UNIT I - GAS POWER CYCLES

1. What is a thermodynamic cycle?

Thermodynamic cycle is defined as the series of processes performed on the system, so that the system attains its original state.

2. What are the assumptions made for air standard cycle analysis?

(i)The working medium is a perfect gas throught i.e., It follows the law **pv = mRT**

(ii) The working medium does not undergo any chemical change throughout The Cycle.

(iii) The compression and expansion processes are reversible adiabatic i.e., There is no loss or gain of entropy.

(iv) The operation of the engine is frictionless.

3. Mention the various processes of dual cycle.

(i) Isentropic compression.

(ii) Constant pressure heat supplied.

(iii) Isentropic expansion, and

(iv) Constant pressure heat rejection.

4. Define air standard cycle efficiency.

Air standard efficiency is defined as the ratio of work done by the cycle to heat supplied to the cycle.

5. Define mean effective pressure as applied to gas power cycles.

Mean effective pressure is defined as the constant pressure acting on the piston during the working stroking. It is also defined as the ratio of work done to the stroke volume or piston displacement volume.

6. Define the following terms (i) Compression ratio (ii) Cut off ratio and (iii) Expansion ratio?

(i) Compression ratio is defined as the ratio between total cylinder volumes to clearance volume.

(ii) Cut off ratio is defined as the ratio of volume after the heat addition to volume before the heat addition.
(iii) Expansion ratio is the ratio of volume after the expansion to the volume before expansion.

7. Which cycle is more efficient with respect to the same compression ratio?
For the same compression ratio, Otto cycle is more efficient than diesel cycle.

8. For the same compression ratio and heat supplied, state the order of decreasing air standard efficiency of Otto, diesel and dual cycle.

$$\eta_{\text{Otto}} > \eta_{\text{Dual}} > \eta_{\text{Diesel}}$$

9. Name the factors that affect air standard efficiency of Diesel cycle.
Compression ratio and cut-off ratio.

10. What is the effect cut-off ratio on the efficiency of diesel cycle when the compression ratio is kept constant?
When cut-off ratio of diesel cycle increases, the efficiency of cycle is decreased when compression ratio is kept constant and vice versa.

11. Write any four major differences between Otto and diesel cycle.

Sl.No.	**Otto cycle**	**Diesel cycle**
1	It consists of two isentropic and two constant volume processes.	It consists of two isentropic, one constant volume and one constant pressure processes.
2	Heat addition takes place of constant volume.	Heat addition takes place of constant pressure.
3	Compression ratio is equal to expansion ratio.	Compression ratio is greater than expansion ratio.

