2000-300}{2000}\right)\times Q_H = 600$$

$Q_H = 705.89$

Entropy change of working fluid during heat addition process $= \dfrac{705.89}{2000} = 0.353$ kW/K

34. Ans: (b)

Sol:



$$W_{\text{net}} = \text{Area of cycle OABC}$$

$$= \frac{\pi}{4}\times 300\times d = 75\pi d$$

Heat supplied,

Q_s = Area of semicircle OAB + Area of rectangle OBQP

$$= \frac{\frac{\pi}{4}\times 300\times d}{2} + 450\times d$$

$$= (37.5\,\pi + 450)d$$

$$\eta_{th} = \frac{W_{net}}{Q_s}$$

$$= \frac{75\pi d}{(37.5\pi + 450)d} = 41.5\%$$

35.

Sol: Net work, W_{net} = Area of ΔABC

$$= \frac{1}{2}\times(400)\times(5-1)$$

$$= 800 \text{ kJ}$$

Heat supplied,

Q_s = Area of rectangle enclosed by line BC

$= 800 \times (5 - 1) = 3200$ kJ

$$\eta = \frac{W_{net}}{Q_s} = \frac{800}{3200} = 25\%$$

36. Ans: (d)

Sol: For irreversible process entropy change never be equal to zero as it always increases.

Entropy once created can not be destroyed.

37. Ans: (a)

Sol: For finding the final properties during an adiabatic mixing process, use the 1st & 2nd law of thermodynamics.

38. Ans: (d)

Sol:

- In an irreversible adiabatic process entropy change, $\Delta S > 0$
- In an reversible adiabatic process entropy change, $\Delta S = 0$

39. Ans: (c)

Sol:

- A mixture of ideal gas also behaves as an ideal gas.
- The enthalpy of an ideal gas is a function of temperature only.
- Entropy of an ideal gas is a function of temperature, pressure and volume.

40. Ans: (d)

Sol: Irreversibility occurs due to

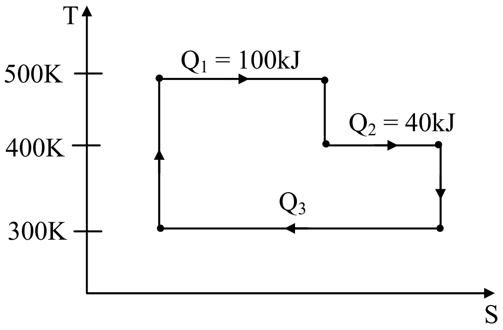
- heat transfer across a finite temperature difference.
- frictional effects.
- free expansion.
- mixing of two dissimilar pure substance.

41. Ans: (d)

Sol: For any process to occur the entropy change of system can be positive, negative or zero but entropy change of universe must be positive (for irreversible process) or zero (reversible process).

42. Ans: (d)

Sol:



It is a reversible engine

$$\oint \frac{\partial Q}{T} = 0$$

$$\frac{Q_1}{T_1} + \frac{Q_2}{T_2} + \frac{Q_3}{T_3} = 0$$

Q_1 and Q_2 heat supplied positive sign

Q_3 = Heat rejected negative sign

$$\frac{100}{500} + \frac{40}{400} - \frac{Q_3}{300} = 0$$

$$0.2 + 0.1 - \frac{Q_3}{300} = 0$$

$$\frac{Q_3}{300} = 0.3$$

Q_3 = 90 kJ

Workdone = 100 + 40 – 90 = 50

43. Ans: (b)

Sol: Constant volume process has greater slope on T-s diagram than constant pressure process. Hence, correct option is option(b).

Chapter- 6
Availability

01. Ans: (b)

Sol: Whenever certain quantity of heat transferred from a system available energy decrease.

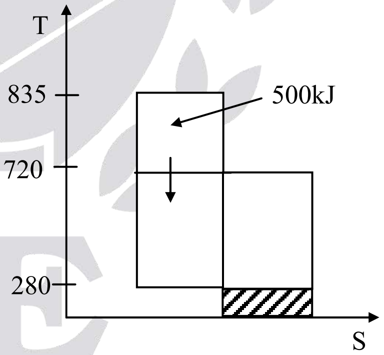
02. Ans: (d)

Sol: Irreversibility is zero in the case of Reversible process.

03. Ans: (b)

04. Ans: 26.77 kJ

Sol:



Loss in A.E = $T_0 S_{gen}$

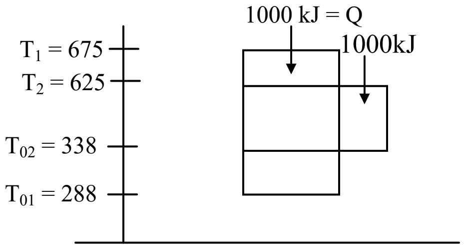
$$= 280\left(\frac{Q}{T_2} - \frac{Q}{T_1}\right)$$

$$= 280\left[\frac{500}{720} - \frac{500}{835}\right]$$

Loss in A.E = 26.77 kJ

05. Ans: 11.2 kJ, 5.25 kJ

Sol:

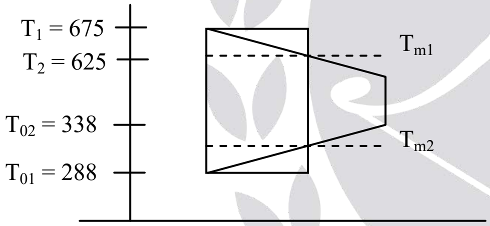


$$AE = Q\left(1-\frac{T_0}{T}\right) = 100\left(1-\frac{288}{675}\right) = 57.33\text{ kJ}$$

$$AE_I = Q\left(1-\frac{T_{02}}{T_2}\right) = 100\left(1-\frac{338}{625}\right) = 45.92\text{ kJ}$$

Loss of available energy = 57.33 – 45.92

= 11.41 kJ



$$T_{m1} = \frac{T_1+T_2}{2} = \frac{675+625}{2} = 650\text{K}$$

$$T_{m2} = \frac{T_{01}+T_{02}}{2} = \frac{288+338}{2} = 313\text{ K}$$

$$AE_{\Pi} = Q\left(1-\frac{T_{m2}}{T_{m1}}\right)$$

$$= 100\left(1-\frac{333}{650}\right) = 51.84\text{ kJ}$$

Loss in AE = $AE_I - AE_{II}$

= 57.33 – 51.84 = 5.49kJ

06. Ans: 5743 kJ

Sol: Given Ideal gas , n = 1 k mol

$P_1 = 1$ MPa, $P_2 = 0.1$ MPa ,

$T_1 = 300$ K $T_f = T_1$

T = constant ⇒ isothermal process

For isothermal process,

$$s_2 - s_1 = mR\, ln\left(\frac{p_1}{p_2}\right)$$

$$= n\overline{R}\ \ln\left(\frac{p_1}{p_2}\right)$$

For Non-flow process

$W_{max} = (u_1 - u_2) - T_0(s_1 - s_2)$

$W_{max} = -T_0(s_1 - s_2)$ (∵ T = constant)

$$W_{max} = T_0\, n\overline{R}\ln\left(\frac{p_1}{p_2}\right) = -T_0(s_1 - s_2)$$

$$= T_0(s_2 - s_1)$$

$$= 300\ (1)\ (8.314)\ ln\left(\frac{1}{0.1}\right)$$

$\therefore W_{max} = 5743$ kJ

07. Ans: 222.7 kJ

Sol: $P_1 = 1.4$ MPa =1400 kPa

$T_1 = 175 + 273 = 448$ K; $V = 1\ m^3$

$$m = \frac{P_1V}{RT_1} = \frac{1400\times1}{0.287\times448} = 10.88\text{ kg}$$

$T_2 = 25°C = 298$ K

$T_0 = 25°C = 298$ K

V = constant

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{1400}{448} = \frac{P_2}{298}$$

$P_2 = 931.25$ kPa

Non flow process:

Availability at state I

$AE_1 = (u_1 - u_0) - T_0\,(s_1 - s_0)$

$$= C_v(T_1 - T_0) - T_0\left(C_p \ln\frac{T_1}{T_0} - R\ln\frac{P_1}{P_0}\right)$$

$$= 0.718\,(448 - 298) - 298\left(1.005\ln\frac{448}{298} - 0.287\ln\frac{1400}{100}\right)$$

= 211.3 kJ/kg

Availability at state 2

$AE_{II} = (u_2 - u_0) - T_0\,(s_2 - s_0)$

$$= C_v(T_2 - T_0) - T_0\left(c_p \ln\frac{T_2}{T_0} - R\ln\frac{P_2}{P_0}\right)$$

$$= 0.718\,(298 - 298) - 298\left(1.005\ln\frac{298}{298} - 0.287\ln\frac{931.15}{100}\right)$$

= 190.82 kJ

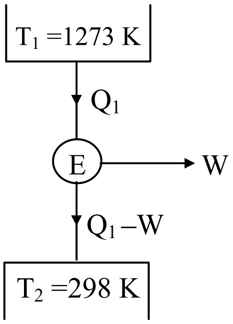
Loss in AE = 20.47 kJ/kg

Total Irreversibility

I = m × loss in AE = 222.7 kJ

08.

Sol:



Maximum work obtained if reaction products could be directly used in heat engine.

Maximum work $(A.E_1) = Q - T_0 dS$

$$A.E_1 = mC_p\left[(T_1 - T_2) - T_0\ln\left(\frac{T_1}{T_2}\right)\right]$$

$$= \frac{5000}{3600}\left[(1273 - 298) - 298\ln\left(\frac{1273}{298}\right)\right]$$

$A.E_1 = 753.18$ kW

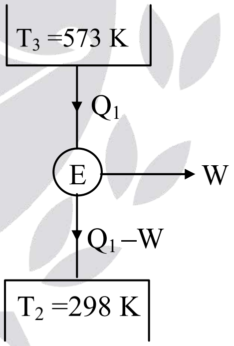
Now as per given

Heat gained by air = Heat lost by gas

$$\dot{m}_a Cp_a(\Delta T)_a = \dot{m}_g C_{P_g}(\Delta T)_g$$

$$\dot{m}_a \times 1(300 - 25) = \frac{5000}{3600}(1)(1273 - 298)$$

$\dot{m}_a = 4.92$ kg /sec



Now it is done by diffusion process

$$AE_2 = \dot{m}_a C_{P_a}\left[(T_3 - T_2) - T_0\ln\left(\frac{T_3}{T_2}\right)\right]$$

$$= 4.92(1)[(573-298)-(298\,ln\left(\frac{573}{298}\right))]$$

$AE_2 = 394.7$ kW

Loss in A.E = $AE_1 - AE_2$ = 753.18 – 394.7

Loss in A.E = 358.48 kW

09. Ans: 25.83 kJ

Sol: Loss in available Energy in pipe

$$(\Delta E)_{lost} = mRT_0 \left(\frac{\Delta p}{p_1}\right)$$

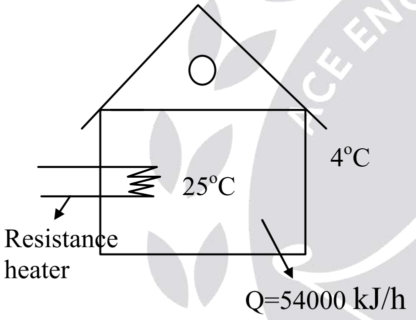
$$= 3 \times 0.287 \times 300 \left(\frac{0.1 p_1}{p_1}\right)$$

$$= 3 \times 0.287 \times 300\ (0.1)$$

$$(\Delta E)_{Lost} = 25.83 \text{ kJ}$$

10. Ans: 7.04 %

Sol:



Second law efficiency,

$$\eta_{II} = \frac{W_{rev}}{W_{act}} \text{ or } \frac{(Cop)_{act}}{(Cop)_{rev}}$$

$$(Cop)_{rev} = \frac{T_H}{T_H - T_L} = \frac{298}{21}$$

$(Cop)_{act} = 14.19$

$$(Cop)_{act} = \frac{\text{Heating effect}}{\text{Work input}}$$

For resistance heater, the entire work in heating is lost as heat

$$\therefore (COP)_{act} = \frac{54000}{54000}$$

$(COP)_{act} = 1$

$$\eta_{II} = \frac{1}{14.19}$$

$\eta_{II} = 7.04$ %

11. Ans: 0.962

Sol: $$\eta_{II} = \frac{\eta_{actual}}{\eta_{reversible}}$$

$$\eta_{actual} = \frac{(1000-20)-(300+20)}{(1000-20)} = 0.6734$$

$$\eta_{reversible} = \frac{(1000-300)}{1000} = 0.7$$

$$\eta_{II} = \frac{0.6734}{0.7} = 0.962$$

12. Ans: (a)

Sol: $\phi = U + P_oV - T_oS$

13. Ans: (a)

Sol: Availability is defined as the maximum theoretical work obtainable which

- is never conserved
- is either positive or zero.

14. Ans: (d)

Sol: Heat transfer from a high temperature body to a low temperature body results in increase of unavailable energy, Entropy change takes place and it increases. But energy is conserved.

Chapter- 7
Properties of Pure Substance

01. Ans: (d)

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

02. Ans: (b)

03.

Sol: Given Non flow process & adiabatic system

$m = 1$ kg at $P_1 = 700$ kPa, $T_1 = 300°C$,

$v_1 = 0.371$ m^3/kg , $h_1 = 3059$ kJ/kg

Due to Paddle work

$T_2 = 400°C$, $v_2 = 0.44$m^3/kg,

$P_2 = 700$ kPa, $h_2 = 3269$ kJ/kg

At $P_1 = 700$ kPa from pressure Table

$T_{sat} = 164.95^0C$

$\Rightarrow T_1 > T_{sat}$ so it is in super heated state.

$$u_1 = h_1 - P_1 v_1 = 3059 - (700 \times 0.371)$$
$$= 2799.3 \text{ kJ/kg}$$
$$u_2 = h_2 - P_2 v_2 = 3269 - 700 \times 0.44$$
$$= 2961 \text{ kJ/kg}$$

It is a non flow process

$P = C$

$${}_1W_2 = P(v_2 - v_1) = 700(0.44 - 0.371)$$
$$W_s = {}_1W_2 = 48.3 \text{kJ/kg}$$

For non flow process

$$u_1 + Q = u_2 + W$$
$$W = W_S + W_P = Q + (u_1 - u_2)$$
$$W_p = Q + (u_1 - u_2) - W_S$$
$$= 0 + (2800 - 2961) - 48.3$$
$$= -209.3 \text{ kJ/kg}$$

04.

Sol: Given Non flow constant volume process

$P_1 = 1.5$MPa $x_1 = 0.9$

$V = 0.03$m^3 $P_2 = 500$kPa

$$v_1 = x_1 v_g = 0.9 \times 0.132 = 0.1188 \text{m}^3\text{/kg}$$
$$h_1 = h_f + x_1 h_{fg} = 845 + 0.9 \times 1947 = 2597.3 \text{kJ/kg}$$
$$u_1 = h_1 - P_1 v_1 = 2597.3 - (1500 \times 0.1188)$$

$u_1 = 2419.1$ kJ/kg , $V = 0.03$ m^3

(i) Mass of wet steam $= \frac{V}{v_1} = \frac{0.03}{0.1188} = 0.253$ kg

$V = C$ (Rigid vessel)

$v_1 = v_2 = x_2 v_{g2}$

$0.1188 = x_2(0.375)$

(ii) $x_2 = 0.317$

$$h_2 = h_{f_2} + x h_{fg_2} = 640 + 0.317 \times 2109$$

$h_2 = 1308.55$ kJ/kg

$$u_2 = h_2 - P_2 v_2 = 1308.55 - 500 \times 0.1188$$
$$= 1249.15 \text{ kJ/kg}$$

(iii) $\Delta H = m(h_2 - h_1) = -1288.75 \times 0.253$

$= -326.054$ kJ

$\Delta U = m(u_2 - u_1) = 0.253(1249.15 - 2419.1)$

$\Delta U = -295.997$ kJ

For constant volume $dV = 0, {}_1W_2 = 0$

(iv) ${}_1Q_2 = m(u_2 - u_1) = \Delta U$

$\Delta U = -295.997$ kJ

05. Ans: (d)

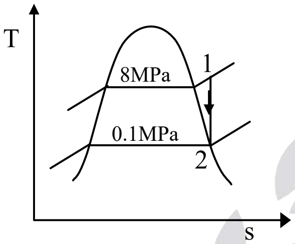
Sol: At P = 1 atm, $h_{fg} = 2256.5$ kJ/kg

$$\text{Power} = \frac{\dot{m}_w \times h_{fg}}{\text{time}} = \frac{0.5 \times 2256.5}{18 \times 60}$$

$$= 1.05 \text{ kW}$$

06. Ans: (a)

Sol:



$\dot{m} = 3$ kg/sec

By applying steady flow energy equation to turbine

$$\dot{m} h_1 + \dot{Q} = \dot{m}_2 h_2 + \dot{W}$$

$\dot{Q} = 0$ (For adiabatic)

$$\dot{W} = \dot{m}(h_1 - h_2)$$

At 8 MPa & 500^0 C, $h_1 = 3399.5$ kJ/kg

At 0.1 MPa, $h_2 = h_{g_2} = 2675$ kJ/kg

$$\dot{W} = 3\times(3399.5 - 2675) = 2173.5 \text{ kW}$$

07. Ans: (a)

Sol: At 200 kPa, $v_f = 0.001061$ m^3/kg,

$v_g = 0.8857$ m^3/kg

$v = 300$ m^3, P = 200 kPa

$m_f + m_v = m$

$v_f + v_v = v$

$(0.25\times m\times 0.001061)+(0.75\times m\times 0.8857) = 300$

$m = 451.44$ kg

08. Ans: (d)

Sol: At P = 10 MPa, $T_{sat} = 311°C$

T = 500°C

$T > T_{sat} \rightarrow$ superheated state

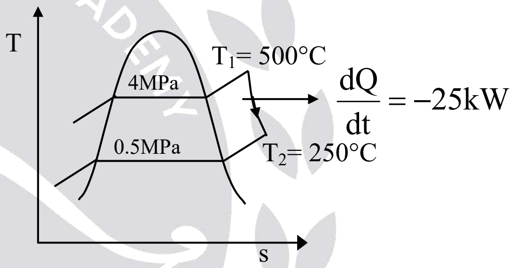
At 10 MPa and 500°C

$v = 0.032811$ m^3/kg

$$\text{Mass} = \frac{V}{v} = \frac{3}{0.032811} = 91.43 \text{ kg}$$

09. Ans: (a)

Sol:



From tables

$h_1 = 3446$ kJ/kg

$h_2 = 2961$ kJ/kg

$\dot{m} = 1350$ kg/hr

Applying first law

$$\dot{m}h_1 + \frac{dQ}{dt} = \dot{m}h_2 + \frac{dW}{dt}$$

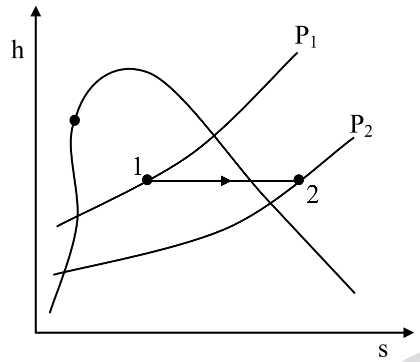
$$\frac{dW}{dt} = \dot{m}(h_1 - h_2) + \frac{dQ}{dt}$$

$$= \frac{1350}{3600}[3446 - 2961] - 25$$

$$= 156.875 \text{ kW}$$

10.

Sol:



$P_1 = 3$ MPa = 30 bar,

$h_{f_1} = 1008.41$ kJ/kg, $h_{fg} = 1795.7$ kJ/kg

$P_2 = 0.1$ MPa, $T_2 = 120^0C$

From steam tables

At $P_2 = 0.1$ MPa,

$T_{sat} = 99.61°C$ and $T_2 = 100°C$,

$T_2 > T_{sat}$ (superheated)

h = 2676.2 kJ/kg

At $P_2 = 0.1$ MPa and $T_2 = 150°C$

h = 2776.4 kJ/kg

At $P_2 = 0.1$ MPa and $T_2 = 120°C$,

$h_2 = ?$

$150°C \rightarrow 2776.6$ kJ/kg

$100°C \rightarrow 2675.8$ kJ/kg

$dT = 50°C \rightarrow dh = 100.8$ kJ/kg

$dT' = 30°C \rightarrow x = 60.48$ kJ/kg

$\therefore h_2 = 2716.12$ kJ/kg $= h_1$

(For throttling process)

$\therefore$ If dryness fraction is x

$\therefore\ h_1 = h_{f_1} + xh_{fg_1}$

$1008.41 + x(1795.7) = 2716.12$

$\therefore\ x = 0.95$

11.

