Engine Emission & Controls

The emissions are

- CO_2
- CO
- Unburnt HC
- Oxides of Nitrogen (NO_x)

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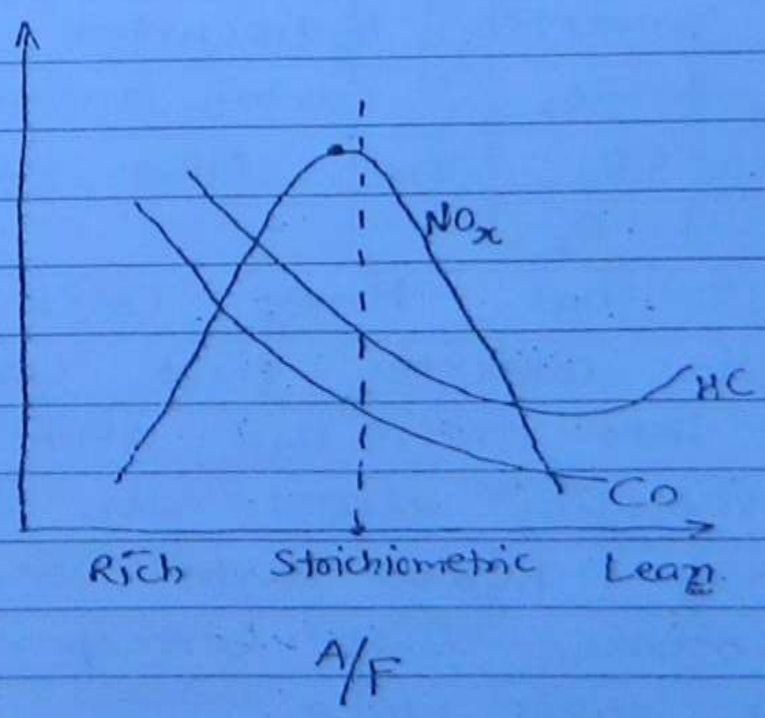
Of these Carbon mono oxide, hydrocarbons & oxides of Nitrogens are main pallutants.

Oxide of N_2 are formed when the temp.s are very-very high and when there is sufficient availability of oxygen.



Emission Control :-

Change in engine design so as to keep lower compression ratios.

slightly leaner mixture must be provided.

(120)

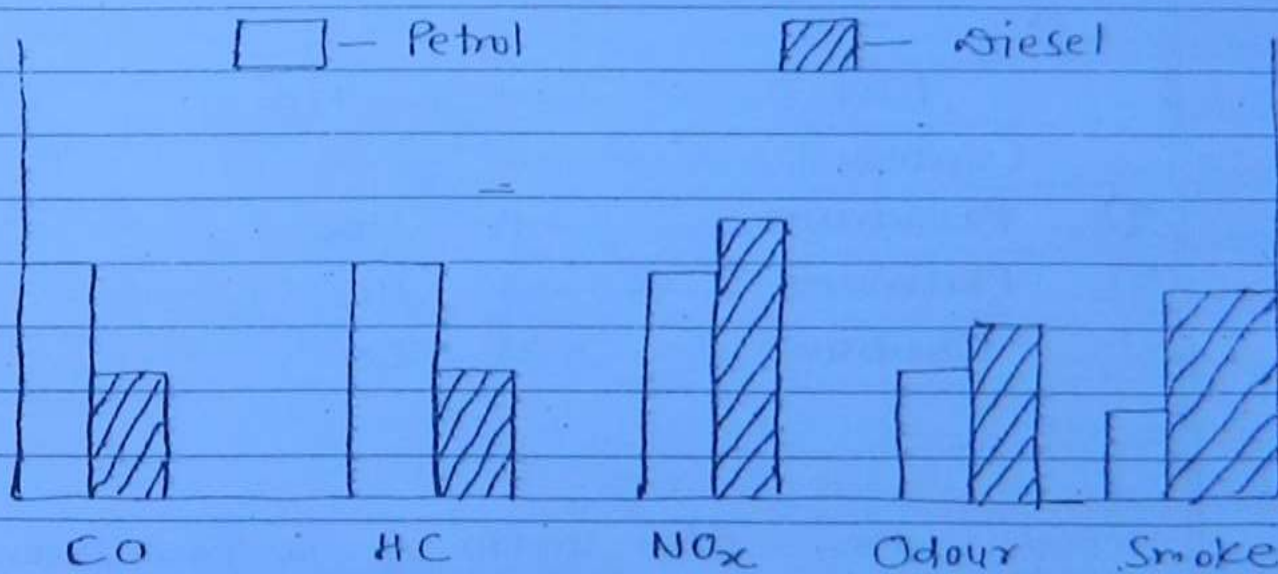
An addition of after burner to the exhaust can completely burn partially burnt Hydro Carbons in exhaust gases.