4	Efficiency is more than diesel cycle for the same compression ratio and heat input.	Efficiency is less.

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THERMAL ENGINEERING QUESTION BANK FOR 16MARKS

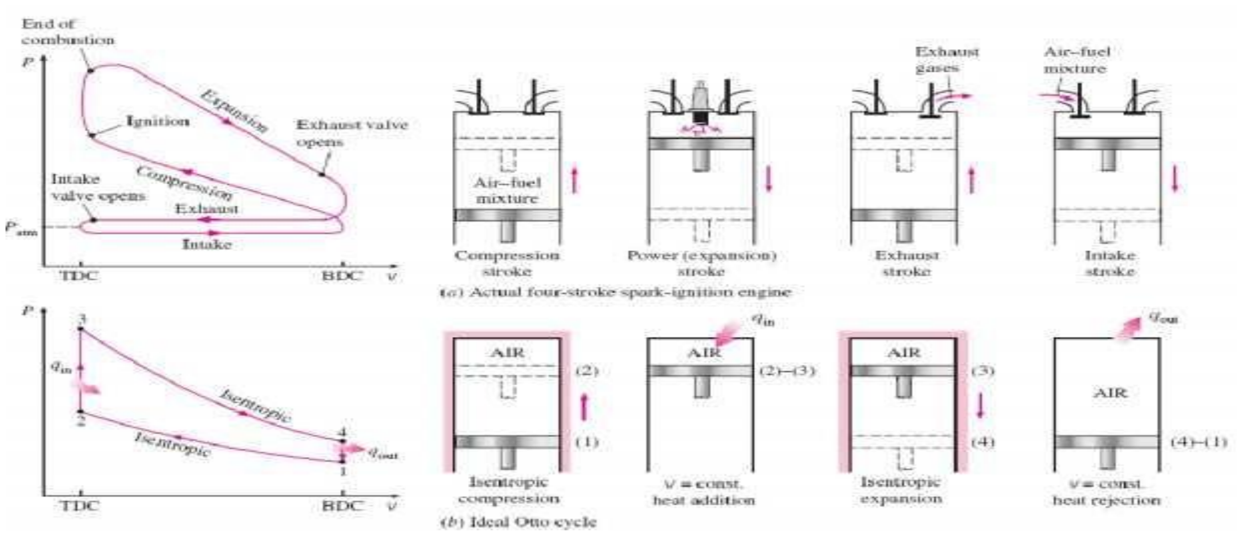
Q.No	UNIT I	In Notes / Answer Key
1	Define Otto Cycle with Derivation for Air Standard Cycle & Mean Effective Pressure	ANSWER KEY
2	Define Diesel Cycle with Derivation for Air Standard Cycle & Mean Effective Pressure	ANSWER KEY
3	Define Dual Cycle with Derivation for Air Standard Cycle & Mean Effective Pressure	ANSWER KEY
4	Define Brayton Cycle with Derivation for Air Standard Cycle & Mean Effective Pressure	ANSWER KEY
5	In an Otto cycle air at 1bar and 290K is compressed isentropic ally until the pressure is 15bar The heat is added at constant volume until the pressure rises to 40bar. Calculate the air standard efficiency and mean effective pressure for the cycle. Take Cv=0.717 KJ/Kg K and R_{univ} = 8.314KJ/Kg K	ANSWER KEY
6	Estimate the lose in air standard efficiency for the diesel engine for the compression ratio 14 and the cutoff changes from 6% to 13% of the stroke	ANSWER KEY
7	The compression ratio of an air standard dual cycle is 12 and the maximum pressure on the cycle is limited to 70bar. The pressure and temperature of the cycle at the beginning of compression process are 1bar and 300K. Calculate the thermal efficiency and Mean Effective Pressure. Assume cylinder bore = 250mm, Stroke length = 300mm, Cp=1.005KJ/Kg K, Cv=0.718KJ/Kg K.	ANSWER KEY
8	A diesel engine operating an air standard diesel cycle has 20cm bore and 30cmstroke.the clearance volume is 420cm^3.if the fuel is injected at 5% of the stroke,find the air standard efficiency	ANSWER KEY
9	Air enters the compressor of a gas turbine at 100 KPa and 25 o C. For a pressure ratio of 5 and a maximum temperature of 850°C. Determine the thermal efficiency using the Brayton cycle	NOTES

UNIT-I-GAS POWER CYCLE-ANSWER KEY FOR 16MARK

Q.No:1 OTTO CYCLE

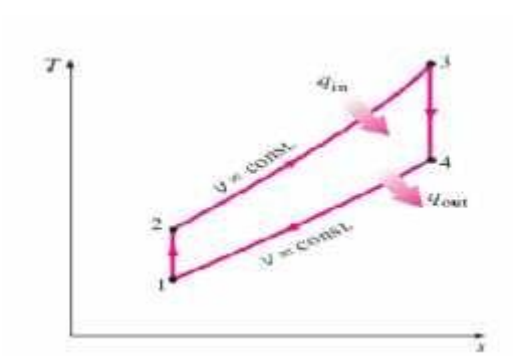
An Otto cycle is an idealized thermodynamic cycle that describes the functioning of a typical spark ignition piston engine. It is the thermodynamic cycle most commonly found in automobile engines. The idealized diagrams of a four-stroke Otto cycle Both diagrams

- Petrol and gas engines are operated on this cycle
- Two reversible isentropic or adiabatic processes
- Two constant volume process