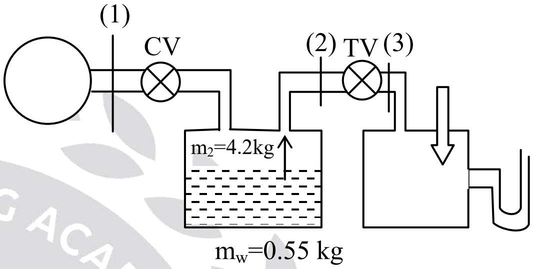
Sol: Given separating & throttling calorimeter

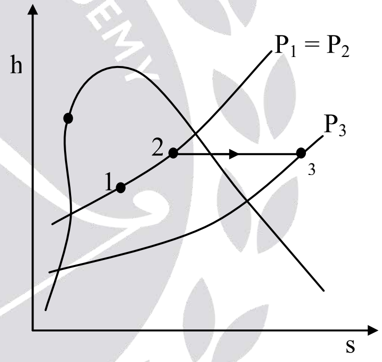
$P_1 = 15$ bar $= P_2$, $m_1 = 0.55$ kg

$T_1 = 198.3°C = T_2$, $m_2 = 4.2$ kg

$P_3 = 1$ bar, $T_3 = 120°C$

$h_3 = 2716.3$ kJ/kg





$$(\text{Dryness fraction})_{\text{separator}},\ x_1 = \frac{m_2}{m_1 + m_2}$$

$$= \frac{4.2}{4.2 + 0.55} = 0.88$$

For throttling

$h_2 = h_3$

$h_{f_2} + x_2 h_{fg_2} = h_3$

$844.55 + x_2(1946.4) = 2716.2$

$x_2 = 0.9616$

Mass of vapour $= m_v = x_2 m_2 = 0.96 \times 4.2$

$= 4.032$ kg

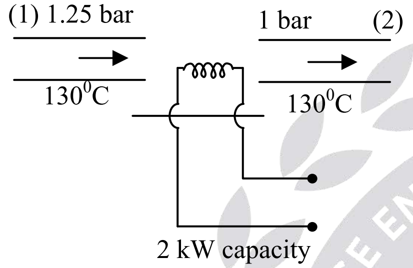
(Dryness fraction)$_{\text{Boiler}}$

$$= x = \frac{m_v}{m_{total}} = 0.8488$$

As quality of steam at boiler is < 90% so only throttling calorimeter can not be used.

12.

Sol:



From steam tables

At 1 bar, 150°C, $h = 2675.8$ kJ/kg

At 1 bar, 100°C, $h = 2776.6$ kJ/kg

A 1 bar, 130°C, $h_2 = ?$

$P_2 = 100$ kPa, $T_{sat} = 99.61$°C

$T_2 > T_{sat}$ (Superheated state)

100°C → 2776.6 kJ/kg

130°C → $h_3 = ?$

150°C → 2675.8 kJ/kg

$dT = 50$°C → 100.8 kJ/kg

$dT' = 20$°C → x

$$x = \frac{100.8 \times 20}{50} = 40.32\text{kJ / kg}$$

$$h_2 = 2776.6 - 40.32$$

$$h_2 = 2736.28 \text{ kJ/kg}$$

$$\dot{m} = \frac{3.4\,kg}{5\,\text{min}} = \frac{3.4}{300} = 0.0113\,\text{kg/s}$$

By steady flow energy equation

$$\dot{m}h_1 + \dot{Q} = \dot{m}h_2 - \dot{W}$$

$$h_1 = h_2 - \frac{\dot{Q}}{m}$$

$$= 2736.28 - \frac{2}{0.0113} = 2559.28\,\text{kJ/kg}$$

$$h_1 = h_{f_1} + xh_{fg_1} = 444.36 + x \times 2240.6$$

$$x = 0.9439$$

13. Ans: (a)

Sol: v_1 = specific volume = $\frac{0.025}{10} = 0.0025\frac{m^3}{kg.}$

$v_1 < v_c$ (critical volume) after heating at constant volume it goes into liquid region hence level of liquid in the vessel rises.

14. Ans: (d)

Sol: Superheated steam enthalpy is less than dry saturated steam at a given temperature. Constant temperature lines are dropping lines in Moiler diagram.

15. Ans: (d)

Sol: At triple point for pure substance degrees of freedom are zero.

For water at triple point, P = 3, C =1

$$F + P = C + 2$$

$$\therefore\ F = 1 + 2 - 3 = 0$$

F = Degrees of freedom,

P = Number of phases

C = Number of components .

16. Ans: (a)

Sol: Pressure and temperature are not enough to define a wet vapour.

17. Ans: (c)

Sol: All the three phases coexist at triple point not critical point.

18. Ans: (d)

Sol: Mixture of gaseous air and liquid air is not a pure substance.

19. Ans: (c)

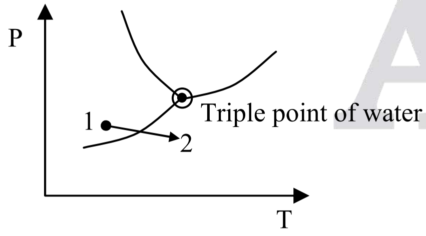
Sol: A substance expands on freezing only if the slope of the fusion line on P-T chart is negative.

20. Ans: (b)

Sol: In vapor dome Isothermal line and constant pressure line are same.

21. Ans: (c)

Sol:



Process 1 – 2 ⇒ sublimation (solid to vapour).

Chapter- 8
Air Cycles

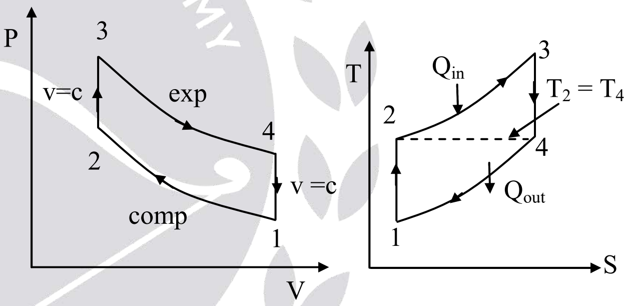
01. Ans: (a)

Sol: 1–2 → Isothermal

3−1 → Adiabatic process

02. Ans: (d)

Sol: For Maximum specific output in case of Otto cycle, the temperature of working fluid at the end of compression and expansion should be equal



03. Ans: (c)

04. Ans: (c)

Sol: Otto cycle

05. Ans: (c)

Sol: $\eta_{Carnot} > \eta_{Stirling}$

(If 100% effectiveness of heat exchanger is given then Carnot efficiency equals to Stirling efficiency).

06. Ans: (d)

Sol: For equal r_k & heat rejected

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

07. Ans: (a) and (d)

Sol: For same maximum pressure in Otto & Diesel cycle

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

And $r_{k\,Diesel} > r_{k\,Otto}$

08. Ans: (c)

09.

Sol: $Q_s = 1500$ kJ/kg, $P_1 = 100$ kPa,

$T_1 = 27°C = 300$ K

$$r_k = 8 = \frac{V_1}{V_2} = \frac{8}{1} = \frac{V_4}{V_3}$$

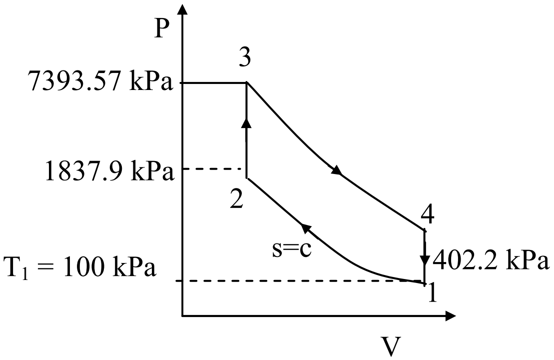
$(C_v)_{air} = 0.72$ kJ/kgK

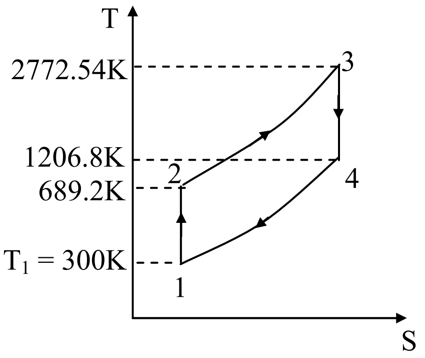
For process 1- 2

$$P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

$$\Rightarrow \quad P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma} = 100 \times 8^{1.4}$$

$$= 1837.9 \text{ kPa}$$





$$T_2 = T_1\left(\frac{P_1}{P_2}\right)^{\frac{1-\gamma}{\gamma}} = 300\times\left(\frac{100}{1837.9}\right)^{\frac{1-1.4}{1.4}}$$

$$= 689.2\text{K}$$

$$Q_S = C_v\,(T_3 - T_2) = 1500 \text{ kJ/kg}$$

$$\Rightarrow 0.72 \times (T_3 - 689.21) = 1500$$

$$T_3 = 2772.54 \text{ K}$$

Process 2 – 3

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

$$\Rightarrow \quad P_3 = P_2 \times \frac{T_3}{T_2} = 1837.9 \times \frac{2772.54}{689.2}$$

$$P_3 = 7393.57 \text{ kPa}$$

Process 3 – 4

$$\Rightarrow P_3\ V_3^{\gamma} = P_4\ V_4^{\gamma}$$

$$\Rightarrow P_4 = P_3 \times \left(\frac{V_3}{V_4}\right)^{\gamma} = 7393.47\times\left(\frac{1}{8}\right)^{1.4}$$

$$\Rightarrow P_4 = 402.2\text{kPa}$$

$$T_3\ V_3^{\gamma-1} = T_4\ V_4^{\gamma-1}$$

$$\Rightarrow T_4 = 1206.8\text{K}$$

$$\eta_{Otto} = 1 - \frac{1}{(r_k)^{\gamma-1}} = 1 - \frac{1}{8^{1.4-1}}$$

$$\Rightarrow \eta_{Otto} = 0.56 = \frac{W}{1500} \Rightarrow W = 847 \text{ kJ/kg}$$

10. Ans: (c)

Sol: $V_c = 0.2\ V_s$

r_k = Compression ratio

$$= \frac{V_s + V_C}{V_C} = \frac{V_s + 0.2V_s}{0.2V} = 6$$

$$\eta_{th} = 1 - \left(\frac{1}{r_k}\right)^{\gamma-1} = 1 - \left(\frac{1}{6}\right)^{1.4-1}$$

$$= 0.5116 \quad \text{or } 51.16\%$$

11.

Sol: $V_C = 2000$ CC

$$V_s = \frac{\pi}{4}D^2L = \frac{\pi}{4}\times 15^2 \times 45 = 7948.125CC$$

Compression Ratio

$$r_k = \frac{V_s + V_C}{V_C} = \frac{7948.125 + 2000}{2000}$$

$$= 4.974$$

$$\eta_{th} = 1 - \left(\frac{1}{r_k}\right)^{\gamma-1}$$

$$= 1 - \left(\frac{1}{4.974}\right)^{1.4-1} = 0.4376 \quad \text{or } 47.36\ \%$$

12. Ans: (a)

Sol: $r_k = \frac{V_1}{V_2} = \frac{2.5}{0.25} = 10$,

$T_1 = 20°C = 293K$

$He \to \gamma = \frac{5}{3}$

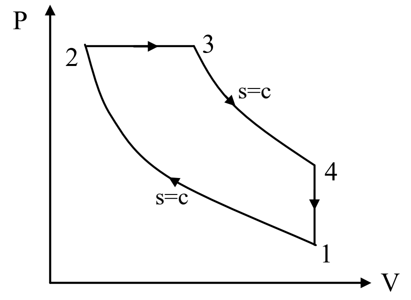
$$T_2 = 293 \times 10^{\frac{5}{3}-1} = 1370.46\,K$$

$T_3 - T_2 = 700°C$

$T_3 = 700 + 1097.46 = 1797.46°C$

13.

Sol:



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

$$V_3 - V_2 = \frac{6.5}{100}(V_1 - V_2) = \frac{6.5}{100}(15V_2 - V_2)$$

$$= 0.91\ V_2$$

$$V_3 = 0.91V_2 + V_2 = 1.91V_2$$

$$r_c = \frac{V_3}{V_2} = 1.91$$

$$\eta_{th} = 1 - \frac{1}{\gamma \cdot r_k{}^{\gamma-1}} . \frac{r_c^{\gamma} - 1}{r_c - 1}$$

$$= 1 - \frac{1}{1.4 \times 15^{0.4}} . \left(\frac{1.91^{1.4} - 1}{1.91 - 1}\right) = 60.8\%$$

14. Ans: (c)

Sol: $V_1 = 3L$,

$V_2 = 0.15L$

Compression ratio

$$r_k = \frac{V_1}{V_2} = \frac{3}{0.15} = 20$$

$$r_c = \frac{V_3}{V_2} = \frac{0.30}{0.15} = 2$$

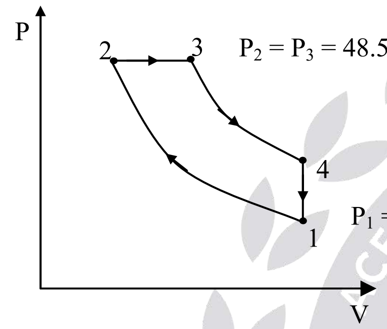
$$\eta_{\text{Diesel}} = 1 - \frac{1}{\gamma}\cdot\frac{1}{r_k^{\gamma-1}}\cdot\frac{r_c^{\gamma}-1}{r_c-1}$$

$$= 1 - \frac{1}{1.4}\times\frac{1}{(20)^{1.4-1}}\times\frac{2^{1.4}-1}{(2-1)} = 0.6467$$

$$= 64.67\%$$

15. Ans: 63.44 %

Sol:



$$\text{Compression ratio} = r_k = \frac{V_1}{V_2}$$

$$\text{Expansion ratio} = r_E = \frac{V_4}{V_3} = \frac{V_1}{V_3} = 10$$

$$P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

$$r_k = \frac{V_1}{V_2} = \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}} = \left(\frac{48.5}{1}\right)^{\frac{1}{1.4}} = 16$$

$$\text{Fuel cut off ratio} = r_C = \frac{V_3}{V_2} = \frac{r_k}{r_E} = \frac{16}{10} = 1.6$$

$$\eta_{th} = 1 - \frac{1}{\gamma . r_k^{\gamma-1}}\left[\frac{r_C^{\gamma}-1}{r_C-1}\right]$$

$$= 1 - \frac{1}{(1.4)16^{(1.4-1)}}\left[\frac{1.6^{1.4}-1}{1.6-1}\right]$$

$$= 1 - \frac{1}{1.4\times 3.0314}\left[\frac{1.9309-1}{1.6-1}\right] = 0.6344$$

16. Ans: 235.5 kPa

Sol: $D_1 = 500 - 200 = 300$ kPa

$D_2 = 0.03 - 0.01 = 0.02$ m^3

$${}_1W_2 = \frac{\pi}{4}\times D_1 \times D_2$$

$${}_1V_2 = V_2 - V_1 = 0.03 - 0.01 = 0.02 \text{ m}^3$$

$$\text{mep} = \frac{\text{work done}}{\text{swept volume}} = \frac{{}_1W_2}{{}_1V_2} = \frac{\frac{\pi}{4}\times D_1\times D_2}{(V_1 - V_2)}$$

$$= \frac{\frac{\pi}{4}\times 300\times 0.02}{0.02}$$

$$= 75\,\pi = 75 \times 3.14 = 235.5 \text{ kPa}$$

17. Ans: (b)

Sol: Swept volume = $V_s = 0.03$ m^3

$$(\text{work})_{\text{net}} = \frac{\text{work(kW)}}{\text{N(rps)}} = \frac{1000}{\frac{2000}{60}} = 30\,\text{kJ}$$

$$\text{mep} = \frac{W_{\text{net}}(\text{kJ})}{V_s(\text{m}^3)} = \frac{30}{0.03} = 1000\text{kPa} = 1\text{MPa}$$

18. Ans: (b)

Sol:

$$V_1 = \frac{1}{\rho_1} = \frac{1}{1.2} = 0.833\,\text{m}^3/\text{kg}$$

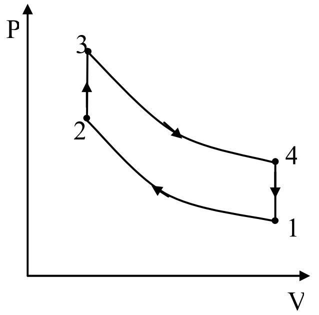
$$r_k = \frac{V_1}{V_2} = \frac{2.2}{0.26} = 8.46$$

$$V_2 = \frac{0.834}{8.46} = 0.098\text{m}^3/\text{kg}$$

$$\text{mep} = \frac{W_{\text{net}}}{V_1 - V_2} = \frac{440}{0.833 - 0.098} = 598.8 \text{ kPa}$$

19.

Sol: $\eta = 0.54 = 1 - \left(\frac{1}{r_k}\right)^{\gamma-1} = 1 - \left(\frac{1}{r_k}\right)^{0.4}$



$$\left(\frac{1}{r_k}\right)^{0.4} = 0.46$$

$$r_k = \frac{1}{(0.46)^{2.5}} = 6.97$$

$P_1 = 1$ bar

$T_1 = 273 + 15 = 288$ K

$P_3 = 75$ bar

$P_2 = P_1 r_k^{\gamma} = 1 \times (6.97)^{1.4} = 15.154$ bar

$T_2 = T_1\, r_k^{\gamma-1} = 288(6.97)^{1.4-1} = 626.16$ K

$$T_3 = T_2 \times \frac{P_3}{P_2} = 626.16 \times \frac{75}{15.154} = 3099\text{K}$$

Heat supplied $= C_v \times (T_3 - T_2)$

$= 0.718(3099 - 626.16)$

$Q_s = 1775.5$ kJ/kg

Work done $= \eta_{th} \times Q_s$

$W = 0.54 \times 1775.5 = 958.77$ kJ/kg

Heat rejected $= Q_S - W = 1775.5 - 958.77$

$= 816.73$ kJ/kg

$$v_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 288}{100} = 0.82656\frac{m^3}{kg}$$

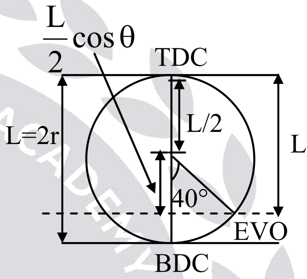
$$v_2 = \frac{RT_2}{P_2} = \frac{0.287 \times 626.16}{1515.4} = 0.1186\frac{m^3}{kg}$$

$$\text{mep} = \frac{W_{net}\left(\frac{kJ}{kg}\right)}{(v_1 - v_2)\left(\frac{m^3}{kg}\right)} = \frac{958.77}{0.82656 - 0.1186}$$

$$= \frac{958.77}{0.70796} = 1354.27\,\text{kPa}$$

20.

Sol:



L = 14 cm ,   θ = 40° ,   D = 10 cm

Effective stroke length

$$L_e = L/2 + \frac{L}{2}\cos\theta$$

$= 7 + 7\cos 40 = 12.36$ cm

Effective stroke volume

$$(V_s)_{eff} = \frac{\pi}{4} D^2 L_e = \frac{\pi}{4} \times 10^2 \times 12.36 = 970.75\text{cm}^3$$

$V_C = 157\ \text{cm}^3$

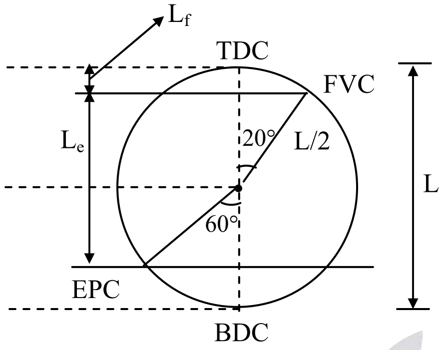
$$(r_k)_{effective} = \frac{(V_s)_{eff} + V_C}{V_C} = \frac{970.75 + 157}{157} = 7.18$$

$$\eta_{th} = 1 - \left(\frac{1}{r_k}\right)^{\gamma-1} = 1 - \left(\frac{1}{7.18}\right)^{0.4}$$

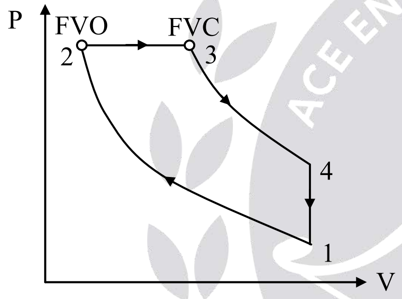
$= 0.54$ or 54%

21.