Catalytic Converter consists of Platinum, Paladium & Rhodium and it converts hydroCarbon into H_2O & CO_2, Carbon mono oxide into CO_2 and NO_x into N_2 & O_2.

It has Honey Comb Structure. Catalytic converter first converts NO_x into N_2 & O_2 and then by supplying excess air conversion of Hydro Carbon and Carbon monooxide into corresponding oxides takes place.

Drawbacks of Catalytic Converter :- (121)

* The exhaust temp. are more when catalytic converter is fitted.
* If lead is used in fuel this lead attacks the converter and hence decreases conversion efficiency.
* If sulphur is present in fuel Catalytic converter converts sulphur into oxides of sulphur And this may result in acid rain.



Diesel engines if properly maintain have very little CO in their exhaust And a small amount of smoke. while petrol engine exhaust significant amount of CO and unburnt HC. So diesel engine is cleaner as Compare to petrol engine and polluts less.

However this fact is not generally noted because a small increase in smoke becomes highly visible. while CO and unburnt HC can not be noticed so easily.

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match the following

List-I (Catalyst)		List-II
A) Palladium	1)	NO_x
B) Platinum	2)	HC
C) Rhodium	3)	CO

Find the A/F ratio of a four stroke single cylinder engine with fuel consumption time for 10 cc is 20.4 sec. and air consumption time for 0.1 m^3 is 16.3 sec. Assume density of air as 1.175 Kg/m^3 and specific gravity of fuel 0.7

Soln:

$$V_f = 10 \text{ cc} / 20.4 \text{ sec.}$$

$$V_a = 0.1 \text{ m}^3 / 16.3 \text{ sec.}$$

(123)

$$\rho_a = m_a / V_a$$

$$m_a = \rho_a V_a$$

$$= 1.175 \frac{\text{kg}}{\text{m}^3} \times \frac{0.1}{16.3} \frac{\text{m}^3}{\text{sec}}$$

$$m_a = 7.2 \times 10^{-3} \text{ kg/s}$$

$$\rho_f = \frac{m_f}{V_f}$$

$$m_f = \rho_f \times V_f$$

$$= \frac{700 \times 10 \times 10^{-6}}{20.4}$$

$$m_f = 0.34 \times 10^{-3}$$

$$\therefore \frac{A}{F} = \frac{m_a}{m_f}$$

$$= \frac{7.2 \times 10^{-3}}{0.34 \times 10^{-3}}$$

$$\frac{A}{F} = 21$$ [illegible]

Page

(3) An 8-cylinder, Four stroke engine of 9 cm. Bore and 8 cm stroke with a Compression ratio of 7 is tested at 4500 rpm on a dynamometer which has 54 cm. radius. During a 10 min. test the dynamometer scale beam reading was 42 kg and the engine consume 4.4 kg of fuel having a calorific value of 44000 KJ/kg. Air at 27°C and 1 bar was supplied to carburetor at the rate of 6 kg/min. Find (124)

i. Brake power
ii. Brake sp. fuel consumption
iii. Brake sp. Air consumption
iv. Brake thermal effn.
v. Volumetric effn. &
vi. A/F ratio

