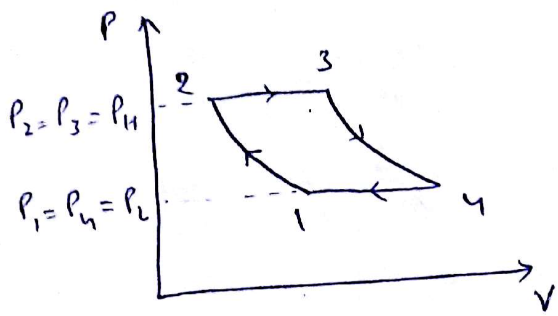
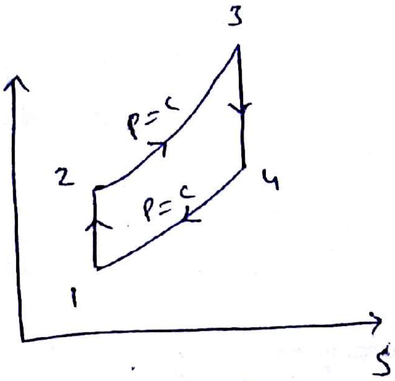
# POWER PLANT

## CHAPTER-1 [SIMPLE GAS TURBINE CYCLE, BRAYTON CYCLE]

- Brayton cycle



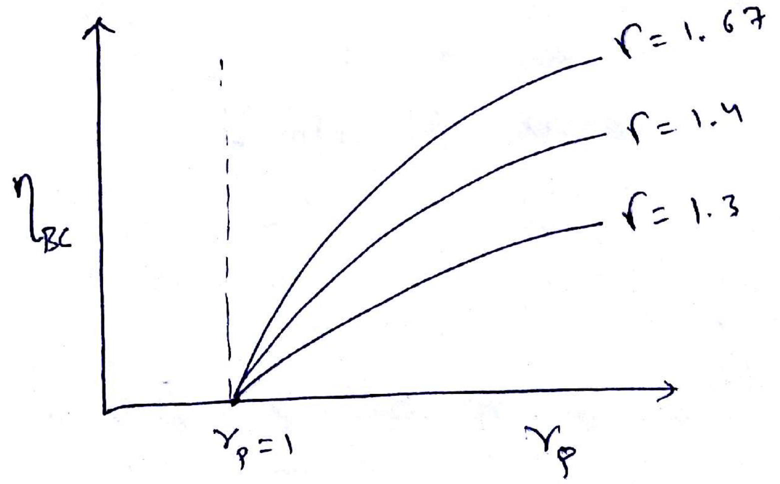

$$T_1 T_3 = T_2 T_4$$

Always

- Back work ratio $(r_{bw}) = \dfrac{-ve\ work}{+ve\ work} = \dfrac{W_c \text{ or } W_p}{W_T}$

work ratio $= 1 - r_{bw} = \dfrac{W_T - W_c}{W_T}$

- $\eta_{Brayton} = 1 - \dfrac{T_1}{T_2} = 1 - \dfrac{1}{\frac{T_2}{T_1}} = 1 - \dfrac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$



