IITians GATE CLASSES

EXCLUSIVE GATE COACHING BY IIT/IISc GRADUATES

A division of PhIE Learning Center

QUICK REVISION

FORMULA SHEET

for

GATE -ME POWER PLANT ENGINEERING

Table Of Content

OUR COURSES

GATE Online Coaching

Course Features

- Live Interactive Classes
- E-Study Material
- Recordings of Live Classes
- Online Mock Tests

TARGET GATE COURSE

Course Features

- Recorded Videos Lectures
- Online Doubt Support
- E-Study Materials
- Online Test Series

Distance Learning Program

Course Features

- E-Study Material
- Topic Wise Assignments (e-form)
- Online Test Series
- Online Doubt Support
- Previous Year Solved Question Papers

OUR COURSES

Online Test Series

Course Features

- Topic Wise Tests
- Subject Wise Tests
- Module Wise Tests
- Complete Syllabus Tests

More About IGC

SAMPLE STUDY MATERIALS
https://bit.ly/3Wu7lsp

SAMPLE MOCK TESTS
https://bit.ly/3FDyF0f

SAMPLE VIDEO LECTURES
https://bit.ly/3V4xU6j

TEAM IGC GATE
https://bit.ly/3G21khi

OUR TESTIMONIALS
https://bit.ly/3Yp2Hh7

IGC TELEGRAM GROUP
https://bit.ly/3j4koCd

POWER PLANT ENGINEERING

Chapter 1: RANKINE CYCLE OR STEAM POWER CYCLE

1. **Specific Steam Consumption (SSC) or Steam Rate:**

   It is mass flow rate of steam to produce 1 kW power output.

   $$SSC = \frac{3600}{W_{net}} \frac{kg}{kWhr}$$

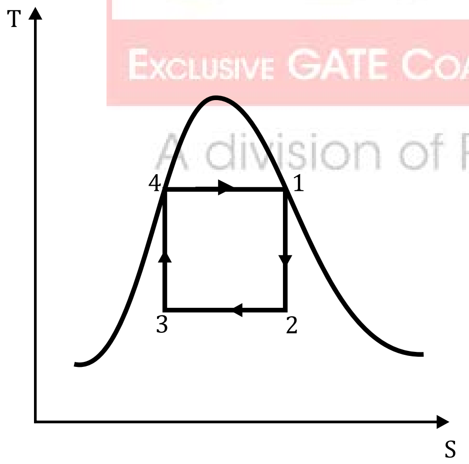
   Where W_{net} is in kJ/kg.

2. **Heat Rate:**

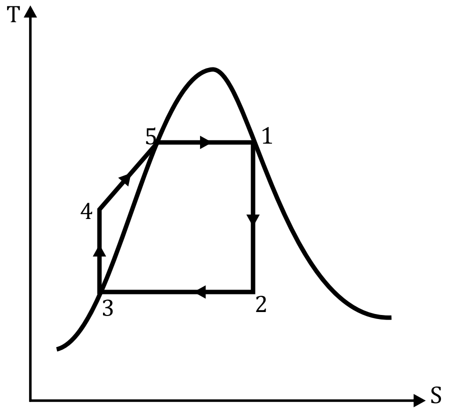
   $$HR = \frac{Q_{input}}{W_{net}} = \frac{1}{\eta}$$

   η
   $=$ efficiency of thermal power cycle

Carnot Vapour Cycle:



Rankine Cycle:



$\eta_{carnot} > \eta_{Rankine}$ (As mean temp of heat addition is higher in Carnot).

$(W_{net})_{rankine} > (W_{net})_{carnot}$

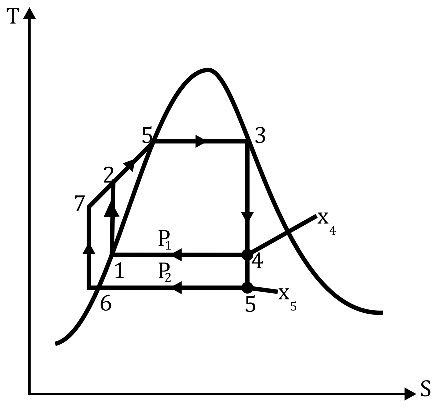
$(W_{pump})_{carnot} > (W_{pump})_{Rankine}$

1-2 → Turbine work

3-4 → Pump work

Methods to Improve Performance of Rankine Cycle:

A. **Decreasing condenser pressure:**



p_1 = Initial condenser pressure

p_2 = Lowered condenser pressure

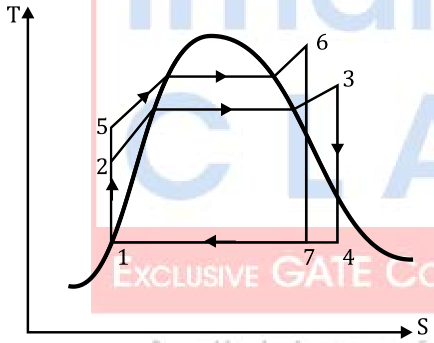
1-2 → Initial pump work

3-4 → initial turbine work

2-3 → initial heat supplied.