Soln:-

4-stroke

$K = 8$

$D = 9\ cm$

$L = 8\ cm$

$r = 7$

$N = 4500\ rpm$

Dyna. radius = 54 cm

$t = 10\ min$

$m = 42$ Kg

$m_f = 4.4$ Kg $\qquad m_f = \frac{4.4}{10}$ Kg/sec

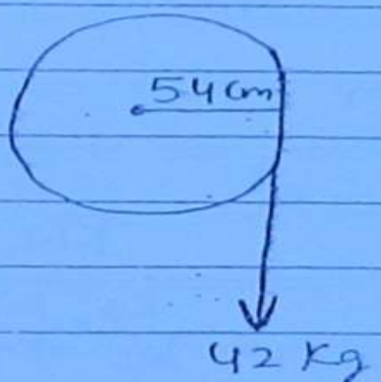
$CV = 44000$ KJ/Kg

$T_1 = 300K$

$P_1 = 1$ bar

$m_a = 6$ Kg/min.

(125)



$T = F \times r$

$= 42 \times 9.81 \times 0.54$

$= 222.49$

$F = 42 \times 9.81$

$$BP = \frac{2\pi NT}{60}$$

$$= \frac{2\pi \times 4500 \times 222.49}{60}$$

$$= 104.8 \times 10^3 \text{ W}$$

or

$BP = 104.8$ KW

BSFC

$$BSFC = \frac{m_f}{B.P.}$$

m_f in Kg/hr.

$$m_f = \frac{4.4 \times 60}{10}$$

$$= \frac{4.4 \times 60}{104.8 \times 10} = 0.044$$

$= 0.251$ Kg/KWhr

(iii)

$$BSAC = \frac{m_a}{B.P.}$$

$$= \frac{6 \times 60}{104.8} \quad (126)$$

$$= 0.0572 \times 60$$

$$BSAC = 3.435 \ kg/kWhr.$$

(iv) Brake Thermal eff^n.

$$\eta_{bth} = \frac{B.P.}{m_f \times C.V.} \qquad \frac{kW}{\frac{kg}{sec} \times \frac{kJ}{kg}}$$

$$= \frac{104.8 \ kW}{\frac{4.4 \ kg}{10 \times 60 \ sec} \times 44000 \frac{kJ}{kg}}$$

$$\eta_{bth} = 0.3248$$

(or)

$$\eta_{bth} = 32.48 \%$$

(v)

$$\frac{A}{F} = \frac{m_a}{m_f}$$

$$= \frac{6 \ kg/min}{\frac{4.4}{10} \ kg/min}$$

$$\frac{A}{F} = 13.63$$

(127)

(vi) Volumetric effn.

$$\eta_v = \frac{\text{Actual volume of Air / cycle}}{\text{Swept volume}} = \frac{V_a}{V_s}$$

$$\rho_a = \frac{m_a}{V_a}$$

$$V_a = \frac{m_a}{\rho_a}$$

$$P = \rho RT$$

$$\rho_a = \frac{P_a}{R_a T_a} = \frac{100}{0.287 \times 300}$$

$$\rho_a = 1.1614 \text{ kg/m}^3$$

$$V_a = \frac{6 \text{ kg/min}}{1.1614 \text{ kg/m}^3}$$

$$V_a = 5.166 \text{ m}^3/\text{min}$$

For 4-S engine

$$4500 \text{ rpm} = \frac{4500}{2} = 2250 \text{ cycle/min}$$

$$V_a/_{cycle} = \frac{5.166\ m^3/min}{2250\ cycle/min}$$

$$= 2.296 \times 10^{-3}\ m^3/cycle$$

$$V_s = \frac{\pi}{4} D^2 L K$$ (128)

$$= \frac{\pi}{4} (0.09)^2 (0.08)\ 8\ m^3$$

$$= 4.07 \times 10^{-3}\ m^3$$

$$\eta_{vol.} = \frac{V_a}{V_s}$$

$$= \frac{2.296 \times 10^{-3}}{4.07 \times 10^{-3}}$$

$$\eta_{vol.} = 0.5639$$

(or)

$$\eta_{vol.} = 56.39\ \%$$

Note:- The volumetric effⁿ. of above engine is very low and volumetric effⁿ. of a well design engine is in the range of 75 — 85 %