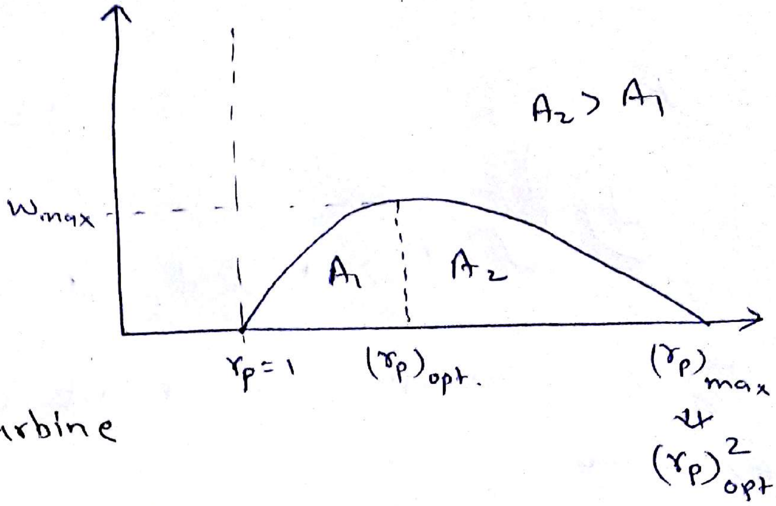

- Optimum pressure ratio for max. work

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

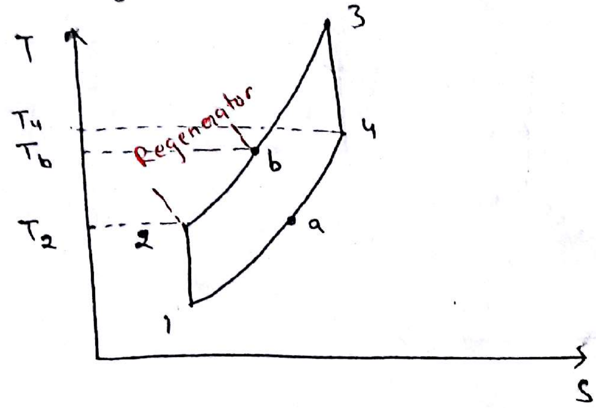
$W_{max} = C_p \left[ \sqrt{T_{max}} - \sqrt{T_{min}} \right]^2$ here $T_{max} = T_3$, $T_{min} = T_1$

$(r_p)_{opt} = \left( \dfrac{T_{max}}{T_{min}} \right)^{\frac{1}{2} \times \frac{\gamma}{(\gamma - 1)}}$

- $(r_p)_{max} = (r_p)^2_{opti}$




- Regeneration in Gas turbine




$W_{net} = \text{const}$

$Q_s \downarrow \Rightarrow \eta \uparrow$

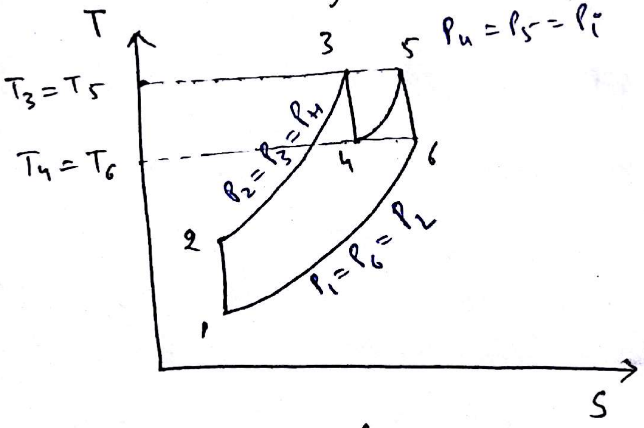
effectiveness of regenerator

$$\varepsilon = \frac{T_b - T_2}{T_4 - T_2}$$

for ideal regenerator $T_b = T_4$ & $T_2 = T_a$

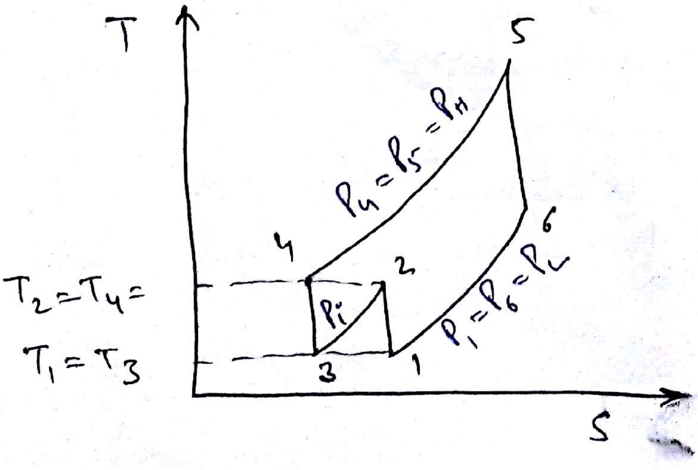
$$\eta_{\substack{reg.\\cycle}} = 1 - \frac{T_1}{T_3}(r_p)^{\frac{r-1}{r}}$$

- Condition for max work output with Perfect reheating




1) $T_3 = T_5$
2) $T_4 = T_6$
3) $P_i = \sqrt{P_H \cdot P_L}$
4) $W_{T_1} = W_{T_2}$

- Condition for mini. work input with Perfect Intercooling




1) $T_1 = T_3$
2) $T_2 = T_4$
3) $P_i = \sqrt{P_H \cdot P_L}$
4) $W_{C_1} = W_{C_2}$

