Elements of Mechanical Engineering

- Mass → Amount of Matter contained in a substance, (m, kg)
- Weight → Weight is a kind of force by which earth attracts the Body towards its centre. ($W = mg$, N)
- ~~Pressure~~
- Pressure → force ~~fo~~ applied from unit resisting area
  (P, N/m^2, N/mm^2, Bar, Pa, kPa, MPa)

$1\ bar = 10^5\ Pa = 10^5\ N/mm^2$ + $1\ atm = 1.01325\ bar = 76.0\ cm\ of\ Hg$

Molten chart → Mahtlum Mehta Steam Table

- Temperature - Degree of Hotness or Coldness [T ⇒ °C, K]

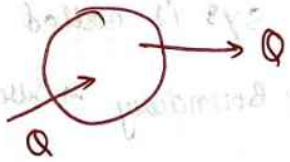
$0°C = 273K$

- Volume - space Occupied By any substance
- Specific volume - Volume per unit mass ~~m³/kg~~ m^3/kg
- Density - Mass per unit volume.

Mass density → kg/m^3

Weight Density → N/M^3

- force - Any ~~force~~ push or pull to any Object, f - N, kgm/sec^2
- Work - Transfer of Heat
- Heat - form of energy



- Energy - Capacity or Ability to Do work.
- specific heat - Heat Req' to inc temp. of unit substance by 1°C → $mc\Delta T$

C_p → Heat Req' to inc temp. of unit substance by 1°C at constant Pressure (KJ/kgK)

C_v → Heat Req' to inc. of unit substance by 1°C at constant volume (KJ/kgK)

$C_p - C_v = R$

$R = \frac{R_y}{M}$ → 8.314

• Latent Heat : Heat Req^{r} to change phase of substance without any change in Temp^{r}

$Q = mL$

• Power - Rate of Doing Work, Power = Watts, Horsepower.

① System
- Closed
- Open
- Isolated

• Properties, State, Path, Process

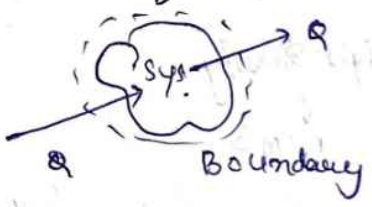
③ Cycle - a) Reversible
b) Irreversible

4) ~~Sys~~ Internal energy

5) Entropy

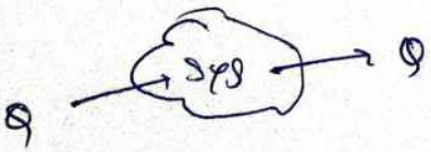
① Flow process → SFEE (Steadey flow Energy eq^{n})

② Non-flow process
a) Constant temp^{r}
b) Constant Pressure / Isobaric
c) Constant Volume / Isochoric
d) Adiabatic / Isentropic
e) Polytropic Process
f) Throttling

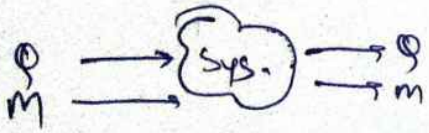


• Any closed region is called System.
• Periphery of the sys is called Boundary
• Space Beyond the Boundary → Surrounding

• Closed Sys → System in which only Heat transfer takes place (No mass transfer) ⇒ Constant Volume Process.
Ex - Pressure cooker



- Open Sys - System in which Both heat & Mass transfer takes place



- Isolated Sys - System in which no heat & no mass transfer takes place.
  ex - thermal flask

- Property - Defined as measurable characteristics ; ex - Pressure, Volume, Temp

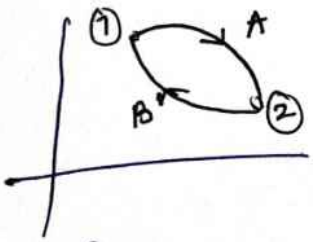
  - There are two types of properties → Extensive → Mass dependent
    → Intensive - mass independent

- Extensive properties → Those properties which depends on mass.
  ex - ~~Volume~~, Density

- Intensive properties - Those properties which ~~depe~~ doesn't depends on mass
  ex - Temp^{r}, Pressure

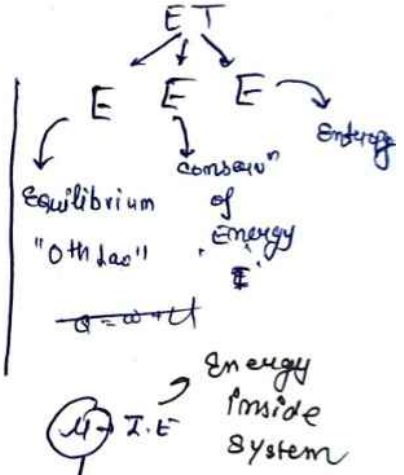
* State - Defined as representat^{n} of property

~~Path~~ - In which property varies ⇒ process.



* Cycle

- Equilibrium - Balanced State



$\Delta U = m C_v \Delta T$

$\gamma = 1.4 = \frac{C_p}{C_v}$ (1.005 / 0.718)

$(C_p)_{Air} = 1.005\ kJ/kg\,k$

$(C_v)_{air} = 0.718\ kJ/kg\,k$

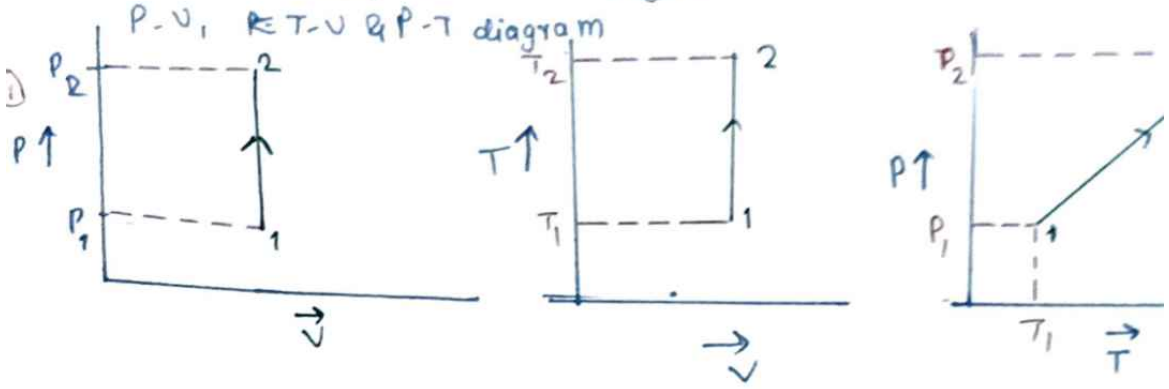
I^{st} law → $h = u + pv$; $dh = m C_p \Delta T$

C_p

* Non - Flow Process.

* Constant Volume Process. ~~(Isobaric)~~ (Isochoric)

① P-V, & T-V & P-T diagram



② Relation ~~Btw~~ $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \Rightarrow \boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}} \Rightarrow P \propto T$

③ Internal Energy : $\boxed{dU = m C_v (T_2 - T_1)}$

④ $\boxed{W = \int P dV} = 0$ as V = constant

$C_p - C_v = R$

$PV = mRT$; $\frac{PV}{T} =$

$m = 1kg$

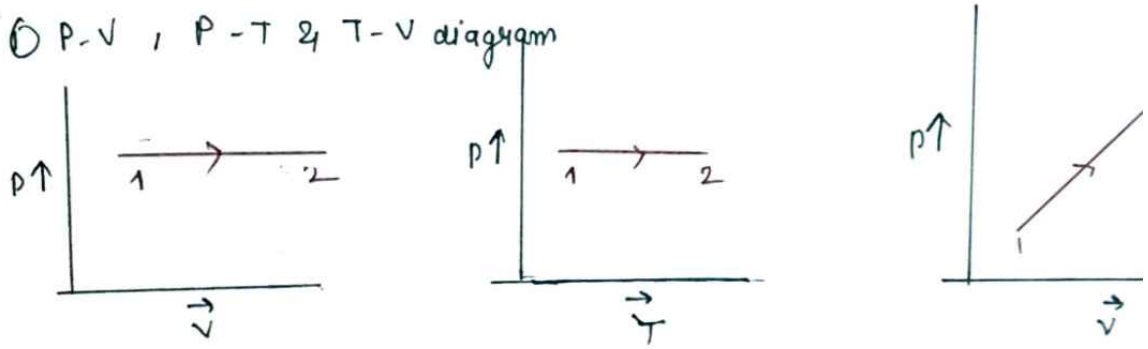
$P \neq R \rightarrow$ constant

⑤ $\boxed{dQ = dU = m C_v (T_2 - T_1)}$

⑥ $\boxed{dh = m C_p (T_2 - T_1)}$

* Constant Pressure Process ('Isobaric)

① P-V , P-T & T-V diagram



② Relation $\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$ as $P_1 = P_2$ = constant $\therefore V \propto T$

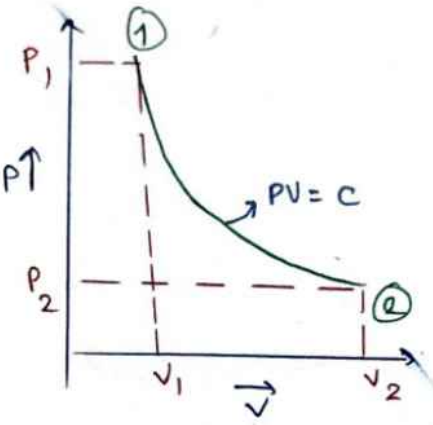
③ $dU = m C_v (T_2 - T_1)$

④ $dW = \int P dV = P_2 V_2 - P_1 V_1 = mR(T_2 - T_1)$ ↳ $P(V_2 - V_1)$

⑤ $dQ = dU + dW = m C_v (T_2 - T_1) + mR(T_2 - T_1) = m C_p (T_2 - T_1)$

⑥ $\boxed{dh = m C_p (T_2 - T_1)}$

* Constat Temperature Process [Isothermal Or Hyperbolic]



$P_1V_1 = P_2V_2$

$dU = 0$

$dW = \int P\,dV = \int_1^2 P\,dV$

$= \int \frac{C}{V}\,dV = P_1V_1 \ln\frac{V_2}{V_1}$

$dW = P_1V_1 \ln\frac{V_2}{V_1}$

$= P_2V_2 \ln\frac{V_2}{V_1}$

$dQ = dW$

$dh = 0$

Q A perfect gas for which the ratio of specific heat is 1.4 occupies a volume of $0.3\,m^3$ at 1 bar ~~at 27~~ and 27°c. The gas undergoes a compression to $0.06\,m^3$. The Heat supplied Or rejected By the gas for the following Methods of Compression -1) constant pressure 2) Hyperpolic

Considering $R = 0.287\,kJ/kg\,K$

Sol^n Given $P_1 = 1$ bar

$T_1 = 27 + 273 = 300K$

$\frac{C_p}{C_v} = 1.4$

$R = 0.287\,kJ/kg\,k$; $C_p - C_v = R$

$V_1 = 0.3\,m^3$

$V_2 = 0.06\,m^3$

• $dQ = dU + dW$; we know $C_p - C_v = R$ & $\frac{C_p}{C_v} = 1.4$ (Given)

$\downarrow$

$mC_v(T_2 - T_1)$

$\therefore C_p = 1.005\,kJ/kgK$

$C_v = 0.718\,kJ/kgK$

① Constant pressure

$P_1 = P_2 = 1$ bar

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$ & $PV = mRT$

$1 \times 0.3 \times 100 = m \times .287 \times 300$

$T_2 = \frac{0.06 \times 300}{0.3} = 60K$ $m = 0.348kg$

$T_2 - T_1 = 300 + 60 = -240$

$dU = -0.348 \times 0.718(240)$

$= -59.96\,kJ$

$dQ = dU + dW$

$dW = (P_2V_2 - P_1V_1) \times 100$

$= 100(0.06 - 0.3)$

$= -24\,kJ$

$dQ = -59.96 - 24 \therefore \boxed{dQ = -83.9678 kJ}$

2) Hyperbolic : $dQ = dW$

$$dW = P_1 V_1 \ln \frac{V_2}{V_1}$$

$$= 1 \times 0.3 \times 100 \ln \frac{0.06}{0.3} = 30 \ln 0.2$$

$$dQ = dW = 80 \ln 0.2 \, kJ$$

$$= -48.2831 kJ$$

Q A perfect gas for which ratio of sp. heat is 1.4 occupies a vol. of $0.06 m^3$ at 10 bar & 500K. The gas undergoes an expansion to $0.3 m^3$. find the heat supplied or rejected for the following process of Expansion.

① Constant temp^r ② Constant pressure. $R = 0.25 kJ/kg K$

Ans Given $\frac{C_p}{C_v} = 1.4$

$V_1 = 0.06 m^3$, $V_2 = 0.3 m^3$

$P = 10 \times 10^5 Pa$

$T_1 = 500K$

$P_1 V_1 = mRT_1$

$10 \times 100 \times 0.06 = m \times 0.25$

$\rightarrow P_1 V_1 = mRT_1$

$10 \times 10 \times 0.6 = m \times 0.25 \times 500$

$m = 0.48 kg$

② for constant pressure (P = constant)

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

$$T_2 = \frac{V_2 \times T_1}{V_1} \quad \therefore T_2 = \frac{0.3 \times 500}{0.06} \; ; \; T_2 = 2500K$$

$W_{12} = p(V_2 - V_1)$ for Constan pressure process.

$= 10 \times 100 \times (0.3 - 0.06) = 240\ kJ$

$\Delta u = m c_v (T_2 - T_1)$; $c_v = \frac{R}{\gamma - 1}$ & $\gamma = \frac{c_p}{c_v} = 1.4$

$= 0.48 \times 0.625 \times (2500 - 500)$ $\quad c_v = \frac{0.25}{0.4} = 0.625$

$\Delta u = 600\ kJ$

- $Q_{12} = W_{12} + \Delta u$

$= 240 + 600 \Rightarrow (Q_{12} = 840\ kJ)$

① Isothermal (T = constant)

$Q_{12} = W_{12} = P_1 V_1 \ln \frac{V_2}{V_1}$

$= 10 \times 100 \times 0.06 \times \ln \frac{0.3}{0.06}$

$Q_{12} = 96.56\ kJ$

③ Heat Rejected or accepted if $PV^{1.125} = C$

$\rightarrow P_1 V_1^{1.125} = P_2 V_2^{1.125} \rightarrow P_2 = P_1 \left(\frac{V_1}{V_2}\right)^{1.125}$; $P_2 = 10 \left(\frac{0.06}{0.3}\right)^{1.125}$

$P_2 = 1.635$; $T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{1.125 - 1} = 500 \left(\frac{0.06}{0.3}\right)^{0.125}$

$T_2 = 408.88\ K$

$W_{12} = \frac{P_1 V_1 - P_2 V_2}{n - 1} = \frac{10 \times 100 \times 0.06 - 1.635 \times 100 \times 0.3}{1.125 - 1} = 87.47\ kJ$

$\Delta u = m c_v (T_2 - T_1) = 0.48 \times 0.625 (408.88 - 500)$

$= -27.33\ kJ$

$Q_{12} = W_{12} + \Delta u = 87.47 + (-27.33)$

$Q_{12} = 60.14\ kJ$

* Adiabatic / ~~Isotropic process~~. Isentropic Process. → Entropy remains constant & $\Delta Q = 0$

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

γ → Ratio of specific heat = $\frac{C_p}{C_v}$

$C_p - C_v = R$

T_2 → Higher Temp^{r} → T_H

T_1 → lower Temp^{r} → T_L

; $P_1V_1^{\gamma} = P_2V_2^{\gamma}$

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

$$\frac{T_1}{T_2} = \frac{P_1}{P_2} \times \frac{V_2}{V_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} \cdot \frac{V_2}{V_1}$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Rightarrow \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

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

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

→ Read it as relat^{n} of Higher Temp / Lower Temp^{r}.

* $dQ = du + dw$; $dh = mC_p(T_2 - T_1)$: $du = mC_v(T_2 - T_1)$

$$dw = \int P\,dV = \int_1^2 \frac{C}{V^{\gamma}}\,dV$$

$$= C\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_1^2 = \frac{C}{-\gamma+1}\left\{V_2^{-\gamma+1} - V_1^{-\gamma+1}\right\}$$

$$= \frac{C}{-1+\gamma}\left\{V_1^{-\gamma+1} - V_2^{-\gamma+1}\right\}$$

$$= \frac{P_1V_1^{\gamma}V_1^{-\gamma+1} - P_2V_2^{\gamma}V_2^{-\gamma+1}}{-1+\gamma}$$

$$dw = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$$

* $dS = \frac{dQ}{T}$; for Adiabatic process S = constant

ΔQ = zero

* Polytropic Process. (Replace γ by η where η is Index)

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

$$dW = \int P\,dV = \int_1^2 \frac{C}{V^{n}}\,dV = C\left[\frac{V^{-n+1}}{-n+1}\right]_1^2 = \frac{C}{1-n}\left[V_2^{-n+1} - V_1^{-n+1}\right]$$

$$= \frac{C}{\eta - 1}\left[V_1^{1-n} - V_2^{1-2}\right] = \frac{P_1 V_1^{n} \cdot V_1^{1-n} - P_2 V_2 \cdot V_2^{1-n}}{\eta - 1}$$

$$\boxed{dW = \frac{P_1 V_1 - P_2 V_2}{\eta - 1}}$$

$$\boxed{\frac{T_H}{T_L} = \left(\frac{P_H}{P_L}\right)^{\frac{n-1}{n}} = \left(\frac{T_L}{T_H}\right)^{n-1}}$$

- $P_1 V_1^{n} = P_2 V_2^{n}$: Taking log on both sides

$$\log P_1 + n \log V_1 = \log P_2 + n \log V_2$$

$$\eta = \frac{\log P_H/P_L}{\log V_L/V_H}$$

→ compression Ratio, r_c ; Pressure Ratio : r_p

Q 2.57 kg of gas for which the Ratio of specific Heat is 1.35 occupies a Vol. of $0.15\,m^3$ at 10 Bar & 500K. The gas undergoes a expansion to $0.6\,m^3$. Determine the Heat absorbed or rejected by the gas for the following Methods of expansion.

1) At constant Pressure
2) Hyperbolic Process
3) Adiabatic Process
4) if $PV^{1.32} = C$

Axis given $\frac{C_p}{C_v} = 1.85$ $m = 2.57 kg$

$V_1 = 0.15 m^3$ $P_1 = 10 Bar$

$V_2 = 0.6 m^3$ $T_1 = 500K$

(1) At Constant pressure

(a) $P_1 V_1 = mRT_1$

$10 \times 0.15 \times 100 = 2.57 \times R \times 500$

$R = 0.1167 kJ/kgK$

$C_p - C_v = 0.1167$

$C_v(1.35 - 1) = 0.1167$; $C_p = 1.35 \times C_v$

$C_v = 0.3335 \ kJ/kgK$

$C_p = 0.4502 \ kJ/kgK$

$\frac{V_1}{V_2} = \frac{T_1}{T_2} \Rightarrow \frac{0.15}{0.6} = \frac{500}{T_2}$

$T_2 = 2000K$

$T_2 - T_1 = 1500K$

$dw = mR(T_2 - T_1)$

$= 2.57 \times 0.1167 \times 1500$

$= 449.8785 \ kJ$

$du = mC_v(T_2 - T_1)$

$= 2.57 \times 0.3335 \times 1500$

$= 1285.6425$ kJ

$dQ = du + dw$

$= 1735.521 kJ$

b) Hyperbolic ; $Q_{12} = W_{12} = P_1 V_1 \ln\frac{V_2}{V_1} \Rightarrow Q_{12} = 10 \times 100 \times 0.15 \ln\frac{0.6}{0.15}$

$Q_{12} = 207.94\ kJ$

c) Acc. to $PV^{1.82} = C$; $\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n \therefore P_2 = P_1\left(\frac{V_1}{V_2}\right)^n$

$P_2 = 10\left(\frac{0.15}{0.6}\right)^{1.82} \longrightarrow \boxed{P_2 = 1.605\ Bar}$

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

$T_2 = 500\left(\frac{0.15}{0.6}\right)^{1.82-1} \longrightarrow \boxed{T_2 = 320.85K}$

$W_{12} = \frac{P_1V_1 - P_2V_2}{n-1} = \frac{100\left[10 \times 0.15 - 1.605 \times 0.6\right]}{1.82-1}$

$W_{12} = 168\ KJ$; $\Delta U = mC_v\Delta T = 0.833 \times 2.57 \times (320.85 - 500)$

$= -153.31\ kJ$

$Q_{12} = W_{12} + \Delta U = 168 - 153.31$

$Q_{12} = 14.69\ kJ$

d) Adiabatic process $(PV^\gamma = C)$; $P_1V_1^\gamma = P_2V_2^\gamma$; Here $\gamma = 1.35$

$P_2 = P_1\left(\frac{V_1}{V_2}\right)^\gamma \therefore P_2 = 10\left(\frac{0.15}{0.6}\right)^{1.35} \Rightarrow P_2 = 1.5389\ Bar$

$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} \therefore T_2 = 500\left(\frac{0.15}{0.6}\right)^{0.35} = 307.78K$

$W_{12} = \frac{P_1V_1 - P_2V_2}{\gamma-1} = \frac{100\left[10 \times 0.15 - 1.5389 \times 0.6\right]}{1.35-1}$

$= 164.75kJ$

$\Delta U = mC_v\Delta T = 2.57 \times 0.83\,(307.78 - 500)$

$= 164.75\ kJ$

$Q_{12} = 164.75 - 164.75 = 0\ kJ$

$(W_{12} + \Delta U)$

* Derive 2.3 following expressions for polytropic process.

a) $W = \frac{mRT_1}{n-1}\left[1 - (r_p)^{\frac{n-1}{n}}\right]$. where $r_p = \frac{P_2}{P_1}$

b) $W = \frac{P_1 V_1}{n-1}\left(1 - \frac{1}{(r_v)^{n-1}}\right)$, where $r_v = \frac{V_2}{V_1}$

c) $Q = W\left[\frac{\gamma - n}{\gamma - 1}\right]$

Ans $W = \frac{P_1V_1 - P_2V_2}{n-1}$; $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{V_1}{V_2}\right)^{n-1}$.

(i) * We know that for a polytropic process, work done is given by

$$W = \frac{P_1V_1 - P_2V_2}{n-1} \quad ; P_1V_1 = mRT_1$$

$$= \frac{mRT_1 - mRT_2}{n-1}$$

$$= \frac{mRT_1\,(1 - T_2/T_1)}{n-1}$$

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

$$W = \frac{mRT_1}{n-1}\left(1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right) \quad \& \quad \frac{P_2}{P_1} = r_p$$

$$W = \frac{mRT_1}{n-1}\left(1 - r_p^{\frac{n-1}{n}}\right)$$

b) We know that for a polytropic process

$$W = \frac{P_1V_1 - P_2V_2}{n-1} = \frac{P_1V_1}{n-1}\left[1 - \frac{P_2V_2}{P_1V_1}\right] \quad ; \quad P_2V_2 = mRT_2, \; P_1V_1 = mRT_1$$

$$W = \frac{P_1V_1}{n-1}\left[1 - \frac{T_2}{T_1}\right] \quad ; \quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1}$$

$$W = \frac{P_1V_1}{n-1}\left[1 - \left(\frac{V_1}{V_2}\right)^{n-1}\right] = \frac{P_1V_1}{n-1}\left(1 - \frac{1}{\left(\frac{V_2}{V_1}\right)^{n-1}}\right)$$

$$\frac{V_2}{V_1} = r_V \quad \therefore \left\{ W = \frac{P_1V_1}{n-1}\left[1 - \frac{1}{(r_V)^{n-1}}\right] \right\}$$

c) We know that a polytropic process for the Non flow Energy Eqn.

$$Q = W + \Delta U$$

$$Q = \frac{P_1V_1 - P_2V_2}{n-1} + mc_v\,(T_2 - T_1)$$

we know that : $c_v = \frac{R}{\gamma - 1}$ & $P_1V_1 = mRT_1$

$$\therefore Q = \frac{P_1V_1 - P_2V_2}{n-1} + \frac{mR}{\gamma - 1}(T_2 - T_1)$$

$$Q = \frac{P_1V_1 - P_2V_2}{n-1} + \frac{P_2V_2 - P_1V_1}{\gamma - 1} = \frac{P_1V_1 - P_2V_2}{n-1} - \frac{P_1V_1 - P_2V_2}{\gamma - 1}$$

$$Q = \frac{P_1V_1 - P_2V_2}{n-1}\left[1 - \frac{n-1}{\gamma - 1}\right]$$

$$Q = W\left[\frac{\gamma - n}{\gamma - 1}\right]$$

Q A certain fluid at 10 bar is contained in a cylinder behind a piston the initial volume is $0.05 m^3$. Calculate the work done by the fluid when it is expanded acc. to law $p = \frac{A}{V^2} - \frac{B}{V}$ to final volume $0.1 m^3$ & the final pressure is 1 bar.

Soln $P_1 = 10$ bar , $V_1 = 0.05 m^3$

$P_2 = 1$ bar $V_2 = 0.1 m^3$

& $p = \frac{A}{V^2} - \frac{B}{V}$

Aise Questions me A & B Nikalna Hai

for $P_1 = 10$ Bar (Initial condn)

$$10 = \frac{A}{(0.05)^2} - \frac{B}{(0.05)} \Rightarrow 10 = 400A - 20B$$

· final condn

$$1 = \frac{A}{(0.1)^2} - \frac{B}{(0.1)} \Rightarrow 1 = 100A - 10B$$

SOLVING FOR A and B

$A = \frac{8}{200}$ & $B = \frac{6}{20}$ ⇒ By putting the value of A & B we get general eqn

$$P = \frac{8}{200V^2} - \frac{6}{20V} \quad \& \quad W = \int_1^2 P\,dV$$

$$W = \int_{0.05}^{0.1} \left(\frac{8}{200V^2} - \frac{6}{20V} \right) dV = \left[\frac{-4}{100V} - \frac{6}{20} \ln V \right]_{0.05}^{0.1}$$

$$W = 0.4 - 6/20\,(0.693) \rightarrow 0.1921 \times 10^5$$

$$[W = 19.21 kJ]$$

1 A fluid system in which Pressure volume Relat^n is given by

$$p = \frac{4.5}{v} + 2 \quad \text{OR} \quad v = \frac{4.5}{p-2}$$ for which during the process the volume changes from $0.12\,m^3$ to $0.04\,m^3$ & the system rejected heat of 40 kJ, determine the change in Enthalpy & change in internal energy

Also Questions me P_1 & P_2 Nikalna hai

1st Given $V_i = 0.12m^3$, $V_f = 0.04m^3$, $Q = -40\,kJ$

we know that $W = \int_1^2 P\,dV = \int_{0.12}^{0.04} \left(\frac{4.5}{V} + 2\right) dV$

$$W = \left[4.5 \ln V + 2V\right]_{0.12}^{0.04} \times 100$$

$$W = -510\,kJ$$

We know $Q = dU + W$

$$-40 = -510 + dU \rightarrow \boxed{dU = 470\,kJ}$$

$V_1 = 0.12m^3 \Rightarrow P_1 = \frac{4.5}{0.12} + 2 = 39.5$ Bar

$V_2 = 0.04m^3 \Rightarrow P_2 = \frac{4.5}{0.04} + 2 = 114.5$ Bar

* The change in enthalpy is given by : $dH = d(PV) + dU$

$$dH = (39.5 \times 0.12 - 114.5 \times 0.04) \times 100 + 470$$

$$= (4.74 - 4.58) \times 100 + 470$$

$$= 16 + 470$$

$$\boxed{dH = 486}$$

Q In a constant pressure process the c_p is given by

$$c_p = \left[2.5 + \frac{40}{T+20}\right] \frac{kJ}{kg\,^\circ C}$$ the pressure is maintained at 2 bar

A Volume changes from $1\ m^3$ to $1.8\ m^3$ & Temp changes from 50°C to 450°C

Determine ① Heat Addn ② Work done ③ Change in Internal energy ④ dH.

