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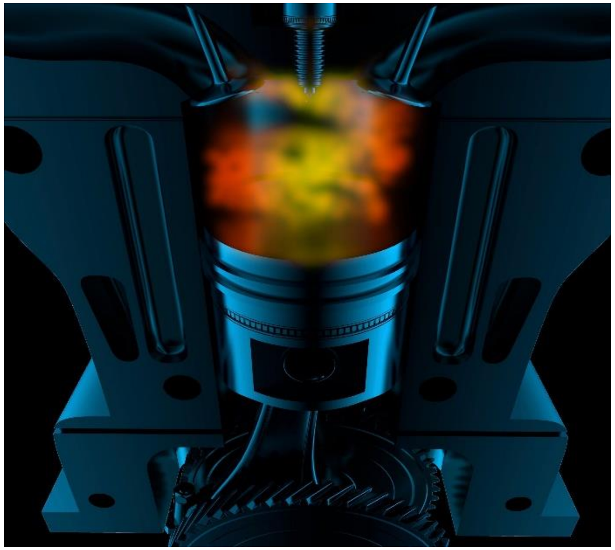
Internal Combustion Engines
ENME 535

Department of Mechanical and Mechatronics Engineering
Dr. Mohammad Karaeen

Chapter 3: Combustion



Combustion Highlights:-

The following points will be considered

- Fuel .
- Combustion Equation .
- Air Fuel Ratio.
- Calorific Value Of Fuels.
- Self Ignition Temperature.
- Combustion in SIE
- Combustion in CIE

- **Combustion** :is a chemical reaction occurring between fuel and oxygen in an oxidation process which is rapid and is accompanied by the evolution of heat.
- **Average molecular weight For air mixture :**

the percent by volume of O_2 x molecular weight of O_2

+ % by volume of N_2 x molecular weight of N_2

= 0.21x32 + 0.79x28 = 28.9 = 29

3.1 Fuels

The most important fuel elements are carbon and hydrogen

Solid fuels: coal is the most important solid fuel and the various types are divided into groups according to their chemical and physical properties.

An accurate chemical analysis by mass of the important elements in the fuel is called **ultimate analysis** . the main groups are shown in the following table.

Fuel	Moisture content % by mass	Ultimate analysis % by mass in dry fuel					Volatile matter % by mass in dry fuel
		Carbon	hydrogen	Oxygen	Nitrogen	Ash	
Anthracite	1	90.27	3	2.32	1.44	2.97	4
Bituminous	2	81.93	4.87	5.98	2.32	4.9	25
coal	5	56.52	5.72	31.89	1.62	4.25	50

Liquid fuels

Most important liquid fuels are hydro-carbons which exist in the liquid phase at the atmospheric conditions

Petroleum oils are complex mixtures of sometimes hundreds of different fuels, but the most important is the relative portion of carbon and hydrogen. The following table gives the ultimate analysis of liquid fuels.

Analysis of liquid fuels

Fuel	carbon	hydrogen	sulpher	ash
100 octan petrol	85.1	14.9	.01	-
Motor petrol	85.5	14.4	0.1	-
Benzole	91.7	8	0.3	-
Kerosene	86.3	13.6	0.1	-
Diesel oil	86.3	12.8	0.9	-
Light fuel oil	86.2	12.4	1.4	-
Heavy oil	86.1	11.8	2.1	-
Residual oil	88.3	9.5	1.2	1.0

Gaseous fuel

These are chemically the simplest of the three groups . some gases exist naturally at atmosphere conditions so methane (CH_4), others are manufactured by various treatments of coal, the following table gives the typical analysis of different gaseous fuels.

Volumetric and molar analysis of some gaseous fuels

Fuel	H2	CO	CH4	C2H4	C2H6	C4H8	O2	CO2	N2
Coal gas	53.6	9.0	2.5	-	-	3	0.4	3	6
Producer gas	12	29	2.6	0.4	-	-	-	4	52
Natural gas	-	1	9.3	-	3	-	-	-	3
Blast furnace gas	2	27	-	-	-	-	-	11	60

3.2 Combustion equations:

In the combustion process between fuel and air in the combustion chamber the following points should be considered.

1. The mass flow remains constant (i.e. total mass of products equals total mass of reactants)

2. The reactants are chemically different from the products and the products are at higher temperature.

3).The total number of atoms of each element concerned in the combustions remains constant, but the atoms rearranged into groups having different chemical properties.

In the chemical equation the information are expressed as follows.

a- The products and reactants of combustion

b- The relative quantities of the reactants and products.