Sol:



D = 10 cm , L = 14 cm



$$L_e = \frac{L}{2} + \frac{L}{2}\cos\theta$$

$$= 7 + 7\cos 60° = 10.5 \text{ cm}$$

$$L_f = \frac{L}{2} - \frac{L}{2}\cos\theta_1$$

$$= 7 - 7\cos 20^0 = 0.42 \text{ cm}$$

$$(V_s)_{eff} = \frac{\pi}{4}D^2L_e = \frac{\pi}{4}\times 10^2 \times 10.5$$

$$= 824.6 \text{cm}^3$$

$$V_C = 40.2 \text{ cm}^3$$

$$(r_k)_{effective} = \frac{(V_s)_{eff} + V_C}{V_C} = 21.51$$

Volume corresponding to fuel cutoff

$$V_3 - V_2 = \frac{\pi}{4}D^2L_f = \frac{\pi}{4}\times 10^2 \times 0.42$$

$$= 32.98 \text{ cc}$$

$$V_3 - 40.2 = 32.98.$$

$$V_3 = 73.18$$

$$r_c = \frac{V_3}{V_2} = \frac{73.18}{40.2} = 1.82$$

$$\eta_{th} = 1 - \frac{1}{\gamma r_k^{\gamma-1}}.\frac{r_c^{\gamma} - 1}{r_c - 1}$$

$$= 1 - \frac{1}{1.4 \times (21.51)^{0.4}} \times \frac{1.82^{1.4} - 1}{1.82 - 1}$$

$$= 66.5\ \%$$

22.

Sol: $IP = \dfrac{p_{mi}\,L\,A\,N\,n}{120,000}$

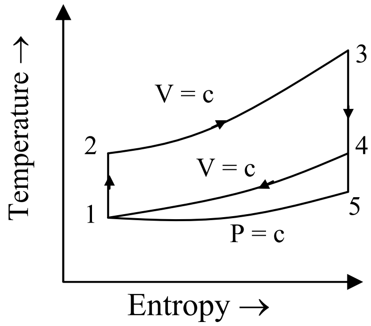
$$= \frac{\frac{A_d}{L_d} \times k \times L \times A \times N \times n}{120000}$$

$$4 = \frac{\frac{A_d}{0.1L} \times 25 \times 10^6 \times L \times \frac{\pi}{4}(0.15)^2 \times 216 \times 1}{120000}$$

$$A_d = 503 \text{ mm}^2$$

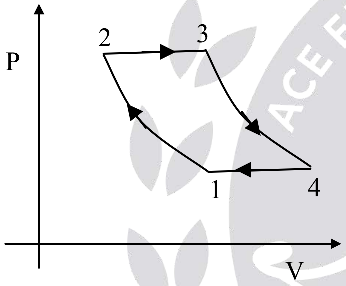
23. **Ans: (c)**

Sol: In Atkinson cycle, heat is supplied at constant volume and rejected at constant pressure.



24. Ans: (c)

Sol: $r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4}$



$$(\eta_{Th})_{Brayton} = 1 - \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}} \quad \ldots\ldots (1)$$

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

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

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

$$(r_k)^{\gamma} = r_p$$

$$(\eta_{Th})_{B\,raton} = 1 - \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}} = 1 - \left(\frac{1}{r_k^{\gamma}}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= 1 - \left(\frac{1}{r_k}\right)^{\gamma-1} = (\eta_{Th})_{OTTO}$$

25. Ans:

Sol: The Ericsson cycle does not find practical application in piston engines but is approached by a gas turbine employing a large number of stages with heat exchangers, insulators and reheaters.

Their ideal efficiencies were, therefore, the same as the Carnot efficiency when working between the same temperature limits.

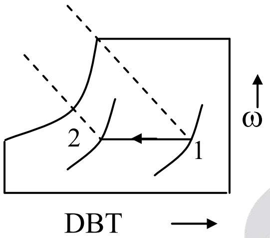
Correct answer is option (b).

26. Ans: (d)

Chapter- 9
Psychrometry

01. Ans: (b)

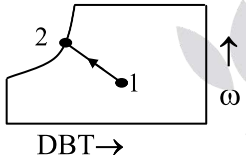
Sol:



During sensible cooling of air
DBT decreases, WBT decreases, h decreases and ω = constant,
DPT = constant, R.H increases

02. Ans: (c)

Sol:



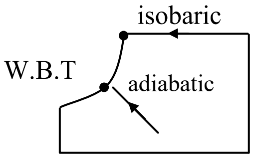
During adiabatic saturation process DBT decreases, WBT = constant, h = constant, specific humidity (ω) increases, DPT increases, relative humidity increases.

03. Ans: (b)

Sol: When warm saturated air is cooled, excess moisture condenses but relative humidity remains unchanged

04. Ans: (c)

Sol: **Case (A):** Moist air is adiabatically saturated
Case (B): Moist air is isobarically saturated



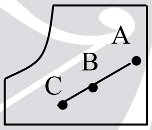
Case-(A): Adiabatically saturated → W.B.T
Case-(B): isobarically saturated → D.P.T

05. Ans (b)

Sol: For dehumidification, the coil temperature should be less than the dew point temperature of the incoming air.

06. Ans: (d)

Sol:

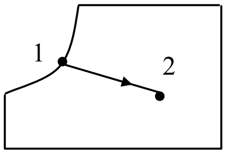


$$\text{By pass factor} = \frac{BC}{AC}$$

07. Ans: (b)

08. Ans: (d)

Sol:



During chemical dehumidification
Enthalpy & W.B.T remains constant, specific humidity decreases, dew point temperature decreases and relative humidity decreases.

09. Ans: (c)

10. Ans: (a)

Sol: T_{coil} is greater than dew point temperature but less than dry bulb temperature hence it is sensible cooling.

11. Ans: (c)

Sol: Temperature of water spray is greater than dew point temperature hence it is a heating process and water molecules are mixing with air hence it is humidification.

12. Ans: (b)

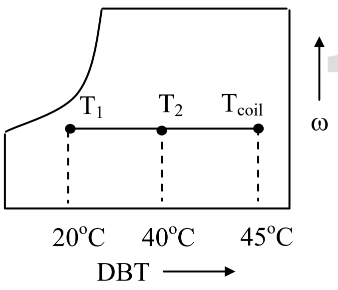
Sol: Heat is absorbed so it is absorption or chemical process in which WBT remains constant & DBT increases.

13. Ans: (a)

Sol: $\mu = \phi \times \left(\frac{P_{atm} - P_{sat}}{P_{atm} - P_v}\right) = \frac{P_b - P_s}{P_b - P_v} \times \phi$

14. Ans: (a)

Sol:



$$\text{By pass factor} = \frac{T_{coil} - T_2}{T_{coil} - T_1} = \frac{45-40}{45-20}$$

$$\text{BPF} = 0.2$$

15. Ans: (c)

Sol: L.H.L = 0.25 S.H.L

$$\text{S.H.F} = \frac{\text{SHL}}{\text{SHL} + \text{LHL}}$$

$$\text{S.H.F} = \frac{\text{S.H.L}}{1.25 \times \text{S.H.L}} = 0.8$$

16. Ans: (d)

Sol: $T_{sat} = 25°C \to \phi = 100\%$

$P_{sat} = 3.1698$ kPa

$P_{total} = 100$ kPa

$$\phi = \frac{P_V}{P_{sat}} = 1 \Rightarrow P_V = P_{sat} = 3.1698\,\text{kPa}$$

$$\omega = 0.622 \frac{P_V}{P_{atm} - P_V} = 0.622 \times \frac{3.1698}{100 - 3.1698}$$

$$= 0.0204 \times \frac{\text{kg Vap}}{\text{kg dry air}}$$

$$\omega = \frac{m_v}{m_a}$$

$$m_V = 100 \times 0.0204 = 2.04\,\text{kg}$$

17. Ans: (c)

Sol: $\omega = \frac{m_v}{m_a} = \frac{0.6}{50} = 0.012 \frac{\text{kg of Vapour}}{\text{kg of dry air}}$

$T_{sat} = 25^0 C$,

$P_{sat} = 3.1698$ kPa

$$\omega = 0.622 \frac{P_v}{95 - P_v} = 0.012$$

$P_V = 1.798$ kPa

$$\phi = \frac{P_v}{P_{sat}} = \frac{1.798}{3.1698} = 0.567 = 56.7\%$$

18. Ans: (c)

Sol: $T_{sat} = 30°C \rightarrow P_{sat} = 4.2469$ kPa

$$P_{atm} = 90\text{ kPa},\quad \phi = \frac{P_V}{P_{sat}} = 75\%$$

$$P_V = 0.75 \times 4.2469 = 3.185\text{ kPa}$$

$$P_a = P_{atm} - P_v$$

$$P_{air} = 86.815\text{ kPa}$$

$$m_a = \frac{P_a V}{R_a T} = \frac{86.815 \times 40}{0.287 \times 303} = 39.93\text{ kg}$$

19.

Sol: $T_{sat} = 30°C$

$P_{atm} = 100$ kPa

$P_{sat} = 4$ kPa

$$\mu = 0.24 = \frac{P_v(P_{atm} - P_{sat})}{P_{sat}(P_{atm} - P_v)} = \frac{P_V(100-4)}{4(100-P_v)}$$

$400 \times 0.24 - 0.24\,Pv = 100\,P_v - 4P_v$

$96.24\,P_v = 400 \times 0.24$

$$P_v = \frac{400 \times 0.24}{96.24} = 0.9975\text{kPa}$$

Relative humidity

$$\phi = \frac{P_v}{P_{sat}} = \frac{0.9975}{4} = 0.2493\text{ or }24.93\%$$

$$\omega = 0.622\,\frac{P_v}{P_{atm} - P_v}$$

$$= 0.622 \times \frac{0.9975}{100 - 0.9975} = 0.00627\frac{\text{kg.vap}}{\text{kg.d.a}}$$

20.

Sol: $P_{atm} = 101$ kPa

$T_{sat} = 40^oC$

$P_{sat} = 7.38$ kPa

$$\phi = 0.5 = \frac{P_v}{P_{sat}} = \frac{P_v}{7.38}$$

$P_v = 3.692$

$$\omega = 0.622\frac{P_v}{P_{atm} - P_v}$$

$$= 0.622 \times \frac{3.692}{101 - 3.692}$$

$$\omega = 0.0235\frac{\text{kgVap}}{\text{kg da}}$$

As gas is compressed partial pressure increases in the same ratio,

$$P_v = 3.692 \times \frac{5.05}{1.01}$$

At 150^{o}C,

$P_{sat} = 475.8$ kPa

$$\phi = \frac{P_v}{P_{sat}} = \frac{18.46}{475.8} \times 100 = 3.9\ \%$$

21. Ans: 1.125 kPa

Sol: $P_1 = 100$ kPa

$P_2 = 500$ kPa

DBT = 35°C

$P_{VS} = 5.628$ kPa

$$\omega_S = 0.622 \times \frac{P_{VS}}{P_2 - P_{VS}} = 0.622 \times \frac{5.628}{500 - 5.628}$$

$= 7.08 \times 10^{-3}$ kg vapour/kg dry air

$\omega_2 = \omega_{s3} = 7.08 \times 10^{-3}$

($\because$ pressure remains constant in after cooler)

Moisture is same throughout the process i.e., in compressor no moisture is removed or added and in after cooler, the pressure is constant so the moisture content will not change.

$$\omega_1 = 0.622 \times \frac{P_V}{P_1 - P_V}$$

$$\frac{7.08\times10^{-3}}{0.622}=\frac{P_V}{(100-P_V)}$$

$\therefore P_V = 1.125$ kPa

22. Ans: (d)

Sol: $T_{sat} = 20°C$, $P_{sat} = 2.339$ kPa

$\phi = 0.5$

$$\phi=\frac{P_V}{P_{sat}}\Rightarrow P_V=0.5\times2.339=1.169\ \text{kPa}$$

Corresponding to partial pressure of vapor whatever the saturation temperature is the temperature at which the water vapor present in air starts condensing and this beginning of this condensation is called as dew point temperature.

At 5°C $\rightarrow$ 0.8725

T_2 - ? $\rightarrow$ $P_2 = 1.169$

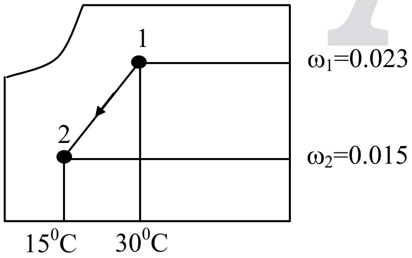
10°C $\rightarrow$ 1.2281

$$\frac{1.2281-0.8725}{1.169-0.8725}=\frac{10-5}{T_2-5}$$

$T_2 = 9.16$ °C

23. Ans: (d)

Sol:



Cooling load on coil h_1

$$=C_{Pa}(T_1-0)+\omega_1\left[(h_{fg})_{0^0C}+C_{PV}(T_1-0)\right]$$

$$=1.005\times(30-0)+0.023[2500+1.88(30-0)]$$

= 88.94 kJ/kg of dry air

$$h_2=C_{Pa}(T_2-0)+\omega_2\left[(h_{fg})_{0^0C}+C_{PV}(T_2-0)\right]$$

$$=1.005(15-0)+0.015[2500+1.88(15-0)]$$

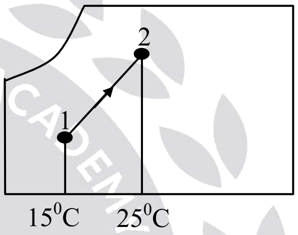
= 52.99 kJ/kg of dry air

Total heat load = m_a (h_2-h_1)

= 0.7(52.99–88.94) = –25 kW

24. Ans: (a)

Sol:



$P_{total} = 90$ kPa, $T_{sat} = 15°C$,

$P_{sat} = 1.7057$ kPa

$$\phi_1=\frac{P_{V_1}}{P_{sat_1}}=0.75$$

$P_{V1} = 1.278$ kPa

$$\omega_1=0.622\times\frac{P_{V1}}{P_{atm}-P_{V1}}=0.622\times\frac{1.278}{90-1.278}$$

$$=0.0089\,\frac{\text{kg of vapour}}{\text{kg of dry air}}$$

$T_{sat} = 25°C$, $P_{sat} = 3.1698$ kPa, $\phi = 0.75$

$$\phi=\frac{P_{V2}}{P_{sat2}}\Rightarrow P_{V2}=2.377\ \text{kPa}$$

$$\omega_2=0.622\times\frac{P_{V_2}}{P_{atm}-P_{V_2}}$$

$$=0.622\times\frac{2.377}{90-2.377}=0.0168\,\frac{\text{kg of Vap}}{\text{kg of dry air}}$$

Mass of vapour added ,

$$\dot{m}_v = \dot{m}_a(\omega_2 - \omega_1)$$

$$= 4(0.0168 - 0.0089)$$

$$= 0.03\,\text{kg of vapor/sec}$$

25.

Sol: $P_{sat} = 3.166$ kPa,

$T_{sat} = 25°C = 298$ K

$$\phi = 0.74 = \frac{P_v}{P_{sat}} = \frac{P_v}{3.166}$$

$P_v = 0.74 \times 3.166 = 2.34$ kPa,

At 2.34 kPa , $T_{sat} = 20^0C = 293\ K = DPT$

Corresponding to saturation temperature whatever the saturation pressure, the water vapor starts condensing.

dT = 298 −293 = 5 K

6.5 K drops in temperature = 1000 m

$$5\text{ K drop temperature} = \frac{5}{6.5} \times 1000$$

$$= 769\text{ m}$$

26.

Sol: At $T_1 = 20°C$

$P_{sat} = 2.337$ kPa, $\phi_1 = 0.65$

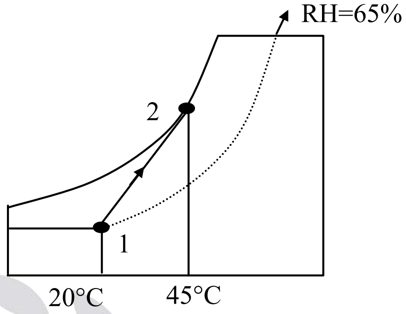
$$\phi_1 = \frac{P_{V_1}}{P_{sat}} \Rightarrow P_{V_1} = \phi_1 P_{sat} = 0.65 \times 2.337$$

$$= 1.52\text{ kPa}$$

$$\omega_1 = 0.622\frac{P_{V_1}}{P_{atm} - P_{V_1}}$$

$$= 0.622 \times \frac{1.524}{100 - 1.524}$$

$$= 0.0096\,\frac{\text{kg of vapour}}{\text{kg of dry air}}$$

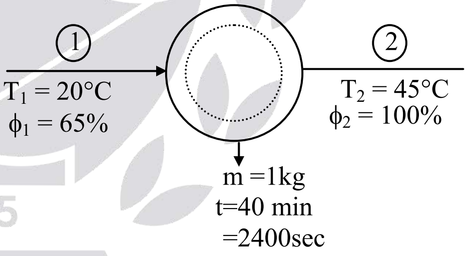


$T_2 = 45°C$, $\phi_2 = 100$ %

$P_{V_2} = P_{sat} = 9.557$ kPa

$$\omega_2 = 0.622 \times \frac{9.557}{100 - 9.557}$$

$$= 0.066\,\frac{\text{kg of vapour}}{\text{kg of dry air}}$$



Mass of water absorbed by air

$$\dot{m}_w = \dot{m}_a \times (\omega_2 - \omega_1)$$

$$\frac{1}{2400} = \dot{m}_a(0.066 - 0.0096)$$

$$= 0.0073\text{ kg/sec}$$

$$\dot{m}_a = 0.0073 \times 3600 = 26.6\text{ kg/hr}$$

27. Ans: 0.02

Sol: $m = m_a + m_{v_1}$

$$\frac{m}{m_a} = 1 + \frac{m_{v1}}{m_a}$$

$$\frac{m}{m_a} = 1 + \omega_1$$

$$\frac{10.1}{m_a} = 1.01$$

$$\dot{m}_a = \frac{10.1}{1.01} = 10 \text{ kg/sec}$$

$$\dot{m}_{v_1} = \omega_1 \times m_a = 0.01 \times 10 = 0.1 \text{ kg/sec}$$

$$\dot{m}_{v_2} = 0.1 \text{ kg/sec}$$

Total mass of vapour after mixing

$$= \dot{m}_v = \dot{m}_{v_1} + \dot{m}_{v_2}$$

$$= 0.1 + 0.1$$

$$= 0.2 \text{ kg/sec}$$

Specific humidity of mixture

$$\omega = \frac{\dot{m}_v}{\dot{m}_a} = \frac{0.2 \text{ kg/sec}}{10 \text{ kg/sec}}$$

= 0.02 kgvap/kgd.a

Chapter- 10
Rankine Cycle

01. Ans: (d)

Sol: Assertion is false and Reason is true

Steam rate or specific steam consumption

$$= \frac{1}{W_T - W_C}\frac{\text{kg}}{\text{kW sec}} = \frac{3600}{W_T - W_P}\frac{\text{kg}}{\text{kW.hr}}$$

For Carnot cycle as pump work is very high so specific steam consumption is very high.

For Carnot cycle the mean temperature heat addition is greater than Rankine cycle, so $\eta_C > \eta_R$

02. Ans: (d)

03. Ans: (d)

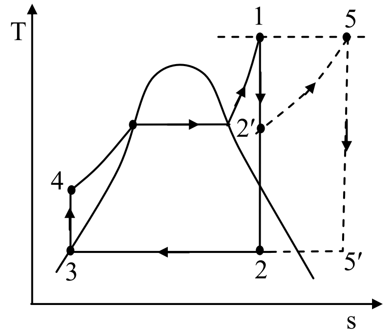
Sol: Process ABCDE is heat addition process in boiler.

04. Ans: (b)

Sol: The expansion process in turbine like 1-2 is carried out in modified Rankine cycle.

05. Ans: (c)

Sol: Due to reheating in Rankine cycle :



(i) Work output of turbine increases as expansion is carried in two stages.