Soln (1) Heat Added : $dQ = m\,c_p\,dt$

$$Q = \int_{50}^{450} 1 \cdot \left[2.5 + \frac{40}{t+20}\right] dt$$

$T_1 = 50^\circ C$ $V_1 = 1 m^3$, $P = 2$ bar

$T_2 = 450^\circ C$ $V_2 = 1.8 m^3$

$$Q = (2.5)\cdot[t]_{50}^{450} + \left[40 \ln (t+20)\right]_{50}^{450}$$

$$Q = 1000 + 40 \ln \frac{470}{70} = 1000 + 76.169$$

$$Q = 1076.17 kJ/kg$$

2) Work done

$$W = \int_{V_1}^{V_2} P\,dV = P(V_2 - V_1)$$

$$= 2(1.8 - 1) \times 10^5 = 160 kJ/kg$$

3) Change in Internal energy

$Q = W + \Delta U \therefore \Delta U = Q - W$

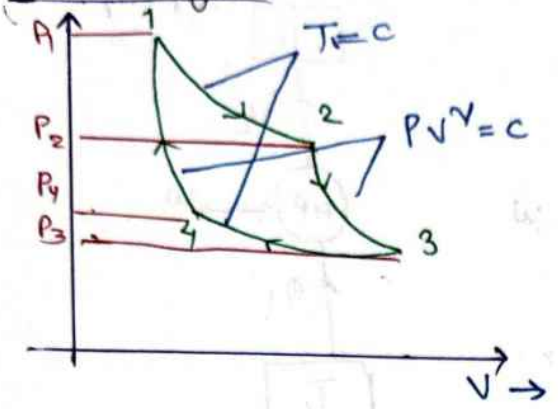
$$\Delta U = 1076.17 - 160$$

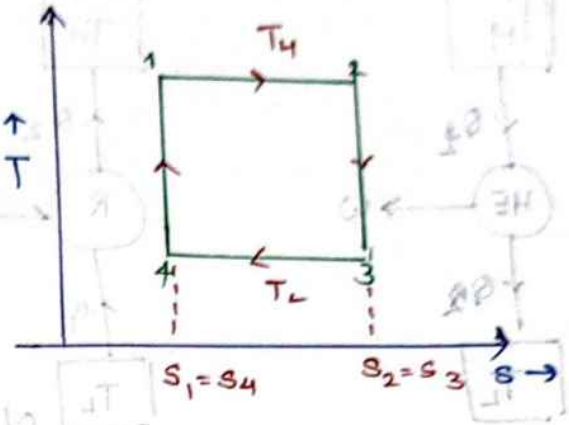
$$\Delta U = 916.17 kJ/kg$$

④ Change in Enthalpy

$$\Delta h = Q = 1076.17 kJ/kg$$

* Carnot Cycle





1-2 : Isothermal Expansion → $Q_S = Q_{1-2} = T_H(S_2 - S_1)$ [Heat supplied & it is known as Q_S]

2-3 : Isentropic expansion. $Q_{2-3} = 0$ [Adiabatic]

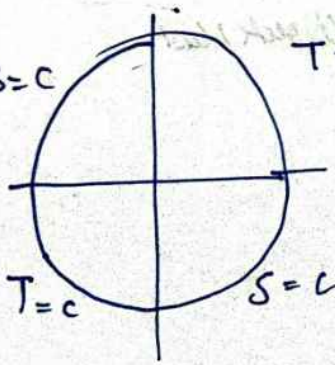
3-4 : Isothermal Compression → $Q_{3-4} = Q_R = T_L(S_3 - S_4) = T_L(S_2 - S_1)$ [Heat Rejected]

4-1 : Adiabatic Compression → $Q_{4-1} = 0$

$$\eta_{carnot} = \frac{Q_S - Q_R}{Q_S} = \frac{T_H(S_2 - S_1) - T_L(S_2 - S_1)}{T_H(S_2 - S_1)}$$

$$\therefore \eta_{carnot} = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$$

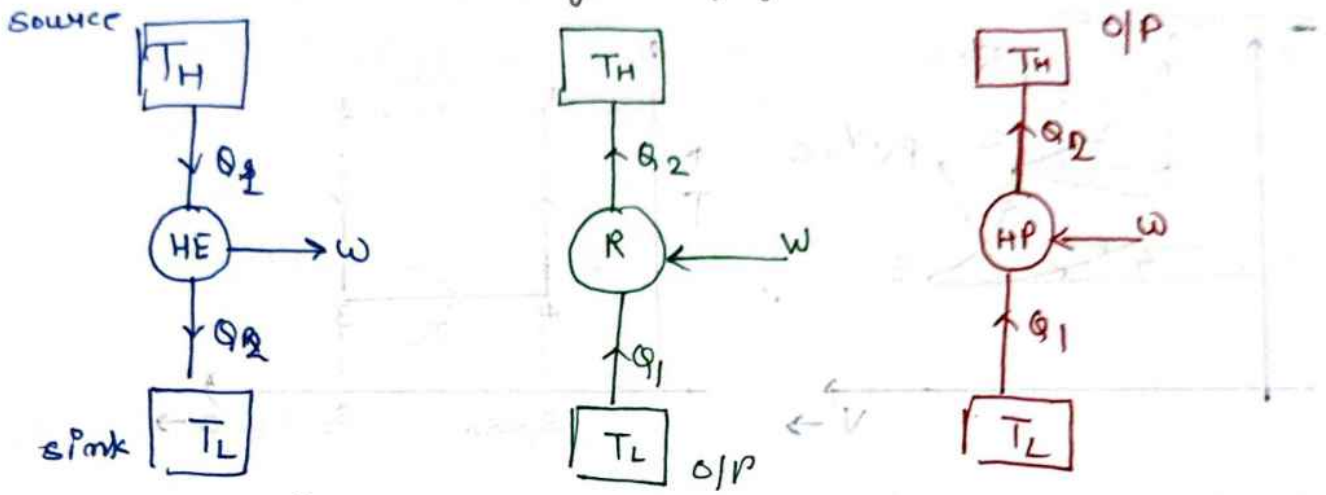
$$* \quad \eta_{carnot} = \frac{Q_S - Q_R}{Q_S} = \frac{T_H - T_L}{T_L} = \frac{W_{net}}{Q_S}$$



→ Different speed is not possible in one cycle

∴ Carnot Cycle is not speedy

* Difference Between Heat Engine, Refrigerator & Heat pump.



$\eta_{HE} = \frac{T_H - T_L}{T_H}$ $\quad \eta_{HE} \leq 1$

$COP_R = \frac{T_L}{T_H - T_L}$ — Coeff. of Performance

$COP_{HP} = \frac{T_H}{T_H - T_L}$

Operating Temp → Low Temp^r.

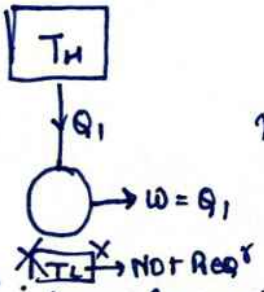
Operating Temp = High Temp^r

* Second law of Thermodynamics.

1) Kelvin Plank's Statement :

$$COP_{HP} = 1 + COP_R$$

2) Claussius's Statement



Kevin plank's Statement: It is impossible to construct a device in which total Heat ~~Supplied~~ is converted to work Supplied.

Claussius Statement - To transfer heat from low temp^r to high Temp^r, External Work Must Be done on system,

Q A heat engine operates on a Carnot cycle with an eff. of 25%. What COP ~~should~~ would a Refrigerator operating on the same cycle would have? Low Temp^r = 0°C

Soln Given $T_L = 0°C = 273K$

$$0.25 = \frac{T_H - 273}{T_H}, \quad \text{As } \eta_{HE} = \frac{T_H - T_L}{T_H}$$

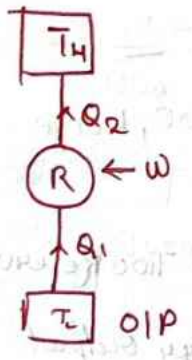
$$T_H - 273 = 0.75\,T_H \rightarrow [T_H = 364K]$$

$$COP_R = \frac{273}{364 - 273} \rightarrow ; COP_R = 3$$

Q Calculate the Req^r Power input to a refrigerator if it operates with COP of 1.75 & provides a cooling effect of 41kW. Determine ~~cool~~ Eff Rate of Heat Transfer to the surrounding.

* $COP_R = \frac{\text{Net Refrigerating Eff}}{\text{Work done}}$

Given $COP_R = 1.75$



$$\therefore 1.75 = \frac{41}{W}$$

$$W_{net} = 23.42\,kW \rightarrow P_{in}$$

* W.D is given by

$W = Q_S - Q_{in}$

$$23.42 = Q_S - 41$$

$$Q = 64.42\,kW$$

Q** ~~son~~ inventor claims to have developed a Refrigerating machine which operates B/W -28°C & 27°C & Consume 1 kW of power. The M/C gives a Refrigerating effect of 27MJ/Hour. Comment on the claim of Inventor.

Given $T_L = -28^\circ C = 250K$

$T_H = 27^\circ C$ 300 K

$COP_R = \frac{250}{300-250} = 5$

(By Temp' Lim)

$(COP)_{Actual} = \frac{27 \times 10^3}{60 \times 60 \times 1} = 7.5$

* Since, the Actual COP is greater than theoretical COP, Hence inventor claim is not justfied.

Q An inventor claims to have developed a Heat pump, which operates b/w $-28^\circ C$ & $27^\circ C$ and consume 1 kW of power. The m/c gives a heating effect of 18 MJ/hr. Comment on claim of inventor.

Sol^n $(COP)_{HE} = \frac{300}{300-250} = 6$

$T_L = -28^\circ C = 250K$

$T_H = 27^\circ C = 300K$

$(COP)_{HE\,Actual} = \frac{18 \times 10^3}{60 \times 60} = 5$

* Since, the Actual COP is lesser than theoretical COP, Hence inventor claim is justfied.

Q Two Carnot Refrigerator operates in series b/w two Reservoirs Maintained at $27^\circ C$ & $207^\circ C$ respectively. The energy output By the first refrigerator is used as Heat energy input to the second Refrigerator, if COPs of the two refrigerators is same, what should be the intermediate temp^r.

Sol^{n} Given $(COP)_1 = (COP)_2$; $T_1 = 27^{\circ}C \rightarrow 300K$

$T_2 = ?$

$T_3 = 207^{\circ}C \rightarrow 480^{\circ}K$

$$(COP)_{R_1} = \frac{T_2}{T_1 - T_2}$$

$$(COP)_{R_2} = \frac{T_3}{T_{12} - T_3}$$

$$\frac{T_2}{300 - T_2} = \frac{480}{T_2 - 480}$$

$$T_2^2 - 480T_2 = 480 \times 300 - 480T_2$$

$$\boxed{T_2 = 379.47K}$$

Q A heat engine working on Carnot cycle $\frac{1}{5}^{th}$ of heat input into work. when the temp^{r} of sink is reduced by 80°c, the efficiency gets doubled calculate the temp^{r} of source & sink

Sol^{n} Let Q_1 = heat input & $W_1 = \frac{Q_1}{5}$

Case-1

$$\therefore \frac{W_1}{Q_1} = \frac{1}{5} = \eta = \frac{T_{H1} - T_2}{T_1}$$

$$T_1 - T_2 = \frac{T_1}{5} \Rightarrow \boxed{T_2 = \frac{4}{5}T_1} \quad -(1)$$

Case-2

- T_2 is reduced to $T_2 - 80^{\circ}$ & efficiency is double ie $2 \times \frac{1}{5}$ (ie $2\eta_1$)

$$\frac{2}{5} = \frac{T_1 - (T_2 - 80)}{T_1}$$

$$2T_1 = 5T_1 - 5T_2 + 400$$

$$5T_2 = 3T_1 + 400$$

$$5 \times \frac{4}{5}T_1 = 3T_1 + 400 \rightarrow \boxed{T_1 = 400K}$$

$$\boxed{T_2 = 320K}$$

$T_2 = T_H = 400K$

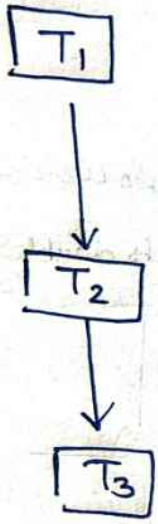
$T_1 = T_L = 320K$

Sol3 A Carnot engine operates in series B/w two Reservoirs at 327°c & 27°c, The energy rejected By the first engine is input into the second engine, if efficiency of 1st energy is 20% greater than the efficiency of 2nd Eng. then calculate Intermediate Temp

Sol2 Given $T_1 = 327 + 273 = 600K$

$T_2 = ?$

$T_3 = 27 + 273 = 300K$



$\eta_1 = \frac{T_1 - T_2}{T_1}$, $\eta_2 = \frac{T_2 - T_3}{T_2} = 1 - \frac{T_3}{T_2}$

$\eta_1 = 1 - \frac{T_2}{600}$ & $\eta_2 = 1 - \frac{300}{T_2}$

Given that, $\eta_1 = \eta_2 + 0.2\eta_2$

$$\boxed{\eta_1 = 1.2\eta_2}$$

$$1.2\eta_2 = 1 - \frac{T_2}{600} \Rightarrow 1.2\left(1 - \frac{300}{T_2}\right) = 1 - \frac{T_2}{600}$$

$$1.2 - \frac{360}{T_2} = 1 - \frac{T_2}{600} \Rightarrow \frac{360}{T_2} - \frac{T_2}{600} = 0.2$$

$$\rightarrow 360 \times 600 - T_2^2 = 0.2 \times 600T$$

$$T_2^2 + 120T_2 - 216000 = 0 \; ; \; T_2 = \frac{-120 \pm \sqrt{(120)^2 - 4 \times 1 \times (-216000)}}{2 \times 1}$$

$$T_2 = \frac{-60 \pm \sqrt{14400 + 864000}}{4} = -60 \pm \frac{\sqrt{878400}}{4}$$

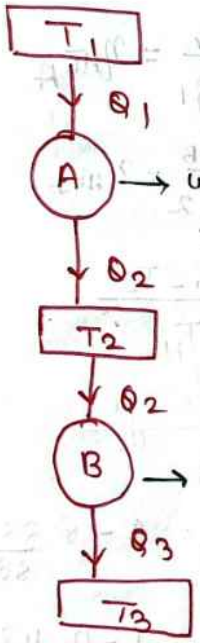
$$= -60 \pm \sqrt{219600} \Rightarrow T_2 = -60 + 468.6149$$

$$\boxed{T_2 = 408.6149\,K = 135.6149^\circ C}$$

* Q Two Reversible Power cycles are arranged in Series, first cycle Recieves energy ~~from~~ By Heat transfer from a reservoir at a temp T_1 & rejects energy to a reservior at an intermediate temp T_2. The second cycle recieves the energy ~~from~~ by the energy rejected by the first cycle at T_2 & Rejects the energy to a reservior at a temp T_3 which is lower than Temp^r T_2. Derive an expression for intermediate temp^r T_2 in terms of T_1 & T_3?

→ When ① The Net Work of Two power cycles are equal
② Thermal efficiencies of the two power cycle are equal.

Soln



We know

$$\eta_A = 1 - \frac{T_2}{T_1} = 1 - \frac{Q_2}{Q_1}$$

$$\frac{T_2}{T_1} = \frac{Q_2}{Q_1}$$

$$\eta_B = 1 - \frac{T_3}{T_2} = 1 - \frac{Q_3}{Q_2}$$

$$\frac{T_3}{T_2} = \frac{Q_3}{Q_2}$$

→ Q $W_A = W_B$ → $Q_1 - Q_2 = Q_2 - Q_3$

$$Q_1 + Q_3 = 2Q_2 \rightarrow \frac{Q_1}{Q_2} + \frac{Q_3}{Q_2} = 2 \rightarrow \frac{T_1}{T_2} + \frac{T_3}{T_2} = 2$$

$$\rightarrow \boxed{T_1 + T_3 = 2T_2}$$

(ii) $\eta_A = \eta_B$, $1 - \frac{T_2}{T_1} = 1 - \frac{T_3}{T_2} \Rightarrow \frac{T_2}{T_1} = \frac{T_3}{T_2}$

$$T_2^2 = T_1 T_3$$

$$\boxed{T_2 = \sqrt{T_1 T_3}}$$

Q Two Reversible ~~System~~ H.E A & B are arranged in Series - Engine A rejects heat Directly to B, Engine A receives 200 kJ at a temp^r of 427°C from the Hot Source, while B is in communication with a low temp^r sink at a temp^r of 7°C.

→ if the work Output of engine is twice that of Engine B. ~~If~~ then find

① Intermediate temp^r B/w A & B

② Efficiency of each engine

③ Heat Rejected to the sink.

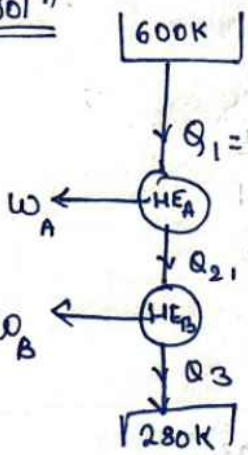
$T_1 = 427°C = 600K$

$T_3 = 7°C = 280K$

given $\boxed{W_A = 2W_B}$ -(1)

$Q_1 = 200kJ$

Sol^n



$\boxed{Q_2 = Q_1 - W}$ ← $W_A = Q_1 - Q_2$ & $\frac{W_A}{Q_1} = \eta_{HE_A}$

$W_B = Q_2 - Q_3$

$\frac{W_B}{Q_2} = \eta_{HE_B}$

$W_A = (\eta_{HE})_A \cdot Q_1$

$W_B = (\eta_{HE})_B \cdot Q$

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

from eq^n ①

$(\eta_{HE})_A \cdot Q_1 = (\eta_{HE})_B \cdot Q_2$

$W_A = 2\left[\frac{T_2 - T_3}{T_2}\right] \cdot [Q_1 - W]$

$Q_1 = \left[\frac{T_2}{2(T_2 - T_3)} + 1\right] W_A$

$\left(\frac{T_1 - T_2}{T_1}\right) \cdot \left[\frac{T_2}{2(T_2 - T_3) + 1}\right] Q_1 = Q_1$

$\frac{T_2}{2(T_2 - T_3)} = \frac{T_1}{T_1 - T_2}$ -1

$\frac{T_2}{2T_2 - 2T_3} = \frac{T_2}{T_1 - T_2}$

$T_1 - T_2 = 2(T_2 - T_3)$

$T_2 = \frac{T_1 + 2T_3}{2}$

$T_2 = 600 + 2 \times 280 / 2$

$\boxed{T_2 = 580K = 307°C}$

② $(\eta_{HE})_A = 1 - \frac{T_2}{T_1} = 1 - \frac{580}{600}$

$(\eta_{HE})_A = 1 - 0.96$

$(\eta_{HE})_A = 0.04 = 4\%$

$W_A = (\eta_{HE})_A \times Q_1 = 0.04 \times 200$

$= 8$

$(\eta_{HE})_B = 1 - \frac{280}{580}$

$(\eta_{HE})_B = 1 - 0.482$

$(\eta_{HE})_B = 0.5172$

③ $Q_3 = ?$, $\frac{W_B}{Q_2} = (\eta_{HE})_B$

$Q_2 = \frac{W_B}{(\eta_{HE})_B} = \frac{W_A}{2 \times \eta_{HE_B}}$

$Q_2 = \frac{8}{2 \times 0.5172} = 7.73kJ$

$W_B = Q_2 - Q_3 \Rightarrow \frac{8}{2} = 7.73 - Q_3$

$\boxed{Q_3 = 3.48kJ}$

General eqn for change of entropy.

- $dQ = du + dw$
- $dQ = c_v dT + p dV$, for $m = 1kg$

$$\frac{dQ}{T} = c_v \frac{dT}{T} + \frac{RT}{T}\frac{dV}{V}$$

$$dS = c_v \frac{dT}{T} + R\frac{dV}{V}$$

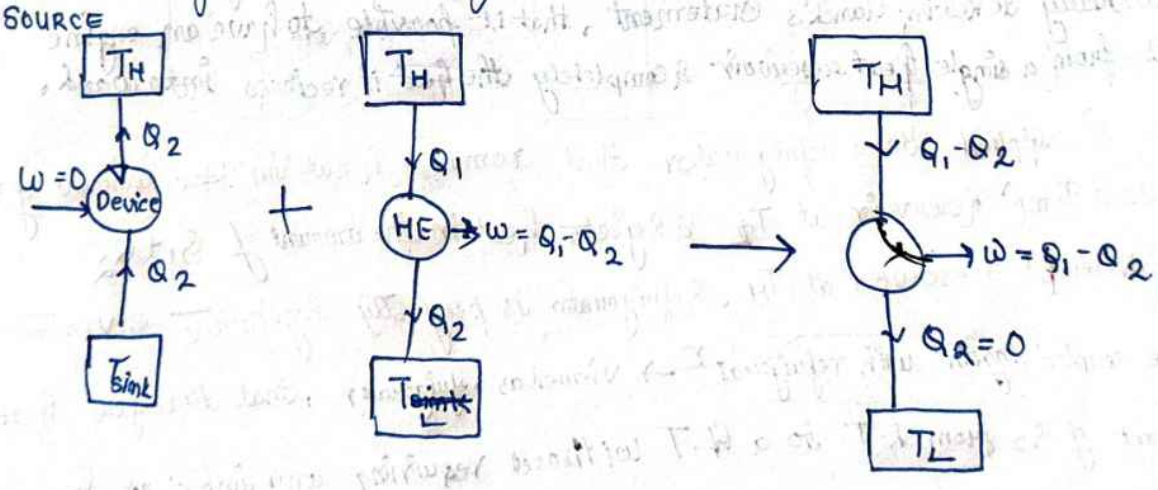
Integrating from 1 & 2

$$\int_1^2 dS = \int_1^2 c_v \frac{dT}{T} + R\int_1^2 \frac{dV}{V}$$

$$\boxed{S_2 - S_1 = c_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}}$$

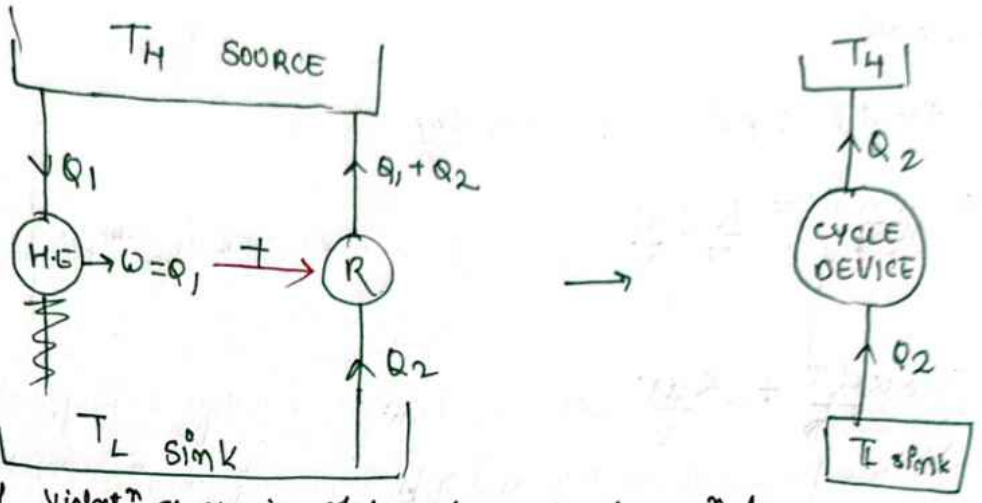
Equivalence of Clausius & Kelvin Statement.

① Violation of Clausius leading to Kelvin



* Any Device that violates the Kelvin - Planck statement Also violates the clausius statement & vice versa ← Equivalence of clausius & Kelvin - Planck statement

② Violation of Kelvin leading to Clausius.



Description of Violation of Clausius statement leading to violation of Kelvin-Planck statement

Assume, Contrary to the corrolary, that a system can be constructed which will operate in cycle & will transfer heat from a sink to source without receiving work from surroundings. * HE operating B/W Two reservoirs (Takes in Q_1 & Rejects Q_2)

→ This H.E is legitimate & violates no law. Coupling the System toger (H.E & one which we have assumed). Q_2 transferred into & out of the lower Temp^r reservoir cancel each other & No Heat transfer at T_2. ∴ A device is formed which now operates continuously from single heat reservoir at T_1; which completely converts heat into work ↖ Violat^n of Kelvin-Planck Statement

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Description of Violation of Kelvin-Planck Statement leading to violation of Clausius Statement.

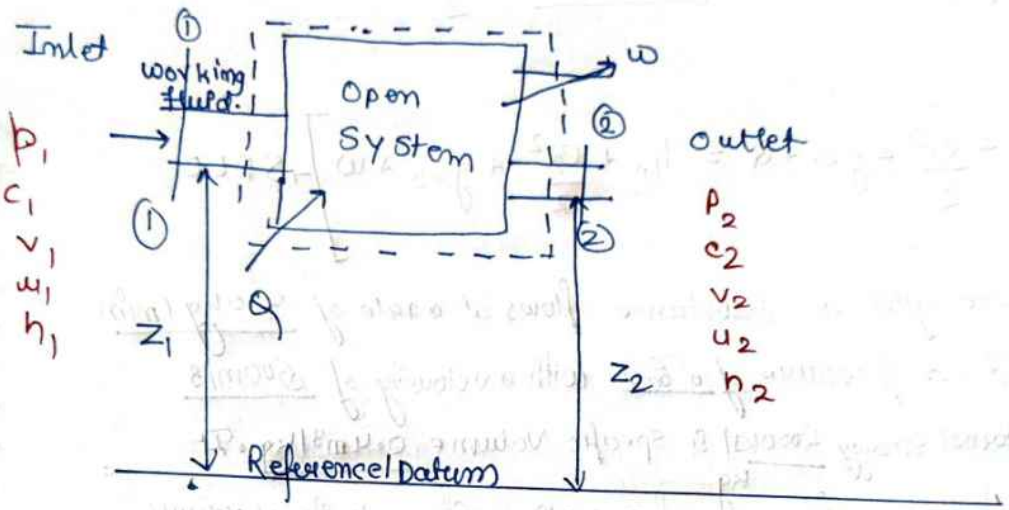
- Assume, Contrary to Kelvin-Planck's Statement, that it possible to have an engine which operates from a single heat reservoir & completely the heat it receives into work.
- This work is supplied to a refrigerator that removes heat in ~~the~~ amount of Q_2 from the low Temp^r Reservoir at T_2 & Rejects heat in the amount of Q_1+Q_2 to the high Temp^r reservoir at T_H. Refrigerator is perfectly legitimate & violates No Law.

