KULKARNI ACADEMY

MECHANICAL ENGINEERING

POWER PLANT ENGINEERING

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Gas turbines

Weight/power → 20 kg/kw

Sousedin Aircraft

Max. temp. = 1300°c

η_{th} = 22-27%

pressure ratio - 10 to 15

Advantages of Gas turbine:

[1] Simple Mechanism

[2] compact

[3] Easy balancing

[4] High speeds can be obtained.

Disadvantages:-

[1] As gas turbines are rotary devices, they are subjected to higher temp. continuously and hence costly material is required.

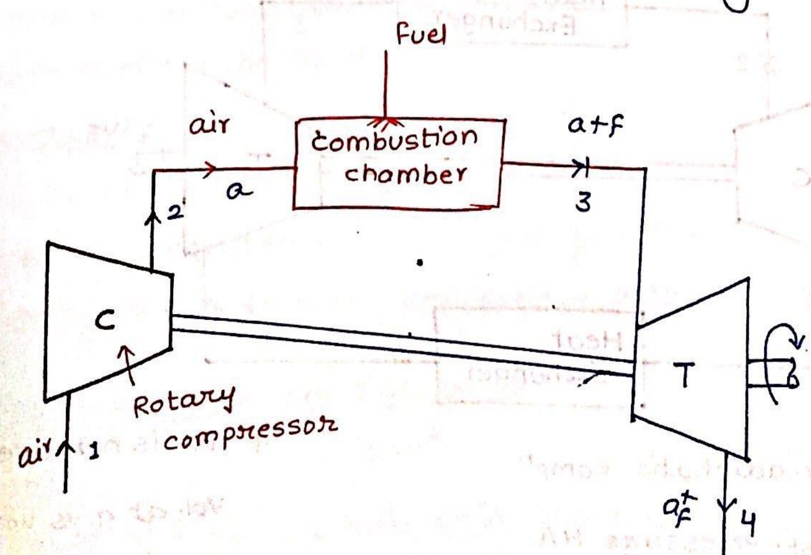
[2] As compressor is used it consumes more works and hence Net work is less.

[3] As speeds are high, reduction gear mechanism must be used.

Gas turbine cycles:-

* Gas turbine cycle works on brayton/Jowle cycle.

[a] open cycle Gas turbine: (internal combustion rotary engine)



1-2- rev. adiabatic compression

2-3- constant. pressure HA

3-4- rev. adiabatic expansion.

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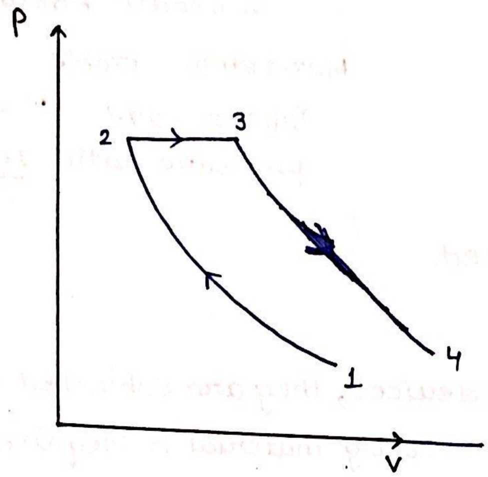
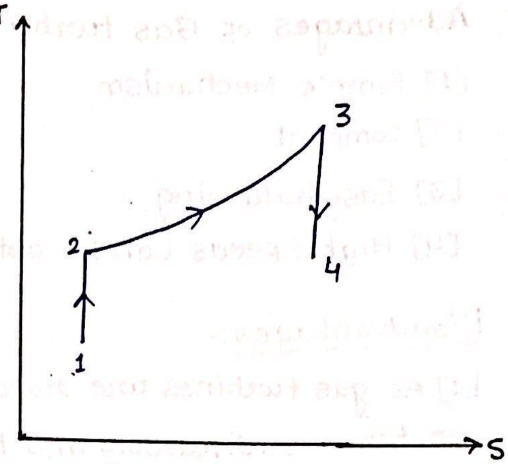
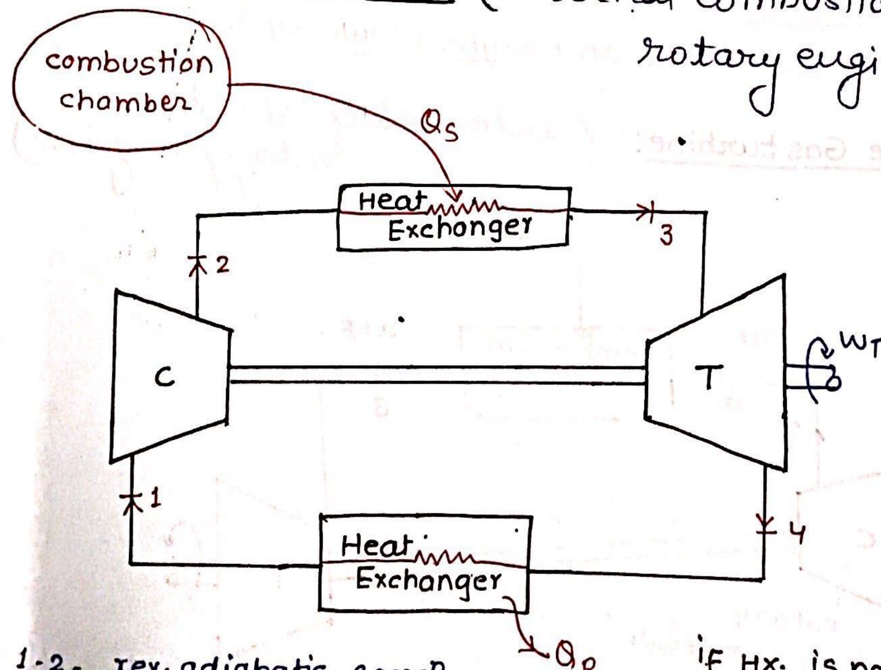