W(without reheat) = $h_1 - h_2$

W(with reheat) = $(h_1 - h_2') + (h_5 - h_5')$

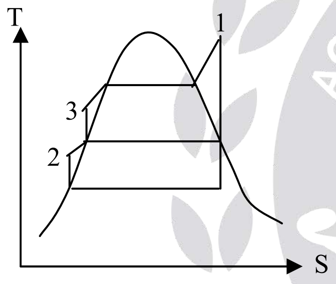
(ii) Turbine efficiency increases as mean temperature of heat addition increases.

(iii) Specific steam consumption = $\dfrac{3600}{W_{net}}$

As W_{net} increases so specific steam consumption decreases.

06. Ans: (b)

Sol:



$h_1 = 3514$ kJ/kg

$W_{HP} = 3$ kJ/kg

$h_2 = 613$ kJ/kg,

$W_{LP} = 1$ kJ/kg

$h_3 - h_2 = W_{HP}$

$h_3 - 613 = 3$

$h_3 = 616$ kJ/kg

$Q_S = h_1 - h_3 = 3514 - 616$

$= 2898$ kJ/kg

07. Ans: (d)

Sol: $\eta = \dfrac{P_W}{\text{Power input}} = \dfrac{vdp}{\text{Power input}}$

$$0.75 = \frac{\frac{0.15}{60}(5000 - 200)}{P_i}$$

$P_i = 16$ kW

08. Ans: 3.6

Sol: Specific steam consumption = $\dfrac{3600}{W_{net}}$

$W_T = 3103 - 2100 - 3 = 1000$ kJ/kg

Specific steam consumption = $\dfrac{3600}{1000}$

= 3.6 kg/kW-hr

09.

Sol: At $T_1 = 500°C$ and 7 MPa

$h_1 = 3410.3$ kJ/kg

$s_1 = 6.7975$ kJ/kgK

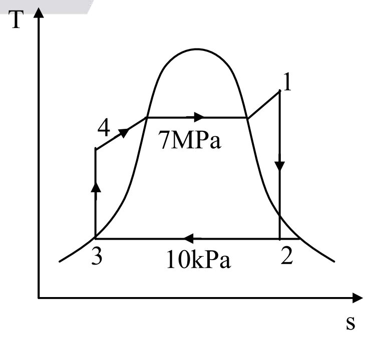
At 10 kPa

$h_3 = h_{f_3} = 191.83$ kJ/kg

$s_3 = s_{f_3} = 0.6493$ kJ/kgK

$v_3 = v_{f_3} = 1.01 \times 10^{-3}$ m^3/kg

$s_{g_2} = 8.1502$ kJ/kgK



Process (1-2)

$Q = 0,\ s = c$

$s_1 = s_2 = 6.7975\ \text{kJ/kg K} < 8.1502\,\dfrac{\text{kJ}}{\text{kgK}}$

So point 2 is in wet state

$s_2 = s_{f2} + x_2 s_{fg_2}$

$6.7975 = 0.6493 + x_2\,(8.1502 - 0.6493)$

$x_2 = 0.82$

$h_2 = h_{f_2} + x_2 h_{fg_2}$

$= 191.83 + 0.82 \times 2392.8$

$= 2153.92\ \text{kJ/kg}$

Process (3-4)

$s_3 = s_4 = 0.6393\ \text{kJ/kgK}$

$W_p = h_4 - h_3 = V_{f_3} \times (P_{boil} - P_{cond})$

$= 1.01 \times 10^{-3}\,(7000 - 10)$

$= 7.05\ \text{kJ/kg}$

$h_4 = 7.05 + 191.83 = 198.88\ \text{kJ/kg}$

$W_T = h_1 - h_2 = 3410.3 - 2153.92$

$= 1256.4\ \text{kJ/kg}$

Heat supplied, $Q_S = h_1 - h_4$

$3410.3 - 198.88 = 3211.5\ \text{kJ/kg}$

$W_{net} = W_T - W_P = 1256.4 - 7.05$

$= 1249.35\ \text{kJ/kg}$

$$\text{Work ratio} = \frac{W_{net}}{W_T} = \frac{1249.35}{1256.4} = 0.99$$

$$\eta_{th} = \frac{W_{net}}{Q_S} = \frac{1249.35}{3211.5} = 38.9\%$$

$$\text{Steam rate} = \frac{3600}{W_{net}} = 2.8816\ \text{kg/kW-hr}$$

$$\text{Heat rate} = \frac{3600}{\eta_{th}} = 9254\ \text{kJ/kW-hr}$$

$\text{Power} = \dot{m}_s \times W_{net} = 30 \times 10^3$

$$\dot{m}_s = \frac{30 \times 10^3}{1249.35} = 24.01\ \text{kg/sec}$$

Boiler capacity is mass flow rate of steam expressed in kg/hr

$= 24.01 \times 3600\ \text{kg/hr}$

$= 86436\ \text{kg/hr}$

$\text{Condenser load} = \dot{m}_s\,(h_2 - h_3)$

$= 24.01\,(2153.92 - 191.83)$

$= 47109.7\ \text{kW}$

$(\Delta T)_w$ = rise in temperature of water

Heat gained by water = condenser load

$\dot{m}_w \times C_{pw} \times (\Delta T)_w = 47109.7$

$$(\Delta T)_w = \frac{47109.7}{2000 \times 4.186} = 5.63°\text{C}$$

10.

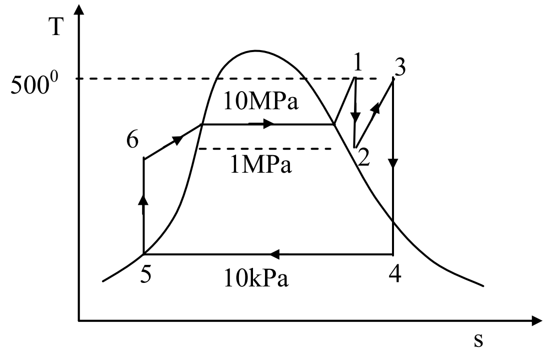
Sol: State – 1

$P_1 = 10\ \text{MPa}$

$T_1 = 500°\text{C}$

$h_1 = 3373.7\ \text{kJ/kg}$

$s_1 = 6.5966\ \text{kJ/kgK}$



State – 2

$P_2 = 1$ MPa

$T_2 = ?$ $\quad T_{sat} = 179.91^0$C , $\; h_2 = ?$

$s_1 = 6.5966$ kJ/kg $= s_2$

$$s_2 = s_{g_2} + C_{P_{Vapur}} \times ln\left(\frac{T_2}{T_{sat}}\right)$$

(As $s_2 > s_{g2}$ it is in superheated state)

$s_2 = 6.5966$ kJ/kgK

$$= 6.5865 + 2.1 \times ln\left(\frac{T_2}{(273+179.91)}\right)$$

$T_2 = 455.09$ K

$h_2 = h_{g_2} + C_{P_{vapour}} \times (T_2 - T_{sat})$

$= 2778.1+2.1[455.09–(273 + 179.91)]$

$= 2782.67$ kJ/kg

State – 3

$P_3 = 1$ MPa

$T_3 = 500^0$ C

$h_3 = 3478.5$ kJ/kg

$s_3 = 7.7622$ kJ/kg K

State – 4

$P_4 = 10$ kPa

$T_4 = 45.81$°C

$h_4 = ?$

$s_4 = s_3 = 7.7622$ kJ/kg K

$s_4 = s_{f_4} + x_4\left(s_{g_4} - s_{f_4}\right)$

$= 0.6493 + x_4(8.1502 – 0.6493)$

$x_4 = 0.94 \rightarrow$ (wet state)

$h_4 = h_{f_4} + x_4\left(h_{g_4} - h_{f_4}\right)$

$= 191.83 + 0.94\ (2584.6 – 191.83)$

$= 2441.03$ kJ/kg

State – 5

$P_5 = 10$ kPa

$h_5 = (h_f)_w = 191.83$ kJ/kg

$s_5 = s_{f_5} = 0.6493$ kJ/kg K

$v_5 = 0.0010\ m^3kg$

State – 6

$P_6 = 1$ MPa

$S_6 = 0.6493$ kJ/kg.K

$W_p = v_{f_5}(P_6 - P_5)$

$= 0.0010 \times (10\times10^3 - 10) = 9.99$ kJ/kg

$W_p = (h_6 - h_5)$

$h_6 = W_p + h_5$

$= 9.99 + 191.83 = 201.82$ kJ/kg

$W_T = (h_1 - h_2) + (h_3 - h_4)$

$=(3373.7–2782.67) + (3478.5–2441.03)$

$= 1628.5$ kJ/kg

$W_{net} = W_T - W_P = 1628.5 – 9.99$

$= 1618.51$ kJ/kg

$$\text{Work ratio} = \frac{W_{net}}{W_T} = \frac{1618.51}{1628.5} = 0.99$$

Heat supplied $Q_S = (h_1 - h_6) + (h_3 - h_2)$

$= (3373.7–201.82)+(3478.5 –2782.67)$

$= 3867.71$ kJ/kg

$$\eta_{th} = \frac{W_{net}}{Q_S} = \frac{1618.51}{3867.71} = 0.418 = 41.8\%$$

11.

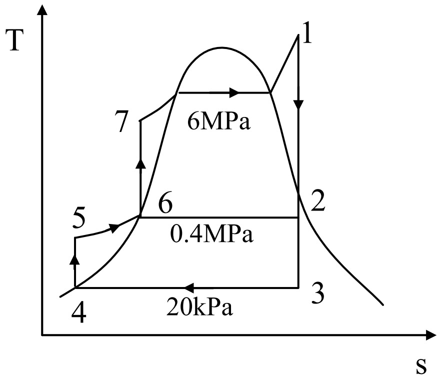
Sol: ***State - 1:*** (super heated)

$P_1 = 6$ MPa

$T_1 = 450$°C

$h_1 = 3301.8$ kJ/kg

$s_1 = 6.7193$ kJ/kgK



State - 2: (wet state)

$P_2 = 0.4\text{MPa}$

$h_2 = ?, \qquad T_2 = ?$

$s_2 = 6.7193$ kJ/kg

$s_{g_2} = 6.8959$ kJ/kg K

As $s_2 < s_{g_2}$ this is in wet state

$$s_2 = s_{f_2} + x_2\left(s_{g_2} - s_{f_2}\right)$$

$$6.7193 = 1.7766 + x_2(6.8959 - 1.7766)$$

$$x_2 = 0.96$$

$$h_2 = h_{f_2} + x_2\left(h_{g_2} - h_{f_2}\right)$$

$$= 604.74 + 0.96\,(2738.6 - 604.74)$$

$$= 2653.24 \text{ kJ/kg}$$

State - 3: (wet state)

$P_3 = 20$ kPa

$h_3 = ?$

$s_2 = s_3 = 6.7193$ kJ/kgK

$s_{g_3} = 7.9085$ kJ/kg K

$$6.7193 = 0.8320 + x_3(7.9085 - 0.8320)$$

$$x_3 = 0.83$$

$$h_3 = h_{f_3} + x_3\left(h_{g_3} - h_{f_3}\right)$$

$$= 251.4 + 0.83\,(2609.7 - 251.40)$$

$$= 2208.8 \text{ kJ/kg}$$

State - 4: **(saturated)**

$P_4 = 20$ kPa

$h_4 = h_{f_4} = 251.40$ kJ/kg

State - 5: **(compressed)**

$P_5 = 0.4$ MPa

State – 6: **(saturated)**

$P_6 = 0.4$ MPa

$h_6 = h_{f_6} = 604.74$ kJ/kg

$s_6 = 1.7766$ kJ/kg.K

State – 7: **(compressed)**

$P_7 = 6$ MPa

High pressure pump work

$$W_{HP} = v_{f_6}\,(P_7 - P_6)$$

$$= 1.084 \times 10^{-3}\,(6 \times 10^3 - 0.4 \times 10^3)$$

$$= 6.0704 \text{ kJ/kg}$$

$$h_7 = h_6 + W_{HP}$$

$$= 604.74 + 6.0704 = 610.08 \text{ kJ/kg}$$

Low pressure pump work

$$W_{LP} = v_{f_4}\,(P_5 - P_4)$$

$$= 1.017 \times 10^{-3}\,(0.4 \times 10^3 - 20)$$

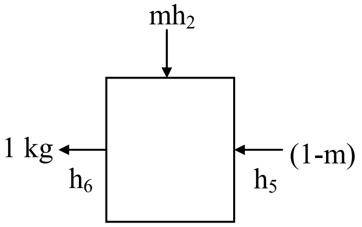
$$= 0.386 \text{ kJ/kg}$$

$$h_5 = h_4 + W_{LP}$$

$$= 251.40 + 0.386 = 251.786 \text{ kJ/kg}$$

The mass of steam m_1 extracted from turbine at 0.4 MPa

Energy balance:



Energy in = Energy out

$(1-m)\,h_5 + mh_2 = 1\times h_6$

$\Rightarrow m\,(h_2 - h_5) = h_6 - h_5$

$$m = \frac{h_6 - h_5}{h_2 - h_5}$$

$$= \frac{604.74 - 251.786}{2653.24 - 251.786} = 0.146\,\text{kg}$$

$W_T = (h_1 - h_2) + (1-m)\,(h_2 - h_3)$

$= (3301.8 - 2653.24) + (1 - 0.146) \times (2653.24 - 2208.8)$

$= 1028.12$ kJ/kg

$W_P = W_{HP} + W_{LP}$

$= 6.0704 + 0.386 = 6.456$ kJ/kg

$W_{net} = W_T - W_P = 1028.12 - 6.456$

$= 1021.66$ kJ/kg

$Q_s = h_1 - h_7$

$= 3301.8 - 610.07 = 2691.73$ kJ/kg

$$\eta_{th} = \frac{W_{net}}{Q_s} = \frac{1021.66}{2691.73} = 0.379 = 37.9\%$$

12. Ans: (a)

Sol: At 5 MPa,

$T_{sat} = 263.9°C$,

At 2 MPa,

$T_{sat} = 212.38°C$

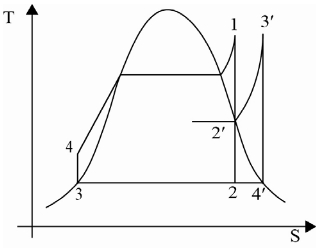
$$\eta_{Carnot} = \frac{263.9 - 212.38}{263.9 + 273} = 0.095$$

Work done = 0.095 × 380 = 36.5 kW

Note: Correct answer is option (a)

13. Ans: (b)

Sol:



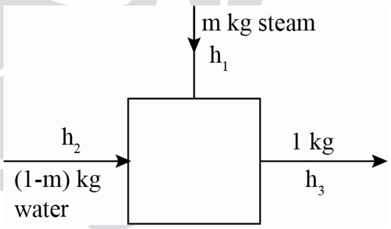
Dryness fraction $x_{4'}$ for reheat cycle is greater than dryness fraction x_2 for simple cycle.

14. Ans: (c)

Sol: Mean temperature of heat supply increases in regenerative cycle hence increase in thermal efficiency.

15. Ans: (c)

Sol:



Energy balance

Energy in = Energy out

$mh_1 + (1 - m)\,h_2 = 1h_3$

$h_3 = h_2 + m\,(h_1 - h_2)$

$= h_2 - m\,(h_2 - h_1)$

16. Ans: (c)

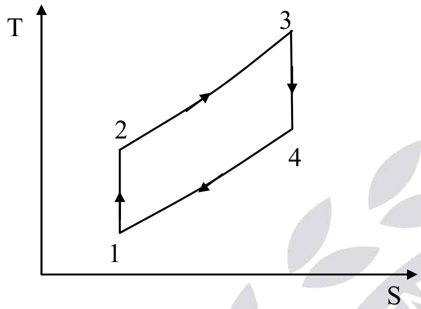
17. Ans: (c)

Sol: As mass is reduced volume flow is less in low pressure stages.

Chapter- 11
Gas Turbines

01.

Sol:



Given

$T_1 = 300$ K

$P_1 = 0.1$ MPa

$$\frac{P_2}{P_1} = 6.25 = \frac{P_3}{P_4}$$

$T_3 = 800 + 273 = 1073$ K

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (6.25)^{\frac{0.4}{1.4}} \quad \{\gamma = 1.4 \text{ for air}\}$$

$T_2 = 506.4$ K

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{0.4}{1.4}} = (6.25)^{\frac{0.4}{1.4}}$$

$$\frac{1073}{T_4} = (6.25)^{\frac{0.4}{1.4}}$$

$T_4 = 635.6$ K

(a) Work done on the compressor

$W_C = m \times C_p \times (T_2 - T_1)$

$= 1 \times 1.005 \times (506.4 - 300)$

$= 207.432$ kJ/kg

(b) Work done by Turbine

$W_T = m \times C_p \times (T_3 - T_4)$

$= 1 \times 1.005 \times (1073 - 635.6)$

$= 439.587$ kJ/kg

(c) Heat supplied

$Q_S = mC_p \times (T_3 - T_2)$

$= 1 \times 1.005 \times (1073 - 506.4)$

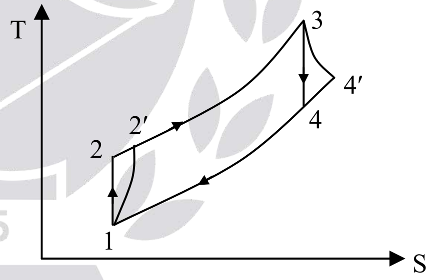
$Q_S = 569.433$ kJ/kg

(d) $$\eta_{th} = \frac{W_T - W_C}{Q_S} = \frac{439.587 - 207.432}{569.433}$$

$= 40.77\%$

02.

Sol:



Caloric value (CV) = 42000 kJ/kg

$\eta_T = 0.85$,

$\eta_c = 0.8$

$T_{max} = T_3 = 875^0C = 1148K$

$P_1 = 1$ atm

$T_1 = 300$ K

$$\frac{P_2}{P_1} = 4 = r_p$$

The temperature after isentropic compression

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

$$= 300\times 4^{\frac{1.4-1}{1.4}} = 446\text{ K}$$

The isentropic efficiency of the compressor

$$\eta_c = \frac{W_{s=c}}{W_{actual}} = \frac{C_P(T_2-T_1)}{C_P(T_2'-T_1)}$$

$$\Rightarrow 0.8 = \frac{445.8-300}{T_2'-300}$$

$$\Rightarrow T_2' = 482.5\text{ K}$$

T_2' = actual temperature at exit of compressor

Process 3-4: Q=0, S=C

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

$$T_4 = \frac{T_3}{(4)^{\frac{0.4}{1.4}}} = \frac{1148}{4^{\frac{0.4}{1.4}}}$$

$T_4 = 773$ K

$$\eta_T = \frac{W_{act}}{W_{S=C}} = \frac{C_P(T_3-T_{4'})}{C_P(T_3-T_4)}$$

$$T_{4'} = 1148-0.85(1148-773)$$

$$T_{4'} = 829\text{K}$$

$$W_T = C_P(T_3-T_{4'}) = 1.005(1148-829)$$

$$= 320.32\text{ kJ/kg}$$

$$W_C = C_P(T_2'-T_1) = 1.005(483-300) = 184\text{kJ/kg}$$

$$Q_S = C_P(T_3-T_2') = 1.005(1148-484)$$

$$= 668.325\text{ kJ/kg}$$

$$W_{net} = W_T - W_C = 320.32-184$$

$$= 136.32\text{ kJ/kg}$$

$$\text{Work ratio} = \frac{W_{net}}{W_T} = 0.428$$

$$\text{Back work ratio} = \frac{W_C}{W_T} = 0.571$$

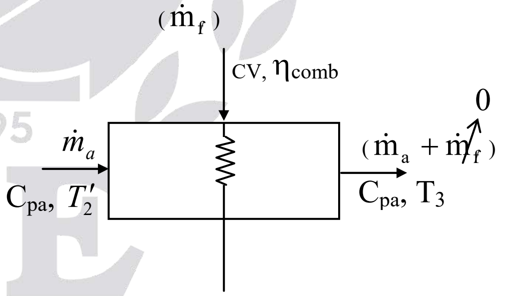
$$\eta_{th} = \frac{W_{net}}{Q_S} = 20.5\%$$

$$\text{Heat rate} = \frac{3600}{\eta_{th}} = 17560.97\ \frac{\text{kJ}}{\text{kW/hr}}$$

$$\text{Air rate} = \frac{3600}{W_{net}} = 26.22\frac{\text{kg}}{\text{kWhr}}$$

$$T_{m1} = \frac{h_3-h_{2'}}{s_3-s_{2'}} = \frac{C_P(T_3-T_{2'})}{C_P\left(\ln\frac{T_3}{T_{2'}}\right)} = 768\text{ K}$$

$$T_{m2} = \frac{h_{4'}-h_1}{s_{4'}-s_1} = \frac{C_P(T_{4'}-T_1)}{C_P\left(\ln\frac{T_{4'}}{T_1}\right)} = 520.4\text{ K}$$



Energy balance:

$$\dot{m}_a C_{Pa} T_2' + \dot{m}_f(CV)\eta_{comb} = \dot{m}_a C_{Pa} T_3$$

$$\frac{\dot{m}_a}{\dot{m}_f} C_{Pa} T_2' + \dot{m}_f(CV)\eta_{comb} = \frac{\dot{m}_a}{\dot{m}_f} C_{Pa} T_3$$

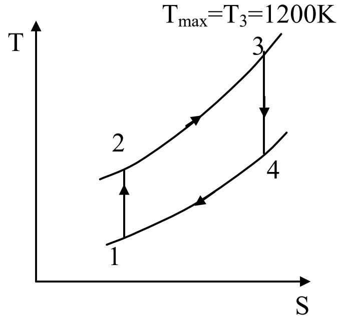
$$(AFR)C_{Pa}T_2' + (CV)\eta_{comb} = (AFR)C_{Pa}T_3$$

$$AFR\times1\times482.5+42000\times0.9 = AFR\times1\times1148$$

$$\therefore AFR = 56.56:1$$

03.