(129)

Gate (4) The following details where noted in a test on a 4- cylinder, 4-S engine

Bore	100 mm
Stroke	120 mm
Speed	1600 rpm
Fuel Consumption	0.2 Kg/min
C.V. of fuel	44000 KJ/Kg
Brake load	40 Kg
Brake circumference	300 cm (or) 3 m
η_m	80 %

Calculate

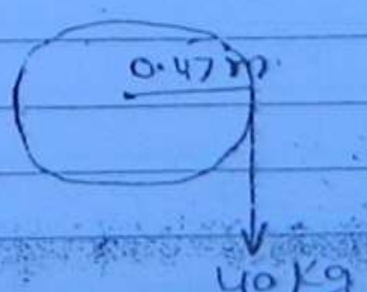
(i) Brake thermal effⁿ.

(ii) Indicated thermal effⁿ.

(iii) Indicated mean effective pressure &

(iv) Brake specific Fuel Consumption

Solⁿ:-



$F = 9.81 \times 40$

$= 392.4$

circumference $= 2\pi r$

$3 = 2\pi r$

$r = 0.477$ m

$T = F \times r$

$= 392.4 \times 0.477$

$= 187.35$

(130)

Brake power $= \dfrac{2\pi N T}{60}$

$= \dfrac{2\pi \times 1600 \times 187.35}{60}$

$BP = 31392 \ W$

(or)

$BP = 31.39 \ KW$

i) Brake thermal effn.

$\eta_{bth} = \dfrac{BP}{m_f \times C.V}$

$= \dfrac{31.39 \ KW}{\frac{0.2}{60} \frac{Kg}{Sec} \times 44000 \frac{KJ}{Kg}}$

$\eta_{bth} = 0.2156$

(or)

$\eta_{bth} \ 21.56\%$

(ii) Indicated Thermal effⁿ.

$$\eta_{ith} = \frac{\eta_{bth}}{\eta_m}$$

(131)

$$= \frac{0.2156}{0.8}$$

$$\eta_{ith} = 0.269$$

(or)

$$\eta_{ith} = 26.9\ \%$$

(iii) Indicated mean effective pressure

$$IP = \frac{P_m LANK}{2 \times 60}$$

$$\eta_m = \frac{BP}{I.P.}$$

$$0.8 = \frac{31.36}{I.P}$$

$$I.P = 39.24\ kW$$

$$39.24 = \frac{P_m \times (0.12) \times \frac{\pi}{4}(0.1)^2 \times 1600 \times 4}{60 \times 2}$$

$$P_m = 780.65\ kPa$$

(or)

$$P_m = 780.65 \times 10^3\ N/m^2$$ (or) $$P_m = 7.8065\ bar$$

(iv) Brake specific Fuel consumption

$$BSFC = \frac{m_f}{B.P}$$

(132)

$$= \frac{0.2 \times 60}{31.39} \frac{kg}{kW\,hr}$$

$$BSFC = 0.3826 \; kg/kW\,hr$$

(5) The power output of a 6-cylinder, 4-stroke engine by measure means of a dynamometer for which the [illegible] is

$$bp = \frac{WN}{20000} \; kW$$

where W = brake load in N
N = speed in rpm.

The following data may be used

Throat diameter	30 mm
Bore	100 mm
Stroke	120 mm
Brake load	500 N
Speed	2500 rpm

$\frac{C}{H}$ by mass $\frac{83}{17}$

(133)

Coeffⁿ for discharge for venturi	0.6
atmp. pressure	1 bar
pressure drop across venturi	14.5 Cm of
Time taken for 100 CC fuel Consumption	20 sec.
atmp. Temp.	27°C
Fuel density	831 kg/m³

Calculate

(i) Brake power
(ii) Brake Torque
(iii) BSFC
(iv) Volumetric effi^n.
(v) Percentage excess of air.