* Heat Engine coupled toget^r with refrigerat^r → viewed as refrigerator, that transfers heat in an amount of Q_2 from L.T to a H.T without requiring any input ~~of~~ from outside.

↑

Violation of Clausius Statement.

Steady flow Energy Equation (SFEE)



Description of Energy	Energy at 1-1	Energy at 2-2
1) flow Energy or flow work	$p_1 v_1$	$p_2 v_2$
2) Internal Energy	u_1	u_2
3) Kinetic Energy	$c_1^2/2$	$c_2^2/2$
4) Potential Energy	gz_1	gz_2
(5) Heat Transfer to the system	Q	
(6) Energy transferred out of System or Shaft Work		W

· By Energy Balancing

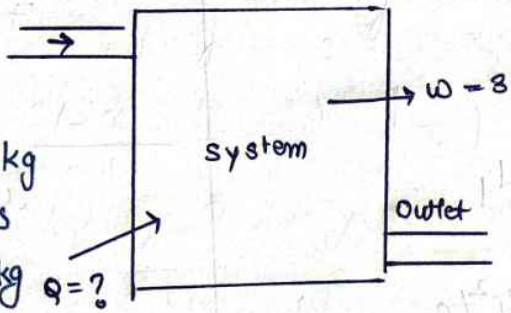
$$P_1V_1 + u_1 + \frac{c_1^2}{2} + gz_1 + Q_{1\text{-}2} = P_2V_2 + u_2 + \frac{c_2^2}{2} + gz_2 + W$$

$$\Rightarrow \left[h_1 + \frac{c_1^2}{2} + gz_1 + Q = h_2 + \frac{c_2^2}{2} + gz_2 + W \right] \rightarrow \text{SFEE}$$

2/6

Q In a steady flow system a substance flows at a rate of 300 kg/min. It enters at a pressure of 6 bar with a velocity of 300 m/s with specific internal energy 2000 kJ/kg & specific volume 0.4 m³/kg. It leaves the system at a pressure of 0.1 MPa with a velocity of 150 m/s. Specific internal energy 1600 kJ/kg & specific volume 1.2 m³/kg. The inlet is 10 m above the outlet. During its passage through the system a work transfer of 3 MW to surrounding. Determine heat transfer in kJ/s.

Ans:



$P_1 = 6$ bar
$v_1 = 0.4\ m^3/kg$
$c_1 = 300$ m/s
$u_1 = 2000$ kJ/kg
$z_1 = 10$

$P_2 = 0.1$ MPa
$v_2 = 1.2\ m^3/kg$
$c_2 = 150$ m/s
$u_2 = 1600$ kJ/kg
$z_2 = 0$

* Applying the steady flow Energy Eqⁿ, $E_{in} = E_{out}$.

$$m = 300\ kg/min = 5\ kg/s$$

$$W = m.w \rightarrow 3000 = 5 \times w$$

$$\boxed{w = 600\ kJ/kg}$$

$$P_1v_1 + u_1 + \frac{c_1^2}{2} + gz_1 + q = P_2v_2 + u_2 + \frac{c_2^2}{2} + gz_2 + w$$

$$600 \times 0.4 + 2000 + \frac{300^2}{2 \times 1000} + \frac{9.81 \times 10}{1000} + q = 100 \times 1.2 + 1600 + \frac{150^2}{2 \times 1000} + 600$$

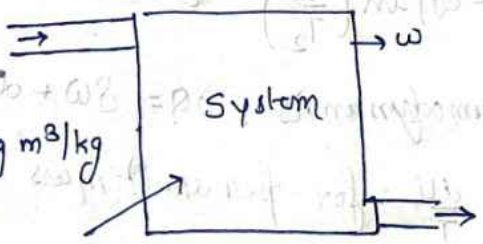
$$q = 46.1519 \text{ kJ/kg}$$

$$Q = q \times m$$

$$Q = 46.1519 \times 5 = 230.7595 \text{ (To the system)}$$

~~A~~ ~~gas~~ air flows ~~with~~ at the rate of 0.4 kg/s through an air compressor entering at 6 m/s with a pressure of 1 bar & a specific vol. of 0.85 m^3/kg & leaving at 4.5 m/s with a pressure of 7 bar & sp. volume of 0.16 m^3/kg. Specific internal energy of the air leaving is 90 kJ/kg greater than that of air of entering. The cooling water in a jacket surrounding the cylinder absorb the heat from the air at the rate of 60 kJ/s. Calculate Power req^r to drive the compressor & inlet & outlet cross sectional area of pipe

Ans



$P_1 = 1$ bar
$v_1 = 0.85$ m^3/kg
$c_1 = 6$ m/s
$u_1 = 0$

$P_2 = 7$ bar
$v_2 = 0.16$ m^3/kg
$c_2 = 4.5$ m/s
$u_2 = 90$

~~$q = \frac{Q}{m} = \frac{60}{0.4} = 150$ kJ~~ , $P_1v_1 = 85$ kJ/kg, $P_2v_2 = $ ~~450 J/kg~~ $= 112$ kJ/kg

$\frac{c_1^2}{1000 \times 2} = \frac{0.036}{2}$ kJ/kg , $\frac{c_2^2}{1000 \times 2} = \frac{0.02025}{2}$

$= 0.018$ kJ/kg $= 0.0101$ kJ/kg

$q = \frac{Q}{m} = \frac{60}{0.4} = 150$ kJ/kg

2.21, 16, 17

Putting in SFEE

$$w = (u_2 - u_1) + (P_2v_2 - P_1v_1) + \frac{c_2^2 - c_1^2}{2000} + q$$

$$= 90 + (112 - 85) + (0.0101 - 0.018) + 150$$

$$w = 266.9921 \text{ kJ/kg}$$

Power $= W = mw$

$$= 0.4 + 266.9921 = 106.79 \text{ kW}$$

$$\eta = \frac{A_1 c_1}{v_1} \quad ; \quad A_1 = \frac{mv_1}{c_1} \text{ & } A_2 = \frac{mv_2}{c_2}$$

$$A_1 = \frac{0.4 \times 0.85}{6} \Rightarrow A_1 = 0.057 m^2$$

$$A_2 = \frac{0.4 \times 0.16}{4.5} \Rightarrow A_2 = 0.0142 m^2$$

Q Prove that change of entropy for a given gas B/w state 1 & 2

$$a) S_2 - S_1 = \frac{\gamma - n}{\gamma - 1} (c_p - c_v) \ln \left(\frac{T_1}{T_2} \right)^{1/n-1}$$

Ans Acc. to first law of Thermodynamics ; $\delta Q = \delta w + dU$

→ Divide By T, $\frac{\delta Q}{T} = \frac{\delta w}{T} + \frac{dU}{T}$; for per unit mass

$$ds = \frac{P\,dv}{T} + c_v \frac{dT}{T}$$

• Integrating B/w the two states (1) & (2)

$$\int_1^2 ds = \int_1^2 \frac{R}{v} dv + \int_1^2 c_v \frac{dT}{T}$$

$$S_2 - S_1 = R \ln \frac{v_2}{v_1} + c_v \ln \frac{T_2}{T_1}$$

We know that $C_v = \frac{R}{\gamma-1}$ & $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\eta-1}$

$\frac{V_2}{V_1} = \left(\frac{T_1}{T_2}\right)^{1/\eta-1}$ ⇒ SUBSTITUTING in eqn (1)

$$S_2 - S_1 = R \ln\left(\frac{T_1}{T_2}\right)^{1/\eta-1} - \frac{R}{\gamma-1} \ln \frac{T_1}{T_2}$$

$$\Delta S = \frac{R}{\eta-1} \ln \frac{T_1}{T_2} - \frac{R}{\gamma-1} \ln \frac{T_1}{T_2} = R \ln \frac{T_1}{T_2}\left(\frac{1}{\eta-1} - \frac{1}{\gamma-1}\right)$$

$$S_2 - S_1 = \frac{\gamma-\eta}{(\gamma-1)(\eta-1)} R \ln \frac{T_1}{T_2} = R \ln\left(\frac{T_1}{T_2}\right)^{1/(\eta-1)} \cdot \frac{\gamma-\eta}{\gamma-1}$$

$$\therefore \left[S_2 - S_1 = \frac{\gamma-\eta}{\gamma-1} (C_p - C_v) \ln\left(\frac{T_1}{T_2}\right)^{1/\eta-1}\right]$$

b) $S_2 - S_1 = \frac{\gamma-\eta}{\eta-1} C_v \ln \frac{T_1}{T_2}$

Ans $\Delta S = R \ln \frac{V_2}{V_1} + C_v \ln \frac{T_2}{T_1}$

$$\Delta S = R \ln\left(\frac{T_1}{T_2}\right)^{1/\eta-1} - \frac{R}{\gamma-1} \ln \frac{T_1}{T_2} = \frac{R}{\eta-1} \ln \frac{T_1}{T_2} - \frac{R}{\gamma-1} \ln \frac{T_1}{T_2}$$

$$\Delta S = R\left(\frac{1}{\eta-1} - \frac{1}{\gamma-1}\right) \ln \frac{T_1}{T_2} = \frac{R(\gamma-\eta)}{(\eta-1)(\gamma-1)} \ln \frac{T_1}{T_2}$$

$$\Delta S = \frac{\gamma-\eta}{\eta-1}\left(\frac{R}{\gamma-1}\right) \ln \frac{T_1}{T_2}$$

$$\left[S_2 - S_1 = \frac{\gamma-\eta}{\eta-1} \cdot C_v \ln \frac{T_1}{T_2}\right]$$

1kg of Air at 1.013 bar & 290K is compressed accordingly $PV^{1.3}$ = until the pressure is 5 Bar. Calculate change of Entropy & sketch on a T-S diagram. Take $C_p = 1.005 kJ/K$, $C_v = 0.718 kJ/kgK$

$R = 0.287 kJ/kgK$

Soln

$P_1 V_1 = mRT_1$, i.e.

$1.018 \times 100 \times V_1 = 1 \times 0.287 \times 290$

$V_1 = 0.8216 m^3/kg$

$P_1 V_1^{1.3} = P_2 V_2^{1.3}$

$V_2 = V_1 \left(\frac{P_1}{P_2}\right)^{1/1.3} = 0.8216 \left(\frac{1.013}{5}\right)^{1/1.3}$

$V_2 = 0.240 m^3/kg$

$P_2 V_2 = RT_2 \therefore 5 \times 100 \times 0.24 = 0.287 \times T_2$

$T_2 = 419.1K$

$S_2 - S_1 = C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1}$

$= 0.718 \ln \frac{419.1}{290} + 0.287 \ln \frac{0.24}{0.82}$

$= 0.2645 - 0.8531 \Rightarrow \Delta S = -0.0866 kJ/kgK$

Q A Thermodynamic sys. operates under steady flow cond^n, the fluid entering at 2 bar & leaving at 10 bar. The entry velocity is 36 m/s & the exit velocity is 12 m/s. During the process 2500 kJ/h of heat from an external source are applied & the increase in enthalpy is 5 kJ/kg. The exit point is 25 m above the the entry point. Calculate the flow of work from the system in kW for a flow of 45 kg/min.

Ans Applying the SFEE ($E_{in} = E_{out}$)

$$h_1 + \frac{c_1^2}{2} + gz_1 + q = h_2 + \frac{c_2^2}{2} + gz_2 + w$$

Here $h_2 - h_1 = +5$ kJ/kg

$c_1 = 36$ m/s

$c_2 = 12$ m/s

$z_1 = 0$ m ; $z_2 = 25$ m

$Q = 25000$ kJ/h $= \frac{25000}{3600}$ kJ/s

$m = 45$ kg/min $= 0.75$ kg/s

$Q = mq \therefore q = \frac{Q}{m} = \frac{25000}{3600 \times 0.75}$

$= 9.26$ kJ/kg

→ Putting in the SFEE Eq^n

$$w = \frac{g(z_1 - z_2)}{1000} + \frac{c_1^2 - c_2^2}{2000} + (h_1 - h_2) + q$$

$$= \frac{9.81(0-25)}{1000} + \frac{36^2 - 12^2}{2000} - 5 + 9.26$$

$$= -0.24525 + 0.576 - 5 + 9.26$$

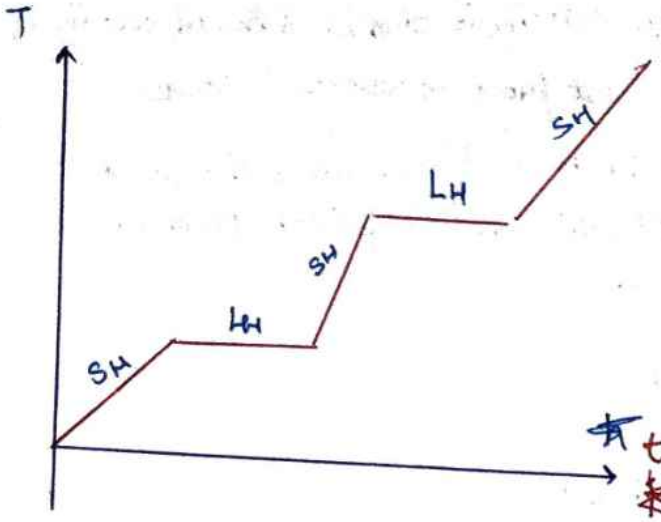
$$w = 4.59 \text{ kJ/kg}$$

$$W = mw$$

$$= 4.59 \times 0.75$$

$$\boxed{W = 3.4425 \text{ kW}}$$

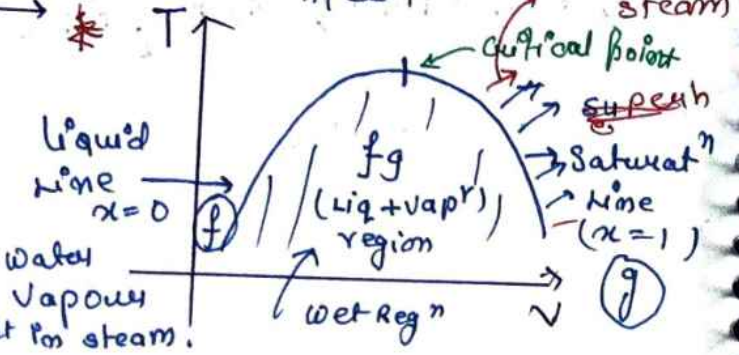
Steam & Its properties.



Latent Heat (LH) → ML

~~Specific~~ Heat (SH)
Sensible
↓
change of Phase
with change in Temp

$mC\Delta T$



* Properties of steam

1) Dryness fraction (x) → Amt. of water vapour present in steam.
2) Enthalpy (h)
3) Entropy (s)
4) Internal energy (u)
5) Specific volume

$$x = \frac{M_w}{M_s}$$

$$h = u + pv$$

* Types of Steam

1) Wet Steam → x lies b/w 0 to 1
2) Dry Saturated Steam, x = 1
3) Superheated Steam

* 100°C of water
↓
0°C of steam

- Enthalpy of Wet Steam;

$$\left[h_{wet} = h_f + x h_{fg}\right]$$

- Enthalpy of Dry Saturated Steam

$$\left[h_g = h_f + h_{fg}\right] ; x = 1$$

Steam Tables
Pg. No. 5

• Enthalpy of Superheated steam - $h_{sup} = h_g + C_{p_{sup}} (T_{sup} - T_{sat})$

↓ Degree of Superheat

[* $C_{p_{sup}}$ = 2.01 to 2.1 ← 2.1 dedama chup chap

If not given then]

→ Entropy of Wet steam : $S_{wet} = S_f + x S_{fg}$

Entropy of Dry Saturated steam : $S_g = S_f + S_{fg}$

In Kelvin

* Entropy of Supersaturated steam : $S_{super} = S_g + C_{p_{sup}} \ln \frac{T_{sup}}{T_{sat}}$

* T_{sup} & T_{satu} from steam table at a given temp

→ Specific Volume of

1) Wet steam ; $v_{wet} = x v_g$

2) Dry Saturated steam : v_g → Directly read from Steam Table at a given Pressure

3) Superheated, $V_{sup} = \frac{T_{sup}}{T_{sat}} \times v_g$

* Sensible Heat, $S_H = m C \Delta T$

Q A steam at 20 bar & D.f = 0.9 is heated at constant pressure to a Temp^r of 300°C, Considering the mass of steam is 1kg, then calculate Heat supplied & Change in ~~Enthalpy~~ Entropy.

Ans State - 1 → Wet Steam

$P_1 = 20$ Bar

$x_1 = 0.9$

State - 2 → Superheated Steam

$P_2 = 20$ Bar

$T_2 = 300°C$

→ $m = 1kg$

from steam Table At cond^n - (1)

$V_{g_1} = $ ~~0.09~~ $\times 0.0996$, $V = 0.08964\ m^3/kg$

$u_{f_1} = 906.4$

$u_{g_1} = 2600.3$

$S_{f_1} = 2.447$

$S_{fg} = 3.894$

$T_g \rightarrow (212-4)$

* from steam Table at cond^n 2

$V = 0.1255$

$u = 2772.6$

$h = 3023.5$

$S = 6.794$

* $V_1 = 0.08964\ m^3/$

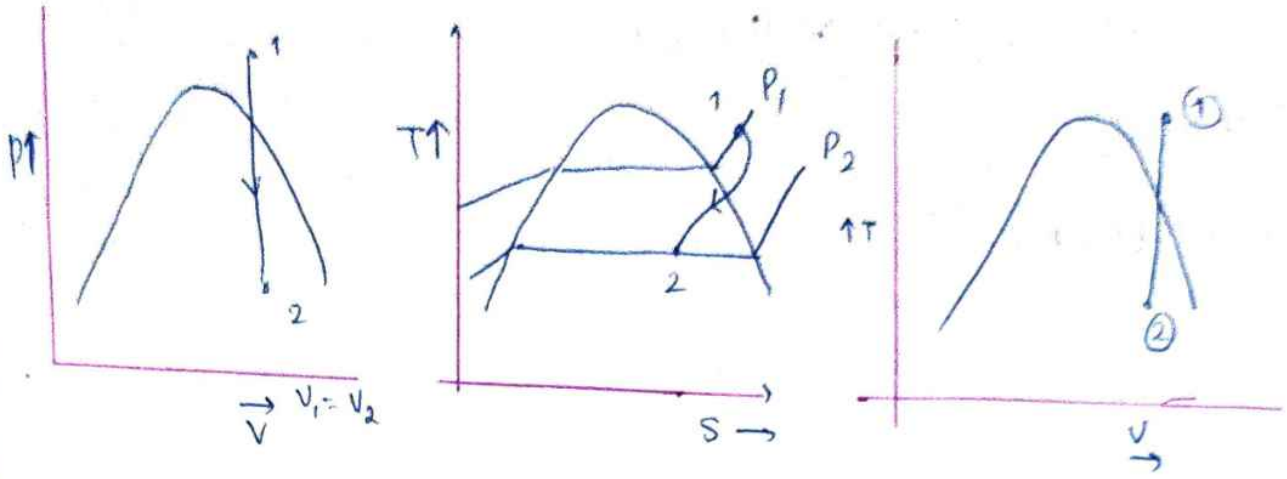
$u_1 = u_{f_1} + x(u_{g_1} - u_{f_1})$

$\simeq 2430.91\ kJ/kg$

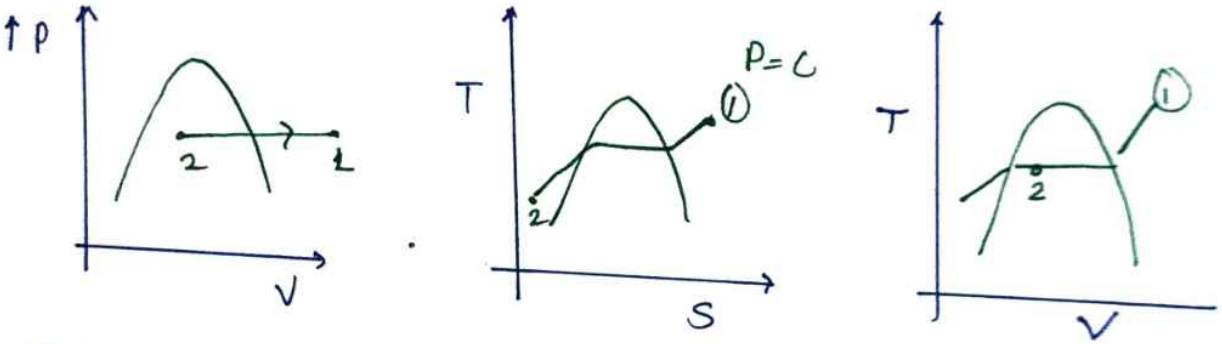
$S_1 = S_{f_1} + x(S_{fg_1})$

$= 5.95\ kJ/kg\ K$

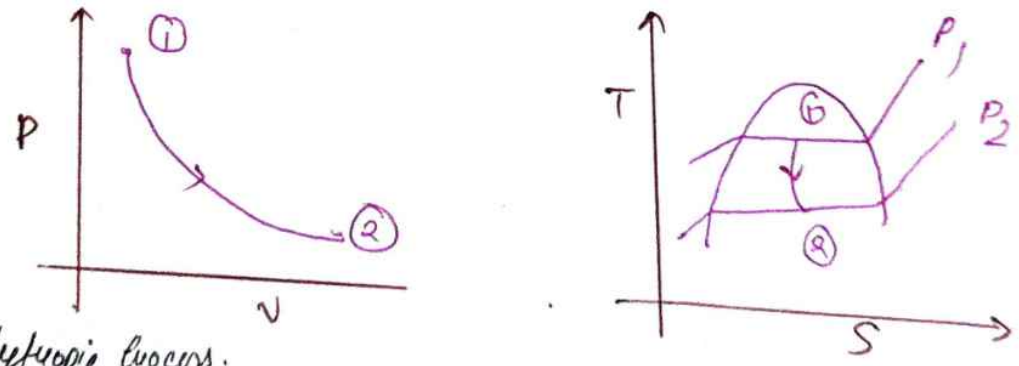
* Constant Volume process on p-V, T-S, T-V diagram for steam:



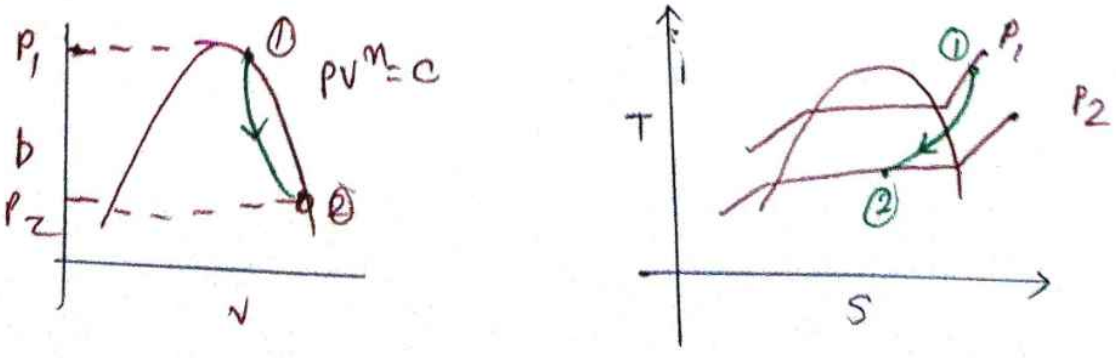
* Constant pressure process.



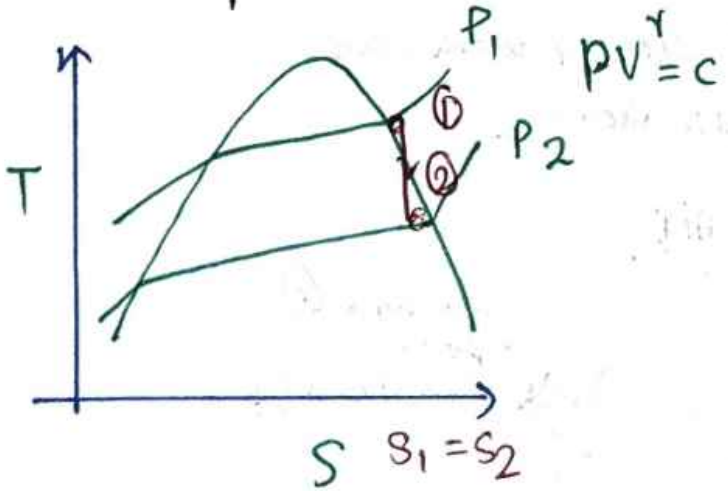
c) Constant Temp^r process

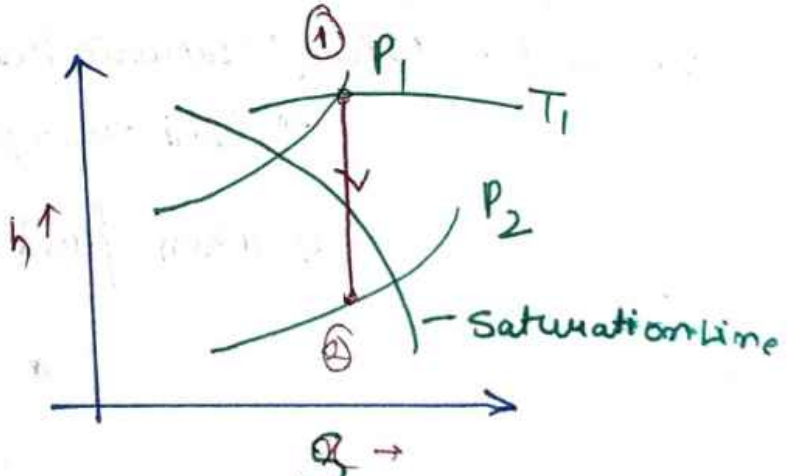


d) Polytropic process.

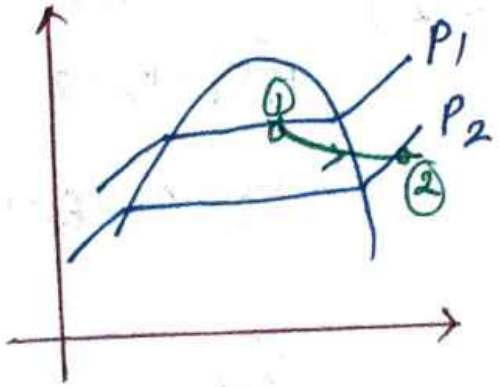


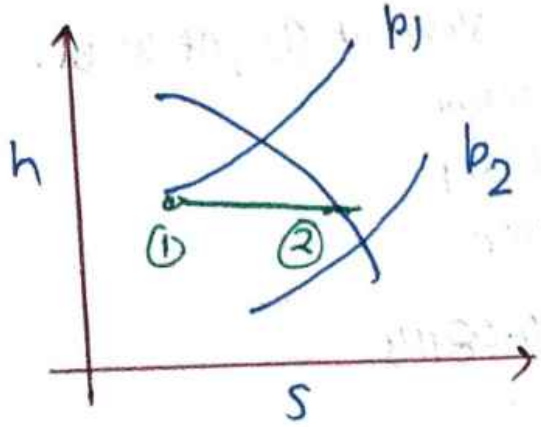
c) Adiabatic process. (Isentropic)





d) Throttling process. (Isenthalpic)



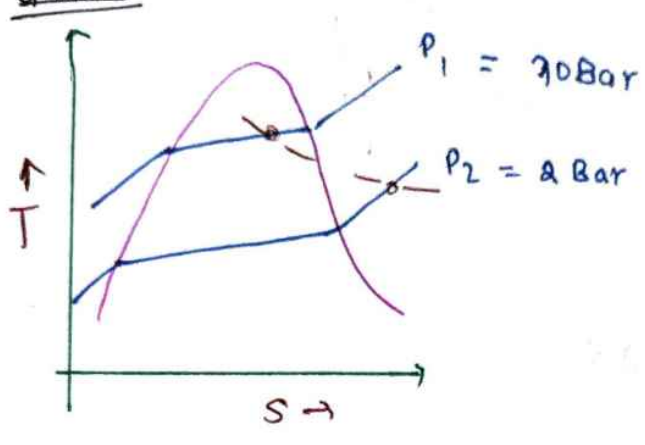


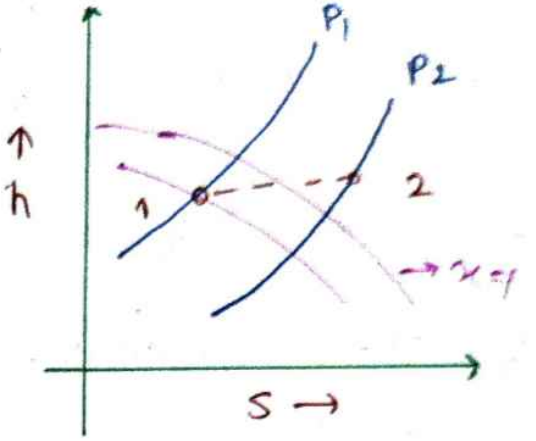
Q. Steam at pressure of 8 Bar & 200°C is expanded isentropically to 4 B

Find ... for 1kg of steam, ...