open cycle gas turbine is a mechanical cycle.

✓ Gas turbines are used in power generation, aircraft engines, and jet propulsion system.

[b] <u>closed cycle Gas turbine</u>: (external Combustion rotary engine)



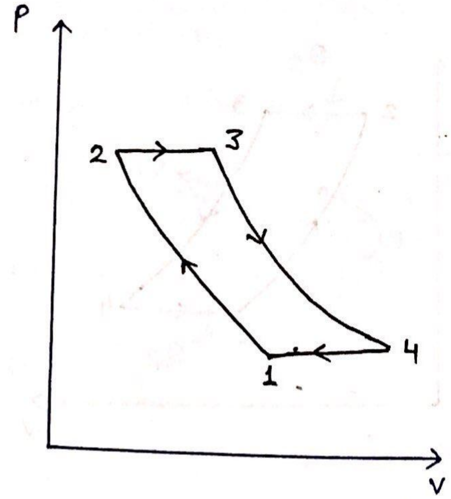
1-2- rev. adiabatic compⁿ

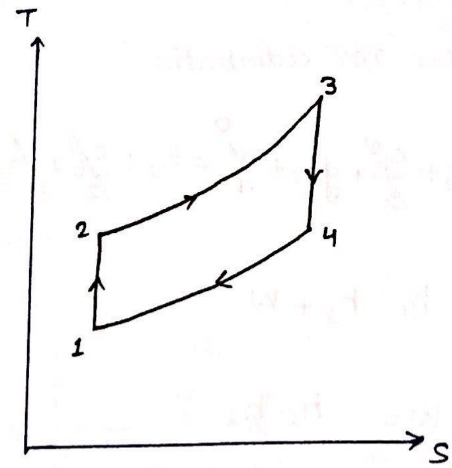
2-3. const. pressure HA

3-4- rev. adiabatic Expansion

4-1- const. pressure HR.

if Hx. is not used. Vol. at 4 is very high so more $W_c = \int v dp$ compressor work is req. so cool it and then enter at 1.





⇒ Closed cycle is a thermodynamic cycle.

⇒ Advantages of closed cycle over open cycle gas turbine:

[1] It is compact.

[2] Any working fluid can be used. in closed cycle gas turbine but in open cycle gas turbine air is required for combustion. Generally in closed cycle gas turbine working fluid with higher γ (monoatomic gases) can be used leading to higher efficiency.

[3] As product of combustion donot enter turbine blade any cheaper fuel can be used.

Disadvantage:

[1] additional heat exchanger is required.

[2] coolant is required in closed cycle gas turbine, where as in open cycle gas turbine atmosphere acts as a sink.

Analysis of a simple gas turbine cycle:

Assumptions:-

[1] The working fluid is treated as an ideal gas.

[2] compression & Expansion are assumed to be rev. adiabatic.