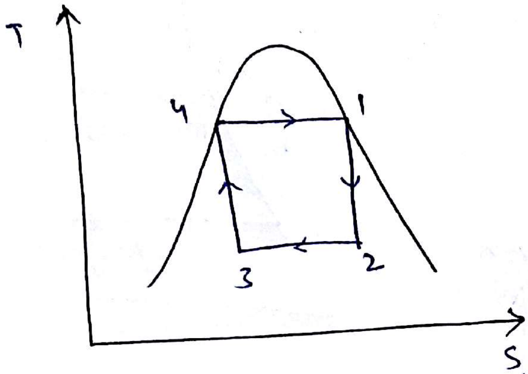
# CHAPTER - 2 [RANKINE CYCLE] or steam Power cycle

- Specific steam consumption

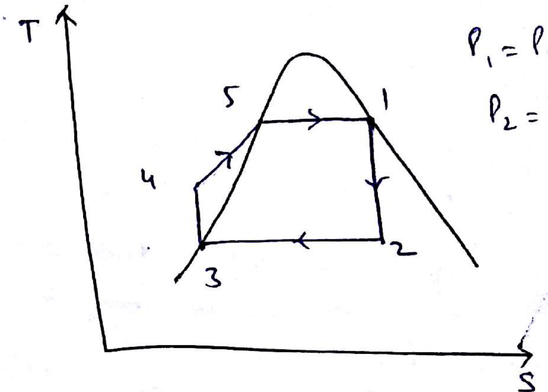
$$SSC = \frac{3600}{W_{net}} \quad \frac{kg}{kW\text{-}hr}$$

- Heat rate $= \frac{1}{\eta}$

- Carnot vapour cycle




- Rankine cycle

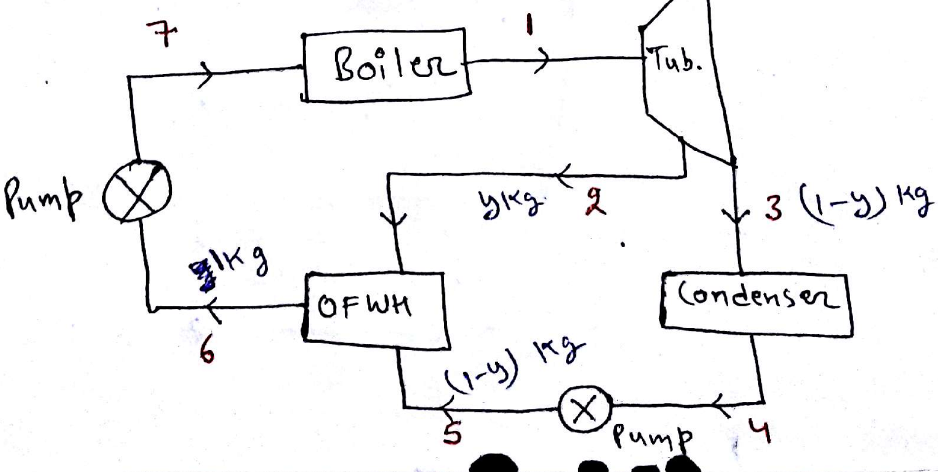


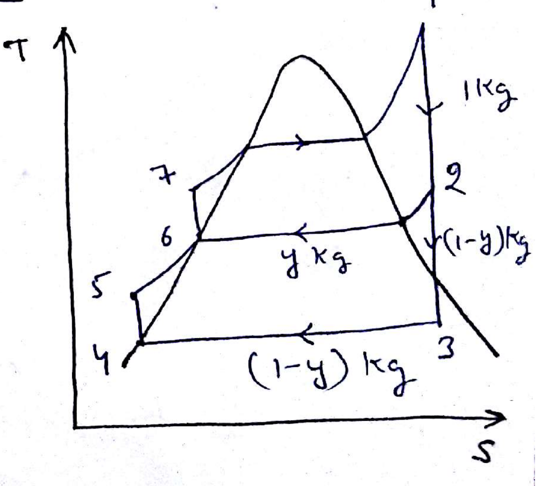

$P_1 = P_5 = P_4 = P_H$
$P_2 = P_3 = P_L$

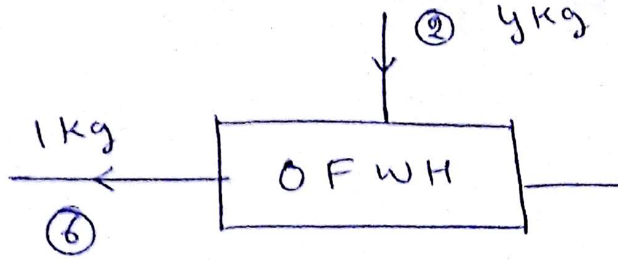
1-2 ⇒ turbine
2-3 ⇒ condensor
3-4 ⇒ pump
4-1 ⇒ Boiler

- mean temp of Heat addition is higher in carnot cycle so $\eta_{carnot}$ is more the $\eta_{Rankine}$.