PROCESS OF OTTO CYCLE

- ***Ideal*** Otto Cycle
- Four internally reversible processes
  - 1-2 Isentropic compression
  - 2-3 Constant-volume heat addition
  - 3-4 Isentropic expansion
  - 4-1 Constant-volume heat rejection



Thermal efficiency of ideal Otto cycle:

Since $V_2 = V_3$ and $V_4 = V_1$

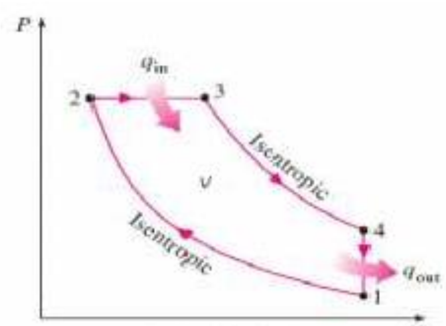
$$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$$

Q.No.2 **DIESEL CYCLE**

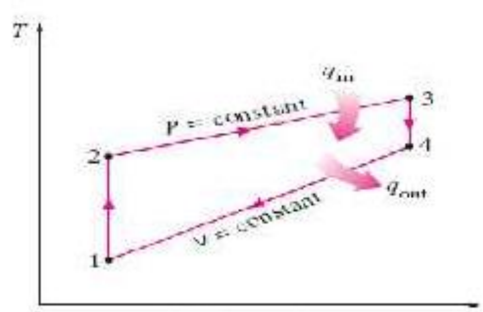
The **Diesel cycle** is a combustion process of a reciprocating internal combustion engine. In it, fuel is ignited by heat generated during the compression of air in the combustion chamber, into which fuel is then injected.

It is assumed to have constant pressure during the initial part of the "combustion" phase

The Diesel engine is a heat engine: it converts heat into work. During the bottom isentropic processes (blue), energy is transferred into the system in the form of work W_{in}, but by definition (isentropic) no energy is transferred into or out of the system in the form of heat. During the constant pressure (red, isobaric) process, energy enters the system as heat Q_{in}. During the top isentropic processes (yellow), energy is transferred out of the system in the form of W_{out}, but by definition (isentropic) no energy is transferred into or out of the system in the form of heat. During the constant volume (green,isochoric) process, some of energy flows out of the system as heat through the right depressurizing process Q_{out}. The work that leaves the system is equal to the work that enters the system plus the difference between the heat added to the system and the heat that leaves the system; in other words, net gain of work is equal to the difference between the heat added to the system and the heat that leaves the system.



(a) P- v diagram



(b) T-s diagram

PROCESSES OF DIESEL CYCLE:

- 1-2 Isentropic compression
- 2-3 Constant-Pressure heat addition
- 3-4 Isentropic expansion
- 4-1 Constant-volume heat rejection

For ideal diesel cycle

$$\eta_{th,Diesel} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{k(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{kT_2(T_3/T_2 - 1)}$$

Cut off ratio r_c

$$r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$$

Efficiency becomes

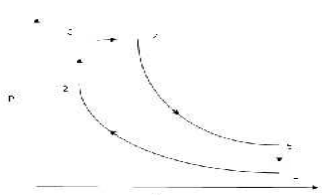
$$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$$

Q.No 3 **DUAL CYCLE**

The dual combustion cycle (also known as the limited pressure or mixed cycle) is a thermal cycle that is a combination of the Otto cycle and the Diesel cycle. Heat is added partly at constant volume and partly at constant pressure, the advantage of which is that more time is available for the fuel to completely combust. Because of lagging characteristics of fuel this cycle is invariably used for diesel and hot spot ignition engines.