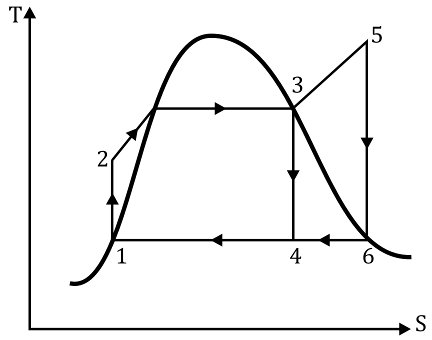
- W_{pump} = can't say (But marginally ↑).
- $W_{Turbine}$ ↑
- W_{net} ↑
- Steam rate ↓
- Q_{Supply} ↑
- $Q_{rejection}$ → can't t say (but marginally ↑)
- T_{mean} of heat addition ↓ (T_{MA})
- T_{mean} of heat rejection ↓↓ (T_{MR})
- $\eta_{Thermal}$ ↑
- x (dryness fraction ↓)
- Moisture ↑

B. **Increasing Boiler pressure**



- W_{pump} ↑
- $W_{Turbine}(W_T)$ ↑↑
- $W_{net} = (W_T - W_{pump})$ ↑
- Q_{supply} → can't say (but ↓)
- $Q_{rejection}$ ↓
- T_{MA} ↑
- T_{MR} → same
- $\eta_{thermal}$ ↑
- x ↓
- moisture ↑
- SSC ↓
- Condenser load ↓

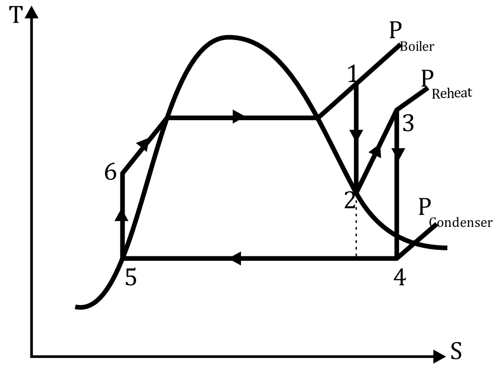
C. **By Superheating:**



- W_{pump} → same
- $W_{Turbine}$ ↑
- W_{net} ↑
- Q_{supply} ↑
- $Q_{rejection}$ ↑
- T_{MA} ↑
- T_{MR} → same
- $\eta_{thermal}$ ↑
- x ↑
- moisture ↓
- SSC ↓ (size of boiler ↓)
- Condenser load ↑

Reheating:

The main aim of reheating is to increase dryness fraction at the outlet of turbine.

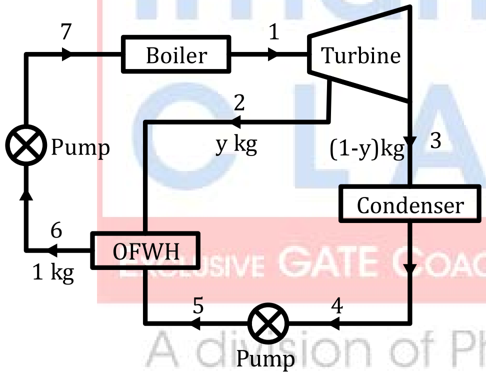


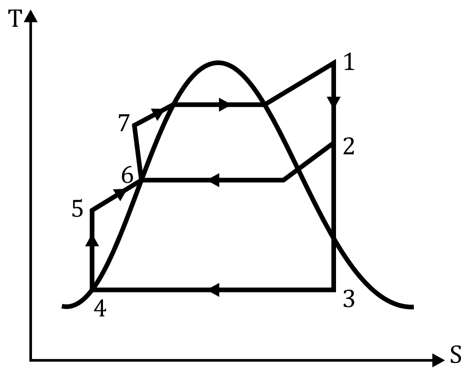
- W_{pump} → same
- $W_{Turbine}$ ↑

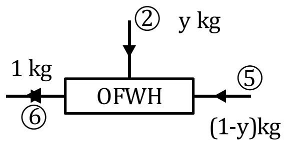
- $W_{net} \uparrow$
- $Q_s \uparrow$
- $Q_{rejection} \uparrow$
- $T_{MR} \rightarrow$ same
- $T_{MA} \rightarrow$ can't say (Can $\uparrow, \downarrow$ or constant)
- $\eta \alpha T_{MA}$
- $x \uparrow$
- Moisture content $\downarrow$
- Condenser load (size) $\uparrow$
- SSC $\downarrow$