- methods to improve Performance of Rankine cycle
  1) Decreasing condenser Pressure
  2) increasing boiler Pressure
  3) Super heating ] → the main Aim is to increase dryness fraction
  4) Reheating ] at outlet of turbine
  5) Regeneration
     a) Open feed water Heater



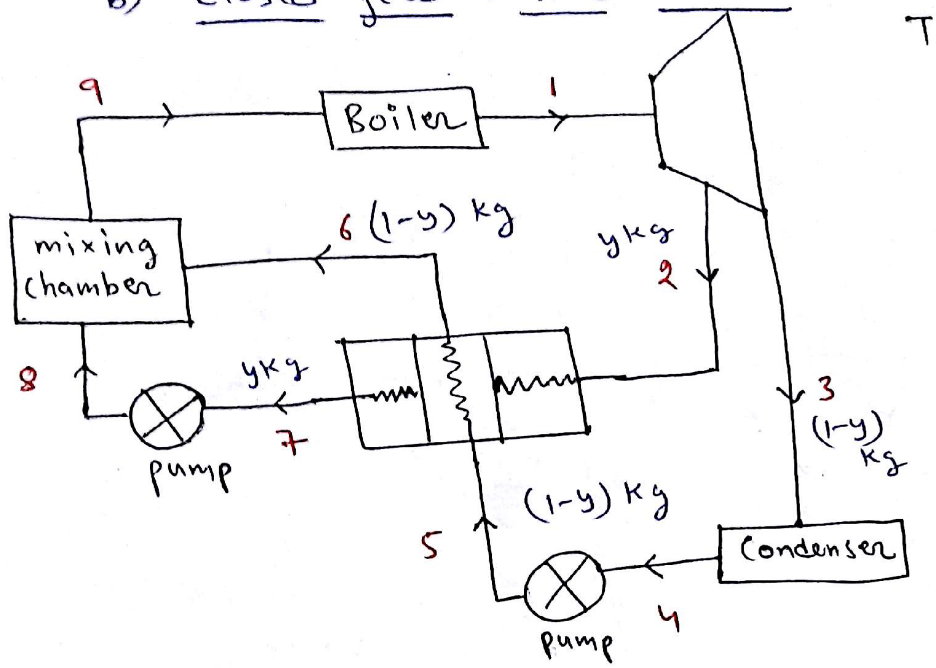



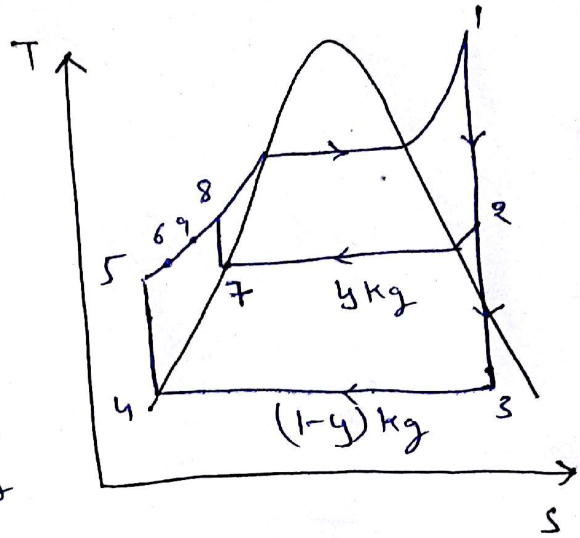



$$y h_2 + (1-y) h_5 = (1) h_6$$

$$m_2 + m_5 = m_6$$

b) Closed feed water heater



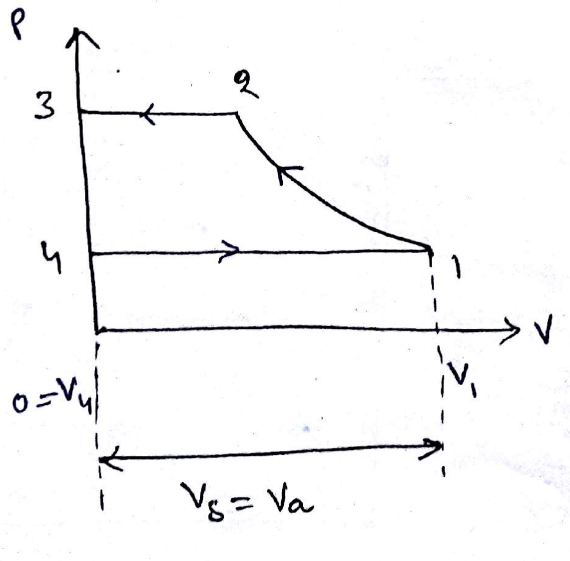

- Position of point ② will be decided by $x_2$ ; by equating $s_1 = s_2$

- $y h_2 + (1-y) h_5 = (1-y) h_6 + y h_7$

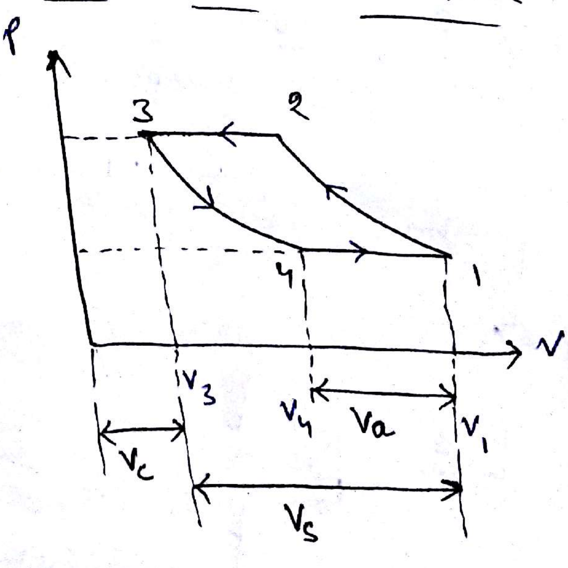
## CHAPTER- 3 [RECIPROCATING COMPRESSOR]

- High Pressure upto 1000 bar
- less Discharge , 5-8 $m^3/min$.

Win without clearance




Win with clearance



$\Rightarrow \quad W_{in} = \left(\frac{n}{n-1}\right) P_1 \times V_a \times \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$ J/cycle