- Heat addition takes place at constant volume and constant pressure process .
- Combination of Otto and Diesel cycle.
- Mixed cycle or limited pressure cycle

PROCESS OF DUAL CYCLE



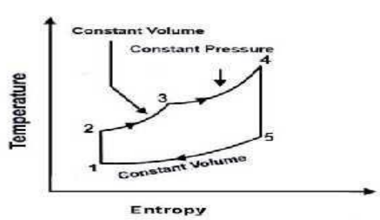


Fig 1.5 T-S Diagram

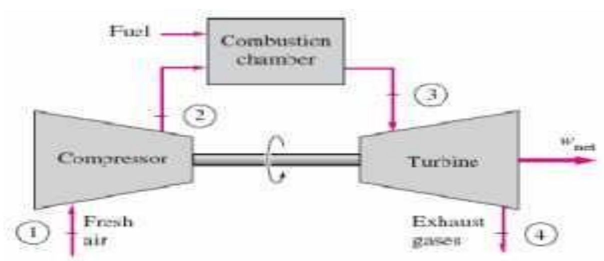
- Isentropic compression
- Constant-*volume* heat rejection
- Constant-*pressure* heat addition
- Isentropic expansion
- Constant-*volume* heat rejection

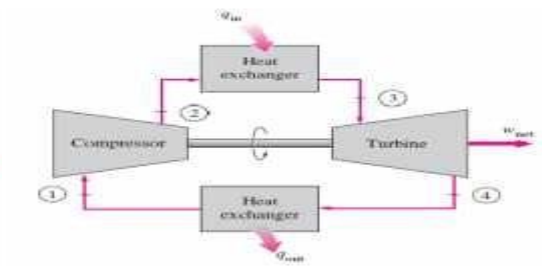
The cycle is the equivalent air cycle for reciprocating high speed compression ignition engines. The P-V and T-s diagrams are shown in Figs.6 and 7. In the cycle, compression and expansion processes are isentropic; heat addition is partly at constant volume and partly at constant pressure while heat rejection is at constant volume as in the case of the Otto and Diesel cycles.

Q.No.4 **BRAYTON CYCLE**

The Brayton cycle is a thermodynamic cycle that describes the workings of a constant pressure heat engine. Gas turbine engines and air breathing jet engines use the Brayton Cycle. Although the Brayton cycle is usually run as an open system (and indeed must be run as such if internal combustion is used), it is conventionally assumed for the purposes of thermodynamic analysis that the exhaust gases are reused in the intake, enabling analysis as a closed system. The Ericsson cycle is similar to the Brayton cycle but uses external heat and incorporates the use of a regenerator.

- Gas turbine cycle
- Open vs closed system model





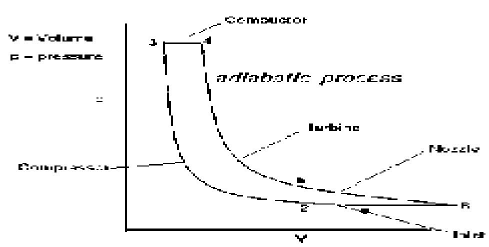


Fig 1.7 PV diagram Brayton Cycle

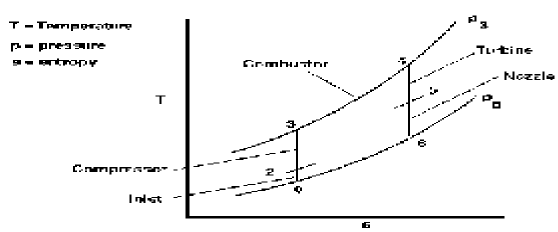


Fig 1.8 TS Diagram

With cold-air-standard assumptions

$$\eta_{\text{th,Brayton}} = \frac{w_{\text{net}}}{q_{\text{in}}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

- Since processes 1-2 and 3-4 are isentropic, $P_2 = P_3$ and $P_4 =$ P

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = \left(\frac{P_3}{P_4}\right)^{(k-1)/k} = \frac{T_3}{T_4}$$

Pressure ratio is

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

Efficiency of Brayton cycle is

$$\eta_{\text{th,Brayton}} = 1 - \frac{1}{r_p^{(k-1)/k}}$$

Q.No 5 **Given Data:**

Pressure (P1) = 1bar = 100KN/m^2

Temperature(T1) = 290K

Pressure (P2) = 15bar = 1500KN/m^2

Pressure (P3) = 40bar = 4000KN/m^2 Cv

= 0.717 KJ/KgK
R_{univ} = 8.314 KJ/Kg K

To Find:

i) Air Standard Efficiency (η_{otto})

ii) Mean Effective Pressure (P_m)