018, II nd Sem

Q4(b)





In a throttling process no heat transfer from OR To the Surroundings & No external work is done

But there is change in entropy thus the process become irreversible.

* Initial condn . To find x_2 & ΔS : for throttling $\boxed{h_1 = h_2}$

P_1 = 10Bar

x = 0.9

$h_1 = h_{f_1} + x\, h_{fg_1}$

$h_1 = 762.8 + 0.9 \times 2015.3$

$h_1 = 2576.57$ kJ/kg

Now $h_1 = h_2$

∴ At condn ②

P_2 = 2 Bar & h_2 = 2576.57 kJ/kg

from Steam Table

$h_{f_1} = 762.8$ kJ/kg

$h_{fg_1} = 2015.3$ kJ/kg

$S_{f_1} = 2.0189$ kJ/kg/K

$S_{fg_1} = 4.448$ kJ/kg/K

$S_1 = 2.0189 + 0.9 \times 4.448$

$\boxed{S_1 = 6.0171 \text{ kJ/kg K}}$

~~$h_2 = h_f$~~ Enthalpy of Dry Saturated Heat at 2 Bar = 2706 kJ/kg

$h_2 < (h_{\text{Dry saturated}})_{2\text{Bar}}$ ⇒ h_2 have some Dryness fraction.

$\therefore h_2 = h_{f_2} + x_2 h_{fg_2}$, $h_{f_2} = 504.7$ kJ/kg

$2576.57 = 504.7 + x \cdot 2201.9$

$h_{fg_2} = 2201.9$ kJ/kg

$\boxed{x_2 = 0.9409}$

$h_2 = 2576.57$ kJ/kg

$s_{f_2} = 1.530$, $s_{fg_2} = 5.597$

$s_2 = 1.580 + 0.9409 \times 5.597$

$s_2 = 6.7962$

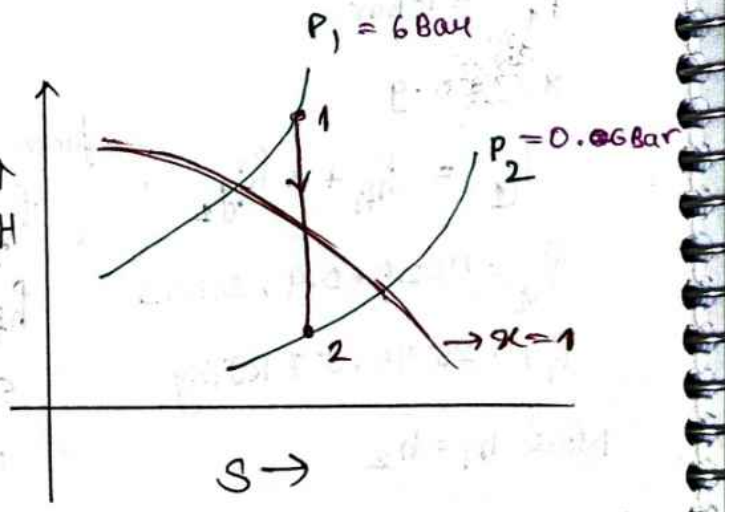
$\Delta S = S_2 - S_1$

$= 6.7962 - 6.0171$

$\boxed{\Delta S = 0.7791 \text{ kJ/kgK}}$

2018, Ist Sem

Q6(b) → 10m



• At point 1,

$P_1 = 600$ kPa $= 6$ Bar

$x_1 = 1$

$v_1 = v_{g_1} = 0.316 \text{ m}^3/\text{kg}$ {from st^m Tb}

$s_1 = s_{g_1} = 6.760$ kJ/kgK

$u_1 = u_{g_1} = 2567.4$ kJ/kgK , $h_1 = h_{g_1} = 2756.8$ kJ/kg

At point ②

$P_2 = 0.6$

$u_{f_2} = 359.8$ kJ/kg

~~u_{fg_2}~~ $= u_{g_2} = 2489.6$ kJ/kg

$h_{f_2} = 359.9$ kJ/kg

$h_{fg_2} = 2293.6$

$s_{f_2} = 1.145$ kJ/kgK

$s_{fg_2} = 6.384$ kJ/kgK

Not Read in this Qn

- Since the cylinder is perfectly thermally insulated therefore $Q = 0$ ∴ Hence the process is adiabatic

∴ $S_1 = S_2$

$$6.760 = 1.145 + x_2(6.887)$$

$$\boxed{x_2 = 0.8791}$$

Now

$$u_2 = u_{f_2} + x(-u_{f_2} + u_{g_2})$$

$$= 359.8 + 0.8791\{2489.6 - 359.8\}$$

$$u_2 = 2,232.107 \text{ kJ/kg}$$

- Acc. to Non flow eqn

$$Q_{12} = w_{12} + \Delta u_{12}$$

$$w_{12} = -(u_2 - u_1)$$

$$= -(2,232.107 - 2567.4$$

$$\boxed{w_{12} = 335.292 \text{ kJ/kg}}$$

2017, 1st Sem

Q 4(a) → 12 marks

Ans Given

$V = 0.04 m^3$, $T = 250\ ^\circ C$, $m = 4kg$

. From steam table corresponding to 250°C {Saturated steam}

P = 40 Bar

$v_g = v_s = 0.0498\ m^3/kg$, $v_1 = v_f = 0.001252\ m^3/kg$

. Total volume occupied By liquid = $M \cdot v_1$

$= 9\ kg \times 0.01252\ \frac{m^3}{kg}$

$= 0.011268\ m^3$

. Total volume of vessel, V

$V = V_L + V_S$ ← Vol. of steam

↑ Vol. of Liq.

$0.04 = 0.011268 + V_S$

$V_S = 0.0287\ m^3$

Mass of steam, $m_S = \frac{V_S}{v_S} = \frac{0.0287\ m^3}{0.0498\ m^3 kg^{-1}}$

$m_S = 0.576\ kg$

* Mass of mixt of steam & liquid, $m = m_1 + m_S$

$= 9 + 0.576 = 9.576\ kg$

. Total specific Vol. of mixt $= \frac{0.04}{9.576}$

. S.V $= 0.00417\ m^3/kg$

• We know

$$v = v_f + x v_{fg}$$

~~$0.0417 = 0.00125 + x(0.0498 - 0.00125)$~~

~~$\frac{0.04045}{0.04975}$~~

$$0.00417 = 0.00125 + (0.0498 - 0.00125)x$$

~~$\frac{0.00829}{0.04855}$~~

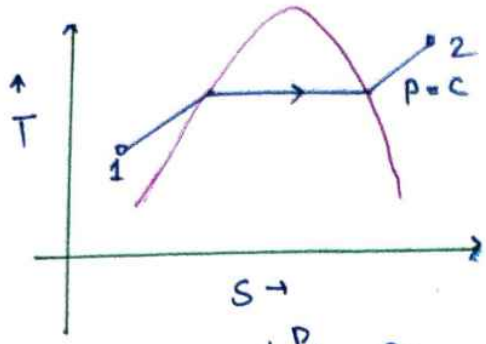
$$0.00417 - 0.00125 = x.0.04855$$

$$x = 0.06$$

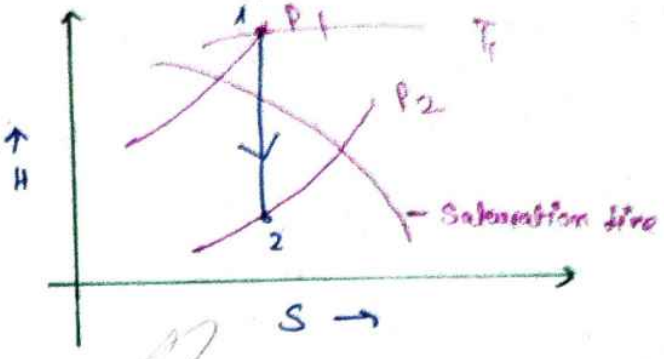
* 2023, I^st SEM

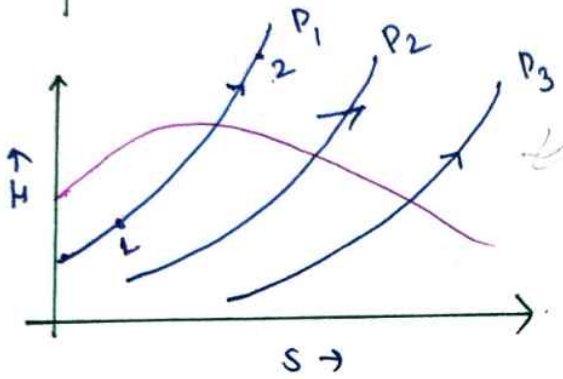
Q5(b) – SN

(1) Constant pressure heating

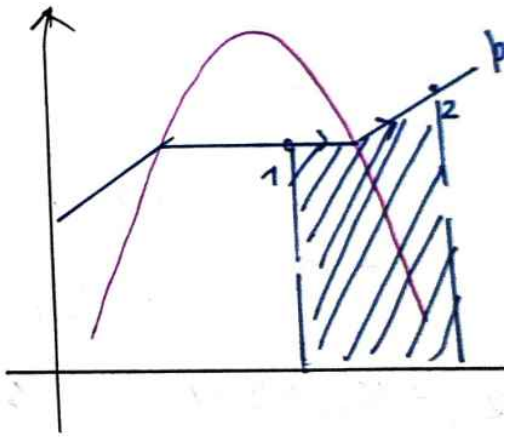


(2) Isentropic process





Q5(c) – 10M → ~~2019 I st Sem~~
2014 II nd Sem



Ans Given at State (1), At state 2

$x = 0.9$ $P_2 = 20$ Bar

$P_1 = 20$ Bar $T_2 = 300^\circ C$

To find heat supplied & ΔS

(1) $S_1 = S_{f_1} + x S_{fg_1}$; $S_2 = 6.766$

$S_{f_1} = 2.447$, $S_{fg_1} = 3.894$

$S_1 = 2.447 + 0.9 \times 3.894$

$= 5.9516$

$\Delta S = 6.766 - 5.9516$

$= 0.8144 \Rightarrow \boxed{\Delta S = 0.8144 \text{ kJ/kg K}}$

$Q = W + \Delta U$; $W = P(V_2 - V_1)$

~~$V_1 = V_{f_1} + x V_{fg_1}$~~ ; ~~$V_{f_1} = 2.441 \times 0.001414\ m^3/kg$~~

$V_{wet} = x V_g$; $V_g = 0.0996$

$= 0.9 \times 0.0996 = 0.08964\ m^3/kg$

$V_2 = 0.1255\ m^3/kg$

$W = 20\,(0.1255 - $ ~~0.08964~~ $- 0.08964)$

~~$= -15.416 \times 100 = -1541.8\ kJ/kg$~~ $= 70.72\ kJ/kg$

$u_2 = u_{f_1} + x_1 (u_g - u_f)$; $u_{f_1} = 906.4$

$u_g = 2600.3$

$u_1 = 906.4 + 0.9\,(2600.3 - 906.4)$

$u_1 = 2430.91$

$u_2 = 2772.6$

$\Delta U = 2772.6 - 2430.91$

$= 341.69\ kJ/kg$

$Q_{12} = W_{12} + \Delta U$

$= 70.72 + 341.69$

$\boxed{Q_{12} = 412.4\ kJ/kg}$

Internal Combustion Engine

- Engine : An engine is a device which transform one form of energy into another form.

- Normally most of the engine converts thermal energy into Mechanical work so that engine are called Heat Engine.

OR

- Heat Engine is a device which transforms the chemical energy of fuel into thermal energy & utilizes this energy into useful work.

Heat Engine → C.E → H.E → Mechanical work

Classification of Heat Engine

: These are of two categories : a) Internal Combustion Engine
b) External Combustion Engine

- **Internal Combustion Engine** : Internal combustion engine are those engine in which combustion of fuel with air take place inside the engine.

Ex - Petrol Engine, Diesel Engine, gasoline Engine, Wankel Engine & Open Cycle Gas Engine.

- **External Combustion Engine** : Those Engines in which the combustion of fuel with air takes place outside the Engine.

Ex - Steam Engine, Steam Turbine, Stirling Engine, Closed cycle Gas Turbine etc.

Advantages of IC Engine

- Mechanical Simplicity
- Higher Power to Weight Ratio
- Low Initial cost
- Higher Efficiency
- Compact and lighter.

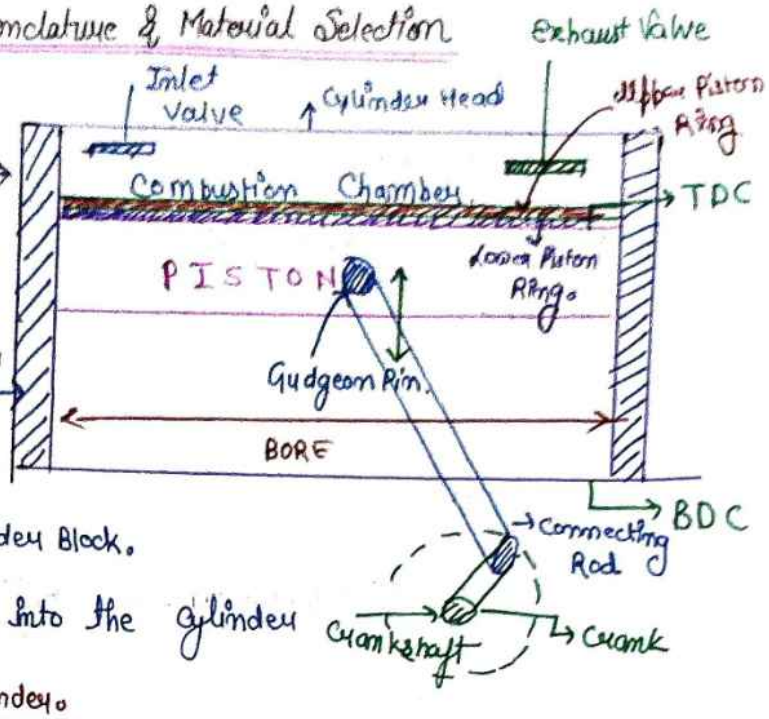
Disadvantages of IC Engine.

- High Maintenance Requirement
- Large amount of Pollution
- Difficult to start
- Complexity
- Noisy.

Applications of IC Engine

- Used for Road Vehicles (eg- Scooter, Bus, Car & Trucks etc).
- Used in Air Crafts
- Power Generation
- Marine (eg- Motorboats & Ships)
- Agriculture (eg - Tractors & pumpsets)
- Earthmoving (eg - Dumpers, Tippers & Mining Equipment)

Engine Nomenclature & Material Selection



- Cylinder Block : It is a supporting structure for various components.
- Cylinder : It is a cylindrical vessel or shape in which piston reciprocates.
- The cylinder is supported by Cylinder Block.

* Piston - Cylindrical Component fitted into the Cylinder

* Material Selection for Piston & Cylinder.

Early Days

Cast Iron – Heavy – Mass ↑ – Inertia ↑ – More Power Required – less Mileage

↓

Chevrolet

↓

Replaced By Alloy Steel

↓

less Heavy

↓

High Mileage

→ Replaced By Aluminium Alloy

↓

Least Safe

↓

Highest Mileage

↙

Duralumin is the alloy of Aluminium

↳ Strong, Hard & Lightweight

→ Used in Aircraft & Hyundai.

- Dead Centre : Here any motion is not present. Mainly of two types.

* Top Dead Centre – Extreme posⁿ of piston at the top of Cylinder of Vertical Engine is called Top Dead Centre.

* In case of Horizontal Engine it is known as Inner Dead Centre (IDC)

* Bottom Dead Centre : Extreme posⁿ of Piston at the Bottom of Cylinder of Vertical Engine is called Bottom Dead Centre.

- In case of Horizontal Engine, it is known as Outer Dead Centre (ODC)

Cylinder Head : It is fitted on top of cylinder

- It covers the cylinder & includes the combustion chamber, spark plug & valve.

* Material - Cast Iron & Aluminium

- Combustion Chamber: The space enclosed in the upper part of cylinder, By the cylinder Head & top of piston is called combustion chamber.
- Bore - The Nominal inside diameter of the engine cylinder is called Bore.
- Piston Ring: Piston Ring are fitted into the grooves of the piston to Maintain good Seal B/W the piston & Cylinder walls
- Upper piston Ring → To stop leakage of gas created after Combustion
- Lower Piston Ring → To stop leakage of lubricating Oil.
- Made of Brittle Material → Smooth ∴ Steel + Silicon + Graphite

* Piston Pin / Gudgeon Pin - Pin that connects end of connecting Rod to Piston
  - Tensile load (σ_T) & Compressive load (σ_C) is high.
  - Forging → Cold forging

* Connecting Rod - The connecting Rod interconnects the piston to the Crankshaft
  - Upper End of Connecting Rod is fitted to the piston & lower end to the Crankshaft
  - Material - Medium Carbon Steel & Alloy Steel. • σ_T & σ_C is high

* Crank : The crank is a lever that is connected to the one end of connected Rod by a pin Joint with its other end connected rigidly to a shaft is called crankshaft.
  ↓
  Converts Reciprocating Motn of piston into useful Rotary Motion of Op shaft.
  - Made of Crankshaft is made of High speed steel (HSS) & forged steel
  - failure will occur at whirling speed.

- Inlet Valve - Allows the fresh air + fuel Mixture into the cylinder
  Made of ↳ Nickel chromium steel.
- Exhaust Valve - Provides passage for Burnt gases to escape from cylinder
  ↳ Made of Silichrome steel.
- flywheel: Heavy wheel that is connected to the extreme end of the Crankshaft.
- The size of flywheel depends upon no. of cylinder & Construction of Engine.
- flywheel stores the excess energy during the Powerstroke of the Engine & Supply the Energy for the movement of piston during remaining stroke.
- Material - Cast Iron.
- Cam: Cam are integral part of Camshaft.

→ Cams are designed in such a way to open valve at correct time & to keep them open for necessary duration.

- Camshaft: Shaft on which cams are Mounted.
- Used to operate the inlet & exhaust valve through cam follower.

* Material of Cam & Camshaft: forged Steel.

2 Stroke Engine

- Two stroke engines performs only two strokes to complete one cycle.
- Suction stroke, Compression stroke, power stroke & exhaust stroke are complete in two stroke of piston i.e one revolution of Crankshaft.
- In a four stroke cycle, the power is obtained by only one stroke in two revolutions of crankshaft. But in two stroke cycle, the power is obtained by only one stroke but in one revolution of Crankshaft.
- In two stroke engine valves are not used, here ports are used.
- Two stroke cycle engines will theoretically give twice the power obtained from a four stroke cycle of engine of similar size.

→ In two stroke engine, ~~strokes~~ strokes are divided into two strokes

∴ Upward stroke - {Suction stroke + Compression stroke}

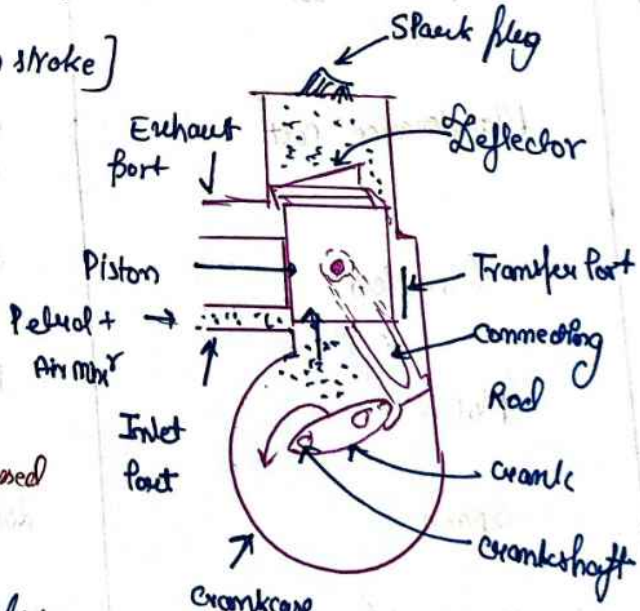
∴ Downward stroke - {Expansion stroke + Exhaust stroke}

2 Stroke Petrol Engine

- Upward stroke → [Suction stroke + Compression stroke]

During the upward Movement of piston from BDC to TDC, Both the transfer & exhaust ports are covered by piston.

- The petrol air Mixture which is already transferred into Engine cylinder is compressed By the moving piston.



→ Compression process in continued until the piston reaches TDC.

- At the same time, inlet port is uncovered by the moving piston & the fresh Air petrol Mixr enters the crankcase through the inlet port.

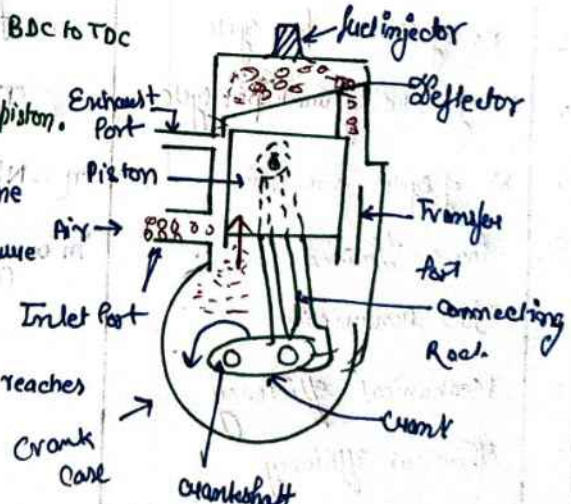
- After the piston almost reaches TDC, the compressed petrol air Mixture is ignited by means of an electric spark produced by a spark plug & combustion starts.
- Admission of fresh charge into crankcase continues till the piston reaches the TDC.

* Downward Stroke [Expansion Stroke + Exhaust Stroke]

- The ignited gases expand & forces the piston to move down, thus useful work is obtained.
- When the piston moves downward, the petrol air mixr is partially compressed in the crankcase. Thus compression is known as crankcase compression.
- Almost at the end of expansion, the exhaust port is uncovered & the combustion products escapes to the atmosphere.
- Immediately, the transfer port is also uncovered & the partially compressed air fuel Mixr from the Crank case enters the cylinder through transfer port.
- The leakage of fresh air fuel Mixture during exhaust stroke is called scavenging process.

* UPWARD Stroke - {Sucn & Compn} # 2 Stroke Diesel Engine

- During the upward Movement of piston from BDC to TDC Both the transfer ports & Exhaust ports are covered By piston.
- The air which is already transferred into the engine is compressed by the moving piston. This inc. the pressure & tempr of the air.
- The compression process is continued until the piston reaches TDC.



- At the same time, the inlet port is ~~continued until the piston reaches~~ uncovered By the Moving piston & the fresh Air enters the crankcase through the inlet port.
- After the piston almost reaches TDC, the fuel (Diesel) is injected through the fuel injector in the cylinder.

- The combustion of fresh fuel injected into the cylinder takes place due to high temp^{r} already developed in the cylinder during compression of the air.
- The admission of fresh air into crankcase continues till the piston reaches the TDC.

* Downward stroke - {Expans^{n} & exhaust stroke}

- The burnt gases expand & forces the piston to move down, thus useful work is obtained.
- When the piston moves down, the air is partially compressed in the crankcase. This compres^{n} is called crankcase compression.
- Nearly at the end of expansion, the exhaust port is uncovered & the combustion products escape to the ~~atm~~ atmosphere.
- Immediately the transfer port is also uncovered & the partially compressed air from crankcase enters the cylinder through transfer port.

COMPARISON

S.N	Details	4 Stroke Engine	2 Stroke Engine
1	No. of strokes per cycle	four	Two
2.	No. of Revolut^{n} of Crank per cycle	Two.	one
3.	No. of cycles per min	$n = N/2$, N = Engine Speed	$n = N$
4.	Power Derived	In every alternate revolut^{n} of CRANKSHAFT	In every revolut^{n} of crankshaft
5.	Fuel Consumption	less	High
6.	Mechanical efficiency	low	Low
7.	Thermal efficiency	High	More
8.	Fuel Added	Charge is added directly during suction stroke	Charge is added into the crankcase & then transferred to the cylinder
9	Torque	More	less
10	Direct^{n} of Rotation of Crankshaft	Crankshafts rotate in one direction only.	Crankshaft rotate in either direction

11	Initial Cost	High	Low
12	Valve / Port	Valve is opened by Cam	Port is covered or uncovered by piston
13	flywheel	Heavy & large flywheel is used	Lighter & Small flywheel is used
~~14~~	~~Starting~~		
14	Starting of Engine	Difficult	easy
15	Wear & Tear	Lesser	Greater
16	Engine Size	Large	Compact
17	Uses.	Buses, Tractors, Cars, Bike etc.	Scooter, Motorcycle etc

Why 2 Stroke Scooter are not conventionally used.

→ 1) Two stroke Scooter are not conventionally used because of leakage of fresh Air fuel Mixture during exhaust stroke. This process is called Scavenging process.

- No Cam - No camshaft - No valve - No piston ring ⟹ Simple Design.

Liquid lubricant is used

⇓

lubricant oil is burnt

⇓

friction losses increases. ⟶ ↑ Thermal Decreases

↓

leakage of fresh air fuel

↓

Pollution.

$\eta_v = 1 + \frac{V_s}{V_c} = 1 + \frac{1}{C}$; C = clearance ratio = $\frac{V_c}{V_s}$

Air standard Cycle

→ Assumptions

- The working Medium is assumed to be an ideal gas & follow the relat^n $pV = mRT$
- Mass of working fluid remains constant in a cycle.
- Specific heat of working fluid remains constant
- All the process are Reversible process
- Some heat is assumed to be rejected to a constant low temp^r. sink during the cycle.
- There is no loss or gain of heat energy
- Operation of engine are frictionless.
- Working Medium doesn't undergoes any chemical change throughout the cycle.