$V_a = V_1 - V_4 = V_1$ for comp. without clearance

$= V_1 - V_4$ for comp. with clearance

$=$ actual volume swept.

- Clearance ratio $= C = \frac{V_c}{V_s}$
- Volumetric efficiency

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

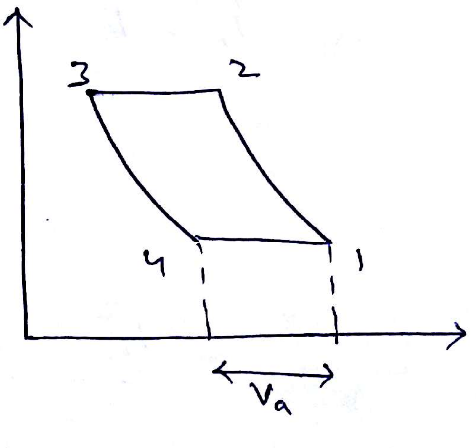
- Use of multistage compressor

1) overall Pressure ratio $= \left(\text{Pressure ratio in each stage}\right)^N$

2) Total work input $= N \times$ (work input in each stage)

$N =$ no. of stages

- Free Air delivery (FAD) ($V_F$)




$\dot{m}_{entering} = \dot{m}_{leaving} = \dot{m}_F$

$$\frac{P_1 (V_1 - V_4)}{R T_1} = \frac{P_2 (V_2 - V_3)}{R T_2} = \frac{P_F V_F}{R T_F}$$

($V_1 - V_4 = V_a$, $V_2 - V_3 = V_a$)

$P_F = 1$ bar

$T_F = 288$ K $= 15°C$

$\Rightarrow$ Calculation of cylinder Dimensions

$$\frac{P_1 V_{a_1}}{T_1} = \frac{P_2 V_{a_2}}{T_2} = \frac{P_3 V_{a_3}}{T_3} \qquad \left[\eta_v = \frac{V_a}{V_s}\right]$$