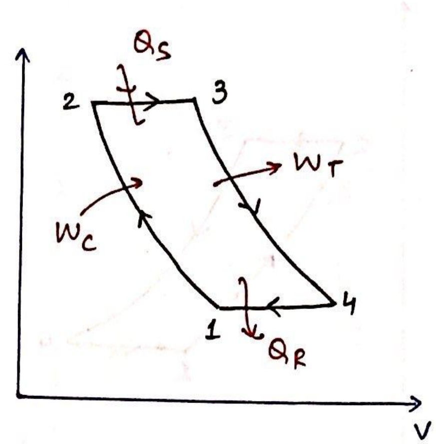
[3] Each device is treated as steady flow device.

[4] K.E. & P.E. changes are Neglected.

[5] C_p & C_v donot change with temperature.

*[6] working fluid is same throughout the cycle. [closed cycle]

1-2 rev. adiabatic



$$h_1 + \frac{c_1^2}{2} + gz_1 + q^0 = h_2 + \frac{c_2^2}{2} + gz_2 + W$$

$$h_1 = h_2 + W$$

$$W = h_1 - h_2$$

$$-W = h_2 - h_1 = W_{comp.}$$

$$\Rightarrow \boxed{W_{comp} = h_2 - h_1 = C_p(T_2 - T_1)}$$

2-3. constant pressure heat addition.

$$h_2 + \frac{c_2^2}{2} + gz_2 + q = h_3 + \frac{c_3^2}{2} + gz_3 + W$$

$$h_2 + q = h_3$$

$$q = h_3 - h_2 = Q_s$$

$$\Rightarrow \boxed{Q_s = (h_3 - h_2) = C_p(T_3 - T_2)}$$

3-4. rev. adiabatic Expansion.

$$h_3 + \frac{c_3^2}{2} + gz_3 + q = h_4 + \frac{c_4^2}{2} + gz_4 + W$$

$$h_3 = h_4 + W$$

$$W = h_3 - h_4$$

$$\Rightarrow \boxed{W_T = h_3 - h_4 = C_p(T_3 - T_4)}$$

4-1. constant pressure Heat Rejection.

$$h_4 + \frac{c_4^2}{2} + gz_4 + q = h_1 + \frac{c_1^2}{2} + gz_1 + W$$

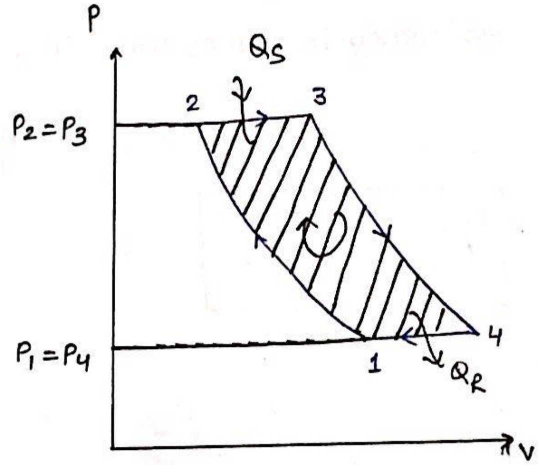
$$h_4 + q = h_1$$

$q = h_1 - h_4$

$\Rightarrow q = -(h_4 - h_1)$

$$\Rightarrow \boxed{Q_R = h_4 - h_1 = C_p(T_4 - T_1)}$$

Efficiency of simple gas turbine cycle:



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

$\Rightarrow \frac{Q_s - Q_R}{Q_s} \Rightarrow 1 - \frac{Q_R}{Q_s}$

$\eta_{th} = 1 - \frac{C_p(T_4 - T_1)}{C_p(T_3 - T_2)}$

$\Rightarrow 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$

$r_p =$ pressure ratio $= \frac{P_2}{P_1}$.

1-2. rev. adiabatic comprn

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

3-4. rev. adiabatic expansion.