Otto cycle OR constant Volume process.

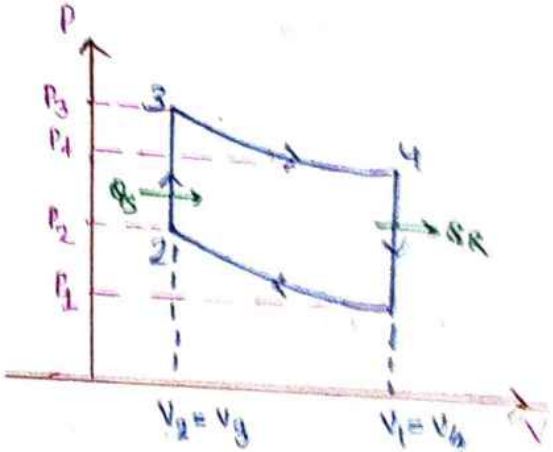
- Process

(1-2) = Isentropic (Reversible Adiabatic) Compression process.

(2-3) = Constan Vol. Heat Add^n process.

(3-4) = Reversible Adiabatic Expansion process.

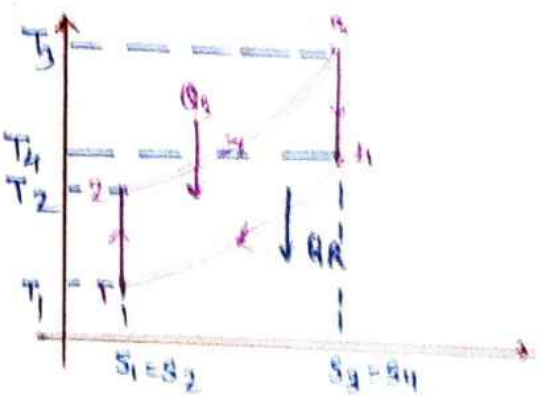
(4-1) = Constan Volume Heat Reject^n process



- $Q = mC\,dt$

$$Q_S = mC_v(T_3 - T_2)$$

$$Q_R = mC_v(T_4 - T_1)$$



• efficiency, $\eta = \frac{\text{Output}}{\text{Input}} = \frac{\text{work done}}{\text{Heat supplied}}$; W.D = Heat supplied - Heat Rejected.

$$\eta = \frac{Q_S - Q_R}{Q_S} = 1 - \frac{Q_R}{Q_S}$$

$$\eta_{OTTO} = 1 - \frac{mC_v(T_4 - T_1)}{mC_v(T_3 - T_2)} = 1 - \left[\frac{T_4 - T_1}{T_3 - T_2}\right] = \frac{1 - T_1\left(\frac{T_4}{T_1} - 1\right)}{T_2\left(\frac{T_3}{T_2} - 1\right)}$$

$$\left[\eta_{OTTO} = 1 - \frac{T_1}{T_2}\left\{\frac{\frac{T_4}{T_1} - 1}{\frac{T_3}{T_2} - 1}\right\}\right] - (A)$$

• Apply Adiabatic Gas Eqn in (1-2) i.e $\frac{T_H}{T_L} = \left(\frac{P_H}{P_L}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_H}{V_L}\right)^{\gamma-1}$

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

• Applying Adiabatic Gas Eqn in (4-1)

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} ; \; V_4 = V_1 \; \& \; V_2 = V_3 \therefore \left[\frac{T_3}{T_4} = r^{\gamma-1}\right] - (2)$$

• from eqn (1) & (2)

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \Rightarrow \frac{T_4}{T_1} = \frac{T_3}{T_2} \Rightarrow (A) \Rightarrow \eta = 1 - \frac{T_1}{T_2}\frac{\left(\frac{T_4}{T_1} - 1\right)}{\left(\frac{T_4}{T_1} - 1\right)}$$

$$\eta = 1 - \frac{T_1}{T_2} \Rightarrow \eta = 1 - \frac{1}{\frac{T_2}{T_1}} \; ; \text{ we know } \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_2}{V_2}\right)^{\gamma-1}$$

$$\eta = 1 - \frac{1}{(V_1/V_2)^{\gamma-1}} \Rightarrow \boxed{\eta_{OTTO} = 1 - \frac{1}{(r)^{\gamma-1}}}$$

⇒ Depends upon compression Ratio & [Adiabatic Index.]
↳ Diff^t for Diff^t Gases.

$\gamma_{mono} = 1.67$

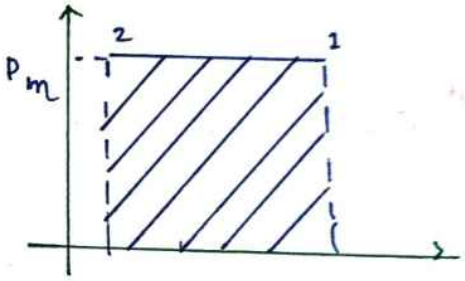
$\gamma_{dia} = 1.4$

$\gamma_{Tri} = 1.33$

* if compression ratio ↑, then efficiency also ↑

* The value of compression ratio for perfect petrol engine lies B/w 6-12.

Mean effective pressure - The constant pressure (Hypothetical pressure) during expansion producing same work as actual work.



- Area under curve on PV diagram → work done

  ar (Rectangle) = work = $P_m(V_1 - V_2)$

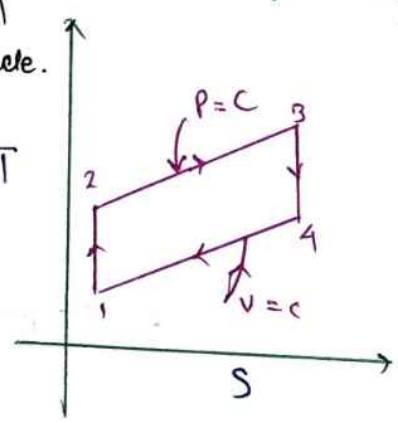
$$P_m = \frac{W}{V_1 - V_2} \Rightarrow \boxed{P_m = \frac{W}{V_S}}$$

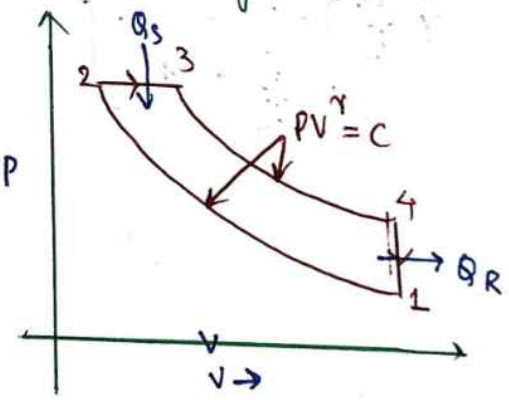
- Detonation - Phenomena of uncontrolled combustion in petrol engine.

- Self Ignition Temperature - Temp^r at which fuel starts to burn itself.

Q(a) - 5M

Diesel cycle.





- Cycle that may be used approximate the operat^n of Compression Ignition IC engine is Diesel cycle.

- All processes are reversible

The cycle is arranged as follows –

1 - 2 - Air is compressed adiabatically (Isentropically)

2 - 3 - Heat Added at constant pressure
(Heat Transfer to the air Replaces the fuel injection & Combustion of Actual engines)

3 - 4 - Air expands adiabatically.

4 - 1 . Heat is Rejected at constan Volume ; Heat is Rejected to a lower temp^{r} Reservoir , completing the cycle.

- Compression ratio, r is the volume ratio , $r = \frac{V_1}{V_2}$

- Cut-off Ratio is Defined as , $\rho = \frac{V_3}{V_2} = \frac{T_3}{T_2}$

- $Q_S = m c_p (T_3 - T_2)$, $Q_R = m_c (T_4 - T_1)$

- Efficiency , $\eta = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{c_v}{c_p}\left(\frac{T_4 - T_1}{T_3 - T_2}\right)$

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

Here $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma - 1} = r^{\gamma - 1}$ & $\rho = \frac{T_3}{T_2}$ due to constant pressure process

~~ρ~~ T, $\frac{T_4}{T_1} = \frac{T_4}{T_3} \times \frac{T_3}{T_2} \times \frac{T_2}{T_1}$

$$\frac{T_4}{T_1} = \left(\frac{V_3}{V_4}\right)^{\gamma - 1} \times \frac{V_3}{V_2} \times \left(\frac{V_1}{V_2}\right)^{\gamma - 1}$$

$$= \left(\frac{V_3}{V_4} \times \frac{V_1}{V_2}\right)^{\gamma-1} \times \frac{V_3}{V_2} \quad \{\text{Here } V_1 = V_4\}$$

$$\left[\frac{T_4}{T_1} = \left(\frac{V_3}{V_2}\right)^{\gamma} = e^{\gamma}\right]$$

* Substituting values in eq (*)

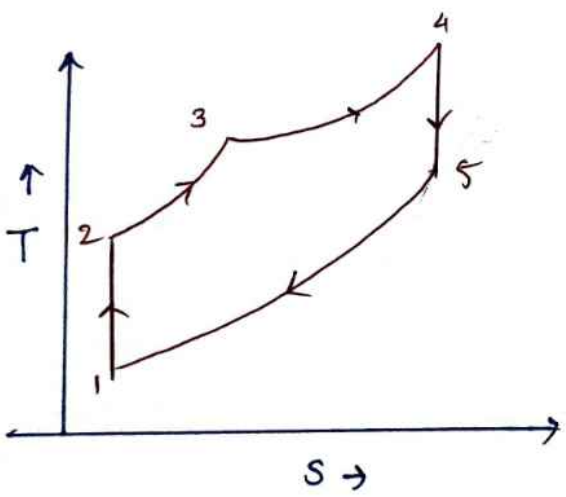
$$\eta = 1 - \frac{1}{\gamma(r)^{\gamma-1}} \left\{\frac{e^{\gamma}-1}{e-1}\right\}$$

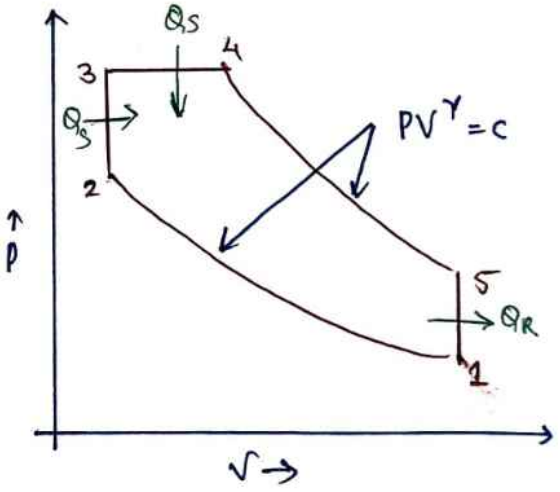
$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} \left\{\frac{e^{\gamma}-1}{\gamma(e-1)}\right\}$$

Dual Cycle / Limited Pressure Cycle / Mixed Cycle

Q4(b)

- In practice combustion occurs at neither at constant volume nor at constant pressure. This leads to dual cycle which has heat addn in two stages
  - (1) at constant ~~pressure~~ Volume
  - (2) At constant pressure
- Its efficiency lies b/w that of Otto & Diesel Cycle.





- Cycle is arranged as follows.

1-2 → Air is compressed adiabatically

2-3-4 → 2-3 - Heat supplied at constant Volume

→ 3-4 - Heat supplied at constant pressure.

4-5 - Air expands adiabatically.

5-1 - Heat is Rejected at Constant Volume do a low temp^r reservoir, completing the cycle.

- Compres^n Ratio, $r = \frac{V_1}{V_2}$, Pressure Ratio, $\alpha = \frac{P_3}{P_2} = \frac{T_3}{T_2}$, Cut off Ratio, $\rho = \frac{V_4}{V_3} = \frac{T_4}{T_3}$

- Heat Supplied at Constant Volume, $Q_{23} = mC_v(T_3 - T_2)$
- Heat Supplied at Constant pressure, $Q_{34} = mC_p(T_4 - T_3)$
- Total Heat Supplied, $Q_H = Q_{23} + Q_{34}$

$$= m\left(C_v[T_3 - T_2] + C_p(T_4 - T_3]\right)$$

* Heat Rejected, $Q_{5-1} = mC_v(T_5 - T_1)$

$$\text{Efficiency}, \eta = \frac{Q_H + Q_L}{Q_H} = \frac{m\left[C_v(T_3 - T_2) + C_p(T_4 - T_3) - C_v(T_5 - T_1)\right]}{m\left[C_v(T_3 - T_2) + C_p(T_4 - T_3)\right]}$$

$$= 1 - \frac{C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$

$$= 1 - \frac{(T_5 - T_1)}{\frac{C_v}{C_v}(T_3 - T_2) + \frac{C_p}{C_v}(T_4 - T_3)}$$

$$\eta = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)} \quad \text{—}$$

- Obtaining all temp^r at the state of Compres^n T_1, we have -

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

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} \Rightarrow T_3 = T_2 \cdot \frac{P_3}{P_2} \Rightarrow \boxed{\alpha\,(r)^{\gamma-1} \cdot T_1 = T_3}$$

- $\frac{T_4}{T_3} = \frac{V_4}{V_3} \Rightarrow T_4 = \rho\, T_3 \Rightarrow \boxed{T_4 = \alpha \rho (\gamma)^{\gamma-1} \cdot T_1}$

- $\frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} = \left(\frac{V_4}{V_{53}} \times \frac{V_3}{V_5}\right)^{\gamma-1}$

$= \left(\frac{\rho}{} \times \frac{V_2}{V_5}\right)^{\gamma-1}$, as $V_2 = V_3$

$T_5 = \left(\frac{\rho}{\gamma}\right)^{\gamma-1} \cdot T_4 = \alpha \rho \gamma^{\gamma-1} \cdot \frac{\rho^{\gamma-1}}{\gamma^{\gamma-1}} \cdot T_1$

$$\boxed{T_5 = \alpha \rho^{\gamma} T_1} \quad - (*)$$

* value for $\frac{T_5}{T_1}$

$$\frac{T_5}{T_1} = \frac{T_5}{T_4} \times \frac{T_4}{T_3} \times \frac{T_3}{T_2} \times \frac{T_2}{T_1}$$

$$= \left(\frac{V_4}{V_5}\right)^{\gamma-1} \times \left(\frac{V_4}{V_3}\right) \times \left(\frac{T_3}{T_2}\right) \times \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$= \left(\frac{V_4}{V_5} \times \frac{V_1}{V_2}\right)^{\gamma-1} \cdot \frac{V_4}{V_3} \times \frac{T_3}{T_2} \quad ; V_5 = V_1 \ \& \ V_2 = V_3$$

$$\frac{T_5}{T_1} = \left(\frac{V_4}{V_3}\right)^{\gamma} \cdot \frac{T_3}{T_2}$$

$$\frac{T_6}{T_1} = \alpha \cdot \rho^{\gamma} \Rightarrow \boxed{T_5 = T_1 \alpha \rho^{\gamma}}$$

Putting value of T_2, T_3, T_4 & T_5 in (*)

$$\eta = 1 - \frac{(\alpha \rho^{\gamma} T_1 - T_1)}{\left[(r)^{\gamma-1} \alpha T_1 - (r)^{\gamma-1} T_1\right] + \gamma\left[\alpha \rho (r)^{\gamma-1} T_1 - \alpha (r)^{\gamma-1} T_1\right]}$$

$$\eta_{DUAL} = 1 - \frac{1}{(r)^{\gamma-1}} \times \left[\frac{(\alpha \rho^{\gamma} - 1)}{(\alpha - 1) + \gamma \alpha (\rho - 1)}\right]$$

Numericals, 23-24, I St Sem

10M

① Derive the following for a polytropic process; $W = \frac{mRT_1}{n-1}\left[1-(r_p)^{\frac{n-1}{n}}\right]$ where $r_p = \frac{P_2}{P_1}$ [Ex 2.3(a)] {10M}

Ans We know that for a polytropic process

$$W = \frac{P_1V_1 - P_2V_2}{n-1} \quad ; PV = mRT$$

$$\therefore W = \frac{mRT_1 - mRT_2}{n-1} = \frac{mRT_1}{n-1}\left\{1 - \frac{T_2}{T_1}\right\} \quad \text{—(1)}$$

- We know that

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad \& \; P_1V_1^n = P_2V_2^n \rightarrow \frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{1/n}$$

$$\therefore \frac{T_2}{T_1} = \frac{P_2V_2}{P_1V_1} = \frac{P_2}{P_1} \times \left(\frac{P_1}{P_2}\right)^{1/n}$$

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

* Substituting in (1)

$$W = \frac{mRT_1}{n-1}\left(1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right) \quad \& \; \frac{P_2}{P_1} = r_p$$

$$\boxed{W = \frac{mRT_1}{n-1}\left(1 - (r_p)^{\frac{n-1}{n}}\right)}$$

② A fluid is confined --- — 10 Marks

(c) (a)

Ans Relation B/w pressure & Volume, $P = A + BV$

Values of A & B can be determined from the values of pressure & volume at initial & final points

$200 = A + 0.02B$

$450 = A + 0.04B$

$250 = 0.02B \Rightarrow \boxed{B = 12500}$ & $\boxed{A = -50}$

$\therefore P = 12500V - 50$

a) Work involved during process

$$W_{12} = \int_1^2 P\,dV = \int_1^2 (12500V - 50)\,dV$$

$$= 6250 \left[V^2\right]_{0.02}^{0.04} - 50 \left[V\right]_{0.02}^{0.04}$$

$$= 6250 \left[(0.04)^2 - (0.02)^2\right] - 50 \left[0.04 - 0.02\right]$$

$$= 6250 \left[(0.06)(0.02)\right] - 50 \times 0.02$$

$$= 7.5 - 1$$

$\boxed{W_{12} = 6.4 \text{ kJ}}$ → Since, W_{12} is +ve, the work has been done By System.

b) Change in Internal energy $= U_2 - U_1$

$$U = 5pV + 100$$

$$\Delta U = 5\left(450 \times 0.04 - 200 \times 0.02\right)$$

$$\Delta U = 5\left(18 - 4\right)$$

$$\Delta U = 70 kJ$$

- Applying Non flow energy eqn

$$\partial Q = \partial W + \partial U$$

$$Q_{12} = 70 + 6.4$$

$Q_{12} = +ve \Rightarrow$ Heat flows into the System.

$$Q_{12} = 76.4 kJ$$

Q3(c) → Ex 2.3 [10M]

Sol^n Given

$\dot{m} = 1 kg/s$

$h_1 = 840 kJ/kg$ $\quad h_2 = 2625 kJ/kg$

$c_1 = 5 m/s$ $\quad c_2 = 50 m/s$

$q = 2300 kJ/kg$ $\quad$ Power = ?

$Z_1 = 4 m$ $\quad Z_2 = 0$

- $Q_{LOSSES} = 1250 kJ/min = \frac{1250}{60} kJ/s = 20.833 kJ/s$

$q_{losses} = 20.833 kJ/kg$ ie $Q_{Losses}/\dot{m}$

- Applying SFEE $[E_{in} = E_{out}]$

$$h_1 + \frac{c_1^2}{2000} + \frac{gZ_1}{1000} + q = h_2 + \frac{c_2^2}{2000} + \frac{gZ_2}{1000} + w + q_{Losses}$$

$$840 + \frac{151^2}{2000} + \frac{9.81 \times 4}{1000} + 2300 = 2625 + \frac{(50)^2}{2000} + 0 + w + 20.833$$

$$w = 3140.05 - 2647.083$$

$$= 492.96 kJ/kg$$

$$P = \dot{m} w$$

$$\boxed{P = 492.96 kW}$$

14(c) Steam at 15 Bar is throttled to 1 bar & a temp^r of 110°C, Calculate the initial dryness fraction of steam, change in entropy. Sketch the process on T-S chart. Take C_p = 2.1k J/kg k {Ex - 4.14} 10 M

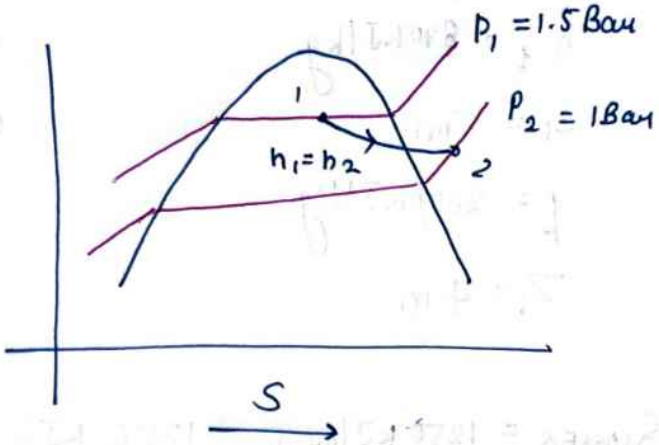
- At point (1) from steam table

$(h_f)_1$ = 844.9 kJ/kg

$(h_{fg})_1$ = 1947.3 kJ/kg

$(s_f)_1$ = 2.315 kJ/kg K

$(s_{fg})_1$ = 4.130 kJ/kg k



- At point 2

P_2 = 1 Bar

T_S = 99.6°C

h_2 = 2700 kJ/kg [from Mollier chart]

S_2 = 7.4 kJ/kg k ["]

a) ~~Change in entropy: $S_2 - S_1 = 7.4 - Sf_1$~~

- for throttling process

$h_1 = h_2$

$hf_1 + x\, h_{fg_1} = h_2$

$844.9 + x\,1947.3 = 2700$

$x = \dfrac{2700 - 844.9}{1947.3}$

$x = 0.95$

$S_1 = S_{f_1} + x S_{fg_1}$

$= 4.13 \times 0.95\,(4.13) + 2.315 = 6.24$

$\Delta S = 7.4 - 6.24 \rightarrow$ **$\Delta S = 1.15$ kJ/kg K**

Q5(c) —10 M

N → Speed = 240 rpm

η_{mech} = 90%

MEP = 7.5 Bar

d = 250mm

l = 400mm = 0.4m

f.c = ~~400~~ 6.6 kg/hr = $\dot{m}_f$

C.V = 44 MJ/kg

(i) I.P = $p_m \cdot l \cdot A \cdot n \cdot k$, A = Area = $\frac{\pi}{4} d^2$

= $7.5 \times 0.4 \times \frac{\pi}{4} \cdot (0.25)^2 \times n \cdot k$

η → Explosion per min for a gas engine , $\eta = \frac{N}{2} = \frac{240}{2} = 120$

K = 1 as no. of cylinders = 1

$$IP = 7.5 \times 0.4 \times \frac{\pi}{4} \times (0.25)^2 \times \frac{120}{60} \times 1 \times 100$$

$$= 29.45 \text{ kW}$$

$\eta_{mech} = \frac{BP}{IP} \Rightarrow BP = \eta_{mech} \times IP$

$BP = 0.9 \times 29.45$

$= 26.50$ kW ; $BP = 2\pi NT$

. $Bsfc = \frac{\dot{m}_f}{BP}$, ~~$\dot{m}_f = \frac{f_c}{N}$~~ $\therefore Bsfc = \frac{6.6}{26.50} = 0.2490$ kg/hr/kW

(iv) indicated thermal efficiency -

$$\eta_{ith} = \frac{1}{isfc \times CV} \quad \text{--- (1)}$$

$$\eta_{ith} = \frac{3600}{\frac{6.6}{29.45} \times 44 \times 1000}$$

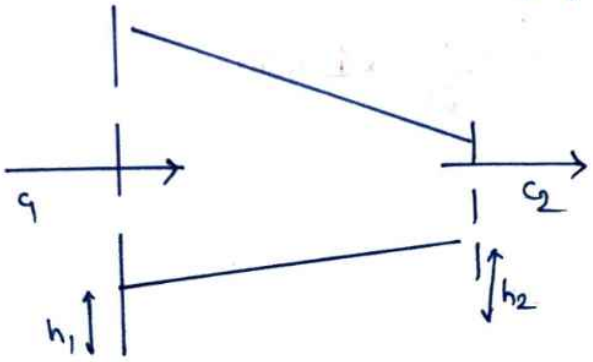
$$\eta_{ith} = 0.365$$

$$\eta_{ith} = 36.5\ \%$$

Q(3) a → 5 Marks

* Nozzles & Diffusers

- A nozzle is a device that increases the velocity of a fluid at expense of pressure



- Nozzle & Diffuser are generally utilized in jet engines, space crafts, rockets etc

- There is neither heat nor work transfer across the boundaries of system.

$$Q = W = 0$$

- However, K.E. effects can't be neglected, Hence applying SFEE equation

$$h_1 + \frac{c_1^2}{2} = h_2 + \frac{c_2^2}{2} \Rightarrow c_2^2 = c_1^2 + 2(h_2 - h_1)$$

- for nozzle $c_2 >>>> c_1$

$$\therefore \boxed{c_2^2 = 2(h_2 - h_1)}$$

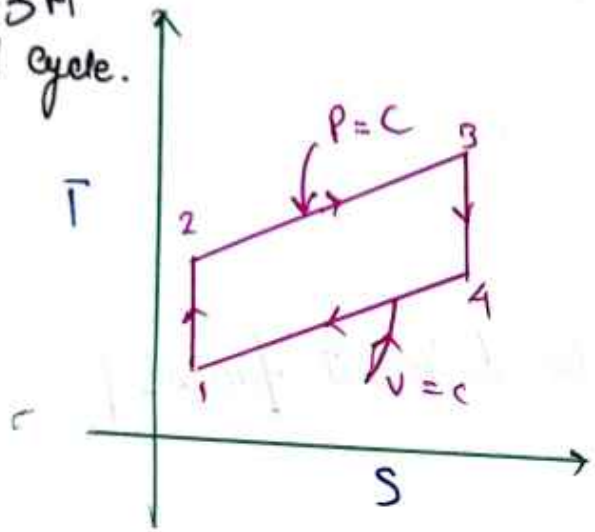
If heat transfer is considered in the nozzle the SFEE is given by

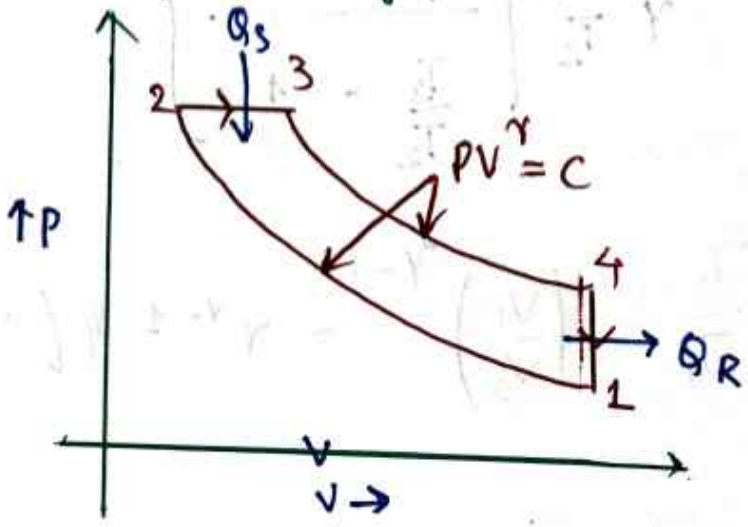
$$\boxed{h_1 = h_2 + \frac{c_2^2}{2} + q}$$

• Self Ignition Temperature - Temp^{r} at which fuel starts to burn itself.

Q Cut - 5M

Diesel cycle.