Solution:

Here it is given R_{univ} = 8.314 KJ/Kg K
We know that ,
$\gamma = Cp/Cv$ (Here Cp is unknown)
$R_{univ} = M \times R$

Since For air (O_2) molecular weight (M) = 28.97
8.314=28.97 $\times$ R
∴ R = 0.2869

(Since gas constant R = Cp-Cv)

0.2869 = Cp – 0.717
∴ Cp= 1.0039 KJ/Kg K

$$\gamma = \frac{Cp}{Cv} = \frac{1.0039}{0.717} = 1.4$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

$$\eta = 1 - \frac{1}{r^{1.4-1}}$$

Here 'r' is unknown.

We know that,

$$r = \left(\frac{V1}{V2}\right) = \left(\frac{P2}{P1}\right)^{\frac{1}{\gamma}}$$

$$= \left(\frac{1500}{100}\right)^{\frac{1}{1.4}}$$

r= 6.919

$$\eta otto = 1 - \frac{1}{6.919^{0.4}}$$

∴ ηotto = 3.87%

Mean Effective Pressure (Pm)= $P_1\, r \frac{[(K-1)(r^{\gamma-1}-1)]}{[(\gamma-1)(r-1)]}$

$$Pm = \frac{(100)(6.919)[(2.67-1)(6.919^{0.4}-1)]}{[(1.4-1)(6.919-1)]}$$

Pm = 569.92 KN/m²

Q.No: 6 **Given Data**

Case (i)	Case (ii)
Compression ratio (r) = 14	compression ratio (r) =14
ρ = 6% Vs	ρ = 13%Vs

To Find

Lose in air standard efficiency

Solution

Compression ratio (r) = $r = \frac{V1}{V2} = \frac{Vc+Vs}{Vc}$

$$14 = 1 + \frac{Vs}{Vc}$$

$$\frac{Vc}{Vs} = 13$$

Case (i):

Cutoff ratio (ρ) =V3/V2

$$\frac{}{V2} = \frac{Vc + 6\%Vs}{Vc}$$

$$= 1 + \frac{6\%Vs}{Vc}$$

$$\rho = \frac{V3}{V2} = 1 + (0.06)(13)$$

$$\rho = 1.78$$

We know that,

$$\eta_{diesel} = 1 - \frac{1}{\gamma \times r^{\gamma - 1}}\left[\frac{\rho^{\gamma} - 1}{\rho - 1}\right]$$

$$= 1 - \left(\frac{1}{(1.4)(14)^{1.4-1}}\right)\frac{[1.78^{1.4} - 1]}{[1.78 - 1]}$$

$$= 1 - (0.2485)(1.5919)$$

$$= 0.6043 \text{x} 100\%$$

$$\eta_{diesel} = 60.43\%$$

<u>case (ii):</u>

$$\text{cutoff ratio } (\rho) = \frac{V3}{V2} = \frac{Vc + 13\%Vs}{Vc}$$

$$= 1 + (0.13)\ (13)$$

$$\rho = 2.69$$

$$\eta_{diesel} = 1 - \frac{1}{\gamma \times r^{\gamma - 1}}\left[\frac{\rho^{\gamma} - 1}{\rho - 1}\right]$$

$$= 1 - \left(\frac{1}{(1.4)(14)^{1.4-1}}\right)\frac{[2.69^{1.4} - 1]}{[2.69 - 1]}$$

$$= 1 - (0.24855)\ (1.7729)$$

$$= 0.5593 \times 100\%$$

$$= 55.93\%$$

Lose in air standard efficiency = $(\eta_{diesel\ CASE(i)}) - (\eta_{diesel\ CASE(i)})$

$$= 0.6043 - 0.5593$$

$= 0.0449$

$= 4.49\%$

Q.No: 7 **Given data:**

Assume $Qs_1 = Qs_2$
Compression ratio (r) = 12
Maximum pressure $(P_3) = (P_4) = 7000\ KN/m^2$
Temperature $(T_1) = 300K$
Diameter (d) = 0.25m
Stroke length (l) = 0.3m