Soln:- * Assume Air as incompressible.

(i) Brake power

$$bP = \frac{WN}{20000}$$

$$bP = \frac{560 \times 2400}{20000}$$

$$bP = 67.2 \text{ KW}$$

(ii) Brake Torque

$$bP = \frac{2\pi NT}{60} \text{ KW}$$

$$67.2\times10^3 = \frac{2\pi \times 2400 \times T}{60}$$

(134)

$$T = \frac{67.2\times10^3 \times 60}{2\pi \times 2400}$$

$$T = 267.3 \text{ N-m}$$

(iii) ~~BSFC~~ % axcess of of Air

$$\left(\frac{A}{F}\right)_{St.} = \frac{100}{23}\left(\frac{8}{3}C + 8H_2\right)$$

$$\left(\frac{A}{F}\right)_{St.} = \frac{100}{23}\left[\frac{8}{3}\times 0.83 + 8\times(0.17)\right]$$

$$\left(\frac{A}{F}\right)_{St.} = 15.536$$

Actual Air/Fuel ratio

$$V_f = 100 \text{ cm}^3 / 20 \text{ sec.}$$

$$\rho_f = 831 \text{ Kg/m}^3$$

$$\rho = \frac{m_f}{V_f}$$

$$m_f = \rho_f \times V_f$$

$$= 831 \frac{kg}{m^3} \times \frac{100 \times 10^{-6}}{20 \text{ sec}} m^3$$

(135)

$$m_f = 4.155 \times 10^{-3} \text{ Kg/sec.}$$

$$m_a = C_{da} A_2 \sqrt{2 \rho_a (P_1 - P_2)}$$

$$(P_1 - P_2) = 14.5 \text{ cm of Hg}$$

$$P = \rho R T$$

$$\rho_a = \frac{P}{RT}$$

$$P = \rho g h$$

$$\rho_a = \frac{100}{0.287 \times 300}$$

$$(P_1 - P_2) = 13.6 \times 10^3 \times 9.81 \times \frac{14.5}{100}$$

$$\rho_a = 1.16$$

$$P_1 - P_2 = 19345.3 \text{ N/m}^2$$

$\therefore$

$$m_a = 0.6 \times \frac{\pi}{4} (0.03)^2 \times \sqrt{2 \times 1.16 (19345.3)}$$

$$m_a = 0.089 \text{ Kg/sec.}$$

$$\left(\frac{A}{F}\right)_{act.} = \frac{0.089}{4.155 \times 10^{-3}}$$

$$= 21.62$$

$$\% \text{ Excess} = \frac{\left(\frac{A}{F}\right)_{act.} - \left(\frac{A}{F}\right)_{st.}}{\left(\frac{A}{F}\right)_{st.}}$$

(136)

$$\% \text{ excess} = \frac{21.62 - 15.536}{15.536}$$

$$\% \text{ excess} = 0.391$$

(or)

$$\% \text{ excess} = 39.1 \%$$

(iv) Brake specific fuel consumption (BSFC)

$$BSFC = \frac{m_f}{bp}$$

$$BSFC = \frac{4.155 \times 10^{-3} \times 3600}{67.2}$$

$$BSFC = 0.222 \text{ kg/kWhr.}$$

(v) Volumetric effn.

$$\eta_v = \frac{V_a/\text{cycle}}{V_s}$$

$$\rho_a = \frac{m_a}{V_a}$$

(137)

$$V_a = \frac{m_a}{\rho_a}$$

$$V_a = \frac{0.089 \ kg/sec}{1.16 \ kg/m^3}$$

$$V_a = 0.0766 \ m^3/sec$$

For 4-S engine 2400 rot./min

$$= \frac{2400}{2} = 1200 \ cycle/min$$

$$\frac{V_a}{cycle} = \frac{0.0766}{\frac{1200}{60}} \ \frac{m^3/sec}{cycle/sec}$$