Regeneration:

A. **Open feed water heater (OFWH) (Direct contact type):**







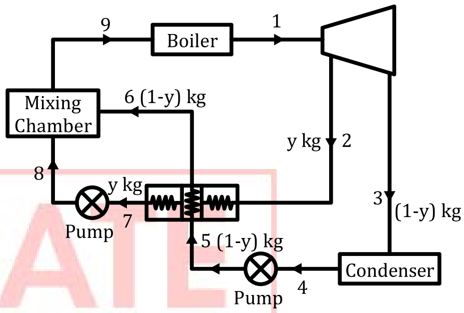
$$yh_2 + (1 - y)h_5 = h_6$$

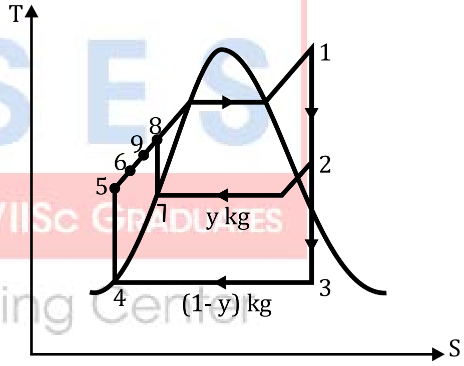
$$m_2 + m_5 = m_6$$

Effect of Regeneration:

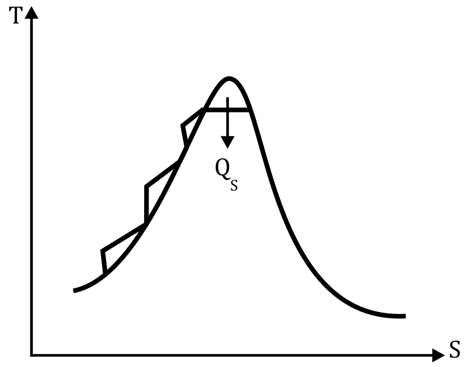
- $\eta \uparrow$
- $W_{Turbine} \downarrow$
- SSC $\uparrow \rightarrow$ Biggest boiler
- $Q_{rejection} \downarrow$
- Condenser load $\downarrow$

B. **Closed Feed Water Heater (Indirect contact type):**





Note:

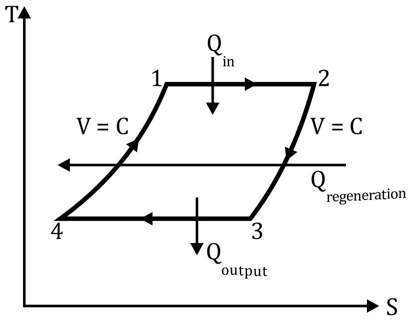


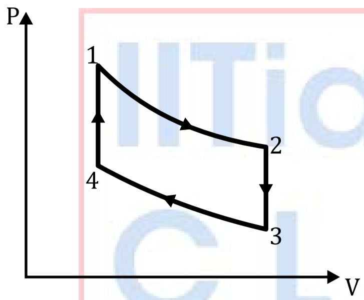
Infinite bleeding points results $\rightarrow$ Ideal Regenerative cycle.

$$\eta_{thermal} = \frac{W_{Turbine} - W_{pump}}{Q_{supply}}$$

Stirling Cycle:

2 isothermal processes and 2 isochoric processes.





$$\eta_{stirling} = 1 - \frac{T_L}{T_H}$$

Note:

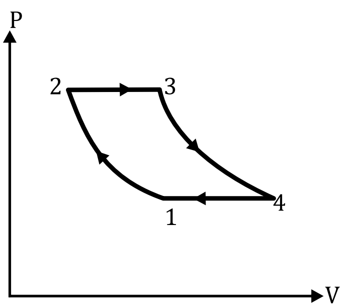
$\eta_{stirling} = \eta_{carnot}$

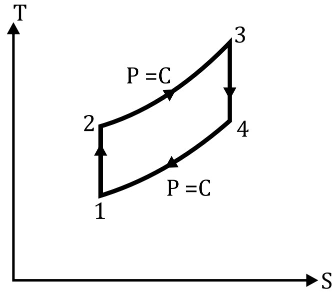
$= \eta_{ideal\ regenerative\ rankine\ cycle}$