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(Heat Transfer to the air Replaces the fuel injection & Combustion of Actual engine

3 - 4 - Air expands adiabatically.

4 - 1 , Heat is Rejected at constan Volume ; Heat is Rejected to a lower temp Reservoir , completing the cycle.

- Compression ratio, r is the volume ratio , $r = \frac{V_1}{V_2}$

- Cut-off Ratio is Defined as , $\rho = \frac{V_3}{V_2} = \frac{T_3}{T_2}$

- $Q_S = m c_p (T_3 - T_2)$, $Q_R = m_c (T_4 - T_1)$

- Efficiency , $\eta = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{c_v}{c_p} \left(\frac{T_4 - T_1}{T_3 - T_2} \right)$

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

Here $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\gamma - 1} = r^{\gamma - 1}$ & $\rho = \frac{T_3}{T_2}$ due to constant pressure process

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

$$\frac{T_4}{T_1} = \left(\frac{V_4}{V_3} \right)^{\gamma - 1} \times \frac{V_3}{V_2} \times \left(\frac{V_1}{V_2} \right)^{\gamma - 1}$$

$$= \left(\frac{V_3}{V_4} \times \frac{V_1}{V_2}\right)^{\gamma-1} \times \frac{V_3}{V_2} \quad \{\text{Here } V_1 = V_4\}$$

$$\left[\frac{T_4}{T_1} = \left(\frac{V_3}{V_2}\right)^{\gamma} = e^{\gamma}\right]$$

* Substituting values in ⊛

$$\eta = 1 - \frac{1}{\gamma(r)^{\gamma-1}} \left\{\frac{e^{\gamma}-1}{e-1}\right\}$$

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} \left\{\frac{e^{\gamma}-1}{\gamma(e-1)}\right\}$$

Q(1)(b) -10M

c) We know that a polytropic process for the Non flow Energy Eqn.

$$Q = W + \Delta U$$

$$Q = \frac{P_1 V_1 - P_2 V_2}{n-1} + m c_v (T_2 - T_1)$$

We know that : $c_v = \frac{R}{\gamma - 1}$ & $P_1 V_1 = mRT_1$

$$\therefore Q = \frac{P_1 V_1 - P_2 V_2}{n-1} + \frac{mR}{\gamma - 1}(T_2 - T_1)$$

$$Q = \frac{P_1 V_1 - P_2 V_2}{n-1} + \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} = \frac{P_1 V_1 - P_2 V_2}{n-1} - \left(\frac{P_1 V_1 - P_2 V_2}{\gamma - 1}\right)$$

$$Q = \frac{P_1 V_1 - P_2 V_2}{n-1}\left[1 - \frac{n-1}{\gamma - 1}\right]$$

$$Q = W\left[\frac{\gamma - n}{\gamma - 1}\right]$$

• 2023 - II^nd Sem

Q1(b) - 10 Marks → NOTES

Q2(c) - 10 M

Am given at Initial Condn

$$m = 2kg$$

$$P_1 = 200kPa$$

$$T_1 = 60°C = 333K$$

* 1 - 2 ⇒ Gas is expanded at constant pressure

$$V_2 = 2V_1 \ , P_2 = P_1$$

2 - 3 ⇒ Gas is heated at constant volume until pressure is doubled

$$V_3 = V_2 = 2V_1 \ , P_3 = 2P_1$$

To find

W_T ie $W_{12} + W_{23}$ & T_3

$$* \quad W_{12} = \int_1^2 P\,dV = P\int_1^2 dV = P\,[V_2 - V_1]$$

$$W_{12} = P\,[2V_1 - V_1] = PV_1$$

By we know

$$P_1V_1 = mRT_1$$

$$P_1V_1 = 2 \times 0.6 \times 833 \ kJ$$

$$\boxed{W_{12} = 399.6 kJ}$$

$W_{23} = 0$ {constant vol. process} ⇒

(a)

$$\boxed{W_T = W_{12} + W_{23} = 399.6 kJ}$$

(b) for T_3 : $P_3 V_3 = mRT_3$

$$2P_1 \cdot 2V_1 = mRT_3$$

$$4(P_1V_1) = 2 \times 0.6\, T_3 \Rightarrow T_3 = \frac{4 \times 399.6}{2 \times 0.6} \text{ OR } \{4 \times 333\}$$

$$\boxed{T_3 = 1332K = 1059^\circ C}$$

Q(3)(a) - 5M

* Assumptions Made for the Derivat^n of efficiency of Carnot cycle

(i) A hot source i.e Heat Reservoir of infinite capacity at Max^m constant Temp^r T_1

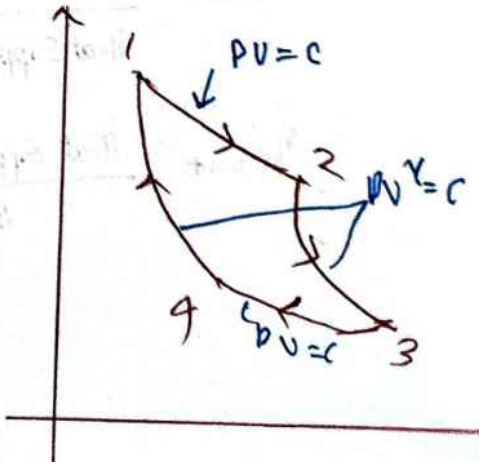
(b) A cold sink i.e Heat Reservoir of infinite capacity at min^m constant temp^r

(c) Working fluid is perfect gas

(d) A frictionless piston sliding in a perfectly sealed cylinder, Both piston & cylinder Being perfect insulators.

(e) A perfect conducting cylinder Head.

(f) Since all processes have to be fully Reversible, it follows that they must be performed infinitely slowly



• 1-2, Isothermal heat Supplied

$$Q_{12} = RT_1 \ln \frac{V_2}{V_1}$$

2-3, Adiabatic Compression $\frac{T_2}{T_3} = \left(\frac{V_3}{V_2}\right)^{\gamma-1}$

3-4 , Isothermal Heat Rejcn

$$Q_{34} = RT_2 \ln \frac{V_3}{V_4} \quad \text{—} \ (*)$$

4-1 Adiabatic Compression

$$\frac{T_1}{T_2} = \left(\frac{V_4}{V_1}\right)^{\gamma-1} \qquad \left(\frac{V_1}{V_4}\right)^{\gamma-1} = \frac{T_4}{T_1} \Rightarrow \frac{T_1}{T_4} = \left(\frac{V_4}{V_1}\right)^{\gamma-1}$$

as $T_1 = T_2$ & $T_3 = T_4$

$$\left\{\frac{T_2}{T_3} = \left(\frac{V_4}{V_1}\right)^{\gamma-1} = \left(\frac{V_3}{V_8}\right)^{\gamma-1}\right\}$$

$$\frac{V_4}{V_1} = \frac{V_3}{V_2} \Rightarrow \left\{\frac{V_3}{V_4} = \frac{V_2}{V_1}\right\}$$

- Putting ~~3-3~~ in — (*)

$$Q_{34} = RT_2 \ln \frac{V_2}{V_1}$$

- But the efficiency of the carnot cycle can be written as

$$\eta_{carnot} = \frac{\text{Work done}}{\text{Heat Supplied}}$$

$$\eta_{Carnot} = \frac{\text{Heat Supplied} - \text{Heat Rejected}}{\text{Heat Supplied.}}$$

$$\eta_{carnot} = \frac{RT_1 \ln\frac{V_2}{V_1} - RT_2 \ln\frac{V_2}{V_1}}{RT_1 \ln\frac{V_2}{V_1}}$$

$$\eta_{carnot} = \frac{T_1 - T_2}{T_2}$$

Q3 (b) → 5M , DUAL CYCLE

Q3 (c) → 10M → Ex - 10.3

Q4 (c) → 10M

Ans Given BP = 100 kW

N = 400 rpm

BMEP = 850 kPa

Bsfc = 0.335 kg/kWhr

C.V = 43500 kJ/kg

Stroke/Bore = 1.25 → $\frac{L}{D} = 1.25 \Rightarrow L = 1.25D$

$\eta_{mech} = 80\%$

- Brake power = pLAnK

$$100 = 850 \times 1.25D \times \frac{\pi}{4} \times D^2 \times \frac{400}{60 \times 2} \quad ; \quad n = \frac{N}{2} \text{ for 4 stroke}$$

$$D^3 = 0.03595$$

$$D = 0.33\ m = 330\ mm$$

$$L = 1.25D = 1.25 \times 330 = 412.5\ mm$$

D = 330 mm

L = 412.5 mm

$$\eta_{BTH} = \frac{3600}{b.sfc \times CV\ (kg/kwh)} = \frac{3600}{0.335 \times 43500}$$

$$\eta_{BTH} = 0.247 = 24.7\%$$

$$\eta_{mech} = \frac{BP}{IP}$$

$$0.8 = \frac{100}{IP} \Rightarrow IP = 125\,kW$$

$$IP = P_m L A \frac{N}{2} \cdot K$$

$$125 = P_m \times 0.4125 \times \frac{\pi}{4} \times (0.33)^2 \times \frac{400}{2 \times 60}$$

$$P_m = 1062.893\,kPa = 10.62\ Bar$$

~~imep = 10.62 bar~~

$$\dot{m}_f = b.P \times Bsfc$$

$$\dot{m}_f = 100 \times 0.335$$

$$\dot{m}_f = 33.5\,kg/h$$

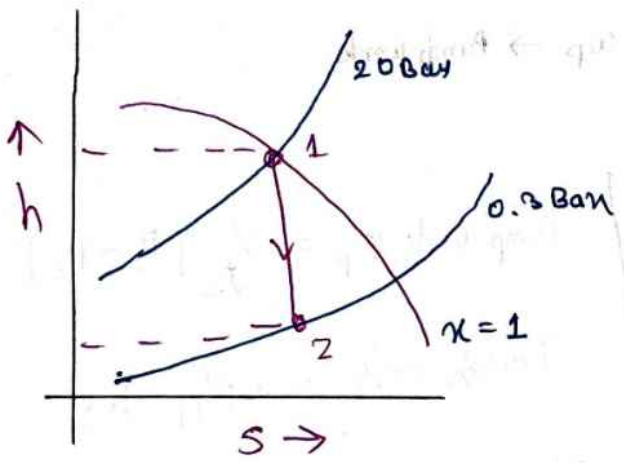
$$\eta_{ith} = \frac{3600}{\frac{\dot{m}_f}{I.P} \times CV} = \frac{3600}{\frac{33.5}{125} \times 43500}$$

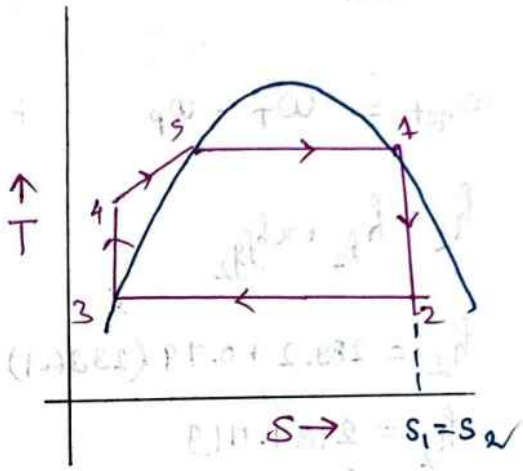
$$\eta_{ith} = 0.3088$$

$$= 30.88\%$$

Q5(c)

Ans





At ① $P_1 = 20 Bar$, $x = 1$

$h_1 = h_{g_1} = 2800 kJ/kg$ [Mollier chart]

$S_1 = S_{g_1} = 6.3$ [Mollier chart]

At ② $P_2 = 0.3 Bar$

$h_{f_2} = 289.2 kJ/kg$, $h_{fg} = 2336.1 kJ/kg$

$S_{f_2} = 0.944 kJ/kg K$, $S_{fg_2} = 6.825 kJ/kg K$

$V_{f_2} = 0.001022 m^3/kg$, $S_2 = S_{f_2} + x S_{fg_2}$

$h_2 = h_{f_2} + x h_{fg_2}$

- for Rankine cycle

$S_1 = S_2$

$6.341 = 0.944 + x \cdot 6.825$

$x_2 = 0.79$

• $\eta = \frac{W_{net}}{Q_{in}}$

$W_T \rightarrow$ Turbine work

$W_p \rightarrow$ Pump work

• $W_{net} = W_T - W_p$ ∴

$h_2 = h_{f_2} + x h_{fg_2}$

$h_2 = 289.2 + 0.79\,(2336.1)$

$h_2 = 2134.719$

$W_T = h_1 - h_2$

$= 2799.5 - 2134.719$

$= 662.984$ kJ/kg

• Due to Que. $W_p = 0$

$\therefore \eta = \frac{W_T - \cancel{W_p}^{\,0}}{Q_{in}}$

Pump Work, $W_p = V_{f_2}(P_1 - P_2)$

Turbine Work, $W_T = h_1 - h_2$

$\eta_R = \frac{W_T - W_p}{(h_1 - h_{f_2}) - W_p}$

$W_p = h_{f_4} - h_{f_3}$

if $W_p = 0$

$h_{f_4} = h_{f_3}$ & $h_{f_3} = h_{f_2}$

$\therefore h_{f_4} = 289.2$

$\eta = \frac{662.984}{2799.5 - 289.2} = \frac{662.984}{2510.3}$

$\eta = 0.2640$

$\boxed{\eta = 26.40\%}$

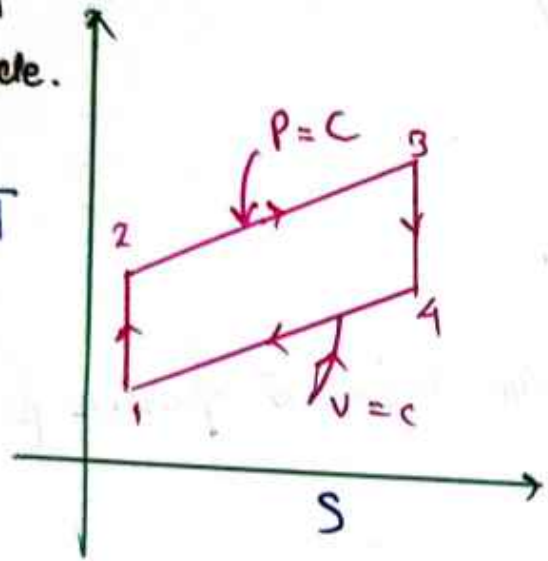
: Work Ratio $= \frac{W_T - W_p}{W_T}$

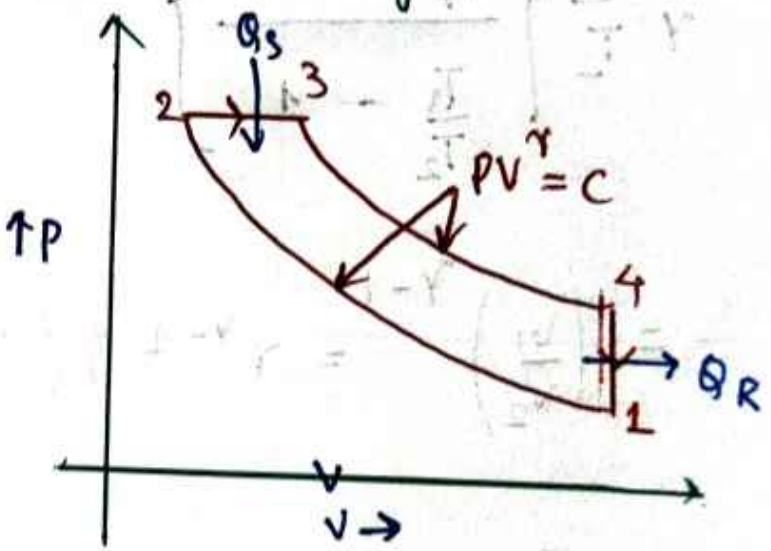
... uncontrolled combustion in petrol engine.

- Self Ignition Temperature - Temp^{r} at which fuel starts to burn itself.

Q<(a)-5M

Diesel Cycle.





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$$\eta = 1 - \frac{1}{\gamma}\frac{T_1}{T_2}\left\{\frac{\frac{T_4}{T_1} - 1}{\frac{T_3}{T_2} - 1}\right\} \quad \text{—} \quad (*)$$

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$$\left[\frac{T_4}{T_1} = \left(\frac{V_3}{V_2}\right)^{\gamma} = e^{\gamma}\right]$$

* Substituting values in eq (*)

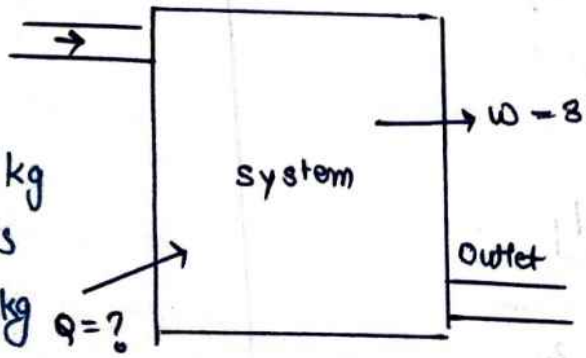
$$\eta = 1 - \frac{1}{\gamma(r)^{\gamma-1}} \left\{\frac{e^{\gamma}-1}{e-1}\right\}$$

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} \left\{\frac{e^{\gamma}-1}{\gamma(e-1)}\right\}$$

Q 3(c) → 10M

In a steady flow system a substance flows at a rate of 300kg/min. It enters at a pressure of 6 bar with a velocity of 300m/s with specific internal energy 2000kJ/kg & specific volume 0.4m³/kg. It leaves the system at a pressure of 0.1 MPa with a velocity of 150m/s. Specific internal energy 1600kJ/kg & specific volume 1.2m³/kg. The inlet is 10m above the outlet. During its passage through the system a work transfer of 3MW to surrounding, determine heat transfer in kJ/s.

Ans



$P_1 = 6 bar$

$v_1 = 0.4 m^3/kg$

$c_1 = 300 m/s$

$u_1 = 2000 kJ/kg$

$z_1 = 10$

$P_2 = 0.1 MPa$

$v_2 = 1.2 m^3/kg$

$c_2 = 150 m/s$

$u_2 = 1600 kJ/kg$

$z_2 = 0$

* Applying the steady flow energy Eqⁿ, $E_{in} = E_{out}$.

$$m = 300 kg/min = 5 kg/s$$

$$W = m.w \rightarrow 3000 = 5 \times w$$

$$w = 600 kJ/kg$$

$$P_1 v_1 + u_1 + \frac{c_1^2}{2} + g z_1 + q = P_2 v_2 + u_2 + \frac{c_2^2}{2} + g z_2 + w$$

$$600 \times 0.4 + 2000 + \frac{300^2}{2 \times 1000} + \frac{9.81 \times 10}{1000} + q = 100 \times 1.2 + 1600 + \frac{150^2}{2 \times 1000} + 600$$

$$q = 46.1519 \text{ kJ/kg}$$

$$Q = q \times m$$

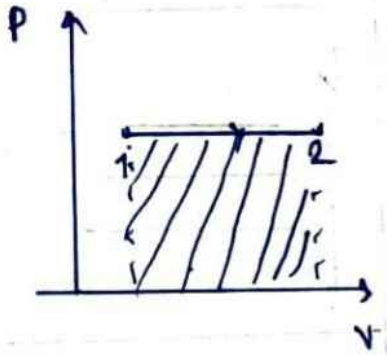
$$Q = 46.1519 \times 5 = 230.7595 \text{ (To the system)}$$

11) Work in Quasi-static Isochoric process

- In thermodynamics, a quasi-static process is a thermodynamic process that happens slowly enough for system to remain in internal equilibrium.

* Work done for a Quasi-static process = $\int_{V_1}^{V_2} P\,dV$

* for isochoric process.

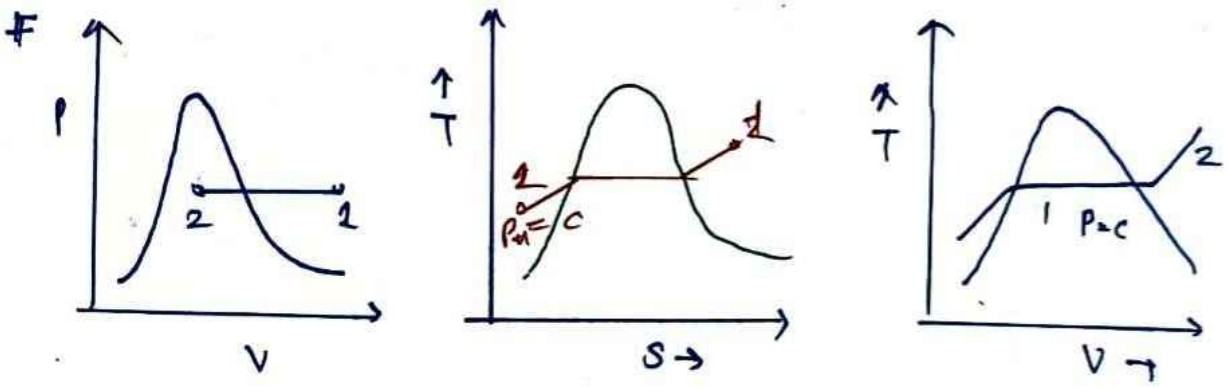


$P_1 = P_2 = P$

$\therefore W_{12} = \int_{V_1}^{V_2} P\,dV = P\int_{V_1}^{V_2} dV$

$$W_{12} = P.(V_2 - V_1)$$

Q4 Constant pressure heating of steam on Temperature - entropy chart. 2-M

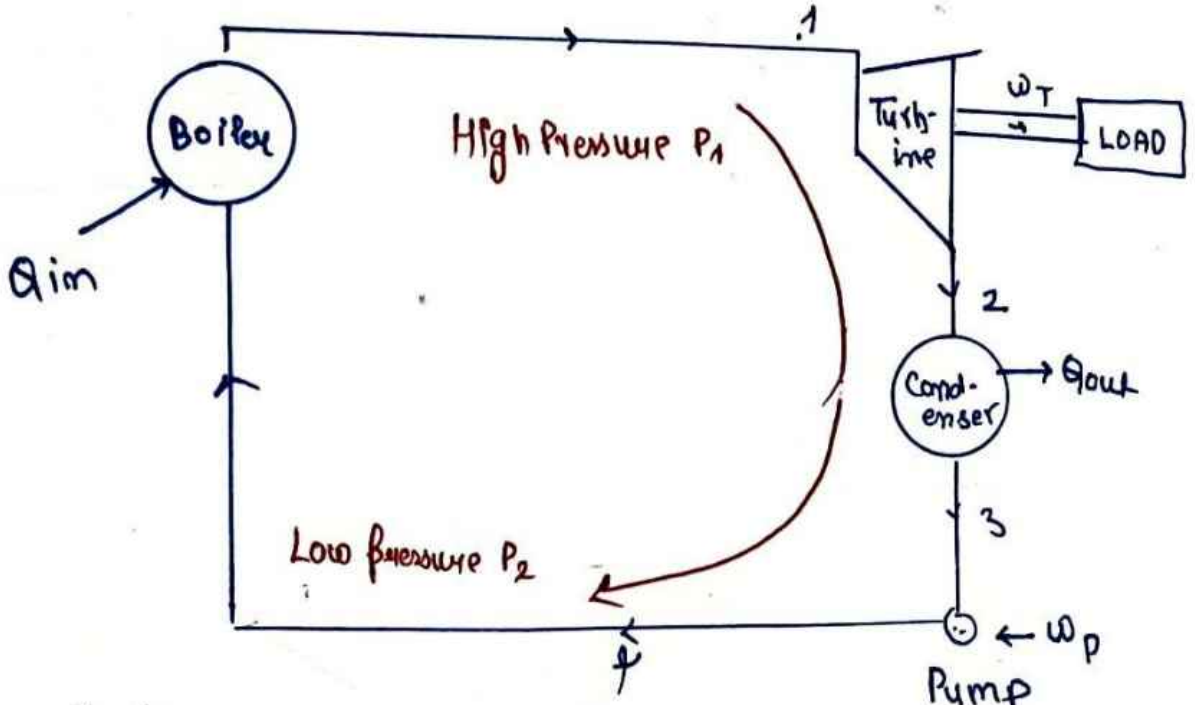


- The head received or rejected in this case is ~~therefore~~ equal to change in enthalpy
- $q_{12} = w_{12} + \Delta u = P(v_2 - v_1) + (u_2 - u_1)$

$= (Pv_2 + u_2) + (Pv_1 + u_1)$

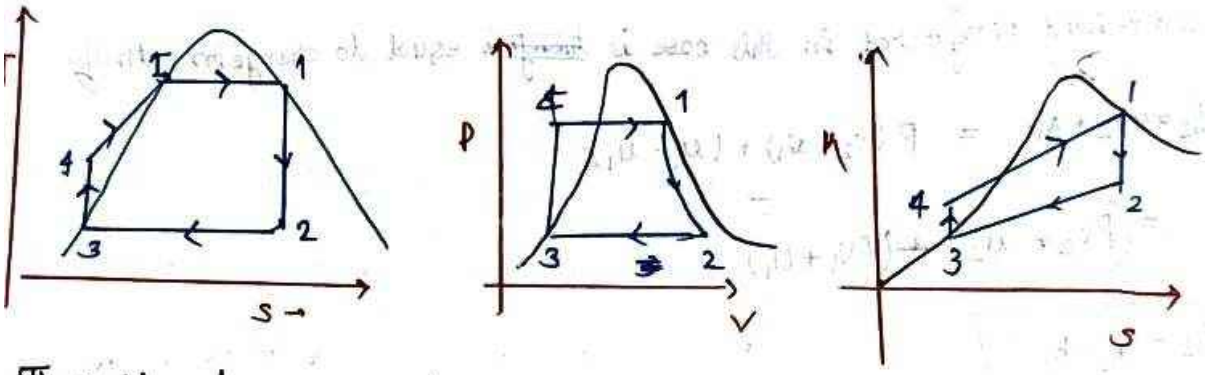
$$q_{12} = h_2 - h_1$$

v) Rankine Cycle



* flow diagram of an ideal Rankine Cycle

- Boiler producing vapour at constant pressure through addition of Heat
- an ideal turbine [isentropic expansion] producing work.
- a condenser having no pressure drop in which heat is removed & the vapour is condensed.
- Ideal Pump (Isentropic) raising the pressure of liquid to pressure of vapour gen^r (Boiler)



The working fluid undergoes following series of Internally Reversible process.

Process 1-2 - Dry saturated working fluid (steam) expands isentropically to pressure P_2 OR condenser pressure

cess 2-3 - The steam is then condensed at const. pressure & temp^r to a saturated liquid, state 3.

the condenser, heat is transferred from the condensing steam to water.

ss 3-4 : The saturated steam leaving the condenser is pumped isentropically into the boiler at pressure P_1 (State 4)

4-1 - Heat transfer to working fluid as it flows at constant pressure P_1 through the Boiler to complete the cycle

* Significance of second law

. The second law indicates ~~that~~ processes that involve the transfer or conversion of heat energy, are irreversible Because they all result in an increase of energy.

. Moving heat from cold body to a hot Body Requires work to be Done by an external energy source

. It is impossible to convert heat energy to Mechanical energy with 100 % efficiency.

* Significance of Second law of Thermodynamics w.r.t. limitations of first law of Thermodynamics.