Sol:



$T_{max} = 1200$ K, $T_{min} = 300$ K

At $(r_p)_{opt}$, $T_2 = T_4 = \sqrt{T_1 T_3} = 600K$

$W_C = C_P (T_2 - T_1)$

$= 1.005(600 - 300) = 301.5$ kJ/kg

$W_T = C_P (T_3 - T_4) = 1.005(1200 - 600)$

$= 603$ kJ/kg

$$\eta_{th,\,(rp)opt} = 1 - \sqrt{\frac{T_{min}}{T_{max}}}$$

$$= 1 - \sqrt{\frac{300}{1200}} = 50\%$$

04. Ans: (a)

Sol:

- Due to Regeneration thermal efficiency increases as heat required in combustor is less.
- Reheating decreases thermal efficiency as mean temperature of heat rejection increases.
- When maximum temperature of the cycle is increased, thermal efficiency increases as mean temperature of heat addition increases.

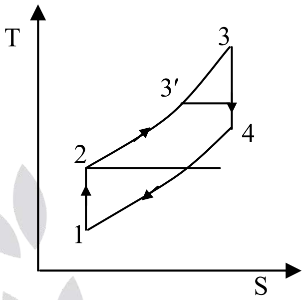
05. Ans: (d)

06. Ans: (a)

Sol: During regeneration process, turbine work and compressor work remain unchanged and only heat supplied decreases so thermal efficiency increases.

07. Ans: (d)

Sol:



$P_1 = 100$ kPa,

$P_2 = 400$ kPa

$T_1 = 298$ K,

$T_3 = 1473$ K

$$r_P = \frac{400}{100} = 4$$

$$T_2 = T_1 (r_P)^{\frac{\gamma-1}{\gamma}} = 298 \times 4^{\frac{0.67}{1.67}} = 519.7K$$

$$T_4 = \frac{T_3}{(r_P)^{\frac{\gamma-1}{\gamma}}} = 844.61K$$

The maximum temperature up to which we can heat the compressed air is turbine exhaust temperature and this will happen when effectiveness of the heat exchanger must be unity.

i.e. $T_3^{'} = T_4 = 844.61K = 573^\circ C$

08.

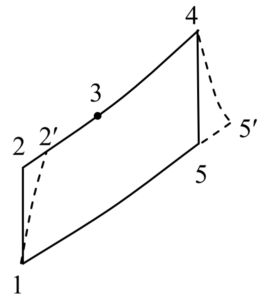
Sol: $T_1 = 300$ K

$r_p = 4$

$T_4 = 833$ K

$\eta_T = 0.85$

$\eta_C = 0.83$



$\xi = 0.75$

$$\frac{T_2}{T_1} = \left(r_p\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_2 = 445.8\,K \ \ \{\gamma = 1.4 \text{ for air}\}$$

$$\eta_C = 0.83 = \frac{T_2 - T_1}{T_2' - T_1} = \frac{445.8 - 300}{T_2' - 300}$$

$$T_2' = 475.66\,K$$

$$\frac{T_4}{T_5} = \left(r_p\right)^{\frac{\gamma-1}{\gamma}} = \left(4\right)^{\frac{0.4}{1.4}} \Rightarrow T_5 = 560.56\,K$$

$$\eta_T = 0.85 = \frac{T_4 - T_5'}{T_4 - T_5} = \frac{833 - T_5'}{833 - 560.56}$$

$$T_5' = 601.43\,K$$

$$\xi = \frac{Q_{act}}{Q_{max}} = \frac{T_3 - T_2'}{T_5' - T_2'} = \frac{T_3 - 475.66}{601.43 - 475.66}$$

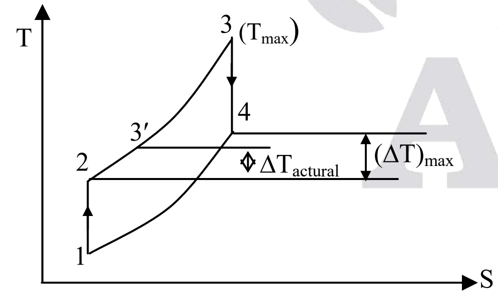
$\Rightarrow T_3 = 569.98$ K

$$\eta_{th} = \frac{W_T - W_C}{Q_S} = \frac{mc_p \times \left(T_4 - T_5'\right) - mc_p \times \left(T_2' - T_1\right)}{m \times c_p \times \left(T_4 - T_3\right)}$$

$$= \frac{\left(833 - 601.43\right) - \left(475.66 - 300\right)}{833 - 569.98} = 21.26\%$$

09. Ans: (d)

Sol:



$P_1 = 80$ kPa, $P_2 = 400$ kPa,

$T_1 = 283$ K $T_3 = 1273$K

$$r_P = \frac{400}{80} = 5$$

$T_3^1 = 450 + 273 = 723$ K

$$T_4 = \frac{T_3}{\left(r_P\right)^{\frac{\gamma-1}{\gamma}}} = \frac{1273}{\left(5\right)^{\frac{0.4}{1.4}}} = 804K$$

Effectiveness of heat exchanger.

$$\in = \frac{\left(\Delta T\right)_{act}}{\left(\Delta T\right)_{max}} = \frac{T_3' - T_2}{T_4 - T_2} \times 100 = 77\%$$

10. Ans: (c)

Sol: $T_{min} = T_1 = 20 + 273 = 293$ K,

$T_{max} = T_4 = 900 + 273 = 1173$ K

$\gamma = 1.3$, $r_p = 6$

$$\left(\eta_B\right)_{\text{ideal regeneration}} = 1 - \frac{T_{min}}{T_{max}}\left(r_p\right)^{\frac{\gamma-1}{\gamma}}$$

$$= 1 - \left(\frac{293}{1173}\right) \times \left(6\right)^{\frac{1.3-1}{1.3}}$$

$$= 0.62 \text{ or } 62\%$$

11. Ans: (d)

Sol: Whenever we reheat, we reheat to the same temperature until unless mentioned in the problem. Whenever, we intercool to the same temperature, if there are infinitely large number of reheats and if there are infinitely large number of intercoolers then reversible adiabatic expansion becomes isothermal expansion and reversible adiabatic compression becomes isothermal compression and thermal efficiency of Brayton cycle becomes equal to Ericsson cycle.

$$\therefore \left(\eta_{th}\right)_{Braton} = \left(\eta_{th}\right)_{Ericsson}$$

Ericsson cycle is an ideal gas turbine cycle

Ideal $(\eta)_{\text{Ericsson}} = (\eta)_{\text{Carnot}}$

$$(\eta)_{\text{Carnot}} = 1 - \frac{T_{\min}}{T_{\max}} = 76\%$$

12. Ans: (c)

Sol: Simple Brayton cycle with Regeneration turbine work and compression work are constant but heat supplied is reduced. Hence thermal efficiency increases. Regeneration is done at constant pressure.

13. Ans: (c)

Sol: Keep the turbine cool, maximum temperatures are determined by highly stressed turbine blades hence high air fuel ratios are used to reduce temperatures.

Correct answer is option (c).

14. Ans: (a)

Sol: With the heat exchanger gas turbine cycle, the cycle efficiency reduces as the pressure ratio increases because as the pressure ratio increases, the delivery temperature from the compressor increases and ultimately will exceed that of the exhaust gas from the turbine.

15. Ans: (a)

Chapter- 12
Refrigeration

01.

Sol: Refrigeration effect = 1 tonne

$= 210$ kJ/min

$= 3.5$ kW

Work input = 1.5 kW

$$\text{COP} = \frac{3.5}{1.5} = 2.33$$

02.

Sol: Maximum COP = Carnot COP

$$= \frac{-30+273}{(273+32)-(273-30)}$$

$$= \frac{243}{62} = 3.92$$

Actual COP = 0.75×3.92 = 2.94

$$2.94 = \frac{5}{W_{\text{input}}}$$

$\Rightarrow W_{\text{input}} = 1.7$ kW

03.

Sol: Actual COP = 0.15 × Carnot's COP

$$= 0.15 \times \frac{273+2}{(273+30)-(273+2)}$$

$= 1.473$

$$\text{R.E} = \frac{8000}{24\times 60\times 60}\text{kN} = 0.093\ \text{kW}$$

$$1.473 = \frac{0.093}{W_{\text{in}}}$$

$W_{in} = 0.063$ kW

$= 0.063 \text{ kJ/s} \times 3600 \times 24 \text{ s}$

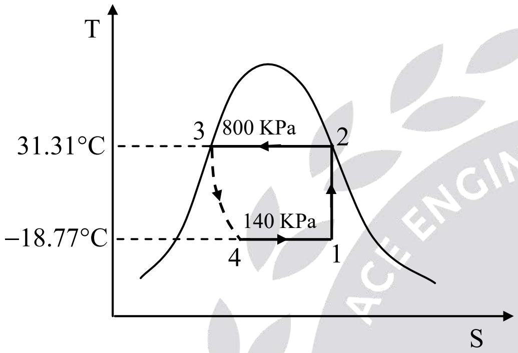
$= 5443.2$ kJ

1 kW-h = 3600 kJ

5443.2 kJ = 1.5 kW-h

04. Ans: (a)

Sol:



$P_1 = 140$ kPa, $P_2 = 800$ kPa

From steam table

$h_2 = h_g = 267.29$ kJ/kg

$h_3 = h_f = 95.49$ kJ/kg

$Q_R = h_2 - h_3$

$= 267.29 - 95.49 = 171.82$ kJ/kg

$$(\text{COP})_{HP} = \frac{Q_R}{W} = \frac{T_2}{T_2 - T_1}$$

$$\frac{171.82}{W} = \frac{273 + 31.31}{(273 + 31.31) - (273 - 18.77)}$$

$W = 28.54$ kJ/kg

05. Ans: (b)

Sol: For minimum required power input condition the COP has to be maximum and the maximum COP is the reversed Carnot cycle COP.

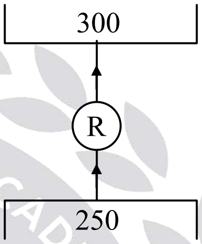
$$[(\text{COP})_{\text{Carnot}}]_{\text{Refrigerator}} = \frac{T_2}{T_1 - T_2} = \frac{Q_2}{W}$$

$$\Rightarrow \frac{268}{293 - 268} = \frac{0.35}{W}$$

$$\Rightarrow \quad W_{min} = 33 \text{ W}$$

06. Ans: 12 kW

Sol:



Total heat to be removed

$= 3600 \times 2 \times [27 - (-3)] + 3600 \times 230 + 3600 \times 20 \times 0.5$

$= 1080000$ kJ

$$\text{Rate of heat removed} = \frac{1080000}{10 \times 3600} = 30 \text{ kW}$$

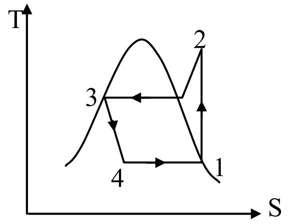
$$\text{Actual cop} = 0.5 \times \frac{250}{300 - 250} = 2.5$$

$$2.5 = \frac{30}{\text{Power}}$$

Power input = 12 kW

07. Ans: (c)

Sol:



Ideal vapour compression means the compression starts from dry and saturated vapor line.

$P_1 = 120$ kPa, $P_2 = 800$ kPa

$h_1 = 236.97$ kJ/kg

$h_3 = h_4 = 95.47$ kJ/kg

Net refrigeration effect (NRE) = 32 kW

$$= \dot{m}_r (h_1 - h_4)$$

$$\dot{m}_r = 0.23 \text{kg/sec}$$

08. Ans: (d)

Sol: $\dot{m}_r = 0.193 \text{kg/sec}$

$s_1 = s_2 = 0.93$ kJ/kgK

After compression the refrigerant is in super heated state with entropy = 0.93 at a pressure 1.2 MPa

$h_1 = 251.88$ kJ/kg

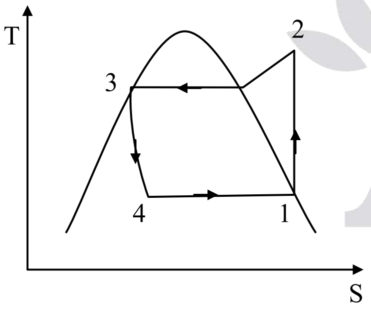
$h_2 = 278.27$ kJ/kg

$h_3 = 117.73$ kJ/kg

Heat supply = $\dot{m}_r (h_2 - h_3) = 30.98 \text{kW}$

09.

Sol:



Refrigeration effect = 5 kW

$h_4 = 75$ kJ/kg, $h_1 = 183$ kJ/kg,

$h_2 = 210$ kJ/kg

(i) $$\text{COP} = \frac{\text{Refrigeration effect}}{\text{work input}} = \frac{h_1 - h_4}{h_2 - h_1} = 4$$

(ii) Cooling capacity = $\dot{m} \times (h_1 - h_4)$

$$5 = \dot{m} \times (183 - 75)$$

$$\dot{m} = 0.0463 \text{kg/s}$$

Power input to the compressor

$$= \dot{m} \times (h_2 - h_1)$$

$$= 0.0463 \times (210 - 183)$$

$$= 1.25 \text{ kW}$$

(iii) Heat transfer at the condenser

$$= 0.0463 \times (h_2 - h_3)$$

$$= 0.0463 \times (210 - 75)$$

$$= 6.25 \text{ kW}$$

10. Ans: (b)

Sol: $h_3 = 107.32$ kJ/kg = h_4 at 1 MPa

$$h_4 = h_{f_4} + x(h_{g_4} - h_{f_4})$$

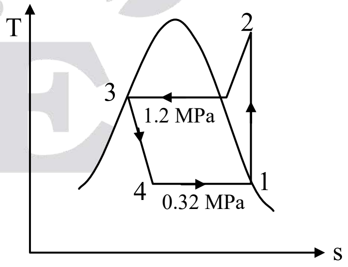
$$107.32 = 22.49 + x\,(226.97 - 22.49)$$

Dry fraction of liquid, x = 0.4

Mass fraction of liquid = 1–x = 0.6

11. Ans: (d)

Sol:



$h_3 = 117.71$ kJ/kg at 1.2 MPa

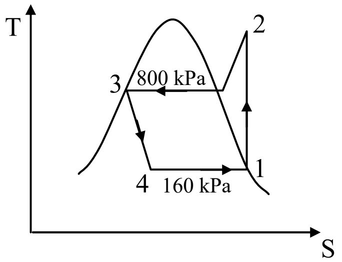
$h_1 = 251.8$ kJ/kg at 0.32 MPa

$h_2 = 278.27$ kJ/kg

$$\text{COP} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{251.8 - 117.71}{278.27 - 251.8} = 5.07$$

12. Ans: (d)

Sol:



$h_1 = 241$ kJ/kg

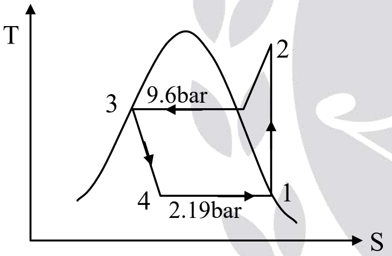
$h_2 = 286.69$ kJ/kg

$h_4 = h_3 = 95.47$ kJ/kg

$$\text{COP} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{\text{NRE}}{W_C} = 3.2$$

13.

Sol:



$h_3 = h_4 = 64.6$ kJ/kg , $h_1 = 195.7$ kJ/kg

$v_1 = 0.082\ \text{m}^3/\text{kg}$

$n = 1.13$

$\text{NRE (kW)} = 3.517 \times 15 = \dot{m}_r (h_1 - h_4)$

$\dot{m}_r = 0.402\ \text{Kg/sec}$

$$W_C(\text{kJ/kg}) = \frac{n}{n-1} P_1 v_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$= \frac{1.13}{1.13-1} \times 219 \times 0.082 \left[\left(\frac{9.6}{2.19}\right)^{\frac{1.13-1}{1.13}} - 1\right]$$

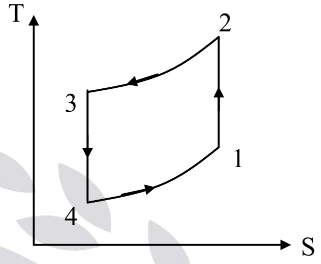
$= 28.92$ kJ/kg

$W_C(\text{kW}) = 0.402 \times 28.92 = 11.62$ kW

$$\text{COP} = \frac{\text{NRE}}{W_C} = \frac{15 \times 3.517}{11.62} = 4.54$$

14. Ans: (a)

Sol:



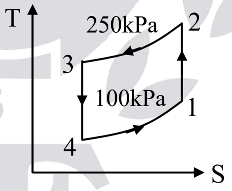
$T_3 = 308\text{K}$

$$T_4 = \frac{T_3}{(r_p)^{\frac{\gamma-1}{\gamma}}} = \frac{308}{\left(\frac{280}{80}\right)^{\frac{0.4}{1.4}}}$$

$T_4 = -58°\text{C}$

15. Ans: (b)

Sol:



For Helium, $\gamma = 1.67$

$\dot{m} = 0.2\ \text{kg/sec}$, $T_1 = -10^0\text{C} = 263$ K

$$\text{Pressure ratio, } r_p = \frac{P_2}{P_1} = \frac{250}{100} = 2.5$$

$$T_2 = T_1 \times (r_p)^{\frac{\gamma-1}{\gamma}} = 263 \times (2.5)^{\frac{0.67}{1.67}} = 379.84\text{K}$$

$$T_4 = \frac{T_3}{(r_p)^{\frac{\gamma-1}{\gamma}}} = \frac{293}{(2.5)^{\frac{0.67}{1.67}}} = 202.87\ \text{K}$$

$$W_C = \dot{m}C_P\left(T_2 - T_1\right)$$

$$= \dot{m}\frac{\gamma\overline{R}}{M(\gamma-1)}\left(T_2 - T_1\right)$$

$$= \frac{0.2\times1.67\times8.314}{4(1.67-1)}(379.84-263)$$

$$= 121 \text{ kW}$$

$$W_E = \dot{m}\frac{\gamma\overline{R}}{M(\gamma-1)}\left(T_3 - T_4\right)$$

$$= \frac{0.2\times1.67\times8.314}{4\times(1.67-1)}\times(293-202.87)$$

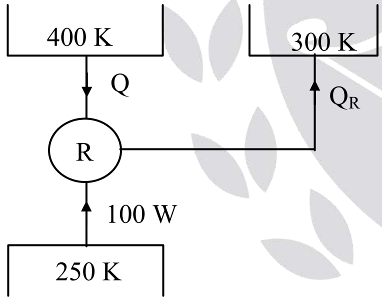
$$= 93.3 \text{ kW}$$

$$W_{net} = W_C - W_E$$

$$= 121 - 93.3 = 27.7 \text{ kW}$$

16.

Sol:



For minimum value of heat required

$S_{gen} = 0$

dS(reservoir at 400 K) + dS(reservoir at 250K) + dS(reservoir at 300K) + dS(working fluid) = 0

$$\frac{-Q}{400} - \frac{100}{250} + \frac{Q_R}{300} + 0 = 0 \text{ ……….. (i)}$$

$Q_R = 100 + Q$ ………… (ii)

Solve (i) and (ii)

Q = 80 W

17. Ans: (a)

Sol: As condenser pressure increases net refrigerating effect decreases and work of compression increases.