$= \eta_{ericsson}$

*****

Chapter 2: GAS TURBINE POWER PLANT





$$\text{Back work ratio} = \frac{W_{Compressor}(W_C)}{W_{Turbine}(W_T)}$$

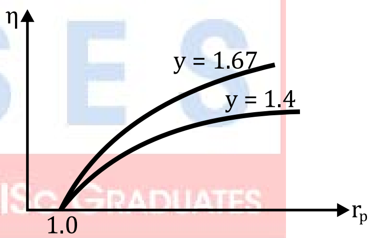
Work ratio = 1 − Back work ratio

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

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

r_p = pressure ratio

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



If $r_p \uparrow \Rightarrow \eta \uparrow$

If $\gamma \uparrow \Rightarrow \eta \uparrow$

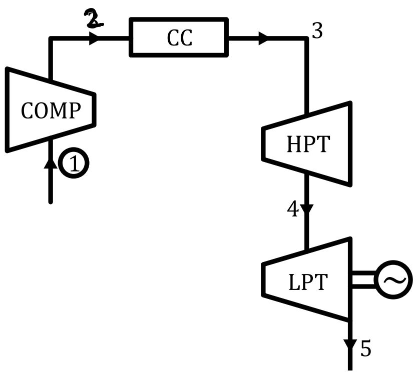
Optimum pressure ratio for Max Work:

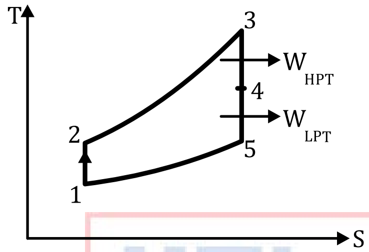
$$T_2 = T_4 = \sqrt{T_1 T_3}$$

$$(W_{net})_{max} = C_p\left(\sqrt{T_{max}} - \sqrt{T_{min}}\right)^2$$

$$(r_p)_{optimum} = \left(\frac{T_{max}}{T_{min}} \times \eta_{Comp}\ \eta_{Turbine}\right)^{\frac{\gamma}{2(\gamma-1)}}$$

Free Shaft Turbine:





$W_{generator} = W_{LPT} = C_p(T_4 - T_5)$

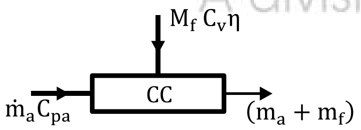
$W_{Compressor} = W_{HPT}$

$T_2 - T_1 = T_3 - T_4$

$r_p = (r_p)_{HPT} \times (r_P)_{LPT}$

Combustion Chamber Types in Brayton Cycle

Open System Combustion Chamber:



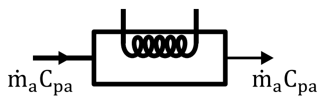
$AFR = \frac{m_a}{m_f}$

$(AFR)C_pT_2 + \eta_c(C_v) = (1 + AFR)C_{Pe}T_3$

C_v = calorific value of fuel

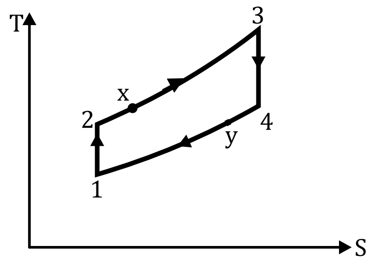
C_{Pe} =Equivalent specific heat at constant pressure

Closed Combustion Chamber:



$(AFR)C_{p_a}T_2 + C_v\eta_c = (AFR)C_{p_a}T_3$

Regeneration in Gas Turbine:



ϵ = Effectiveness of regenerator

$$\epsilon = \frac{T_x - T_2}{T_4 - T_2}$$

$$\eta_{reg} = \frac{W_T - W_c}{Q_{Supply}}$$

For Ideal Regenerative Cycle:

$T_x = T_4$

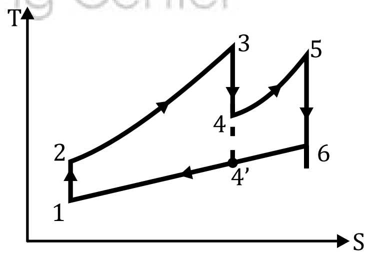
$T_2 = T_y$

$$\eta_{ideal\ reg} = \left(1 - \frac{T_{min}}{T_{max}}(r_p)^{\frac{\gamma-1}{\gamma}}\right)$$