To find:

Dual cycle efficiency (η_{dual})
Mean Effective Pressure (P_m)

Solution:

By Process 1-2:

$$\frac{T2}{T1} = \left[\frac{V2}{V1}\right]^{\gamma-1}$$

$$= [r]^{\gamma-1}$$

$$T2 = 300[12]^{1.4-1}$$

$$T_2 = 810.58K$$

$$\frac{P2}{P1} = \left[\frac{V1}{V2}\right]^{\gamma}$$

$$P2 = [12]^{1.4} \times 100$$

$$P_2 = 3242.3KN/m^2$$

By process 2-3:
Assuming $Qs_1 = Qs_2$
By process 4-5:
We know that,

$$P3 \quad T3$$

$$\frac{T2}{P2} = \frac{T3}{T2}$$

$$T3 = \left[\frac{7000}{3242.3}\right] 810.58$$

T_3 = 1750K

$$= \left[\frac{r}{\rho}\right]^{1.4-1}$$

$$= \frac{V4}{V3} = \frac{T4}{T3} = \frac{2421.1}{1750}$$

$$\frac{T4}{T5} = \left[\frac{12}{1.38}\right]^{0.4} 15$$

$$T5 = \frac{}{\left(\frac{12}{1.38}\right)^{0.4}}$$

T5 = 1019.3K

Heat supplied $Q_s = 2 \times m\, C_v \times [T3 - T2]$

$$= 2 \times 1 \times 0.718 \times [1750 - 810.58]$$

Q_s = 1349KJ/Kg

Heat rejected $Q_r = m\, C_v\, [T5 - T1]$

Q_r

= 516.45 KJ/Kg

$$\eta_{dual} = \frac{Q_s - Q_r}{Q_i} = \frac{832.55}{1349} \times 100$$

η_{dual} = 61.72%

Stroke volume $(V_s) = \frac{\pi}{4} \times d^2 \times l$

$$= \frac{\pi}{4} \times 0.25^2 \times 0.3$$

$V_s = 0.0147 m^3$

Mean Effective Pressure (P_m) $= W/V_s$

= 832.58/0.0147

$P_m = 56535\ KN/m^2$

Q.No:8 **Given Data:-**

Bore diameter (d) =20cm=0.2mk

Stroke, (l) =30cm=0.3m

Clearance volume, (v_2) =420cm^3=420/100^3= 4.2×10^{-4}m^3

To Find:-

Air standard efficiency,(d_{iesel})

Solution:-

Compression ratio, $r = v_1/v_2$

We know that, $= (v_c+v_s)/v_c$

Stroke volume, v_s=area*length

$=\left(\frac{\pi}{4}\right) d^2 \times l$

$\left(\frac{\pi}{4}\right)(0.2^2)\times 0.3$

$V_s = 9.4 \times 10^{-3}\ m^3$

Therefore,

Compression ratio, $(r) = \frac{4.2\times10^{-4} + 9.42\times10^{-3}}{4.2\times10^{-4}}$

$r = 23.42$

Cut off ratio, $\rho = v_3 / v_2$

$= (v_c+5\%\ v_s) / v_c$

$= 1 + \frac{(0.05\times9.42\times10^{-3})}{4.2\times10^{-4}}$

$\rho = 2.12$

We know the equation,

$$\eta_{diesel} = 1 - \left(\frac{1}{\gamma(r)^{\gamma-1}}\right) \times \left(\frac{\rho^{\gamma}-1}{\rho-1}\right)$$

$$-1 - \frac{1}{1.4\times23.42^{1.4-1}}\left(\frac{(2.12^{1.4}-1)}{2.12-1}\right)$$

$$= 1 - (0.20229)(1.6636)$$

$$= 0.6634 \times 100$$

$$\eta_{diesel} = 66.34\%$$