If condenser pressure is less pressure ratio is low work of compression is less and COP increases.

18. Ans: (d)

19. Ans: (b)

Sol: As evaporator temperature decreases work of compression increases and cop decreases $\frac{HP}{TR} = \frac{4.72}{COP}$ as COP decreases $\frac{HP}{TR}$ increases.

20. Ans: (c)

Sol: m_w (kg/sec) × C_{pw} × $(\Delta T)_w$ = NRE (kW)

$V_w \rho_w C_{pw} (\Delta T)_w$ = NRE (kW)

$$\frac{20}{3600}\times1000\times4.187\times\left(12-T_2\right) = 30\times3.517$$

$12 - T_2 = 4.54$

$\Rightarrow T_2 = 12 - 4.5 = 7.5°C$

21. Ans: (a)

22. Ans: (c)

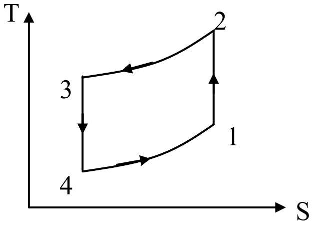
Sol: NRE = 300 − 150 = 150 kJ/kg = $h_1 = h_4$

WC = 330 − 300 = 30 kJ/kg = $h_2 - h_1$

$$(COP)_R = \frac{NRE}{WC} = \frac{150}{30} = 5$$

23. Ans: (a)

Sol: $T_3 = 300$ K, $T_4 = 180$ K



$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

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

$$= \frac{180}{300-180} = 1.5$$

24. Ans: (d)

25. Ans: (c)

Sol: Throttling process is isenthalpic process (h = c)

26. Ans: (c)

Sol: Subcooling increases net refrigerating effect and has no effect on work of compression

27. Ans: (b)

Sol: By using an expander temperature difference is more when compared to throttle valve which has no temperature difference for perfect gas.

Chapter- 13
Thermodynamic Relations

01. Ans: (b)

Sol: Clayperon equation is given by

$$\left(\frac{dP}{dT}\right)_h = \frac{(h_g - h_f)}{T_s(v_g - v_f)}$$

$$\therefore \ (v_g - v_f) = \frac{dT_s}{dP}\frac{(h_g - h_f)}{T_s}$$

02. Ans: (a)

Sol: Joule Thomson coefficient is

$$\mu_j = \left(\frac{dT}{dP}\right)_h$$

It is the constant enthalpy line in temperature pressure curve of real gases.

03. Ans: (c)

Sol:

(a) $(c_p - c_v) = -T\left(\frac{\partial V}{\partial T}\right)_P^2 \left(\frac{\partial P}{\partial V}\right)_T$

$\because \left(\frac{\partial P}{\partial V}\right)_T$ is always negative

$\therefore c_p - c_v > 0$

Hence, c_p is always greater than c_v.

(b) For an ideal gas

$$Pv = RT$$

$$\left(\frac{dP}{dv}\right)_T v + P = 0$$

$$\left(\frac{dP}{dv}\right)_T = -\frac{P}{V} \quad \text{-----(1)}$$

$$\left(\frac{dv}{dT}\right)_P = \left(\frac{R}{P}\right) = \left(\frac{v}{T}\right) \text{-----(2)}$$

From (1) and (2)

$$\therefore\ c_p - c_v = -T \times \frac{v^2}{T^2}\left(-\frac{P}{v}\right) = \frac{Pv}{T} = R$$

$\therefore\ c_p - c_v = R$

(c) $\left(\frac{\partial P}{\partial v}\right)_T$ is always negative.

$\left(\frac{\partial v}{\partial P}\right)_P^2$ is always positive

(d) For water (incompressible fluid)

$\therefore\ c_p \approx c_v$

04. Ans: (a)

Sol: Gibb's energy 'G' is given by

$G = H - TS$

05. Ans: (c)

06. Ans: (c)

Sol: Helmholtz function is given by

$H = U - TS$

07. Ans: (b)

Sol: Joule Thomson coefficient is

$\mu_j = \left(\frac{\partial T}{\partial P}\right)_h$ = slop of constant

Enthalpy line in on T-P diagram

08. Ans: (b)

09. Ans: (d)

10. Ans: (b)

Sol: Clapeyron's equation for dry saturated steam is given by

$$\left(v_g - v_f\right) = \left(\frac{dT_s}{dP}\right)_h \frac{\left(h_g - h_f\right)}{T_s}$$

11. Ans: (c)

12. Ans: (c)

Sol: $C_P = T\left(\frac{\partial S}{\partial T}\right)_P$

$C_V = T\left(\frac{\partial S}{\partial T}\right)_V$

$C_P - C_V = R$

13. Ans: (c)

14. Ans: (a)

15. Ans: (a)

Chapter- 14
Reciprocating Air Compressors

01. Ans: (b)

Sol: $n = 2$, $P_s = 1.5$ bar, $P_d = 54$ bar

Intercooler pressure, $P_i = \sqrt{P_s P_d}$

$$= \sqrt{54 \times 1.5}$$

$$\Rightarrow \quad P_i = 9 \text{ bar}$$

02. Ans: (a)

03. Ans: (a)

Sol: $\eta_v = 1 - C\left[\left(\frac{P_d}{P_s}\right)^{\frac{1}{n}} - 1\right]$

If clearance (C) is large volumetric efficiency (η_v) decreases hence volume flow rate decreases.

04. Ans: (c)

Sol: Mass of air in clearance volume has no effect on work done per kg of air.

05. Ans: (d)

Sol: Volumetric efficiency is given by

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

where,
C = clearance ratio,
P_2 = delivery pressure,
P_1 = suction pressure
n = index of expansion

06. Ans: (c)

Sol: $\eta_v = 1 - C\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]$

where,
C = clearance ratio,
P_2 = delivery pressure,
P_1 = suction pressure

07. Ans: (d)

Sol: Total work of 3-stages is given by

$$W = \frac{3n}{(n-1)} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{3n}} - 1\right]$$

08. Ans: (a)

Sol: $\eta_{Vol} = 1 + C - C\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}$; $P_1 V_1^n = P_2 V_2^n$

$$\eta_{Vol} = 1 + C - C\left(\frac{V_1}{V_2}\right) \; ; \quad \left(\frac{V_1}{V_2}\right)^n = \frac{P_2}{P_1}$$

$$\eta_{vol} = 1 + 0.05 - 0.05\left(\frac{0.04}{0.02}\right) = 0.95 \text{ or } 95\ \%$$

09. Ans: (b)

Sol: Advantages of multi-stage compression are

- Improved overall volumetric efficiency. If all compression were done in one cylinder the gas in the clearance volume would expand to a large volume before the new intake could begin. This results in a very low volumetric efficiency. By cooling the gas between the stages a much higher efficiency can be obtained.
- A reduction in work required per stroke, and therefore the total driving power.
- Size and strength of cylinders can be adjusted to suit volume and pressure of gas.
- Multi-cylinders give more uniform torque and better mechanical balance thus needing smaller flywheel.

10. Ans: (d)

Sol: $\eta_v = 1 - C\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]$

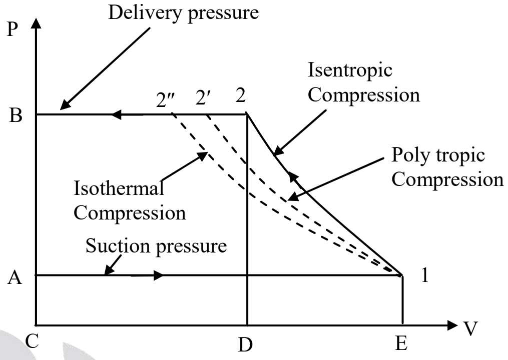
where, C = clearance ratio,

$\frac{P_2}{P_1}$ = pressure ratio

We can observe from the above expression that as C and $\frac{P_2}{P_1}$ increases η_v decreases.

11. Ans: (a)

Sol:



P-V representation of cycle in a reciprocating compressor

From the P.V. diagram we can see that work done is minimum when the compression process is isothermal.

12. Ans: (b)

13. Ans: (d)

Sol: Cooling of reciprocating compressor

1. increases volumetric efficiency
2. decreases work input

14. Ans: 3

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

$\frac{423}{300} = \left(\frac{P_2}{1}\right)^{\frac{1.25-1}{1.25}}$

$P_2 = 5.57$ bar

For optimum intercooling pressure ratios are same

$$\frac{P_2}{P_1}=\frac{P_3}{P_2}=\frac{P_4}{P_3}=\frac{P_{n+1}}{P_n}$$

$$\left(\frac{P_2}{P_1}\right)^n=\frac{180}{1}$$

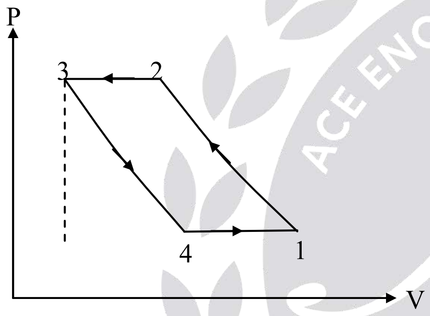
$(5.57)^n = 180$

$\Rightarrow\ n \approx 3.023$

$\Rightarrow\ n = 3$ stages.

15.

Sol:



Swept volume, $V_S = V_1 - V_3 = \frac{\pi}{4}\times D^2 \times L$

$$= \frac{\pi}{4}\times 0.2^2\times 0.3 = 9.42\times10^{-3}\,m^3$$

Clearance volume $= V_3 = 0.05 \times (V_1 - V_3)$

$= 4.71 \times 10^{-4}\ m^3$

$V_1 = V_S + V_3 = 9.89 \times 10^{-3}\ m^3$

$$\frac{V_4}{V_3}=\left(\frac{P_3}{P_4}\right)^{\frac{1}{n}}=\left(\frac{550}{97}\right)^{\frac{1}{1.3}}$$

$V_4 = 1.79 \times 10^{-3}$

Effective swept volume $= V_1 - V_4$

$= 8.1 \times 10^{-3}\ m^3$

$$\frac{P_aV_a}{T_a}=\frac{P_1\times(V_1-V_4)}{T_1}$$

$$=\frac{101.325\times V_a}{288}=\frac{97\times8.1\times10^{-3}}{293}$$

(i) $V_a = 7.622 \times 10^{-3}\ m^3$/cycle

$V_a = 7.622 \times 10^{-3} \times 500 = 3.81\ m^3$/min

(ii) Power required

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

$$=\frac{1.3}{1.3-1}\times97\times8.1\times10^{-3}\times\left[\left(\frac{550}{97}\right)^{\frac{1.3-1}{1.3}}-1\right]$$

$$= 1.676\,kJ/cycle$$

$$=1.676\times\frac{500}{60}=13.97\,kW$$

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

$$=1+0.05-0.05\times\left(\frac{550}{97}\right)^{\frac{1}{1.3}}$$

$= 86\%$

Chapter- 15
Fuels & Combustion

01. Ans: (d)

Sol: $2H_2 + O_2 \rightarrow 2H_2O$

2moles of H_2 + 1 mole of O_2 → 2 moles of H_2O

1 mole of H_2 + 1/2 mole O_2 → 1 mole H_2O

As volume of water is very less when compared to gas, change in volume is 3/2.

02. Ans: (c)

Sol: CO_2 → KOH - Pottasium hydroxide

CO → Cu_2Cl_2 – cuprous chloride

O_2 → Pyrogallic Acid.

03. Ans: (d)

Sol: Excess air is less in natural draught. Natural draught is due to temperature differences in chimney hence draught is less.

Artificial draught is utilized by using FD fans and ID fans.

04. Ans: (b)

Sol: About 40% excess Air is supplied for combustion.

Excess Air reduces temperature of air.

05. Ans: (a)

Sol: O_2 content in exhaust gas is high which indicates use of excess air.

06. Ans: (d)

Sol: CO_2 → KOH - Pottasium hydroxide

CO → Cu_2Cl_2 – cuprous chloride

O_2 → Pyrogallic Acid.

07. Ans: (b)

08. Ans: (c)

Sol: Hydrogen in fuel reacts with oxygen forms steam and heat is carried away by steam

$$LCV = HCV - \underset{\text{mass of steam}}{\underset{\downarrow}{m_S}} \times \underset{\text{Latent heat of steam}}{\underset{\downarrow}{(LH)}}$$

Heat carried by steam due to moisture in fuel is also responsible but that combination is not given.

09. Ans: (d)

Sol: $C + O_2 \rightarrow CO_2$

12Kg C + 32kg O_2 → 44kg CO_2

$$1\text{kg}\,C + \frac{8}{3}\text{kg}\,O_2 \rightarrow \frac{11}{3}\text{kg}\,CO_2$$

10. Ans: (d)

Sol: $CH_4 + 2\,(O_2 + 3.76\,N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$

$$AFR = \frac{m_a}{m_f} = \frac{2[2\times16+3.76\times28]}{1\times12+1\times4} = 17.16$$

11. Ans: (d)

Sol: It is a constant volume process (Control mass) and gases do not escape from the chamber.

LCV = HCV– 9 ×H_2 × latent heat of steam

Bomb calorimeter determines HCV of steam

Sometimes water in fuel and moisture in air are also considered as steam in addition to water formed due to hydrogen in fuel.

12. Ans: (c)

Sol: In pipette 1 → CO_2 absorbed

In pipette 2 → O_2 absorbed

In pipette 3 → CO absorbed

% CO_2 = 100 – 89 =11

% O_2 = 89 – 84 =5

% CO = 84 – 82 =2

13. Ans: (b)

Sol: Hydrometer → Specific gravity

Bomb calorimeter → Heating value of fuel

Reid Bomb → Vapor pressure

Orsat Apparatus → Composition of products of combustion

14. Ans: (a)

Sol: CO_2 → KOH - Pottasium hydroxide

CO → Cu_2Cl_2 – cuprous chloride

O_2 → Pyrogallic Acid.

15. Ans: (b)

Sol: In a separating calorimeter, pressure in Boiler and separator is same. Throttling calorimeter is constant enthalpy process.

Gas thermometer – constant volume process.

16. Ans: (a)

Sol: HCV takes into account when heat liberated by cooling of water vapor.

17. Ans: (b)

Sol: $2CO+a(O_2+3.76N_2)\rightarrow 2CO_2 + bN_2$

$a = 1$

$2b = 7.52\ a$

$b = 3.76a = 3.76\times 1 = 3.76$

$$AFR = \frac{1\times 4.76}{2} = 2.38$$

18. Ans: (a)

Sol: Deficit air causes CO formation.

19. Ans: (c)

Sol: 1 – 1.5 grams water is added to saturate internal atmosphere, thus ensuring that all water produced is liquid and removing the need to include enthalpy of vaporization in calculations.

Chapter- 16
IC Engines

01. Ans: (c)

Sol: Knock happens in later part of combustion for SI Engines and in early part of combustion for CI Engine.

02. Ans: (a)

Sol: Mix fuel and air and meter fuel are essential function of carburetor.

03. Ans: (a)

04. Ans: (d)

Sol: Pre combustion chamber – Combustion induced swirl.

Turbulent chamber – Compression swirl.

Open combustion chamber – Masked inlet valve ignition.

F – head combustion chamber – Spark ignition.

05. Ans: (d)

Sol: Speed Increases reduce detonation.

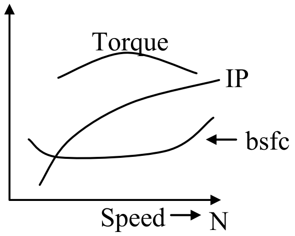
Slightly rich mixtures have high flame speeds which reduce detonation.

06. Ans: (a)

07. Ans: (a)

08. Ans: (d)

Sol:



09. Ans: (d)

Sol: At higher compression ratios phenomenon of knocking occurs.

10. Ans: (b)

Sol: IVO before TDC

IVC before BDC

If valve opening is less then volumetric efficiency decreases.

11. Ans: (d)

Sol: Iso-octane – Octane number 100

Normal – heptane – ‘0’ Octane number

12. Ans: (a)

13. Ans: (a)

Sol: p/p loop mep = 20 – (–15) = 35 kPa

Work mep = 1000 – 200 = 800 kPa

$(\text{work})_{\text{net}}$ mep = 800 – 35 = 765 kPa

14. Ans: (b)

Sol: At full load bsfc (Brake specific fuel consumption) is minimum.

Brake power increases directly with load.

15. Ans: (b)

Sol: Ignition delay should be high for SI Engine fuels higher the compression ratio higher the temperature.

16. Ans: (d)

Sol: Air injection increases cost, weight and reduces power output.

Highly viscous fuels can be used with Air injection.

17. Ans: (a)

Sol: Higher velocity at throat indicates higher pressure drop hence more fuel is admitted.

18. Ans: (a)

19. Ans: (c)

Sol: Volume of Air drawn $= \eta_{vol} \times \text{vol}$

$$= 0.88 \times 300 = 264 \text{ C.C}$$

20. Ans: (b)

21. Ans: (d)

Sol: Willans line test. A graph connecting fuel consumption (y-axis) and brake power (x-axis) at constant speed.

22. Ans: (b)

Sol: Increase in engine speed decreases time of combustion, but not proportionally. Hence spark is advanced.

Increase in engine speed, increases turbulence as well as flame speed. Effect of spark advance is not significant on flame speed.

23. Ans: (b)

Sol: Higher compression ratios lead to higher work outputs hence better mechanical efficiencies. High delay period results in knocking. Low delay period results in smooth combustion.

24. Ans: (b)

Sol: At high temperatures in SI engine

CO_2 absorbs heat (endothermic) forms CO + O_2 and peak temperature decreases.

H_2O absorbs heat (endothermic) forms H_2 + O_2 and peak temperature decreases.

In expansion stroke (CO + O_2) recombines to CO_2 ; liberating heat. (Exothermic reaction).

(H_2 + O_2) recombines to H_2O liberating heat. (Exothermic reaction).

25. Ans: (d)

Sol:

- Cold starting – Very rich mixture.
- Idling – Rich mixture. (avoid exhaust gas dilution problem)
- Cruising – Best economy mixture (save fuel)
- High Power – Slightly Rich mixture (10% Rich to prevent over heat of exhaust valve)

26. Ans: (b)

Sol: Thermal efficiency of gas turbine plant around 27% whereas Diesel engine plant is 35%.

Peak pressures in gas turbines 20 bar where as in IC Engine 40 – 60 bar. Peak temperatures in gas turbines 1100°C - 1200°C in IC Engines around 4000° C.

27. Ans: (c)

Sol: CI Engine efficiency 30 – 35%

SI Engine efficiency 22 – 28%

For same compression ratio SI is more efficient than CI

28. Ans: (d)

Sol: The rate of pressure rise and maximum pressure is lower compared to open chamber.

29. Ans: (d)

Sol: Rich mixtures are required at starting condition.

30. Ans: (d)

Sol: Aromatics are SI engine fuels have highest antiknock properties. Paraffins are CI engine fuels have high heating value because of larger number of Hydrogen atoms.

31. Ans: (b)

Sol: Calorific value Diesel fuel and thermal efficiency of Diesel engine are high when compared to SI cycle. Hence specific power output (kJ/kg) is high in diesel cycle. Diesel engine is stronger due to high pressure.

32. Ans: (a)

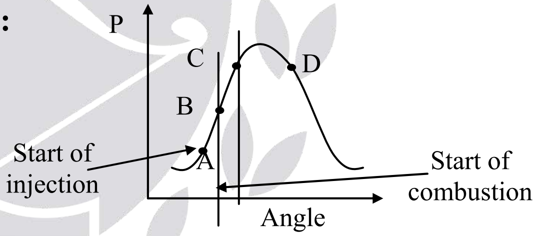
Sol: Over cooling results in slow engine warm up and high fuel consumption and overall efficiency decreases.

33. Ans: (d)

Sol: NO_x emissions are maximum at equivalence ratio 1.

34. Ans: (b)

Sol:



In diesel engine knock occurs at the beginning of combustion.

35. Ans: (c)

Sol: NO_x is the primary cause of photochemical smog chemical reaction of automobile exhaust and atmospheric air in presence of sunlight

NO_2 + Energy from sunlight $\rightarrow$ NO + O + Smog

$O + O_2 \rightarrow O_3$ at ground level is harmful to lungs and other biological tissues.

36. Ans: (a)

Sol: $IP = nB - \{(B_1 + B_2 \ldots.. + B_n)\}$

$= 2 \times 9 - (4.25 + 3.75)$

$= 18 - 8 = 10$ KW

$$\eta_{mech} = \frac{BP}{IP} = \frac{9}{10} = 0.9$$

37. Ans: (a)

Sol: The catalytic converter is called three way converter. Rhodium for converting NO_x to N_2, platinum, palladium for oxidation of HC and CO Oxygen liberated in reduction of NO_x is used for oxidizing HC and CO.