Effects of Regeneration:

$W_c \to$ same, $W_T \to$ same, $Q_s \downarrow, Q_{rej} \downarrow$, $T_{MA} \uparrow, \eta \uparrow, T_{MR} \downarrow$

Reheating:



Effects of reheating:

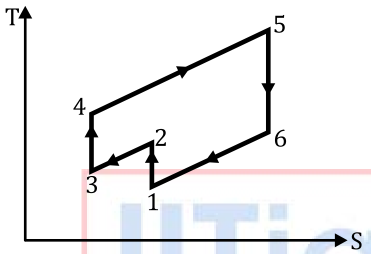
- $W_{Comp} \to$ same
- $W_{Turbine} \uparrow$
- $W_{net} \uparrow \to$ Main purpose of reheating
- $Q_s \uparrow, Q_{rej} \uparrow$
- $T_{MA} \uparrow, T_{MR} \uparrow\uparrow$
- $\eta \downarrow$

Condition for max work output with perfect reheating: ($T_3 = T_5$)

1. $T_3 = T_5$
2. $T_4 = T_6$
3. $P_{intermediate} = P_4 = P_5 = \sqrt{P_3 P_6}$
4. $W_{T_1} = W_{T_2}$

   $W_{3\text{-}4} = W_{5\text{-}6}$

Intercooling:



Effects:

1. $W_{Comp} \downarrow \rightarrow$ Main purpose of intercooling.
2. $W_{Turbine} \rightarrow$ same
3. $W_{net} \uparrow$
4. $Q_{supply} \uparrow$
5. $Q_{rej} \uparrow$
6. $T_{MA} \downarrow\downarrow$
7. $T_{MR} \downarrow$
8. $\eta \downarrow$

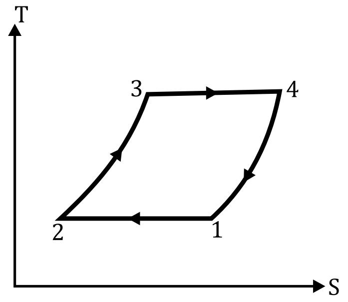
Condition for minimum work input with perfect intercooling:

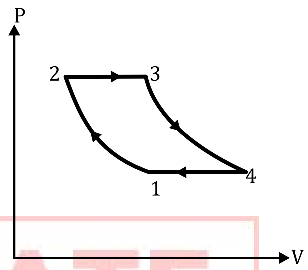
1. $T_1 = T_3$
2. $T_2 = T_4$
3. $P_i = \sqrt{P_H P_L}$
4. $W_{c_1} = W_{c_2}$

   $W_{1\text{-}2} = W_{3\text{-}4}$

Ericsson Cycle:

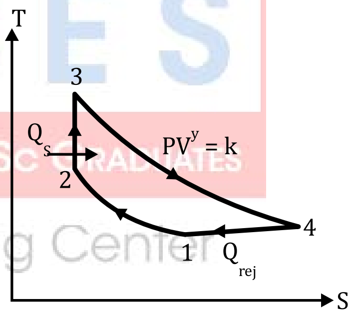
2 constant pressures + 2 constant temp process





Atkinson Cycle:

Also called as constant volume gas turbine.



$$\eta = \frac{(W.D)_{net}}{Q_{supplied}}$$

$$Q_{rej} = mc_p(T_4 - T_1)$$

$$\eta_{Thermal} = 1 - \gamma\left(\frac{r_e - r_k}{r_e^\gamma - r_k^\gamma}\right)$$

$$r_e = \text{Expansion ratio} = \frac{V_4}{V_3}$$

$$r_k = \text{Compression ratio} = \frac{V_1}{V_2}$$

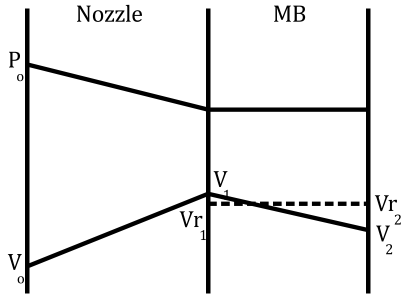
$$W_{net} = Q_s - Q_{rej}$$

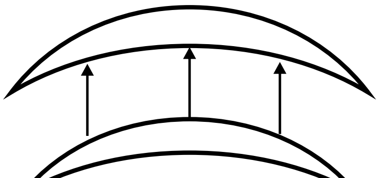
$$Q_s = mC_v(T_3 - T_2)$$

*****

Chapter 3: STEAM TURBINE

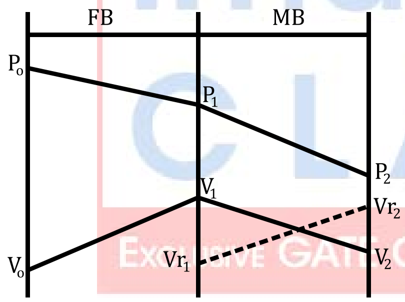
Impulse Turbine (De laval Turbine)