$P_2 = P_3$

$P_1 = P_4$

$\frac{T_3}{T_4} = (P_3/P_4)^{\frac{\gamma-1}{\gamma}} = (P_2/P_1)^{\frac{\gamma-1}{\gamma}} = (r_p)^{\gamma-1/\gamma}$

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

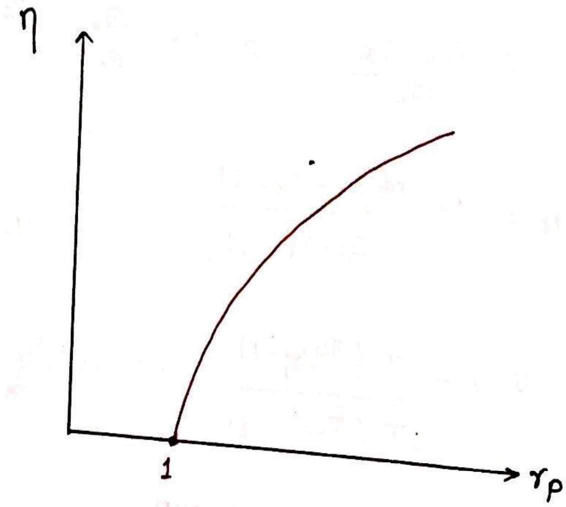
$= \frac{T_4}{T} = \frac{T_3}{T_2}$

$\eta_{th} = 1 - \frac{T_1}{T_2} \Rightarrow \boxed{\eta_{th} = 1 - \frac{1}{(r_p)^{\gamma-1/\gamma}}}$

⇒ Efficiency of a simple gas turbine cycle depends on pressure ratio (r_p)

With increase in pressure ratio the efficiency increases because greater the pressure ratio, greater is the compression and more is the scope for expansion and hence for a given input efficiency increases with increase in pressure ratio.

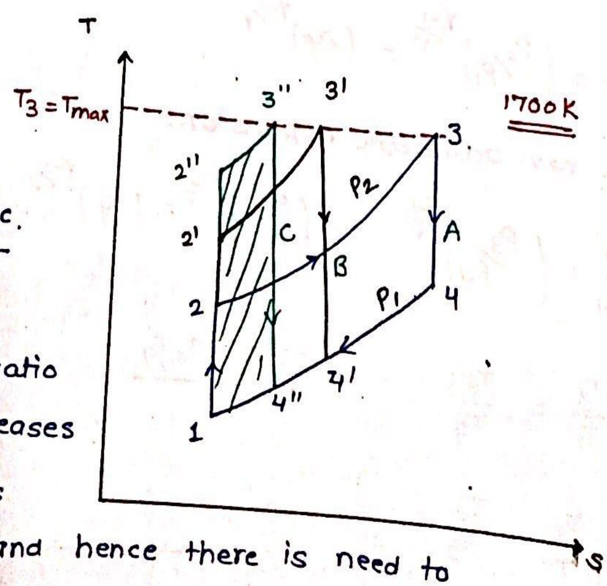
$$\eta = 1 - \frac{1}{(r_p)^{\gamma-1/\gamma}}$$



$(r_p)_A < (r_p)_B < (r_p)_C$

$\eta_A < \eta_B < \eta_C$ But

$(W_{net})_A > (W_{net})_B > (W_{net})_C$.



With increase in pressure ratio though the efficiency increases at higher pressure ratio's the network decreases and hence there is need to calculate a pressure ratio where the network output is maximum, this pressure ratio at which the network is maximum is known as optimum pressure ratio.

$W_{net} = W_T - W_c$

$\Rightarrow C_p(T_3 - T_4) - C_p(T_2 - T_1)$

$\Rightarrow C_p(T_3 - T_4 - T_2 + T_1)$

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

T_1 & T_3 are Fixed.

$W_{net} = C_p\left[T_3 - \frac{T_1 T_3}{T_2} - T_2 + T_1\right]$ for max. net work $\frac{dW_{net}}{dT_2} = 0$

$$\frac{dW_{net}}{dT_2} = C_p\left[0 + \frac{T_1 T_3}{T_2^2} - 1 + 0\right] = 0$$

$T_1 T_3 = T_2^2$

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

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

$W_{net} = C_p\left[T_3 + T_1 - 2\sqrt{T_1 T_3}\right] = W_{max}.$

$\boxed{W_{max} = C_p\left[\sqrt{T_1} - \sqrt{T_3}\right]^2}$ or $C_p\left[\sqrt{T_3} - \sqrt{T_1}\right]^2$

Optimum pressure ratio-

$r_p = \frac{P_2}{P_1}$

1-2. rev. adiabatic ~~pr~~ compression.

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

$r_p = \left(\frac{T_2}{T_1}\right)^{\gamma/\gamma-1} \Rightarrow T_2 = \sqrt{T_1 T_3}$

$$r_p = \left(\sqrt{\frac{T_3}{T_1}}\right)^{\gamma/\gamma-1}$$