* limitations of first law of T.D

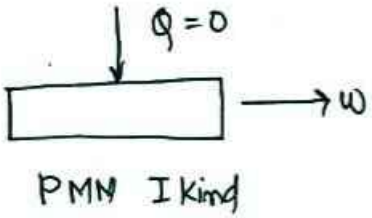
- It doesn't give any information regarding the direction of flow of Heat & Work. It doesn't give any cond^{n} under which this transfer takes place.
- All work can be converted to heat But ~~not~~ all heat can't Be Converted into work

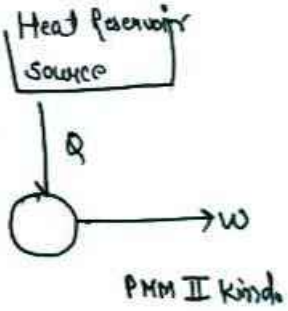
* Second law

- At ~~Various~~ a very macroscopic level, it can be stated that if a system is isolated, any natural process in that system progresses in the direction of increasing disorder, or entropy of the system.

° Kevin - Planck Statement

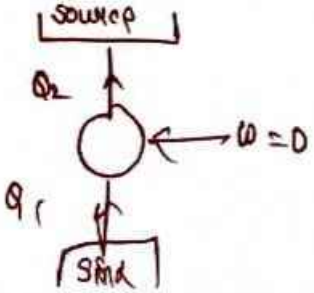
- It is impossible to construct a system which operate in a cycle, extract heat from a single reservoir & do an equivalent amount of work





* Clausius Statement

- It is impossible to construct a system which will operate in a cycle & transfer heat from cooler to a hotter Body without work Being Done on system By Surroundings



- Differences

1) Nature of Transfer

- Heat is the transfer of energy due to a temp^{r} difference b/w system & surroundings
- Work is transfer of energy due to a force acting through a distance.

2) Sign Conventions

In thermodynamics:

- Heat transfer is considered +ve when it flows into the system & -ve when it flows out.
- Work Done on Sys. = +ve , Work done By Sys. = -ve

3) Reversibility

- Heat Transfer is generally irreversible.
- Work , can be reversible if process is carried out in a Quasi-Static Manner.

4) Order of Energy

- Heat - Disordered kind of Energy

  Work - Ordered kind of Energy

* Similarities Bw Work & Heat

→ Similarities

1). Both Heat & Work are energy transfer mechanisms

- Heat & Work are Both ways in which energy can be transferred into or out of a System
- They are Both form of energies that can be used to cause a change in System.

2) Both are Path functions

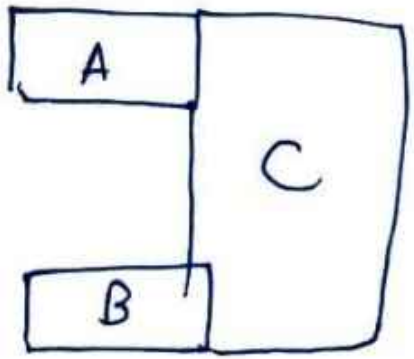
- Their values depends upon path taken to reach a particular ~~change~~ state of System Rather than initial & final states.

3) Both Heat & Work are Inexact Differentials

4) Heat flow is associated with entropy. while no work is associated with entropy.

• Zeroth law of Thermodynamics - 2m

• When two bodies are in thermal equilibrium with third body, the two bodies are in thermal equilibrium with each other, & all three are said to be at same temperature.



If $T_A = T_C$

& $T_B = T_C$

Then

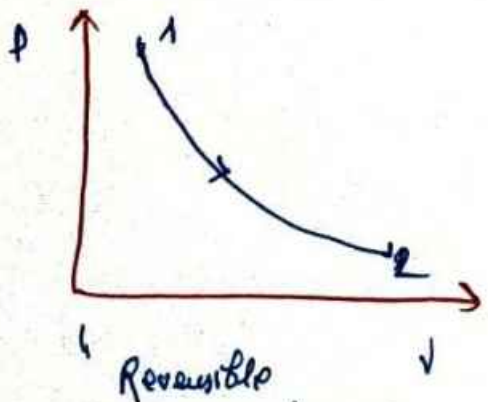
$T_A = T_B$

- Reversible & Irreversible process :

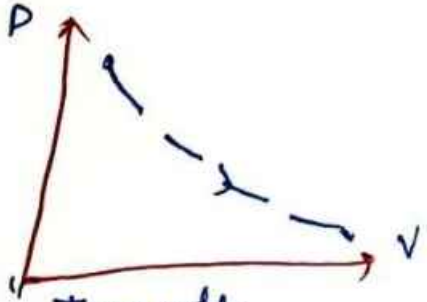
- A thermodynamic process is said to be reversible if at any time during the process, Both the system & surrounding can be returned to their initial ~~stage~~ states without any evidence of any change remaining in sys. or surroundings.

- A process is said to be completely reversible if can be interrupted at any stage & means can be found to Restore Both the sys. & surrounding to their respective initial stages without leaving a trace in either the sys. OR surrounding

- If changes are left in either the sys. or the surrounding after the process occurs is called an irreversible process.



Reversible



Irreversible process

- Flow & Non flow processes

- The processes undergone by the fluid in a closed system are described as Non flow processes.

- No exchange of Mass is done

- Ex – Isochoric process, Adiabatic process etc.

- The processes undergone by fluid in a an open system are refered to as flow processes.

- Exchange of mass takes place.

Work as path function - 2M

- Certain Quantities that can't be located on graph by points But are given by area or so on that graph.
- In that case, the values on the graph, pertaining to particular process, is a func^n of path of process. Such ∄ quantities are called path function.
- $W = \int P dV$ = $\int$(intensive property) × (Extensive property)

↓

Path func^n ∴ Can't be integrated until the pressure volume path is known

$$W_{12} = \int_1^2 \partial W = W_{1-2} \text{ OR } {}_1W_2$$

&

Can't be written as

$$W = \int_1^2 \partial W = W_2 - W_1 \quad \times$$

First law of Thermodynamics

- When a system undergoes a thermodynamic cycle then the net heat supplied to the system from its surroundings is equal to net work obtained from the system to surrounding.

$$\# \quad \left[\oint \delta Q = \oint \delta W\right] \Rightarrow \text{Mathematically first law of Thermo-D}$$

- Corollary 1

- There exist a property of closed system called energy s.t. a change in its value is equal to the difference B/w Heat Supplied & Work Done during any change of state

$$\delta Q - \delta W = \Delta E \Rightarrow Q_{12} - W_{12} = E_2 - E_2$$

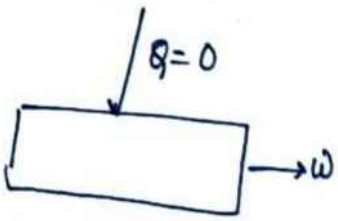
(Point func^n)

- Energy E is composed of internal, kinetic & potential energy.
- Since in a closed system KE & PE effects play a negligible part ∴ E is considered internal energy

Non-flow Energy Eq^n. $\leftarrow \left[Q_{12} = W_{12} + (U_2 - U_1)\right]$

* Perpetual Mot^n Machine of first kind.

- Perpetual Mot^n Machine of first kind is impossible.
- A pmm is a device which produces a continuous supply of work without requiring any interact^n from surrounding OR other systems.
- Such a device would, in effect, create energy
- Eq^n (#) states that if $\oint \delta Q = 0$ then $\oint \delta W = 0$ ⇒ ∴ Existence of pmm would violate first law of Thermo-D {Which can't be Proved}



PMM - I

* Basics of Mechanical Engineering , 5Q → 4Q T & 4Q N
1Q → compulsory

→ Overview

- Basics of Subjects & Their Terminology (N)
- Heat & its law "Numerical" (N)
- IC engine & its terminology And Properties of steam (N) (N)
- Intro to Casting, Welding, Brazing & its effects
- Heat Treatment process, Iron-carbon Diagram & its importance

- Books - Nakhwa Mehta, RK Purohit (Any one)

- Machine Tool → Productive Output
  Machine → Idle condⁿ

- Heat → Grade of Energy [High Grade → Low Grade]

- M.E
  - Thermal
  - Design
  - Metal cutting

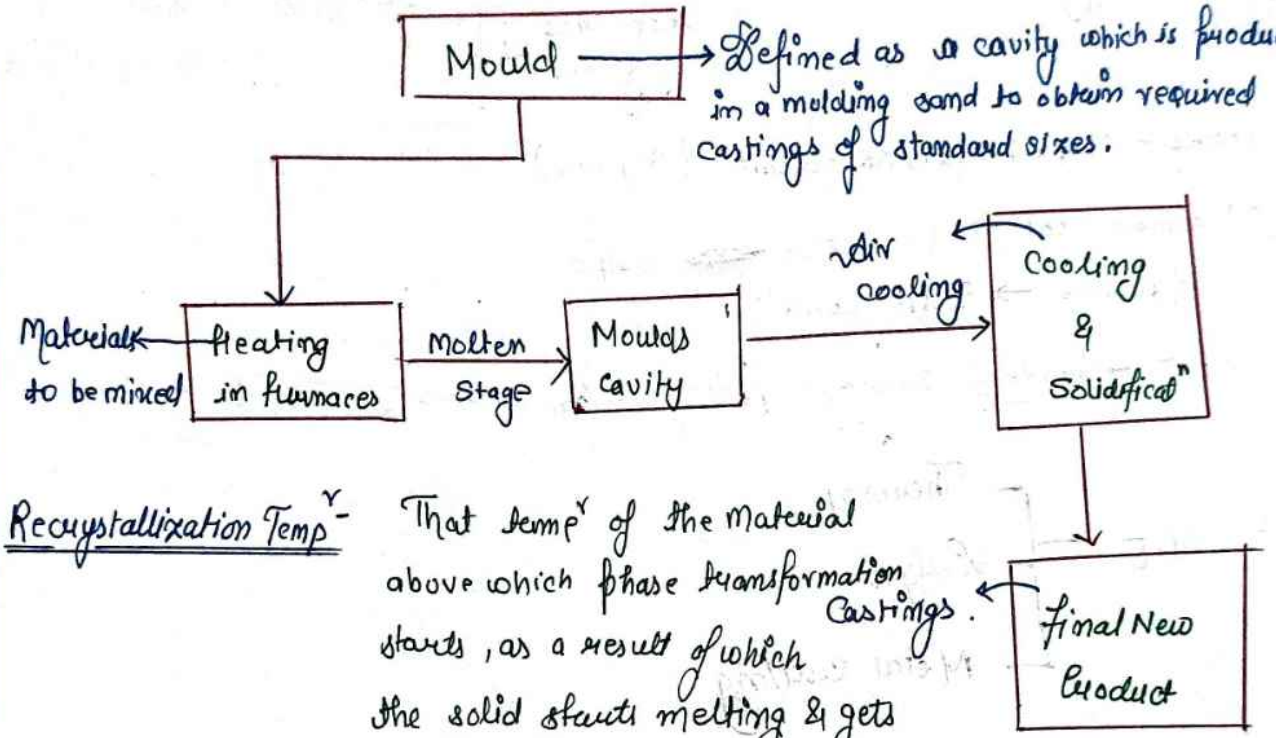
** Temperature Transformation Diagram
Iron Carbon Diagram

Casting

Introduction to Casting

Casting

↳ It is a process in which two or more materials are heat up in various furnaces to form a combined mixture. Above recrystallisation temperature to form a new product.



Recrystallization Temp^{r} - That temp^{r} of the material above which phase transformation starts, as a result of which the solid starts melting & gets completely converted into liquid phase

- **Moulding Sand** → · It is defined as a sand which is used to form mold cavities.
  · It is slightly different from normal sand consists of
  a) Binding Materials → Bentonite.
  b) flux
  c) Molasses → Gud ka Paani
  & d) Moisture (from Water)

• Properties of Moulding Sand.

→ Adhessivness - Property that causes sand particles to stick to the sides of moulding Box, facilitating proper lifting of the cope along with the sand.

→ Refractoriness - Property of sand to withstand the high Temp^{r} of Molten metal without fusion or softening

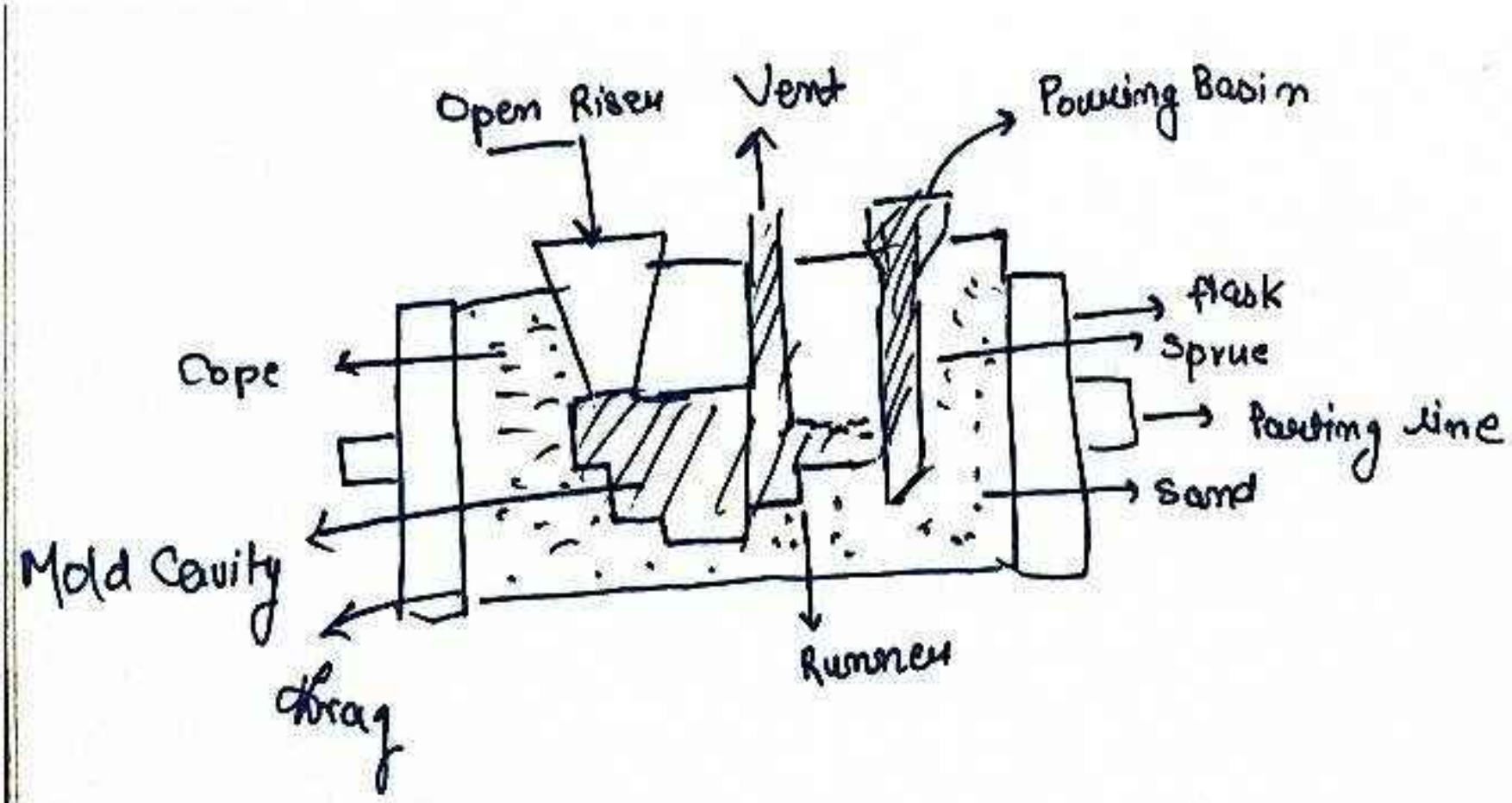
→ Permeability → a.k.a porosity - Property of sand, representing its ability to allow gases to pass through during the pour^{n} of metal into the sand cavity gases & steam are gen^{r}.

→ Flowability - Sand's ability to free flow & fill the recesses & fine details in the pattern)

→ Cohessivness - Sand's ability to hold its particles together, providing strength to Moulding Sand.

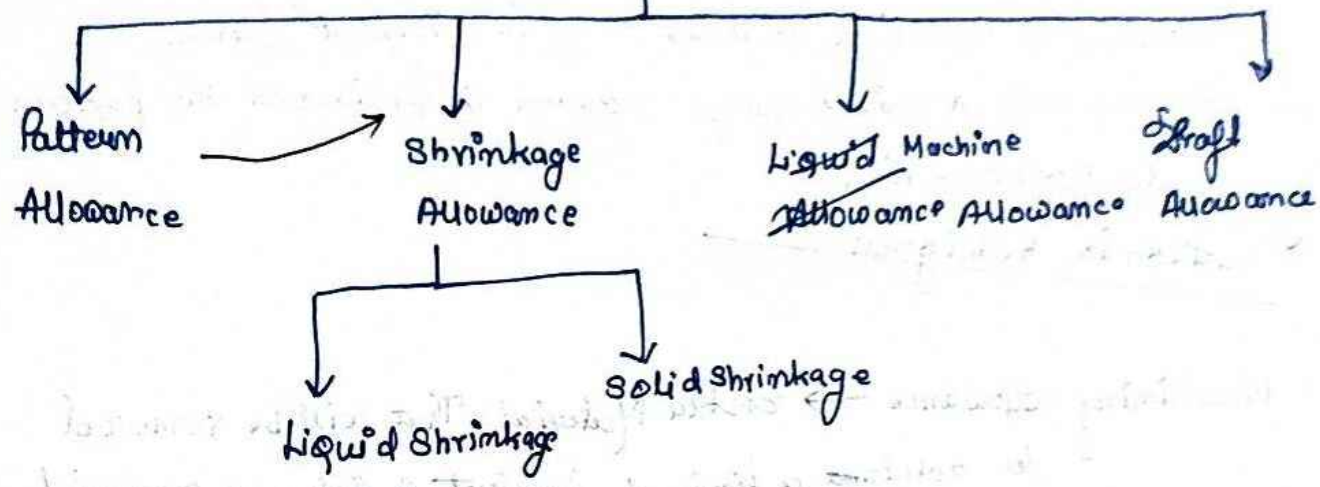
→ Collapsibility - Property of sand ~~to withstand~~ that causes the sand mould to collapse automatically after the solidificat^{n} of the Casting.

 # Pattern: It is defined as the exact replica of the standard component


Open Riser
Vent
Pouring Basin
flask
Sprue
Parting line
Sand
Cope
Mold Cavity
Runner
Drag

** Molding Box **

- Patteurn Allowances → Distortion Allowance.



- Patteurn Allowance - In this allowance the Qty. of Liquid Molten metal is always considered at higher side as compared to the Req^r

NOTE - The patteurn allowance is always greater as compare d to Shrinkage allowance & Machine allowance

- Shrinkage Allowance - As we all know that when the Metal cools down to Room Temp^r, it contracts in the dimensions to consider that the allowance is provided i.e called as shrinkage allowance.

* Classified into two categories

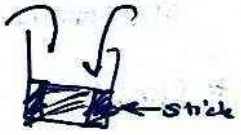
Liquid Shrinkage - When the Metal changes from liq. State to solid state. The vol. of the Metal reduces To compensate that loss of Valeume, The excess liq is feed with the help of Risers to compensate that loss of volume i.e called liquid shrinkage Allowance.

* Solid Shrinkage – In no. of cases after Solidification process there is reduction in volume, when Metal starts to loses it temp^{r} in solidification process to compensate a solid shrinkage allowance is provided on the pattern to overcome this;

↓ Pattern is Redesigned.

. Machining Allowance → Extra Material That will be removed to obtain a finished product & that excess material formed due to inadequate supply of liquid metal during casting process & that rough surface in the cast product will be eliminated to obtain a standardised finished product, that complete process is considered under Machining Allowance

Draft Allowance – All the surfaces parallel to the direction in which the pattern will be removed are Tapered slightly so that liquid Molten Metal can be transferred in the mould cavity at a appropriate Rate

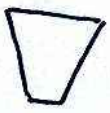


Distortion Allowance – Sometimes during Material Handling process the final casting Might be damaged so overcome that product loss, Distortion Allowance will be provided

Transfer Device

↓

Necahe or Tapered

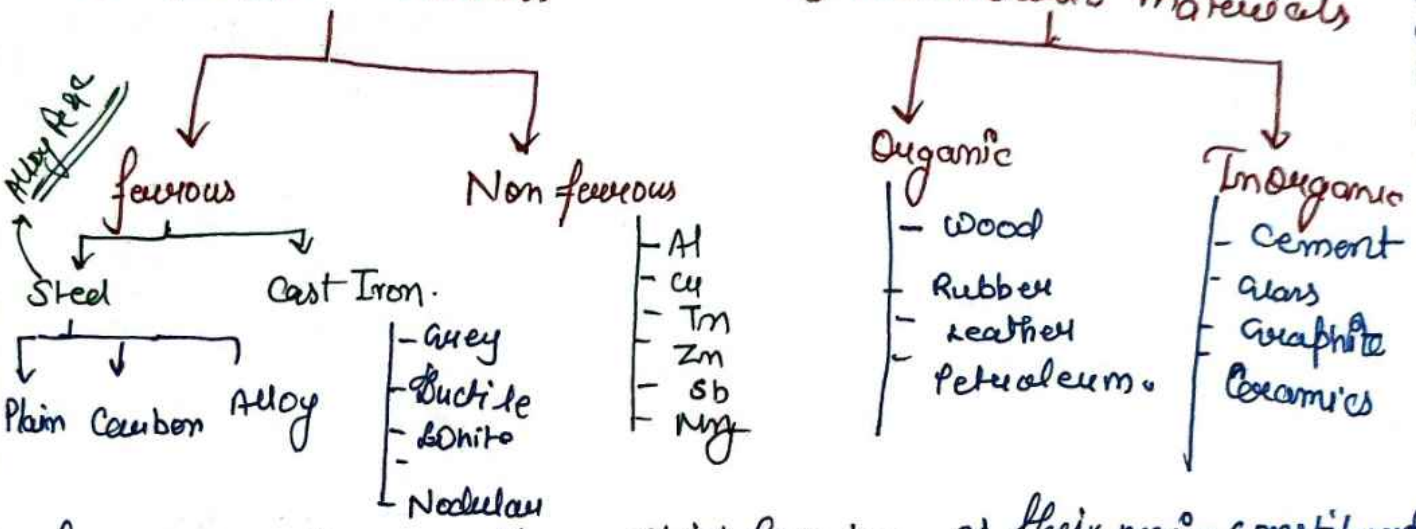


Introduction to Engineering Materials

- Those materials which are used in the Manufacturing of various Engineering products are considered as engineering materials.
- They are generally classified in two categories

① Metallic Materials

② Non Metallic Materials



- Ferrous materials are those which have iron as their main constituent. eg. Grey Cast Iron, Wrought iron, etc
- Whereas Non-ferrous metals are those which have a metal other than an iron as their main constituent eg. Copper, Aluminium, Brass, tin etc
- Ferrous Materials are classified in TWO categories ie Cast iron & Steels
- Non Metallics Materials are generally classifies into two categories - Organic & Inorganic
- Cast Iron - In this the Carbon Content varies from 1.7% to 6.6%. It also contains Silicon, Phosphorus & Sulphur in the form of Impurities.
- Generally Brittle in Nature so can't be used for Making Bolts & Machine Parts which are always under Tensile forces.

· Due to its high compressive strength, generally it is used in the frame part of various loading machines.

① Gray Cast Iron - Carbon - 2.5% to 3.8%
Silicon - 1.1% to 2.8%
Phosphorus ≤ 0.15%
Sulphur ≤ 0.1%

Generally it appears as gray in colour, it has lowest M.P. among all the ferrous Materials.
· Generally it is used as Manhole covers

· It is also used in piston rings & Manufacturing of IC engine cylindrical Blocks & units.
· Also used in Manufacturing of Machine tool structure like frames & Columns.

② White Cast Iron
C - 3.2% to 3.6%
Si - 0.4% to 1.1%
P ≤ 0.3%
S ≤ 0.2%

: Generally it appears bright white in colour & it has highest wear & tear resistance property.
· It also have highest Tensile Strength & generally the Railway Breaks, Rim of Car wheels are Made up of White Cast iron.

③ Ductile Cast Iron
C - 3.2% to 4.2%
Si - 1% to 4%
Mg - 0.1% to 0.8%
Ni - 0.2% to 3.5%
Mn - 0.5% to 0.8%
Remaining % → Iron

· The M.P of Ductile Cast Iron is 810°C
· Generally, it is soft in nature as Compared to other elements.
· Generally, They are used in Agricultural Tools & various Mountings of a Automobile Car.
· Also used in various parts of Textile Machines, Crank levers etc.

- The toughness & Ductility of Ductile Cast Iron Materials are very high.
- The Machineability of this Material is highest among all the various Cast Irons

- Nodular Cast Iron – Very Hard in Nature. & Generally used in manufacturings of locks, various pipe settings & Hubs of Wagons.

C - 2.6% to 3.2%
Si - 1.5% to 3.5%
Mg - 0.25% to 0.65%
Ni - 0.6% to 2.8%
Mn - 0.3% to 0.5%
Remaining % → Fe

* Rockwell Testing Machine
↓
Hardness.

% C ↑ → Hardness ↑

Steel -

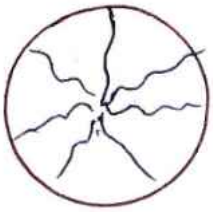
- It is defined as an alloy of iron & carbon and it has been observed. If the percentage of Carbon is increased the hardness of that mixture goes on increasing.

- When steel is observed under microscope various structures are formed. Based on % of C. If the % of C is less than .8% the microstructure is called ferrite.

- if the % of C upto 0.8% then structure is called Pearlite

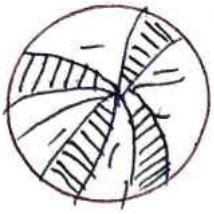
- if the % of C lies b/w 0.9 % to 6.6% then it is called Asterite

- if the % of C is exact 1 % then that of steel is called Cementite.



a) Ferrite grain

b) Pearlite
(0.3%)



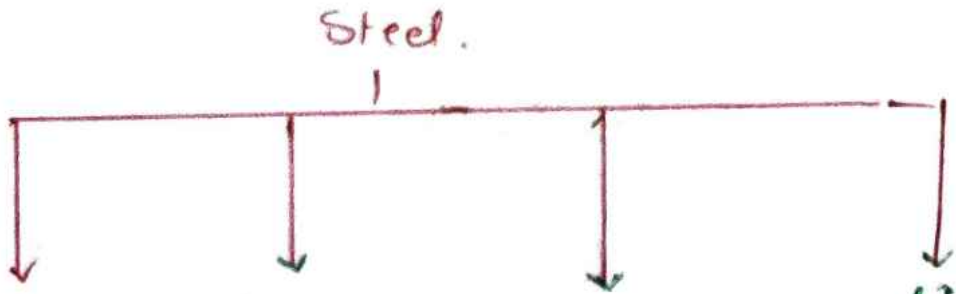
c) Austenite
or
Austenite
(0.8 to 0.6%)

d) Cementite
(1%)

* Microscopic View of Steel
Structure

Classification of Steel

- Steel is generally classified into a four categories.