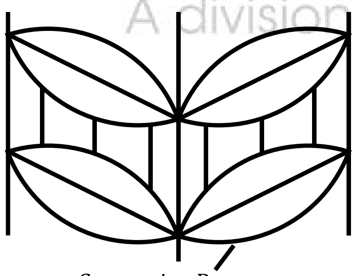




Symmetrical Blade

Reaction Turbine:



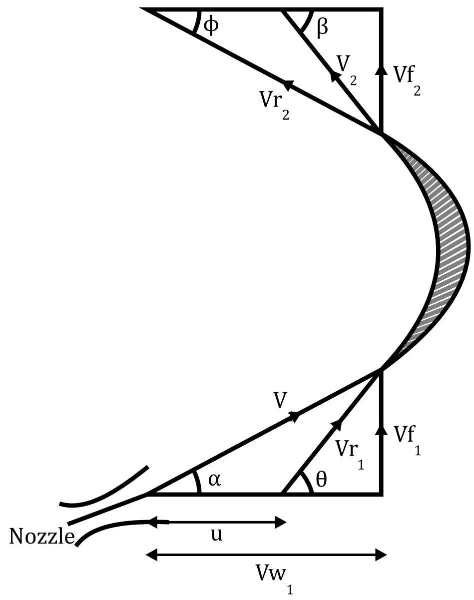


Converging Passage

Note:

All Steam turbines are axial flow machines.

De laval Turbine:



α = Fixed blade outlet angle or nozzle angle

β = Fixed blade inlet angle

$(u_1 = u_2)$

Euler Turbine Equation:

$$\text{Power/Stage} = \dot{m}\left(V_{w_1} + V_{w_2}\right)u$$

$$= \dot{m}\left(\frac{V_1^2 - V_2^2}{2} + \frac{V_{r_2}^2 - V_{r_1}^2}{2}\right)$$

$$\boxed{W_{total} = N \times \text{Power/Stage}}$$

N = No. of stages

$\dot{m} = \rho A\, V_f$

$$A = \frac{\pi}{4}\left(D_t^2 - D_h^2\right) = \pi d_m h_m$$

$$h_m = \text{height of blade} = \frac{D_t - D_h}{2}$$

$$F_t = \dot{m}\left(V_{w_1} + V_{w_2}\right)$$

Energy lost in moving blade due to friction

$$= \frac{\dot{m}}{2}\left(V_{r_2}^2 - V_{r_1}^2\right)$$

$$\text{Speed ratio} = \frac{u}{V_1}$$

$$\text{Flow ratio} = \frac{V_f}{u}$$

$$\eta_{Blade/diagram} = \frac{\dot{m}(V_{w_1} + V_{w_2})u}{\frac{1}{2}\dot{m}V_1^2}$$

Condition for maximum blade efficiency

$$\boxed{\frac{u}{V_1} = \frac{\cos\alpha}{2}}$$

$$\eta_{max} = \frac{(1 + kC)\cos^2\alpha}{2}$$

$$k = \frac{V_{r_2}}{V_{r_1}}$$

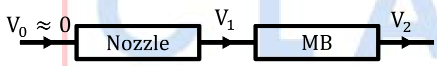
$$C = \frac{\cos\phi}{\cos\theta}$$

Note:

1. For symmetrical blade without friction

   $\eta_{max} = \cos^2\alpha$

2.



$$\eta_{nozzle} = \frac{(\Delta h)_{actual}}{(\Delta h)_{isentropic}}$$

$$\eta_{Blade} = \frac{(V_{w_1} + V_{w_2})u}{V_1^2/2}$$

$$\boxed{\eta_{gross} = \eta_{nozzle} \times \eta_{blade}}$$

Reaction Turbine:

$$\text{Inlet Energy} = \frac{V_1^2}{2} + \frac{Vr_2^2 - Vr_1^2}{2}$$

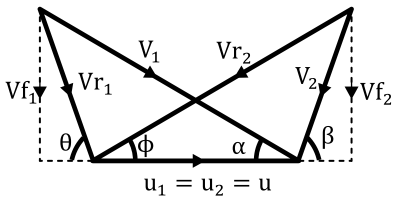
$$\eta_{Blade} = \frac{(V_{w_1} + V_{w_2})u}{\frac{V_1^2}{2} + \frac{V_{r_2}^2 - V_{r_1}^2}{2}}$$

.