$$\frac{V_a}{cycle} = \frac{60 \times 0.0766}{1200} \ m^3$$

$$V_a/cycle = 3.8315 \times 10^{-3} \ m^3$$

$$V_s = \frac{\pi}{4} D^2 L K = \frac{\pi}{4} (0.1)^2 (0.12) \times 6$$

$$V_s = 5.652 \times 10^{-3} \ m^3$$

$$\eta_v = \frac{V_a}{V_s}$$

(138)

$$= \frac{3.8315 \times 10^{-3}}{5.652 \times 10^{-3}}$$

$$\eta_v = 0.6877$$

(or)

$$\eta_v = 68.77\%$$

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(5) A 6-cylinder, 4-stroke engine delivers a brake power of 120 kW at 1600 rpm. The fuel to be used has a calorific value of 43000 KJ/kg. And its percentage composition by mass is C = 86%, H = 13% & 1% non-combustibles. The volumetric effn. assume to be 80%. Indicated thermal effn. is 40%. mechanical effn. 80%. The air consumption is 110 axcess with resp. to stoichiometic conditions.

(i) Estimate volumetric composition of dry exhaust gases.

(ii) determine bore & stroke of

the engine. Taking stroke to Bore ratio $L/D = 1.5$.
Assume density of air as $1.298 \frac{kg}{m^3}$ and air contains 23 kg of oxygen in 100 kg.

(134)

Soln:

4 - Stroke

$K = 4$

$N = 1600$ rpm

$bp = 120$ kW

$CV = 43000$ kJ/kg

$\%C = 0.86$, $\% H_2 = 0.13$

$\eta_{vol.} = 0.8$

$\eta_{ith} = 0.4$

$\eta_m = 0.8$

$\left(\frac{A}{F}\right) =$ 110 % Excess

$\rho_a = 1.298$ kg/m³

$\frac{L}{D} = 1.5$

Stoichiometric A/F ratio

$$\left(\frac{A}{F}\right)_{st.} = \frac{100}{23}\left[\frac{8}{3}(0.86) + 8(0.13)\right]$$

$$\left(\frac{A}{F}\right)_{st.} = 14.5$$

$$\left(\frac{A}{F}\right)_{act.} = 14.5 + 1.1(14.5)$$

$$\left(\frac{A}{F}\right)_{act.} = 30.45$$ (1140)

Excess air supply per kg fuel

$$= 30.45 - 14.5$$
$$= 15.95$$

Fuel + Air ⟶ CO_2, H_2O

[CH] [14.5 + 15.95] O_2, N_2

(St.) $N_2 + O_2$ (St.) ↓ Consumed; $N_2 + O_2$ ↓ Excess

O_2 ↓ Excess; N_2 ↓ Total (N_2(St.) + N_2)

Note :- As excess air is used stoichiometric oxygen will react with fuel resulting in CO_2 & H_2O whereas excess O_2 will comeout in exhaust gases. as N_2 is innert it does not undergo any reaction and hence stoichiometric N_2 & [illegible] and excess N_2 will comeout in exhaust gases.

$$\eta_m = \frac{bp}{ip}$$

$$ip = \frac{bp}{\eta_m}$$ (141)

$$= \frac{120}{0.8} \text{ kW}$$

$$ip = 150 \text{ kW}$$

$$\eta_{ith} = \frac{i.p.}{m_f \times C.V.}$$

$$0.4 = \frac{150 \text{ kW}}{m_f \times 43000 \frac{kJ}{kg}}$$

$$m_f = 8.72 \times 10^{-3} \text{ kg/sec}$$

For actual

$$\frac{m_a}{m_f} = 30.45$$

$$m_a = 30.45 \times m_f$$

$$m_a = 30.45 \times 8.72 \times 10^{-3}$$

$$m_a = 0.265531 \text{ kg/sec}$$

$$\eta_{vol} = \frac{V_a/cycle}{V_s}$$

(142)