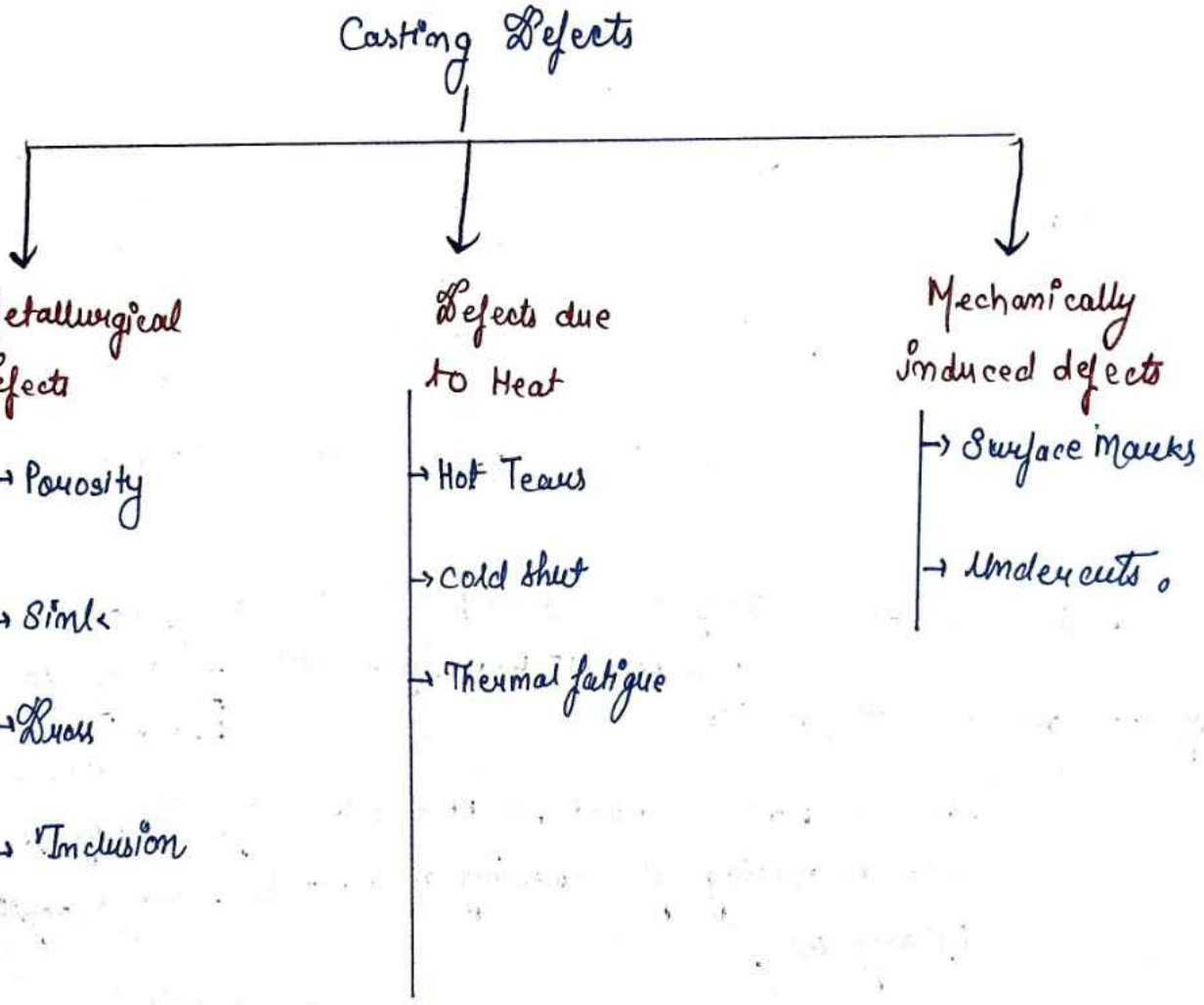
1) Lead Carbon steel - % of carbon is upto 0.15% having hardness number 115 BHN, generally it used to making of steel wires, rivets, nails.

BHN → Brinell's Hardness No.

2) Mild steel - Hardness No- 140 BHN, M.Pt - 1410°C & generally it is used in making of connecting rods, tubes, crank shafts, Railway axle.

- Medium Carbon Steel: It can easily absorb impact load & shocks.
  - Its tensile strength is always better than cast iron & wrought iron.
- N.Pt – 1460°C
- Generally They are used in making of Crank pins of heavy Machines, Gear shafts, Piston rods springs, bolts, Hacksaw, Cold Chisels & Hammers
- Hardness No – 146 HBN
- High Carbon Steel. • Hardness of High carbon steel varies from 450 to 550 BH No.
- NOTE. when it is heated from 200° to 250°C, it starts losing its hardness.
- Generally used in mak" of wheels, for railway services, Jaws for vices leafsprings

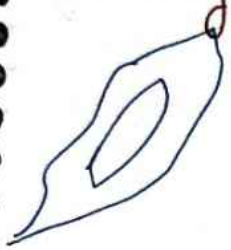
Casting Defects & their Remedies



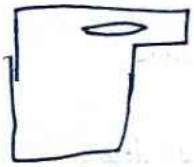
1. Metallurgical Defects

- Arises Due to improper Alloy Composition, Variation in Melting Temp^r, due to internal stresses.

a) Porosity - When the gases are trapped & the moisture from the water is not dried up in the Moulding Sand then During molten Metal Transformat^n, Bubbles are formed on the surface of Casting product & this defect is called as porosity defect.



→ Remedies : (i) Keep the temperature of mould low.



(ii) Use vent wire before transferring the molten metal into the mould cavity.

(iii) Pouring of Metal is performed at standard rate.

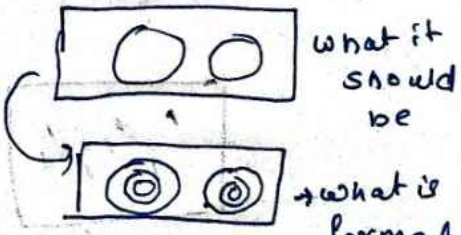
(iv) The % of moisture should not be more than 5% in the molding Box.

b) ~~Sand~~ Sink - It is formed Due to presence of sub-surface cavity

Causes - (i) Low injection speed

(ii) Short cooling time of metal

(iii) Higher temp^r of metal



Remedies

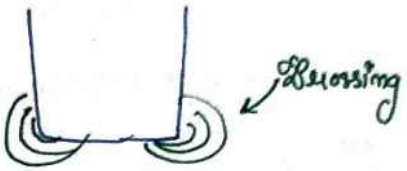
(i) High injection speed

(ii) Long cooling time of metal

(iii) Lower temp^r of metals

(III) Drossing : It is defined as produced due to Metal loss for ex. in aluminium Castings which generally contains 60% of Al. by wt. but due to drossing defect the aluminium oxides which are formed during melting process are collected on the surface of the castings.

What it should have been

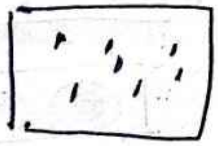


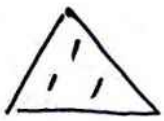
what it becomes

Causes	Remedies
1) Temp^{r} of metal is very high	1) Temp^{r} of metal should be low
2) The reaction time is high (of Transform^{n} Rxn)	2) The react^{n} time should be low.

IV) Inclusion - It may be be produced due to non-metallic particles. During casting process they are present in the form of Dust particles, sometimes slag, sometimes nails & sometimes in the form of oxides.

Also called COSMETIC DEFECT





Causes

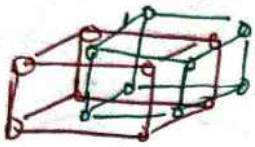
1) Addn of those Materials which have not completely dissolved during melting process
2) Improper gating system
3) Sand & dust particles are not properly cleaned from moulds.

Remedies

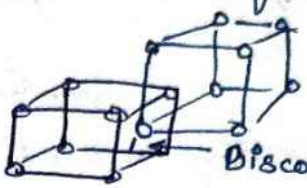
1) Removal of Materials which have not completely dissolved during melting process.
2) Proper gating System. Improved.
3) Proper cleaning of Sand & Dust & Regular particles from moulds

* Defects due to thermal Effect

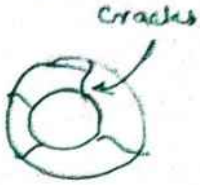
① Cracks - It is a geometrical discontinuity in casting. Cracks are easily visible with the naked eye.



Defect



Discontinuity



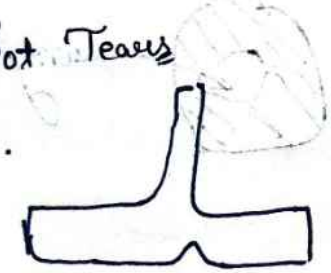
Causes

1) High Thermal Concentration
2) Selection of damaged excavaties
3) More stress localisation at particular Area.

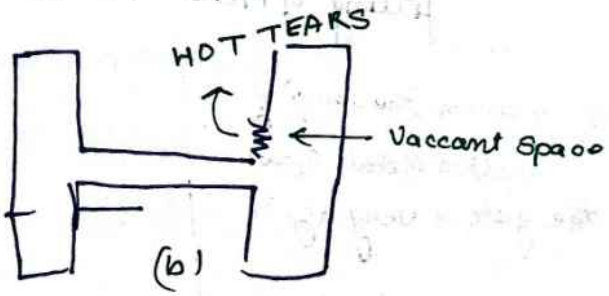
Remedies

① Inspection & selection of proper ~~dyes~~ dies Before performing casting operations.
② Reduced proper pouring Temperature
③ Give proper time for cooling of Metal.

④ Hot Tears



(a)



. It is a the main casting Defect produced due to failure of Semisolid Casting. Hot tears are always produced in the last stage of solidification

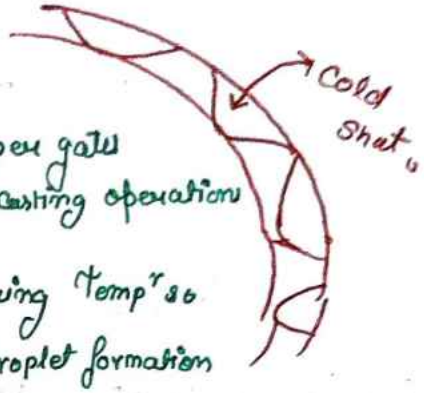
Causes.

1) Improper placement of Gates.
2) Very thin sections
3) Incorrect Metal pouring Temp^r.
4) faulty solidification Methods.

Remedies

1) proper placement of Gates near the mold cavity
2) use Accurate Metal pouring Temp^r
3) provide feeders so that appropiate amount of molten metal should be transferred throughout the castings.

③ Cold Shut: It is a type of crack with round edges. Generally they are produced when small droplets from metal fall into casting molds and a result they combine with the final castings. To form round edges crack.



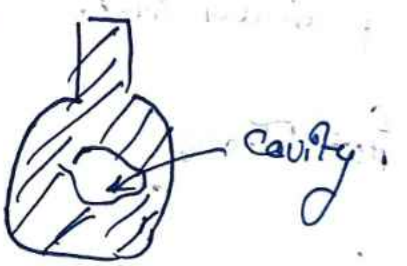
Causes

1) Low pouring Temp^r of Material
2) Improper Selection of Gate Design
3) Thickness of Castings of final product is very less

Remedies

1) Selection of proper gate before performing casting operation
2) Increasing the pouring temp^r so that chances of Droplet formation is reduced.
3) Select the standard & appropiate thickness of metal to perform casting operation.

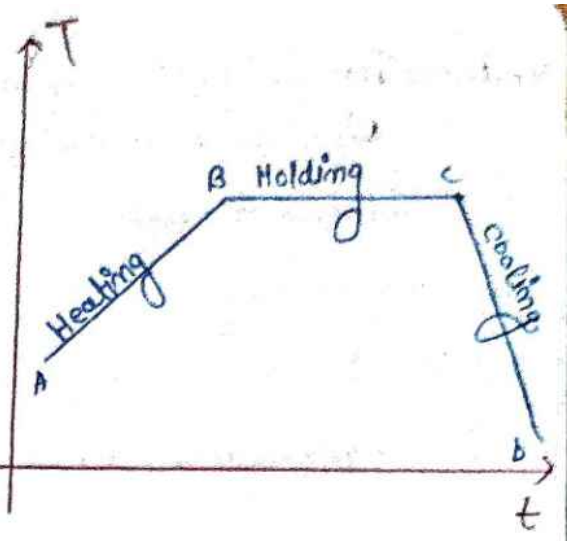
④ Misrun - It is produced due to incomplete filling of Metal in Mold cavity.



Cause 1) when the temp^r of Molten Metal near the gate is very high
2) long flow distance inside the Mold Cavity.
3) Inadequate venting system

Heat Treatement – To Attain Req^{r} Mechanical Prop^{r}

- It is the process of heating the metals below its molten stage, then hold up at that temp^{r} for some duration of time & afterwards cooling the metal in a controlled way to obtain desired Mechanical Properties after Casting



* OBJECTIVES OF HEAT TREATEMENT

1. To improve ductility & toughness
2. To improve electrical & magnetic properties
3. To improve machineability
4. To increase wear & corrosion resistance of metals
5. To Harden & strengthen Metals.
6. To Relieve the internal stresses to refine grain size of metals.

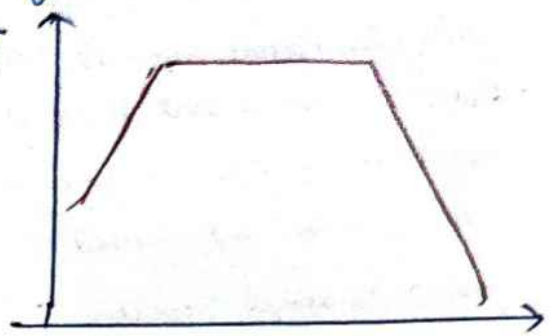
* TYPES OF HEAT TREATEMENT PROCESS.

- Heat Treatement
  - → Annealing
  - → Hardening
  - → Normalizing
  - → Tempering
  - → Austempering
  - → Martempering
  - → Case Hardening

1) Annealing - It involves heating to a predetermined temperature, holding at that temp^r & cooling at a very slow rate

- It involves 4 steps

1) full Annealing
2) Stress Relief Annealing
3) Recrystalization Annealing
4) Spherodizing Annealing



a) full annealing - It consists of heating the steel above upper critical temp^r & slow down cooling in the furnace.

- This Method is eligible for High Carbon Steels.
- Generally used to improve machinability & electrical & Magnetic properties of metals.

* Upper critical temp^r for steel : 550°c - 650°c

b) Stress Relief Annealing.

* lower critical temp^r for steel - 450°c - 550°c

- Applicable for ferrous & Non ferrous metals
- Used to Reduce internal stresses, within the casting process.
- Generally this process is used to refine grain structures which was produced during casting processes.

c) Recrystallisation Annealing

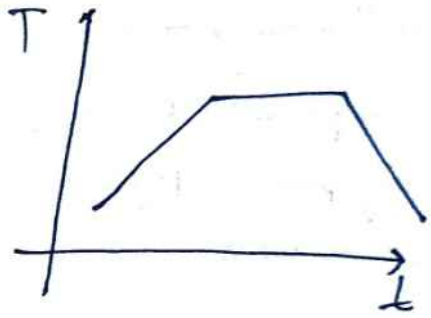
- In this process steel is heated to a temp^r below the critical temp^r range - Temp^r Range - 550°c to 680°c
- Afterwards, it goes cool down.
- Generally this process is used in sheet metal working & Wire Making Industries

d) Spheroidising Annealing.

- Generally used to improve strength & ductility
- Also used to Help to improve Machinability of high carbon steels.
- In this process the steel is heated to Upper Critical Point Temp^r (550°C) & Afterwards cooled down to (600°C) at cooling rate of 20°C/hour.

② Normalising

- It is the second process of heat treatement in this the steel is heated about 40 to 50°C in the range of Upper Critical Temp^r & Held at that temp^r for a sufficient period of time & then cooled down at Room Temp^r



- Purpose →
  1. To improve machineabrlity of Material.
  2. To decrease residual stresses.
  3. Used to obtain a Homogeneous structure

③ Quenching OR HARDENING

- It is a process in which the steel is heated upto 640°c & Hold the material for some time at that temp^r, afterwards Rapid cooling process is performed with help of Oil, Brine Sol^n or sometimes water.

→ The Tensile strength & Compressive strength of the Materials are improved.
→ Wear & Corrosion Resistance and Cutting Ability of steel are improved.
→ The Machinability of the material also increases.

④ Tempering

- After quenching process, steel is heated to improve Ductility & Toughness
- It is performed in three stages - a) Low Temp^r Tempering process
  b) Medium Temp^r Tempering process
  c) High Temp^r Tempering process.

- Low Temp^r Tempering – Plain carbon & Alloy steels are heated for 1 to 2 hours at 450°C

- Medium Temp^r Tempering - Material is heated from 250°C to 500°C, During this step, hardness of the Material is reduced & brittleness of Material Also Decreases.

- High Temp^r Tempering - Material is heated from 500°C to 650°C

* As a result of all the processes, structure obtained in the end, is very tough & Have higher impact strength & Better Tensile Strength.

⑤ Aus Tempering → Always Done for Harden Material.

- In this process, The steel is heated from 725°C to 1370°C & afterwards Quenching process is performed in the presence of Salt in Brine Sol^n down to 250°C to 800°C

- Generally used to Obtain High Hardness & Ductility.
- Generally Thick Sections can't Be Heat Treated By This process.
- Also Helps To Reduce Residual stress & inc. tensile strength of the Material

⑥ Martempering → for Harden Materials

- In this process, steel is heated above critical point in the range of 150° to 200°C
- It is held at particular Temp^r for that period & cooled down in the presence of air to the R.T.
- Always suitable for high carbon steels & Alloy Steels.
- Steel has less Tendency to crackdown, to distort & produce residual stresses during Heat Treatement process.

- Not suitable for larger & Thicker sections.
- Always helps to refine grain size of the particles, to inc. the hardness & strength of the steel, improve ductility & Toughness. Also inc. wear & corrosion resistance properties of metals.

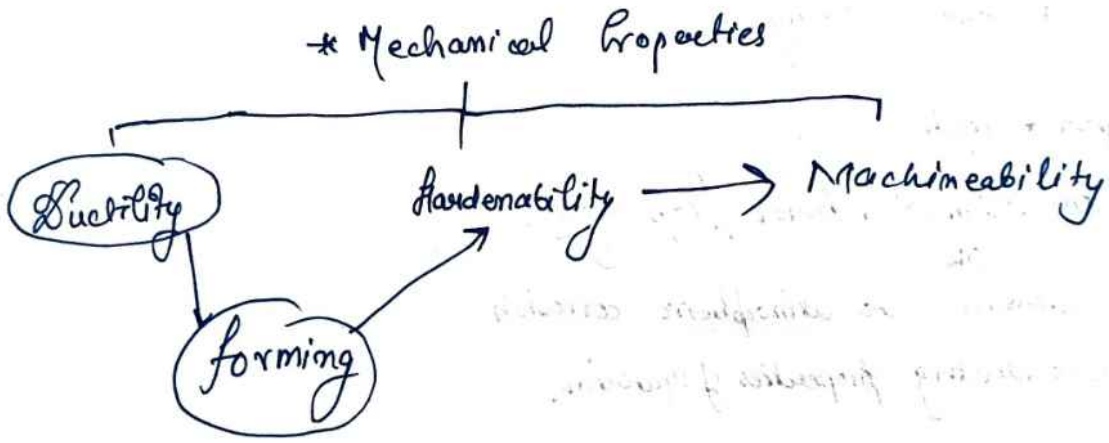
(7) Case-Hardening

- Outer surface of the Metal & its hardness is increased.
- It is a technique in which the Nitrogen is used to Make a surface layer at High Temp.^{r} To inc. the hardness of the case.
- Sometimes in presence of Carbon, the Material is heated. Like Gears, Bearings & various alloy steels that are used as a power Transmission Devices.

Effects of Alloying Element

* Purpose of Alloying

1) To improve Corrosion Resistance
2) To improve Ductility → [forming]
3) To improve toughness
4) To improve machinability
5) To improve High or low temp^r stability
6) To Attain ~~free~~ greater Strength
7) Improve Wear Resistance
8) To improve hardenability → [to deformat^n Reduces]



1) Nickel -

1. Nickel → Steel + Carbon : a) It increases toughness.
   b) Reduces chances of distortion of Material during Quenching process.
   c) inc. strength of steel
   d) inc. resistance to impact Loading
   e) improve machineability

2) Chromium → Iron + Carbon

a) Improve. Wear resistance of steel.

b) Inc. Hardness

c) Improve & inc melting pt. of material.

d) Improve Abrasion property of material

3) Titanium + Steel

a) Prevents Austenite formation in high Chromium Steels

b) Reduce Hardness & hardenability in Medium chromium steels.

4) Tungsten + steel

a) Resist Heat

b) promotes strength at elevated temp^r

c) Inc. Hardness

d) inc. grain size stability

5) Copper + steel.

a) inc. corrosion resistance property.

OR

inc. resistance to atmospheric corrosion

b) improve conducting properties of Material.

6) Carbon + steel

a) inc. Hardness.

b) Inc. It's Melting point

c) Inc tensile strength.

d) improve machineability properties.

Tool Steel

- Special type of steel which have been developed to form, cut or change the shape of the Material into finish or semfinish products.

* Application

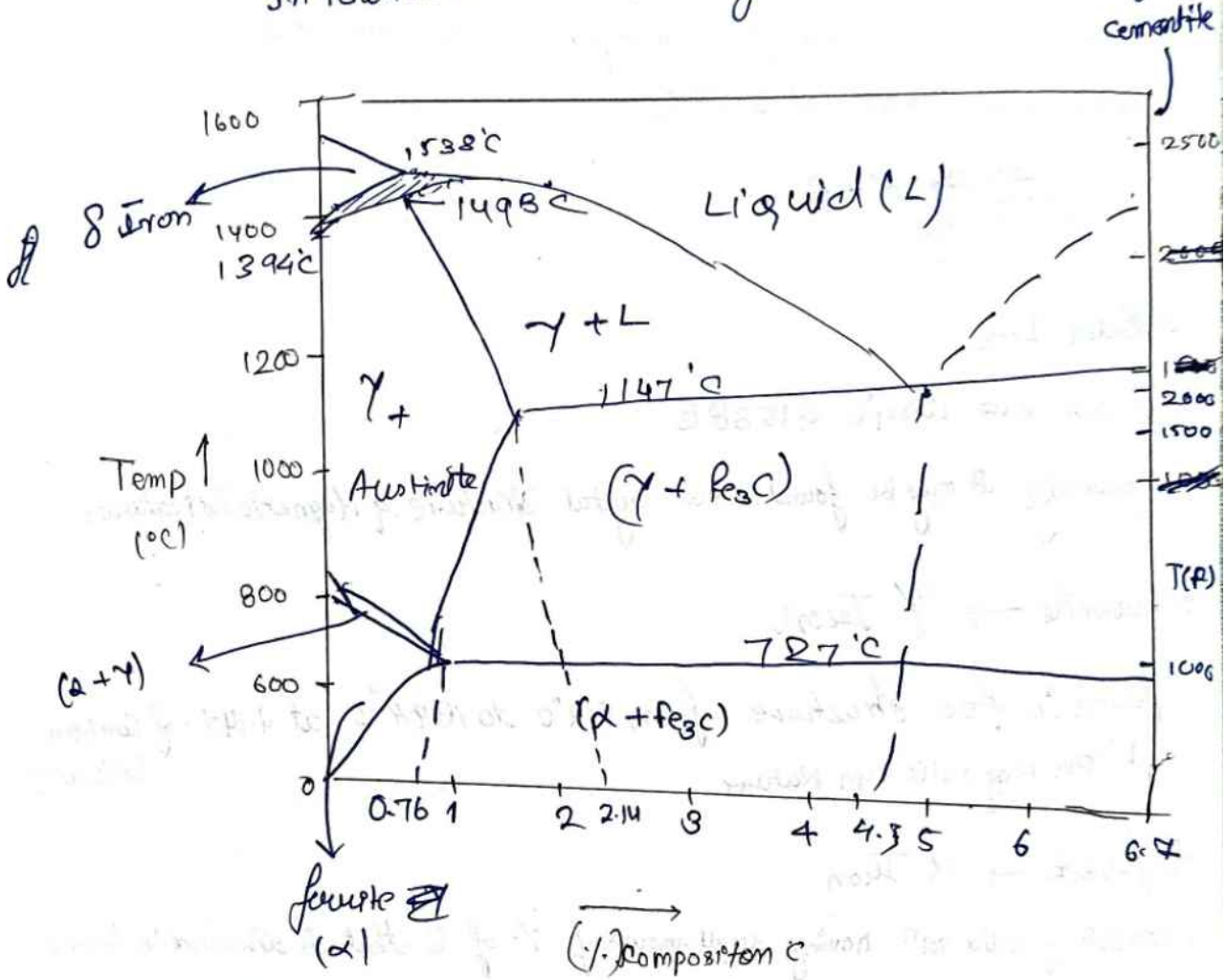
- Used in Drills
- Pnumetic Tools & ~~Punches~~ Punches
- Reamers
- Tools used for hot forging machines.

'Ledebuite - Contains 4.3% C & forms at 1130°C

- Rockwell No. B-70, Tensile strength - 1,30,000 psi

. It is the third hardest str. in the iron Carbon diagram

Iron Carbon Diagram - Defined as a Map of the temp^r at which diff^r phase changes occurs on very slow heating & cooling in relation to Carbon percentage is called Iron Carbon diagram



* Peritectic Rx^n - Solid + Liquid → B

In peritectic Reac^n, ~~Solid combine~~ one solid phase combines with Liq. phase to form a new solid

$\delta + L \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}} \beta$

* This Rx^n occurs at 1490°C with lowest percentage of Carbon.

* Eutectic Reaⁿ

↳ Liquid phase transforms into two solid phase, Solid ph 1 & Solid 2

· Rxⁿ is produced at 1130°C at 4.3% of carbon

$$L \underset{\text{Heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + \beta$$ By @t

* Eutectoid Rxⁿ

- In this Rxⁿ, one solid phase transforms into two another solids
- Occurs at 723°C at 0.8% C

$$\gamma \underset{\text{Heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha + \beta$$

* Delta Iron

- Exists B/w 1394°C & 1538°C
- Generally it may be found in BCC crystal structure & Magnetic in Nature.

* Austenite → γ Iron

- found in fcc structure from 912°C to 1394°C at 2.14% of Carbon (Max^m)
- Non Magnetic in Nature

* ferrite → α Iron

- Consists of solid soln having small amount of % of C that is dissolved in iron.
- BCC Crystal Structure
- Softest on Iron Carbon Diagram
- Magnetic in Nature Below 768°C

* Cementite

- Chemical formula - Fe_3C
- Hard & Brittle in Nature
- Have High Compressive Strength.
- found in Orthorhombic Str.

1 Differentiate B/w welding, Brazing, soldering ?

2 Write a short note on classificat^{n} of Steels :

3 Explain the 5 Tools that are used in foundry shop to form a Mould Cavity

4. Define forging & explain any 5 tools used in forging process in forging shop

5 Explain Any 5 Tools that are used to perform casting process in founder shop

6) Describe

1) Mould & Pattern

2) Runner & Riser

3) Cope & Drag

4) Core & Core Print

5) Various Types of Allowances

6) Properties of Moulding sand

7) Write a short Note on heat Treatment of steels

7) Short Note on Iron Carbon Diagram