50% Reaction Turbine (Parson's Turbine)

$\alpha = \phi, \quad \beta = \theta$

$V_{r_2} = V_1, V_{r_1} = V_2$



For max η

$$\boxed{\frac{u}{V_1} = \cos\alpha}$$

$$(\eta_{blade})_{max} = \frac{2\cos^2\alpha}{1 + \cos^2\alpha}$$

Degree of reaction(DOR)

$$= \frac{(\Delta h)_{MB}}{(\Delta h)_{MB} + (\Delta h)_{FB}}$$

$$DOR = \frac{V_{r_2}^2 - V_{r_1}^2}{2(V_{w_1} + V_{w_2})u}$$

$$(DOR)_{De\ laval\ Turbine} = 0$$

*****

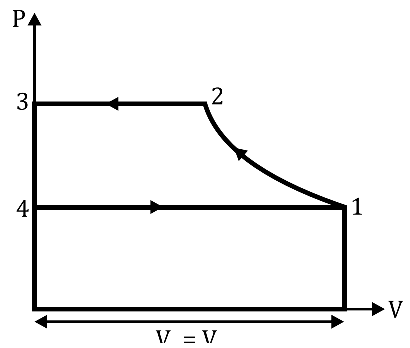
Chapter 4: RECIPROCATING COMPRESSOR

High pressure upto 1000 bar

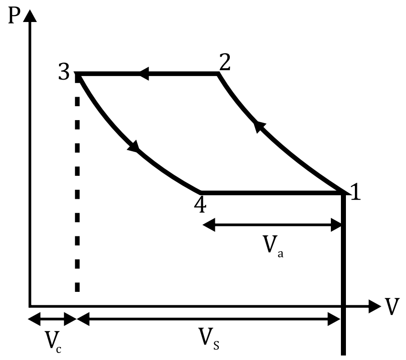
Less discharge 5- 8 m^3/min

Case A:

W_{input} without Clearance



W_{input} with Clearance



$$W_{input} = \frac{n}{n-1}(p_1 v_a)\left(\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right) J$$

/cycle

$v_a = v_1 - v_4 = v_1$ for without clearance

$v_a = v_1 - v_4$ for with clearance

Clearance ratio (C) $= \frac{v_c}{v_s}$

Volumetric Efficiency

$$\eta_{vol} = 1 + C - C\left(\frac{p_H}{p_L}\right)^{1/n}$$

If $\left(\frac{p_H}{p_L}\right)\uparrow \rightarrow \eta_{vol}\downarrow$

If $C\uparrow \Rightarrow \eta_{vol}\downarrow$

Multistage Compressor:

1. Overall pressure ratio = (pressure ratio in each stage)^N
2. Total work input = N ×(Work input in each stage)

   N = No. of stages

*****

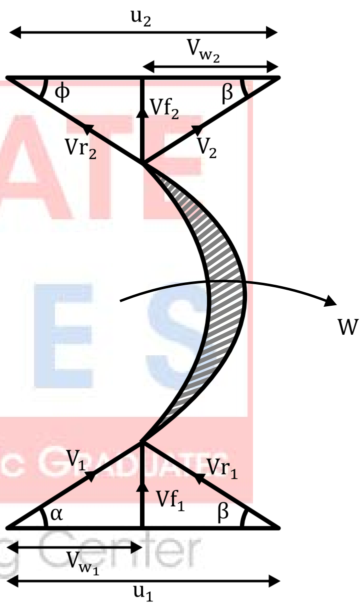
Chapter 5: CENTRIFUGAL COMPRESSOR

$$V_{w_2}u_2 - V_{w_1}u_1 = \underbrace{\frac{V_2^2 - V_1^2}{2}}_{\text{Impulse Effect}} + \underbrace{\frac{u_2^2 - u_1^2}{2}}_{\text{Centrifugal effect}} + \underbrace{\frac{Vr_1^2 - Vr_2^2}{2}}_{\text{Reaction effect}}$$

Euler power $= \dot{m}(V_{w_2}u_2 - V_{w_1}u_1)$

V_{w_1} = Whirl velocity at inlet

V_{w_2} = Whirl velocity at outlet.