$\eta_{v_1} P_1 V_{s_1} = \eta_{v_2} P_2 V_{s_2} = \eta_{v_3} P_3 V_{s_3}$ when $T_1 = T_2 = T_3$ Perfect inter cooling

$\Rightarrow \eta_{v_1} P_1 D_1^2 = \eta_{v_2} P_2 D_2^2 = \eta_{v_3} P_3 D_3^2$ when $l_1 = l_2 = l_3$

CHAPTER-4 [CENTRIFUGAL COMPRESSOR]

- General concepts for all type of compressors

Euler's Power $= \dot{m}(V_{w_2}u_2 - V_{w_1}u_1)$ $J/kg \times \frac{kg}{s} = watt$

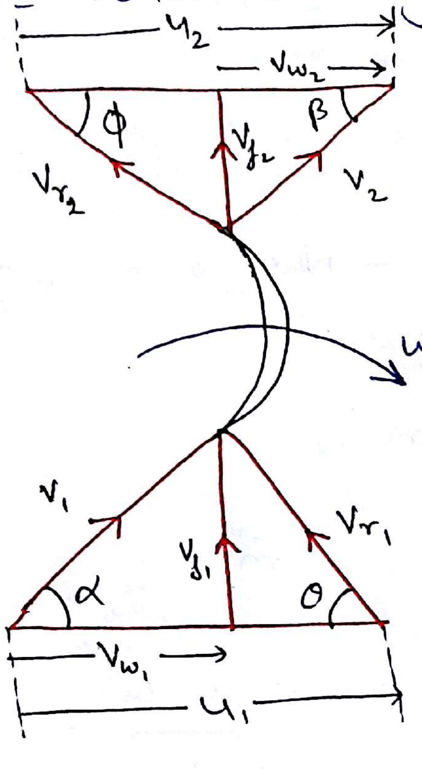
$W_c = V_{w_2}u_2 - V_{w_1}u_1$

$W_T = V_{w_1}u_1 - V_{w_2}u_2$

$V_{w_1}$ = whirl velocity at inlet $(V_1 \cos\alpha)$

$V_{w_2}$ = whirl velocity at outlet $(V_2 \cos\beta)$

$u_1$ & $u_2$ = rotor velocity at inlet & outlet



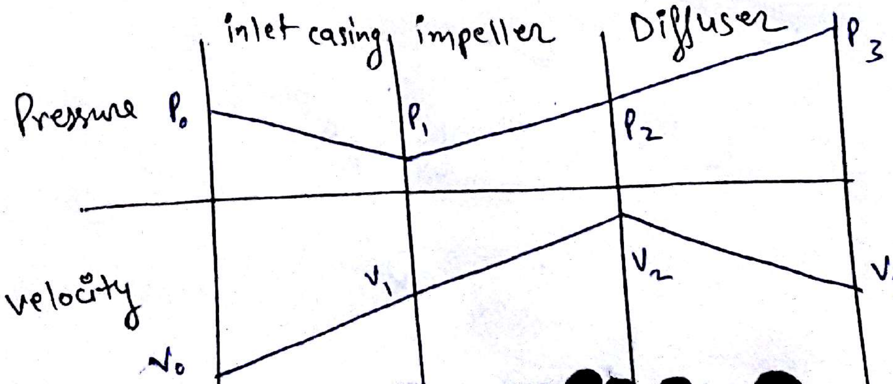

$\theta$ & $\phi$ = blade angle at inlet & outlet

$V^2 = V_w^2 + V_f^2$

$\vec{u} + \vec{V_r} = \vec{V}$

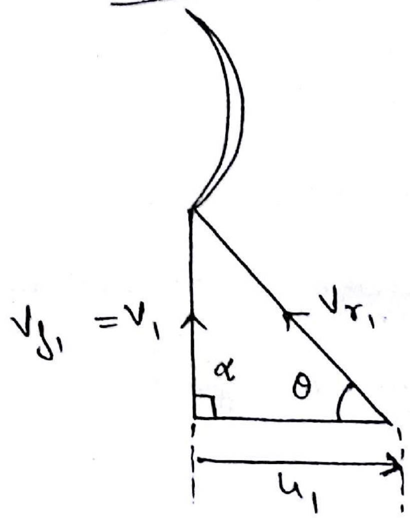
$$V_{w_2}u_2 - V_{w_1}u_1 = \underbrace{\frac{V_2^2 - V_1^2}{2}}_{\text{impulse effect}} + \underbrace{\frac{u_2^2 - u_1^2}{2}}_{\text{centrifugal effect}} + \underbrace{\frac{V_{r_1}^2 - V_{r_2}^2}{2}}_{\text{reach effect}}$$