Rhodium promotes reaction of NO_x.

$NO + CO \rightarrow \frac{1}{2} N_2 + CO_2$

$2NO + 5CO + 3H_2O \rightarrow 2NH_3 + 5CO_2$

$2NO + CO \rightarrow N_2O + CO_2$

$NO + H_2 \rightarrow \frac{1}{2} N_2 + H_2O$

$2NO + 5H_2 \rightarrow 2NH_3 + 2H_2O$

$2NO + H_2 \rightarrow N_2O + H_2O$

Cerium oxide causes water gas shift reduces carbon monoxide by using water vapor as oxidant instead of oxygen.

38. Ans: (d)

Sol: Engine knock can be caused by surface ignition (due to local hot spots). Worst kind of surface ignition is pre ignition.

Ethylene dibromide is a seavenging agent for lead deposits.

39. Ans: (a)

Sol: A number of different impurities contained in fuel lubricating oil and air poison the catalyst head; sulphur from fuels; zinc; phosphorous, Antimony; calcium magnesium from oil additives

40. Ans: (a)

Sol: Supercharging increasing density of air is best suited for CI engine diesel knock is suppressed due to supercharging

41. Ans: (c)

Sol: As piston approaches TDC the gas mixture occupying is volume at outer radius forced radially inwards as the outer volume is reduced to zero. The radial inward motion of gas mixture is called squish.

42. Ans: (b)

Sol: Last charge is responsible for knock in SI and early charge is responsible for knock in CI.

43. Ans: (b)

Sol: Because of high compression ratio CI engines have high efficiency than SI

44. Ans: (b)

Sol: Period measured in degree of cam rotation during which contact points remain closed is dwell.

Dwell angle must be sufficiently large to allow magnetic saturation of primary coil.

Too small a dwell angle results in poor spark and misfiring due to lower secondary voltage

Large dwell angle burns the condenser due to over saturation of windings

As number of cylinders increase dwell decreases.

45. Ans: (b)

Sol: Exhaust gas recirculation is done by inducting some of exhaust flow into intake after Throttle (30% of total intake). It reduces maximum Temperature; reduces NO_x ; but increases HC emissions and lowers thermal efficiency.

46. Ans: (c)

Sol: Octane number is percentage by volume of isooctane in isooctane n – heptane mixture

47. Ans: (d)

Sol: Power generated in Two stroke cycle is greater than four stroke because for every revolution there is one power stroke.

48. Ans: (a)

Sol: Time of injection $= \frac{\theta}{360} \times \frac{60}{N}$

$$1.5 \times 10^{-3} = \frac{\theta}{360} \times \frac{60}{2000}$$

$$\theta = 18^0$$

49. Ans: (b)

Sol: $\eta_{Br.thermal} = \dfrac{BP(kW) \times 3600}{\dot{m}_f\left(\frac{kg}{hr}\right) \times C_V\left(\frac{kJ}{kg}\right)}$

$$0.3 = \frac{10 \times 3600}{\dot{m}_f \times 40{,}000}$$

$$\dot{m}_f = 3 \text{ kg/hr.}$$

50. Ans: (d)

Sol: Palladium → CO

Platinum → HC

Rhodium → NO_x

51. Ans: (c)

Sol: $\eta_{mech} = \dfrac{BP(kW)}{IP(kW)}$

$$0.8 = \frac{40}{IP(kW)}$$

$$IP(kW) = \frac{40}{0.8} = 50kW$$

FP = IP – BP = 50 – 40 =10kW

BP(kW) at 50% load = $40 \times 0.5 = 20$ kW

$$\eta_{mech} = \frac{BP}{BP + FP} = \frac{20}{20 + 10} = 0.67$$

52. Ans: (c)

Sol: Supercharging is best in CI Engines. Supercharging promotes knock in SI.

53. Ans: (c)

Sol: In T head knock is high. Spark plug is biased to exhaust valve.

54. Ans: (a)

Sol: Idling jet provides rich fuel at start.

55. Ans: (b)

Sol: Maximum NO_X emissions occurs at AFR of around 17 or equivalence ratio 0.95 at which high temperature is required for NO_X emission.

56. Ans: (b)

Sol: $$\eta_{mech} = \frac{BP}{IP} = \frac{BP}{BP+FP}$$

$$0.8 = \frac{BP}{BP+25}$$

$\therefore$ BP = 100 kW

IP = BP + FP = 100 +25 = 125 kW

Where, IP = Indicated power,

BP = Brake power,

FP = Frictional power.

57. Ans: (a)

58. Ans: (a)

59. Ans: (a)

60. Ans: (c)

Sol: Cold starting - 3

Idling - 10

Cruising - 16

Maximum power - 13

61. Ans: (b)

Sol: $$\eta_{Th} = \frac{W_{net}}{m_f \times cv} = \frac{80}{\frac{1}{80}\times 40000} = 0.16 \text{ or } 16\%$$

62. Ans: (c)

Sol: NO_x is primary cause of photochemical smog.

NO_2 + Energy from sunlight → NO + O + Smog.

$(O+O_2) \rightarrow O_3$ Ozone at ground level is harmful to human beings.

63. Ans: (c)

Sol: Spark plug is biased to Exhaust valve so that exhaust valve stops acting as a separate spark plug.

64. Ans: (b)

Sol: Stage one time = 1×10^{-3} sec

$$t = \frac{\theta}{360}\times\frac{60}{N}$$

$$1\times10^{-3} = \frac{\theta}{360}\times\frac{60}{1000}$$

$$\theta = 6°$$

Stage one time in the second case is also same.

$$t = 1\times10^{-3} \text{ sec}$$

But the speed is 2000 r.p.m

$$t = 1\times10^{-3} = \frac{\theta_1}{360}\times\frac{60}{N} = \frac{\theta_1}{360}\times\frac{60}{2000}$$

$$\theta_1 = 12°$$

Spark advance = $\theta_1 - \theta_2 = 12 - 6 = 6°$

65. Ans: (c)

Sol: High compression gives high NO_X because of high temperature and pressures.

Reducing compression ratio will decrease NO_X.

Exhaust gas recirculation reduces NO_X.

Using 5% lean mixtures gives high NO_X

66. Ans: (c)

Sol: Presence of O_2 in exhaust indicates excess air is used for combustion.

67. Ans: (c)

Sol: To find friction power of multi cylinder SI engine and determine mechanical efficiency.

68. Ans: (a)

Sol: As speed decreases knocking reduces in CI engine.

69. Ans: (b)

Sol: In Air injection system fuel is forced into cylinder by means of compressed air.

70. Ans: (a)

Sol: Higher compression ratios lead to high pressures and temperatures and knocking.

71. Ans: (c)

Sol: Heat loss area

$$= 2\times\frac{\pi}{4}d^2 + \pi dL = \frac{\pi}{2}\times 4 + \pi\times 4 = 6\pi$$

72. Ans: (c)

73. Ans: (d)

Sol: Power output of S.I engine per cubic inch > Power output C.I engine per cubic inch

Specific Power output (kJ/kg) in C.I engine > specific power output of S.I engine

SI engine 0.5 hp/cubic Inch.

CI engine 0.3 hp/cubic Inch

SI engines use higher air fuel ratio and at high speeds gives higher outputs.

CI engines use leaner AFR

74. Ans: (c)

Sol: Highest useful compression ratio (HUCR) is used for SI engine

CI engine compression ratio range is 12-20. Generally it is around 16.

Even in CI engine, high compression ratio is possible for high thermal efficiency.

75. Ans: (c)

Sol: The spray cone angle of single orifice nozzle is 15° which is less than Pintle type of nozzle which has 60°. Hence wall impingement of fuel particles is less in single orifice nozzles.

76. Ans: (c)

Sol: Induction swirl is done by

(i) Masked inlet valve

(ii) Tangential inlet port

(iii) Casting a lip

Chapter- 17
Steam Nozzles

01. Ans: (c)

Sol: Due to friction there is irreversibility and velocity falls with increase in entropy and dryness fraction.

02. Ans: (a)

03. Ans: (d)

Sol: Supersonic nozzle is diverging.

Subsonic diffuser is diverging.

De-laval Nozzle is convergent-divergent supersonic nozzle .

04. Ans: (a)

Sol: Supersonic diffuser is converging in shape.

05. Ans: (b)

Sol: Critical pressure ratio = $\left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$

06. Ans: (b)

Sol: Converging-Diverging nozzle is a supersonic nozzle.

Subsonic diffuser diverges and subsonic nozzle converges.

07. Ans: (a)

Sol: $\eta = \frac{(w)_{s=c}}{w_{act}} = \frac{(\Delta H)_s}{(\Delta H)}$

08. Ans: (a)

09. Ans: (b)

Sol: $\left(\frac{P_c}{P}\right) = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$

$$= \left(\frac{2}{1.135+1}\right)^{\frac{1.135}{0.135}} = 0.577$$

10. Ans: (a)

Sol: In a Delaval Nozzle in convergent section flow is always subsonic

11. Ans: (b)

Sol: $V_e = 44.72\sqrt{(\Delta h)}$

$$= 44.72\sqrt{400} = 894.4 \text{ m/sec.}$$

$\Delta h \rightarrow \frac{kJ}{kg}$

12. Ans: (a)

13. Ans: (c)

Sol: at critical pressure ratio flow is maximum and at throat velocity is sonic

14. Ans: (a)

Chapter- 18
Steam Turbines

01. Ans: (a)

Sol: All the three methods are used.

By pass governing is for producing additional power during peak loads.

02. Ans: (a)

Sol:

- De laval turbine - simple impulse turbine
- Rateau Turbine: Pressure compounded steam turbine
- Curtis - Turbine velocity compounded steam turbine
- Parson-simple reaction steam turbine

03. Ans: (c)

Sol: In compounding high speeds of rotors are brought down to normal levels.

04. Ans: (c)

Sol: Blade speed $= U = \frac{\pi DN}{60}$

As power generated in the IIIrd stage is more than I and II stage

$U_3 > U_2 = U_1$

$D_3 > D_2 = D_1 \quad (\because \text{N is same for all stages})$

05. Ans: (c)

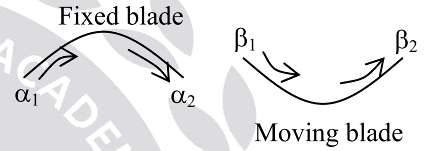
Sol: $\frac{U}{V_1} = 0.42$

$$V_1 = \frac{U}{0.42} = \frac{\frac{\pi DN}{60}}{0.42}$$

$$= \frac{\pi \times 1.2 \times 3000}{60 \times 0.42} = 450\ m/\text{sec}$$

06. Ans: (b)

Sol:



Exit of fixed blade = Exit of moving blade ($\alpha_2 = \beta_2$)

Inlet of fixed blade = Inlet of moving blade. ($\alpha_1 = \beta_1$)

07. Ans: (c)

Sol: Steam passages are reduced in nozzle governing.

08. Ans: (a)

Sol: Higher moisture at turbine exhaust causes Corrosion and Erosion

09. Ans: (c)

10. Ans: (c)

Sol: Ljungstrom turbine is steam turbine in which flow is in radial direction from inside to the outside and consists of two halves that rotate against each other.

11. Ans: (a)

Sol: $\frac{U}{V} = \cos\alpha. \Rightarrow V = \frac{320}{\cos 30} = \frac{640}{\sqrt{3}}\frac{m}{s}$

12. Ans: (a)

Sol: Impulse turbine blades are delaval blades which are thick at centre and thin at edges.

13. Ans: (a)

Sol: Pressure compounding.
Velocity compounding.
Pressure and Velocity compounding.

14. Ans: (a)

Sol: In throttle governing due to restriction of passage in the valve, steam is throttled and leads to significant pressure loss.

15. Ans: (a)

Sol: The speed of a turbine is always maintained in the range of 3000 ± 60 rpm only 2% variation from base speed is permitted. Control is done by regulating flow of steam.

16. Ans: (b)

Sol: 1 Simple impulse stage = 2 Reaction stages
1Curtis stage = 8 Reaction stages for same power out put.

17. Ans: (d)

Sol: Power $= F_T \times V$

$50\text{ kW} = F_T \times 400$

$$F_T = \frac{50 \times 1000}{400} = 125\text{ N}$$

18. Ans: (b)

Sol: Volume flow rate (m^3/sec) = $\pi D_m h V_f$

D_m = Mean diameter of blade

h = height

V_f = Velocity of flow

$5.4 = \pi \times 1.8 \times h \times 49$

$$h = \frac{5.4}{\pi \times 1.8 \times 49} = \frac{3}{154}\text{ m} = 2\text{ cms}$$

19. Ans: (a)

Sol: Continuous pressure drop in both fixed and moving blades.
Enthalpy drops by equal amounts. Hence 50% reaction turbine.

20. Ans: (b)

Sol: For pure reaction turbines enthalpy drop is only in moving blades which are difficult to construct.

21. Ans: (c)

Sol: Variation in maximum speed ratio exists.

(Δh) 50% : $(\Delta h)_{SIS}$: $(\Delta h)_{curtis}$
1 : 2 : 8

22. Ans: (b)

Sol: (Disc friction loss + scavenges loss) is called as windage loss

DFL $\propto (D^2 V^3)$

23. Ans: (c)

Sol: 50% Reaction – Parson

Two row Velocity compounded – Curtis

Simple impulse stage – De Laval

Pressure compounded – Rateau

24. Ans: (a)

Sol: Enthalpy drop in moving blades is 50% of enthalpy drop in stage. Symmetrical blades are used.

25. Ans: (b)

Sol: Velocity compounding and simple impulse stages are generally high pressure stages. They are used to reduce length of turbine.

Tip leakage occurs in reaction stages through clearance tip of blade and casing, due to pressure difference across the blades.

Tip leakage can be reduced by decreasing the clearances. The clearance between blade tip and turbine casing is 0.5 mm

26. Ans: (b)

Sol: High pressure stages are generally Curtis and simple impulse stages

27. Ans: (a)

Sol: In a 2 – row Curtis stages $\frac{1}{4}$ of total work is done in last stage.

In a 3 – row Curtis stage $\frac{1}{9}$ of total work is done in last stage

As number of stages increase work done in last stage decreases.

28. Ans: (a)

Sol: Due to throttling heat drop reduces and steam flow rate decreases

29. Ans: (b)

Sol: Deaerators are used in steam power plants

Inverted T – attachment is for blades of steam turbine.

Laybrinth – sealing system.

Anticipators gear- Turbine governing

30. Ans: (a)

Sol: Change in KE of steam = Work Done

$$\frac{1}{2}m\left(V_2^2 - V_1^2\right) = \text{Work}$$

$$\frac{1}{2}\times 1\left(30^2 - 10^2\right) = 400\text{Nm}$$

31. Ans: (c)

Sol: $(\Delta h)_R = 2.38\,\text{kJ/kg}$

$(\Delta h)_S = 4.62$ kJ/Kg.

$$DR = \frac{(\Delta h)_R}{(\Delta h)_R + (\Delta h)_S}$$

$$= \frac{2.38}{2.38 + 4.62} = 0.34$$

32. Ans: (b)

33. Ans: (a)

Sol: High pressure stages are generally impulse type like simple impulse stage or 2 Row – Velocity compounding (Curtis stage) as it will reduce length of Turbine.

34. Ans: (d)

Sol: Throttle governing is used for small medium and large plants.

35. Ans: (d)

36. Ans: (d)

Sol: $W = U^2$

37. Ans: (d)

Sol: As pressure drop is gradual in both fixed and moving blades it is reaction turbine.

38. Ans: (c)

Sol: Single stage impulse Turbines is Delaval Turbine and has a speed of 30,000 rpm.

39. Ans: (b)

Sol: In super saturated flow steam is in an unnaturally dry state at 97% decline.

40. Ans: (a)

Sol: In pressure compounding losses are less hence high efficiency.

41. Ans: (c)

42. Ans: (b)

Sol:

- In modern steam turbines, a velocity compounded stage is generally used in first stage followed by pressure compounding. The use velocity compounding reduces the length of the rotor i.e., the number of stages required and hence cost of rotor significantly, at the expense of some loss in efficiency.
- Tip leakage occurs in reaction stages through the clearance between outer periphery of moving blades and the casing because of pressure difference across the blades. In high pressure region of reaction stage tip leakage occurs due to higher pressure difference.

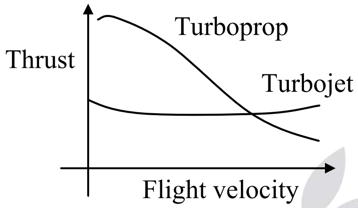
43. Ans: (b)

Sol: A steam turbine in which a part of steam after expansion is used for process heating and remaining steam is further expanded for power generation is pass out turbine.

Chapter - 19
Jet Propulsion & Rocket Engine

01. Ans: (d)

Sol:



02. Ans: (a)

Sol:

	Sp. impulse	**Jet speed**
LiqO_2 + liq H_2	360	12000
LiqO_2 + C_2H_5OH	245	8150
LiqO_2 + gasoline	235	8100

03. Ans: (d)

Sol: Turboprop < 800 kmph

Turbojet > 800 kmph.

At high speeds propeller efficiency falls.

04. Ans: (b)

Sol: Rockets carry their own supply of Oxygen.

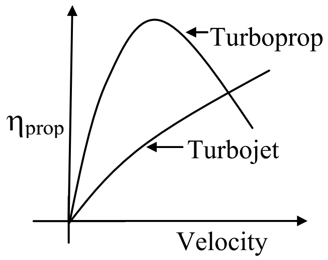
05. Ans: (b)

Sol: Propulsive efficiency of rocket

$$=\frac{2\frac{V_0}{V_1}}{1+\left(\frac{V_0}{V_1}\right)^2}$$

06. Ans: (b)

Sol:



07. Ans: (c)

Sol: Reversible adiabatic expansion is done in nozzle which gives higher velocity to exhaust gases.

08. Ans: (a)

Sol: In turboprop designed is modified by additional stages which produce more power. Fuel is economized. Overall efficiency is more when compared to turbojet.

09. Ans: (a)

Sol: Turbofan or bypass jet engine give high propulsive efficiency and better fuel economy and low exhaust velocity.

10. Ans: (c)

11. Ans: (b)

Sol: $\eta_{propulsion}=\dfrac{2V_e\,V_0}{V_e^2+V_0^2}$

$$=\frac{2\times2700\times1350}{(2700)^2+(1350)^2}$$

$$=\frac{1}{1+\left(\frac{1350}{2700}\right)^2}=\frac{1}{1+\frac{1}{4}}=\frac{4}{5}\text{ or }80\%$$

12. Ans: (d)

Sol: $\eta_P = \dfrac{2V_1}{V_e + V_1}$

V_1 = velocity of aircraft, V_e = Jet velocity

$$\eta_P = \frac{2\times900\times\frac{5}{18}}{250+500} = \frac{500}{750} = 0.667$$

13. Ans: (a)

Sol: Turbo prop has higher efficiency at low and medium speeds. At high speeds, efficiency falls.

14. Ans: (b)

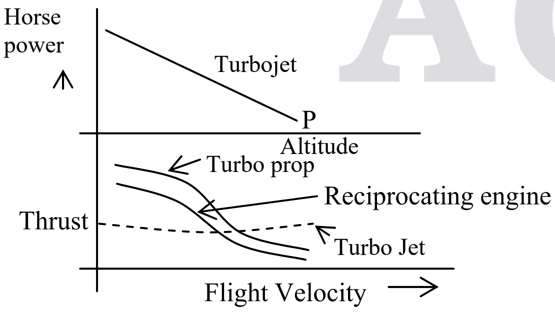
Sol: Turbine output operates compressor and drives the vehicle 20% expansion in nozzle gives thrust.

15. Ans: (b)

Sol: Turbine work is used to operate compressor and auxiliaries $\dfrac{W_T}{W_C}$ is slightly more than one.

16. Ans: (c)

Sol:



17. Ans: (b)

Sol: After burning is by injecting fuel into exhaust gases, which increases the thrust.

18. Ans: (b)

Sol: Specific impulse is defined as thrust produced per unit weight rate of propellant consumption.

It is desirable to use propellants with greatest possible specific impulse as this allows greater useful load to be carried for a given over all weight of rocket.