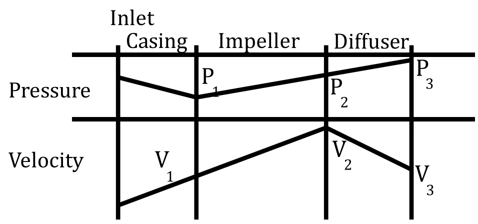
General Compressor

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

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

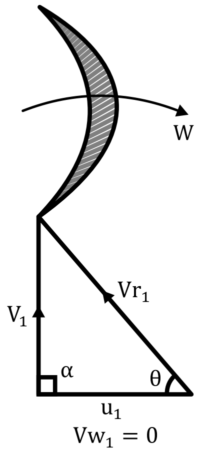
θ and ϕ → Blade angle of inlet and outlet.

For Centrifugal Compressor



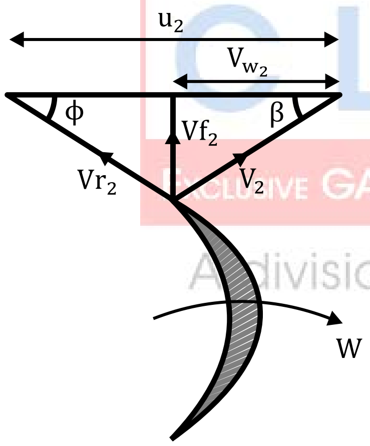
Velocity triangles for centrifugal compressor.

Inlet:

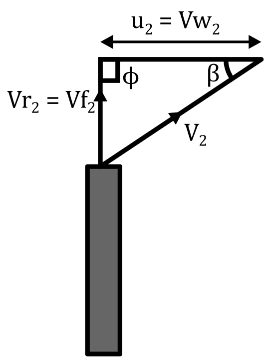


Outlet:

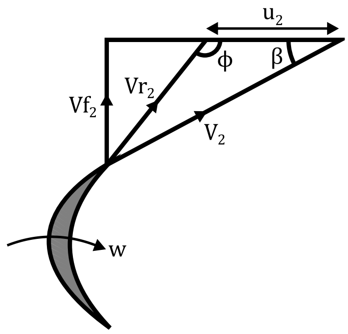
Case 1: Backward curved vane (for maximum efficiency)



Case 2: Radially Outward Vane (For minimum stress)



Case 3: Forward Curved Vane (For higher pressure ratio)



$w_{input} = V_{w_2}u_2 - V_{w_1}u_1$

$V_{w_1} = 0$ for centrifugal compressor

$w_{input} = V_{w_2}u_2$ J/kg

$w_{input} = \dot{m}V_{w_2}u_2$ Watt)

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

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

$\boxed{w_{input} = \sigma\, u_2^2}$ J/kg

Power factor $(\psi) = \dfrac{\text{Actual } w_{input}}{\text{Theoretical } w_{input}}$

> 1

$(w_{input})_{actual} = \psi V_{w_2}u_2$

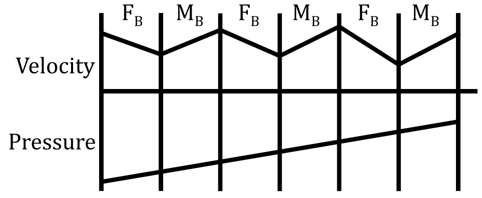
$\boxed{w_{input} = \psi\sigma \cdot u_2^2}$ J/kg

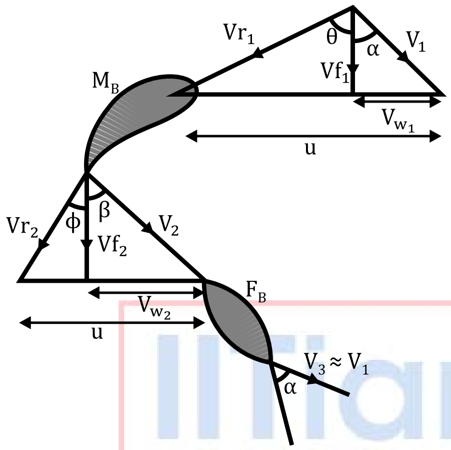
$W.D = h_2 - h_1 = C_p(T_2 - T_1) =$

$V_{w_2}u_2 = \sigma u_2^2 = \psi\sigma u_2^2.$

*****

Chapter 6: AXIAL FLOW COMPRESSOR





$\alpha, \beta \rightarrow$ Flow angle measured from axial direction made with V_f.

Work Input:

$$\frac{W_{in}}{stage} = (V_{w_2} - V_{w_1})u$$

$$= V_f \cdot u(\tan\beta - \tan\alpha)$$

$$W_{Total} = N \times (W_{input})_{single\ stage}$$

*****