⇒ Centrifugal Compressor



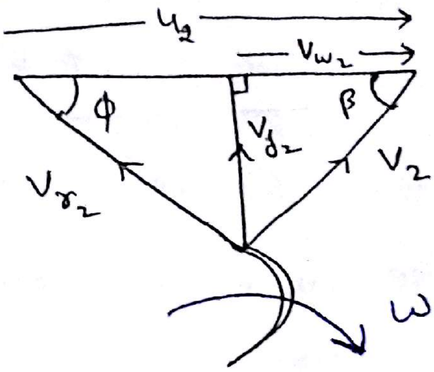
- Velocity triangles for centrifugal compressor

Inlet

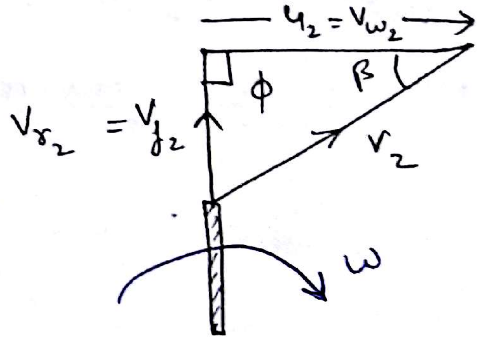



Outlet

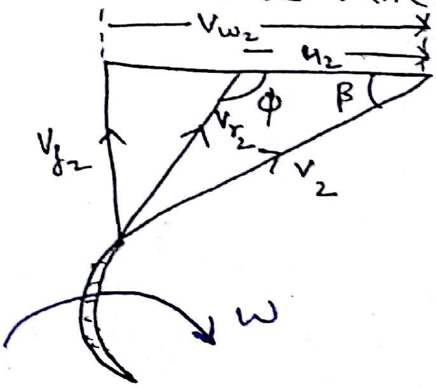
maximum efficiency ⇐ Case-1 Backward curved vane




minimum stresses ⇐ Case-2 radially outward vane




higher Pressure ratio ⇐ Case-3 Forward curved vane




- $W_{in} = V_{w_2} u_2 - V_{w_1} u_1 \quad J/kg$

  $V_{w_1} = 0$ for centrifugal compressor

$$\boxed{W_{in} = V_{w_2} u_2} \quad J/kg$$

$$W_{in} = \dot{m} V_{w_2} u_2 \quad J$$

- slip factor $(\sigma) = \dfrac{V_{w_2}}{u_2}$

$$\Rightarrow V_{w_2} = \sigma u_2$$

$$\boxed{W_{in} = \sigma \cdot u_2^2} \quad J/kg$$

- Power factor ($\psi$) = $\dfrac{\text{Actual } W_{in}}{\text{theoretical } W_{in}} > 1$

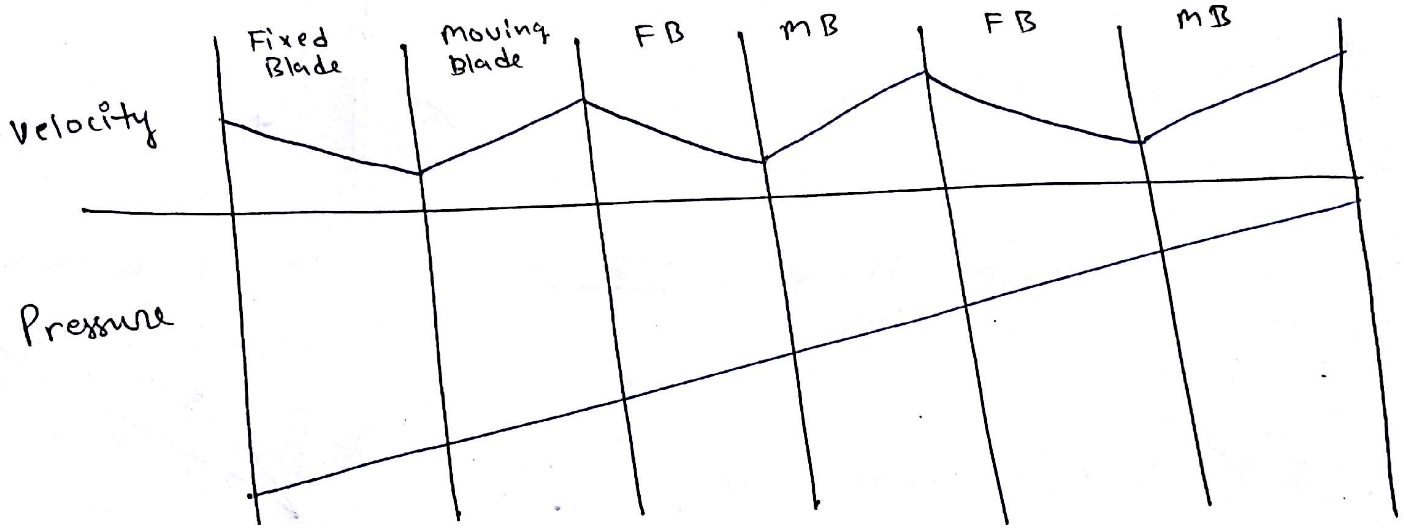
$$(W_{in})_{actual} = \psi V_{w_2} u_2$$