$$\rho_a = \frac{m_a}{V_a}$$

$$V_a = \frac{m_a}{\rho_a} = \frac{0.2655 \ kg/sec}{1.298 \ kg/m^3}$$

$$V_a = 0.2045 \ m^3/sec$$

For 4-stroke engine

$$1600 \ rpm \Rightarrow 800 \ cycle/min$$

$$= \frac{800}{60} \frac{cycle}{sec}$$

$$\frac{V_a}{cycle} = \frac{0.2045 \ m^3/sec}{\frac{800}{60} \ cycle/sec}$$

$$\frac{V_a}{cycle} = 0.0153 \ m^3$$

$\therefore$

$$0.8 = \frac{0.0153 \ m^3}{\frac{\pi}{4} D^2 L K \ m^3}$$

$$\frac{\pi}{4} D^2 L K = \frac{0.0153}{0.8}$$

$$\frac{\pi}{4} D^2 (1.5D) \times 6 = \frac{0.0153}{0.8}$$

$$D = 0.139 \text{ m.}$$ (143)

(or)

$$D = 13.9 \text{ cm} \simeq 14 \text{ cm.}$$

$$L = 1.5D$$
$$= 1.5 \times 14$$
$$L = 21 \text{ cm.}$$

Exhaust Gases,

CO_2, N_2, O_2

$$C + O_2 \longrightarrow CO_2$$

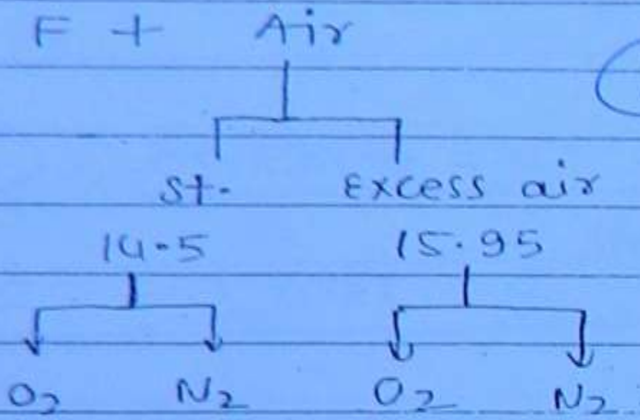
12 Kg C $\longrightarrow$ 44 Kg of CO_2

1 Kg C $\longrightarrow$ $\frac{44}{12}$,, CO_2

1 Kg C produces $\longrightarrow$ $\frac{44}{12}$ Kg of CO_2

0.86 ,, $\longrightarrow$ $\frac{44}{12} \times 0.86$

0.86 Kg C ,, $=$ 3.153 Kg of CO_2



100 Kg of air —— 23 kg of O_2

15.95 Kg " —— $\frac{15.95 \times 23}{100}$

15.95 Kg Air = 3.6685 Kg of O_2

100 Kg air —— 77 Kg of N_2

30.45 — " ⟶ $\frac{77 \times 30.45}{100}$

30.45 Kg Air = 23.446 Kg of N_2

The above analysis is known as Gravimetric (or) Mass analysis

CO_2 — 3.153

O_2 — 3.668

N_2 — 23.446

Volumetric Analysis of Exhaust Gases :-

	Grav.	Volum.
CO_2	3.153	$3.153/44 = 0.7165$
O_2	3.668	$3.668/32 = 0.1145$
N_2	23.446	$23.446/28 = 0.8373$
		1.023

(145)

$$\frac{0.07165}{1.023} \times 100 = 7\%$$

$$\frac{0.1145}{1.023} \times 100 = 11.2\%$$

$$\frac{0.8373}{1.023} \times 100 = 81.8\%$$

Volumetric Analysis of Exhaust Gases :-

	Grav.	Volum.	
CO_2	3.153	$3.153/44 =$	0.7165
O_2	3.668	$3.668/32 =$	0.1145
N_2	23.446	$23.446/28 =$	0.8373
			1.023

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$$\frac{0.07165}{1.023} \times 100 = 7\%$$

$$\frac{0.1145}{1.023} \times 100 = 11.2\%$$

$$\frac{0.8373}{1.023} \times 100 = 81.8\%$$