19. Ans: (d)

Sol: $(\text{Turbo prop})_{\text{velocity}} < 800$ kmph

$(\text{Turbo jet})_{\text{velocity}} > 800$ kmph

$(\eta_{\text{prop}})_{\text{Turbo prop}} > (\eta_{\text{prop}})_{\text{Turbojet}}$

at < 800 Kmph,

Thrust power = T.V,

Where T = Thrust,

V = Flight velocity

Velocity of Turbo prop is less than turbo jet for equal thrust

$\therefore$ $(\text{Thrust power})_{\text{Turbo prop}} < (\text{Thrust power})_{\text{Turbojet}}$

(i) The turboprop can operate economically over a wide range of speeds ranging from low speed where pure jet engine and rockets is uneconomical to high speed of about 800kmph.

(ii) In turbo prop engine power to weight ratio is 4 times less than that of turbojet engine.

(iii) For the same thrust, the turbine in the turbo prop aircraft is larger than in the turbo jet aircraft.

20. Ans: (a)

Chapter - 20
Centrifugal Compressor

01. Ans: (a)

Sol: $\beta > 90^0$ Forward curved

$\beta < 90^0$ Backward curved

$\beta = 90^0$ Radial Blades

02. Ans: (b)

Sol: Discharge $\propto D^3 \propto N$

Power $\propto D^5 \propto N^3$

Pressure head $\propto D^2 \propto N^2$

03. Ans: (c)

Sol: $\beta_2 > 90^0$ for forward curved blades.

Angle between peripheral velocity and relative velocity must be $> 90^0$.

04. Ans: (b)

Sol: Energy is transferred to the fluid in impeller, thus stagnation pressure rise in a centrifugal compressor stage takes place only in the impeller.

05. Ans: (a)

Sol: Head is high for forward curved blades for same discharge.

06. Ans: (c)

Sol: Backward curved blades have high efficiency and gives stable performance.

07. Ans: (a)

Sol: Low pressure ratios.

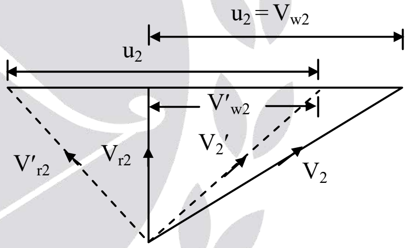
08. Ans: (a)

Sol: For centrifugal compressor constant velocity of flow no whirl at outlet.

$$DR = 1 - \frac{V_{W2}}{2U_2}$$

09. Ans: (c)

Sol:



Dotted line is with slip and solid line is without slip

$$\text{Slip} = \frac{V'_{w2}}{V_{w2}}$$

10. Ans: (c)

Sol: Pressure increases in impeller due to centripetal acceleration and diffuser converts high velocity air to low velocity air with increase in pressure because of centrifugal as well as diffusing action.

11. Ans: (c)

Sol: Pressure coefficient $= \dfrac{\text{isentropic work}}{\text{Eulers work}}$

12. Ans: (c)

Sol: $w = \mu v^2 = \dfrac{0.9 \times 400 \times 400}{1000} = 144\, kJ$

13. Ans: (b)

Sol: Centrifugal compressors run at high speeds have low pressure ratios and high discharges.

14. Ans: (a)

Sol: Tip of inducer eye is the point where highest inlet relative Mach number occurs attention is paid to inducer eye tip diameter. For mass flow rate and impeller speed d_t is chosen to get minimum relative mach number. To further reduce mach number (IGV) are used.

IGV – Inlet Guide Vanes . penalty for (IGV) is reduction in energy transfer in impeller.

15. Ans: (a)

Sol: Power = u^2

$$\left(\frac{\pi DN}{60}\right)^2 = \left(\frac{\pi \times 0.45 \times 7200}{60}\right)^2$$

$= 28{,}779$ W/kg/s

$= 28.78$ kW/ kg/s

16. Ans: (c)

Sol: At choking condition mass flow rate is maximum hence statement (3) is not correct

17. Ans: (c)

Sol: Choking is maximum discharge.

Separation of flow is stalling, hence reason is not correct.

Chapter - 21
Axial flow Compressor

01. Ans: (a)

Sol: $$W_1 = \frac{m}{m-1}.p_1v_1\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$W_2 = \frac{n}{n-1}p_1v_1\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$\frac{W_1}{W_2} = \frac{m(n-1)}{n(m-1)}$$

02. Ans: (c)

Sol: Low frontal Area less drag

03. Ans: (b)

Sol: Separation of flow is called stalling,complete breakdown of steady through flow is called surging.

Surging effects whole machine, stalling is local phenomenon.

04. Ans: (a)

05. Ans: (b)

Sol: As angle between U_2 and Vr_2 is 90^0 at exit it is having radial blades.

06. Ans: (c)

Sol: Back ward curved blades consumes less power.

In axial flow compressors centrifugal effect is zero.

07. Ans: (b)

Sol: $DR = 1 - \frac{V_{W2}}{2u_2}$;

$$= 1 - \frac{1}{4} = 0.75$$

$$V_{W2} = \frac{U_2}{2}$$

08. Ans: (d)

Sol: Separation of flow from blade surfaces is called stalling.

09. Ans: (c)

Sol: Radial inlet and as angle between U_2 and Vr_2 is obtuse at exit it is forward curved blades.

10. Ans: (a)

Sol: Avogadro’s law is equal volume of all gases under similar conditions of temperature and pressure have equal number of molecules.

11. Ans: (a)

12. Ans: (b)

Sol: Axial flow compressors have low frontal Area.

13. Ans: (c)

14. Ans: (d)

Sol: For symmetrical blading $(\Delta h)_{drop}$ is equal.

15. Ans: (d)

Sol: Stalling occurs at low mass flow rates and large values of incidence flow separation occurs on suction side which is called positive stall.

Negative stall is due to separation of flow occurring large pressure side due to large values of negative incidence.

16. Ans: (d)

Sol: Polytropic efficiency concept is used in Axial flow compressors.

Polytropic efficiency depends on pressure ratio.

17. Ans: (c)

18. Ans: (c)

Sol: Degree of Reaction $= \frac{(\Delta h)_{rotor}}{(\Delta h)_{Stage}}$

$$= \frac{(\text{Pressure rise})_{\text{rotor}}}{(\text{Pressure rise})_{\text{stage}}}$$

Chapter - 22
Air Conditioning

01. Ans: (a)

Sol: Frost is an insulator.

02. Ans: (c)

Sol: Exchange of heat between man and environment **M–W = Q+S**

M→ Metabolic Rate

W→ Work done by man

Q→ Convective, Radiative evaporative heat losses

S→ Rate of heat Storage.

03. Ans: (d)

Sol: Hydraulic mean diameter, $D = \frac{4A}{P}$,

P = perimeter

A = cross-sectional area.

For rectangular duct $D = \frac{2ab}{a+b}$

04. Ans: (b) & (a) both are correct.

05. Ans: (b)

Sol: Frictional pressure drop per unit length of duct maintained is constant.

06. Ans: (a)

Sol: In heavy work environment heat dissipated is high and perspiration is high.

07. Ans: (c)

Sol: Fin spacing is more, contact is less hence high BPF

number of tube rows are less contact is less, hence high BPF.

Opposite phenomenon for low BPF.

08. Ans: (b)

Sol: Effect of fan is to cause comfort by evaporation and convection

09. Ans: (d)

Sol: SHL (kW) = $mC_{Phs}\,dt$

$$= \frac{\rho V}{60} Cp_{hs} dt$$

$$= \frac{1.2 \times 3 \times 10}{60 \times 60} \times 1.0 \times 20$$

$$= 1.0216 = 0.2 \text{ kW}$$

10. Ans: (c)

Sol: If BPF of a single row coil is X then the BPF of a coil n rows deep is X^n.

$(\text{BPF})_{3 \text{ row coil}} = X^n$

$(0.7)^3 = 0.343$

11. Ans: (c)

Sol: Equal friction method the frictional pressure dropper unit length is maintained constant velocity in main duct is selected from sound level considerations.

Velocity reduction method, main duct design is similar to equal friction method. Arbitrary reduction in velocity is done down the stream considerable practical experience is required for design.

High velocity duct/pipe system (1800 rpm) are used for Air conditioning Aircraft

Static regain method static pressure remains constant through out the duct. Friction and dynamic pressure losses are compensated by velocity loss.

12. Ans: (c)

Sol: $\text{RSHF} = \dfrac{\text{RSH}}{\text{RSH} + \text{RLH}}$

$$0.75 = \frac{\text{RSH}}{100}$$

$$\text{RSH} = 75\,\text{kW}, \ \text{RLH} = 25\,\text{kW}$$

$$\text{RLH} = 50 \times \dot{V}(\Delta\omega)$$

$$25 = 50 \times 100 \times (\omega_1 - \omega_2)$$

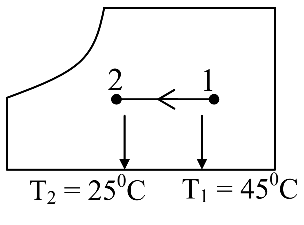
$$(\omega_1 - \omega_2) = \frac{25}{100 \times 50} = \frac{1}{200} = 0.005$$

$$0.01 - \omega_2 = 0.005$$

$$\omega_2 = 0.005$$

13. Ans: (d)

Sol:



$$\text{SHL (kW)} = \frac{\rho V}{3600} \times C_p \times (\Delta T)$$

$$= 1.2 \times \frac{20 \times 30 \times 5}{3600} \times 1.02 \times (45 - 25)$$

$$= 20.4 \text{ kW}$$

One air change per hour means volume of air is turned out only once in one hour and volume of room is multiplied with one

14. Ans: (c)

Sol: Comfort depends on Air velocity; humidity and purity

15. Ans: (d)

Sol: Energy balance equation for human comfort is given by M–W = Q+S

16. Ans: (d)

Sol: $\text{RSHL} = 0.0204\ (\dot{V})\ (\Delta T)$

$$= 0.0204 \times 1000 \times (25\text{-}15)$$

$$= 204 \text{ kW}$$

$\text{RLHL} = 50\ (\dot{V})\Delta\omega$

$\dot{V}$ is in $\frac{m^3}{\min}$

$$= 50 \times 1000\ (0.01 - 0.007)$$

$$= 150 \text{ kW}$$

17. Ans: (a)

Sol: SHL (kW) = 0.0204 × (cmm)× (ΔT)

cmm = flow rate of air interms of cubic meters of air per minute.

$$\text{SHL} = 0.0204 \times \left(\frac{20 \times 30 \times 4}{60} \times 1\right) \times (40 - 25) \text{ kW}$$

$$= \frac{734.4}{60} = 12.24 \text{ kW}$$

18. Ans: (b)

Sol: $m_r\,(\text{kg/sec})(h_1 - h_4)\left(\frac{\text{kJ}}{\text{kg}}\right) = \text{NRE}\,(\text{kW})$

$$\frac{420}{60}(X - 40) = 100 \times 3.517$$

$\Rightarrow$ X = 90 kJ/kg.

19. Ans: (b)

Sol: $\text{RSHF} = \frac{\text{RSH}}{\text{RTH}} = \frac{50}{50 + 50} = 0.5$

20. Ans: (b)

Sol: In winter body gets accustomed to lower temperatures.

21. Ans: (a)

Sol: For electrical resistance heating, heat supplied equal to the work done.

Incase of heat pump

Heat supplied = work done × COP

As COP > 1 (for heat pump)

Heat supplied > Work done.

22. Ans: (b)

Sol: Definition of effective temperature.

23. Ans: (a)

Sol: Closest values to effective temperature.

Chapter - 23

Boilers

01. Ans: (a)

Sol: Economizer is in between superheat / reheater and Air preheater.

02. Ans: (a)

Sol: Air pre-heaters utilize some of the energy left in the flue gases before exhausting them to the atmosphere. Preheating the air saves fuel that would otherwise be used for that heating.

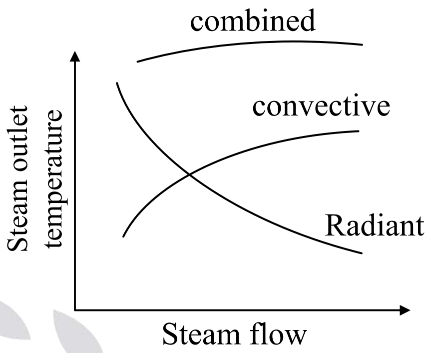
The air is heated from forced draft outlet temperatures to higher temperature.

The fuel savings are nearly directly proportional to the air temperature rise in the pre-heater.

03. Ans: (a)

04. Ans: (c)

Sol: In Radiant superheater the heat transfer is accomplished by radiation. Radiation heat transfer is proportional to $T_f^4 - T_w^4$, where T_f and T_w are the flame and tube wall absolute temperatures respectively. Because T_f is not strongly dependent on load, the heat transfer per unit mass flow of steam decreases as the steam flow increases. Thus an increase in steam flow due to an increased load demand would result in a reduction in exit steam temperature.



05. Ans: (a)

06. Ans: (b)

Sol: Safety valve is boiler mounting.

07. Ans: (a)

08. Ans: (d)

Sol: Boiler mountings protect the boiler.

09. Ans: (a)

Sol: As heat recovery is possible from exhaust gases; efficiency increases.

10. Ans: (a)

Sol: Water wall absorbs heat by radiation

Radiant energy $\propto \left(T_g^4 - T_w^4\right)$

$T_g \rightarrow$ Gas Temperature K

$T_w \rightarrow$ Wall Temperature K

11. Ans: (d)

Sol: Exhaust gas flows through super heater; Economizer; Air preheater; ID Fan; Chimney.

12. Ans: (d)

Sol: Benson boiler

- Water tube
- Forced circulation
- Oil
- Steam throttled to 137.3 bar to reduce erosion of blades due to water formation.
- Thermal η = 90%
- No drums

13. Ans: (b)

Sol: Feed water is heated in Economizer by using hot gases coming out of super heater.

14. Ans: (b)

Sol: Lancashire → Horizontal straight tube, fire tube boiler

Benson → High pressure boiler

Stirling → Bent tube, water tube boiler

Babcock and Wilcox → Horizontal straight tube, water tube boiler

15. Ans: (b)

Sol: Low combustion temperatures formation of NO_x is less. Dolomite and lime stone react with SO_2 and forms sulphates reduces SO_2 emissions.

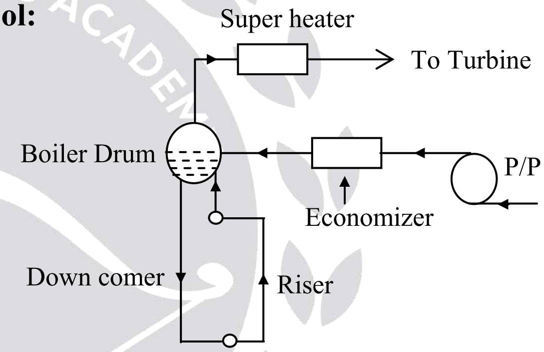
Higher Thermal efficiency, Low excess Air

16. Ans: (b)

Sol: Combustion chamber → super heater → Reheater → Economizer → Air preheater → Electrostatic precipitator → ID Fan → Stack.

17. Ans: (a)

Sol:



18. Ans: (b)

Sol: Fire tube Boilers operate upto 2 MPa pressure only.

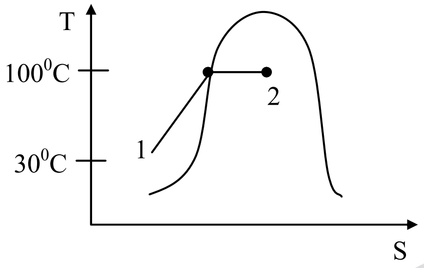
Water tube boilers operate upto 170 – 180 bar or greater than 222 bar.

As anything subjected to high temperature for long duration results in creep. Hence, the second statement is not a comparison but only with respect to fire tube boiler. Hence, answer is (b). Water tube boilers also fail by creep due to high pressures and temperature.

19. **Ans: (c)**

20. Ans: (c)

Sol:



$$Q_s = C_{pw}(T_2 - T_1) + x\,h_{fg}.$$

$$= 1(100-30)+0.9\times 2400$$

$$= 280 + 2160 = 2440 \text{ kJ/kg},$$

21. Ans: (a)

Sol: If exit temperature of flue gases is less than 100°C, heat recovery is better.

22. Ans: (a)

Sol: Water is heated in economizer and air is heated in Air preheater.

23. Ans: (b)

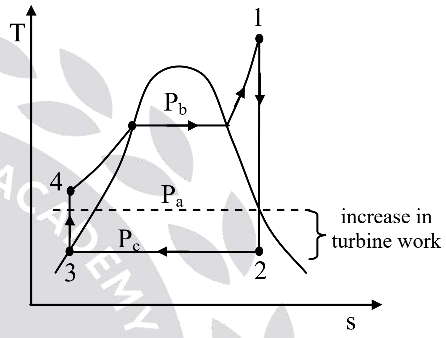
Sol: Fire Tube boilers are for low pressures and low mass flow rates. High pressure and large diameter increase cost.

24. Ans: (a)

Chapter - 24
Steam Condensers

01. Ans: (b)

Sol:



P_a = atmospheric pressure,

P_c = condenser pressure,

P_b = boiler pressure

By using the condenser in thermal power plant, we can expand the steam upto the lower pressure. Therefore, the mean temperature of heat rejection will be reduced as shown in the figure.

$$\eta_{\text{thermal}} = 1 - \frac{(T_{\text{mean}})_{\text{min}}}{(T_{\text{mean}})_{\text{max}}}$$

If $(T_{\text{mean}})_{\text{min}}$ decreases $\Rightarrow \eta_{\text{thermal}}$ increases.

02. Ans: (a)

Sol: If air molecules are removed from the condenser, the absolute pressure in condenser will be reduced.

03. Ans: (c)

Sol: Vacuum efficiency of the condenser

$$= \frac{\text{Actual vacuum in condenser with air present}}{\text{Theoretical vacuum in condenser with no air present}}$$

04. Ans: (a)

Sol: The cooling section in the surface condenser reduces the quantity of vapour and increases the quantity of water after condensation.

05. Ans: (a)

Sol: Condenser efficiency,

$$\eta_c = \frac{\text{Actual temperature rise of the cooling water}}{\text{Maximum possible temperature rise in cooling water}}$$

$$\eta_c = \frac{(\Delta T)_c}{(\Delta T)_{max}}$$

06. Ans: (b)

Sol: In regenerative surface condenser, there are two pumps required to remove air and condensate.

07. Ans: (a)

Sol: If the temperature of air decreases, rate of condensation increases. Therefore, quantity of water will be more and quantity of vapour will be less.

08. Ans: (d)

Sol: **Function of a condenser :**

In a steam power plant, the condenser plays a very important role. The main functions of a steam condenser are listed below:

1. The condenser lowers the back pressure at the turbine exhaust. Thus, steam expands through a higher pressure ratio across the turbine. It results into
   - (i) increased work done per cycle.
   - (ii) improved thermal efficiency of the cycle, and
   - (iii) reduced steam consumption
2. The condenser enables the recovery and recirculation of pure feed water into the plant. Thus,
   - (i) the cost of water softening plant is reduced, and
   - (ii) it also saves the cost of fresh water to be supplied to the boiler.
3. The condenser enables the removal of air and non-condensable gases from steam. Thus the heat-transfer rate is improved and tube corrosion is reduced.

09. Ans: (c)

Sol: The vacuum maintained in the condenser is mainly depends on the temperature of cooling water. If the cooling water temperature is more, vacuum pressure of the condenser will be less and vice-versa. For proper heat transfer, there should be 6°C to

10°C temperature difference required between condensate temperature and cooling water temperature.

10. Ans: (a)

Sol: In evaporative condenser : Steam in pipe surrounded by water

Note: In surface condenser: Water in tubes surrounded by steam.

Chapter - 25
Real Gases

01. Ans: (a)

Sol: The relation among the reduced properties, P_r, T_r and v_r is known as the law of corresponding states.

where, T_r = reduced temperature = $\frac{T}{T_c}$

P_r = reduced pressure = $\frac{P}{P_c}$

v_r = reduced volume = $\frac{v}{v_c}$

Subscript 'c' denotes the property at the critical state.

02. Ans: (b)

Sol: The compressibility factor (z) is equal to one for an ideal gas.

03. Ans: (a)

Sol: At very low pressure and high temperature, the gas can be treated as ideal gas but at high pressure it can be considered as real gas which follow the Vander's Waals gas equation.

04. Ans: (b)

Sol: Compressibility factor (z) can be obtained for value of P and T, and the volume can then be obtained from the equation

$$Pv = ZRT \Rightarrow Z = \frac{Pv}{RT}$$