$$\boxed{W_{in} = \psi \sigma u_2^2} \quad J/kg$$

- if $\psi$ & $\sigma$ are not given, then assume it to be 1.
- if Prewhirl in centrifugal compressor is given then, $W_{in} = V_{w_2}u_2 - V_{w_1}u_1$

$\Rightarrow$ $W.D. = h_2 - h_1 = C_p(T_2 - T_1) = V_{w_2}u_2 = \sigma u_2^2 = \psi \sigma u_2^2$

## CHAPTER-5 [AXIAL FLOW COMPRESSOR]




- Area of flow = $\frac{\pi}{4}(D_t^2 - D_h^2)$

  $D_t$ = tip / outer diameter

  $D_h$ = hub diameter

- $u_1 = u_2 = \dfrac{\pi D_m N}{60}$ ; $D_m$ = mean dia = $\dfrac{D_t + D_h}{2}$

- $V_{f_1} = V_{f_2}$

- $\alpha_1$ & $\alpha_2$ $\Rightarrow$ absolute velocity angle made with $V_f$

  $\beta_1$ & $\beta_2$ $\Rightarrow$ Blade angles made with $V_f$

- Degree of Reaction ($R_D$)

$$R_D = \frac{\Delta h_{MB}}{\Delta h_{stage}} = \frac{V_{r_1}^2 - V_{r_2}^2}{2u(V_{w_2} - V_{w_1})} = \frac{V_f}{2u}(\tan\beta_1 + \tan\beta_2)$$

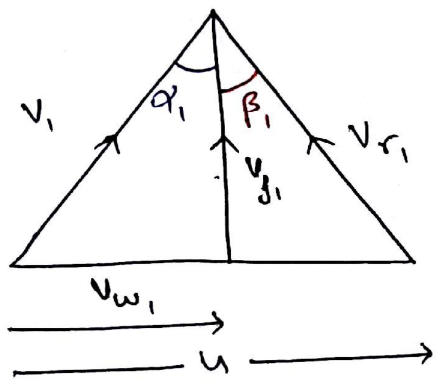
- Work input

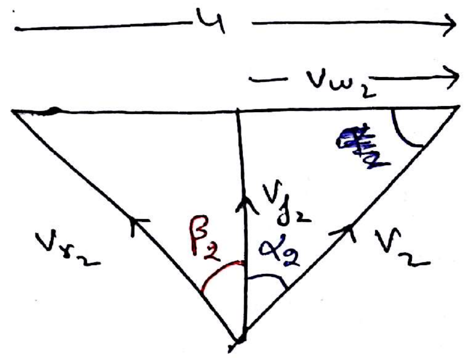
$$W_{in} = (V_{w_2} - V_{w_1})u = V_f \cdot u \cdot (\tan\beta_1 - \tan\beta_2)$$

$$W_{Total} = N \times (W_{in})_{\text{single stage}} \qquad [\because N = \text{no. of stages}]$$

- $W.D. = C_p(T_2 - T_1) = N \times V_f \cdot u \cdot (\tan\beta_1 - \tan\beta_2)$

⇒ Velocity triangles




⇒ For 50% $R_D$

$\alpha_1 = \beta_2$

$\beta_1 = \alpha_2$

$V_1 = V_{r_2}$

$V_2 = V_{r_1}$

- Fluid deflection angle $= \beta_1 - \beta_2$