- **Mole**: is defined as a quantity of gas equivalent to M kg of the gas, where M is the molecular weight.

Analysis of air for combustion

	O_2	N_2
By mass	23.3%	76.7%
By volume	21%	79%

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The combustion equation

$$2H_2+O_2 \rightarrow 2H_2O$$

This tells that

a)hydrogen reacts with oxygen to form steam or water

b)two molecules H_2 + 1 molecule O_2 gives two molecules of water

or 2 volume H_2 + 1 volume O_2 → 2 volumes H_2O

then there is a volumetric contraction or combustion using atomic weights

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$2x(2x1) + 2x16 \rightarrow 2x(2x1+16)$$

$$4 \text{ kg } H_2 + 32 \text{ Kg } O_2 \rightarrow 36 \text{ Kg } H_2O$$

$$\text{or } 1\text{kg } H_2 + 8 \text{ Kg } O_2 \rightarrow 9 \text{ Kg } H_2O$$

For Complete Combustion

Combustion with air

$$2H_2 + O_2 + \frac{79}{21} N_2 \Rightarrow 2H_2O + \frac{79}{21} N_2$$

Combustion of carbon

$$C + O_2 + \frac{79}{21} N_2 \Rightarrow CO_2 + \frac{79}{21} N_2$$

By mass

$$12\text{Kg } C + 32 \text{ Kg } O_2 + \frac{79}{21}(2x14)\ N_2 \Rightarrow (12+2x16) \text{ Kg } CO_2 + \frac{79}{21}(2x14) \text{ Kg } N_2$$

i.E

$$.\ 12 \text{ Kg } C + 32 \text{ Kg } O_2 + 105.3\ N_2 \Rightarrow 44 \text{ Kg } CO_2 + 105.3 \text{ Kg } N_2$$

$$1 \text{ Kg } C + \frac{8}{3} \text{Kg } O_2 + \frac{105.3}{12} N_2 \Rightarrow \frac{11}{3} \text{Kg } CO_2 + \frac{105.3}{12} \text{ Kg } N_2$$

For incomplete combustion :

When insufficient supply of O2 to burn the carbon completely to carbon dioxide.

$$2C + O_2 + \frac{79}{21} N_2 \rightarrow 2CO + \frac{79}{21} N_2$$

$$24kgC + 32kg\ O_2 + \frac{79}{21}(28kg)\ N_2 \rightarrow 2x\ (12 + 16)\ kg\ CO + \frac{79}{21}(2x14\ kg)\ N_2$$

$$24kgC + 32kg\ O_2 + 105.3\ kg\ N_2 \rightarrow 56\ kg\ CO + 105.3\ Kg\ N_2$$

$$1\ Kg\ C + \frac{4}{3}\ Kg\ O_2 + \frac{105.3}{24}\ Kg\ N_2 \rightarrow \frac{7}{3}\ Kg\ CO + \frac{105.3}{24}\ Kg\ N_2$$

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3.3 Stoichiometric, or Chemically correct Air Fuel Ratio:

- **A stoichiometric mixture** of air and fuel is one that contains just sufficient oxygen for the complete combustion of the fuel .
  - **Weak or lean mixture** which has an excess of air.
  - **Rich mixture** which has deficiency of air

$$\textbf{Percent excess air} = \frac{\text{Actual A/F ratio} - \text{stoichiometric A/F ratio}}{\text{Stoichiometric A/F ratio}}$$

$$\textbf{Mixture strength (equivalent ratio)} = \frac{\text{stoichiometric A/F ratio}}{\text{Actual A/F ratio}}$$

- **Example 3.1** Find the volumetric and gravimetric air fuel ratio of chemically correct combustion for CH_4

Solution:

$$CH_4 + X(O_2 + \frac{79}{21})N_2 \rightarrow a\ CO_2 + B\ H_2O + d\ N_2$$

There are four unknowns X,a,b,d thus we need 4 equivalent to solve the problem.

Carbon Balance $a=1$

Hydrogen Balance $4=2b \quad b=2$

Oxygen Balance **2X =2a+b =2+2=4 => X=2**

Nitrogen Balance $2x(\frac{79}{21}) + x = 2d \rightarrow d = \frac{79}{21}x2=7.52$

Then the combustion equation is

$CH_4 + 2\ O_2\ \ + 7.52\ N_2 \rightarrow CO_2 + 2\ H_2O + 7.52\ N_2$

1 moles of $CH_4 + 9.52$ moles of air $\rightarrow CO_2 + 2\ H_2O + 7.52\ N_2$

$\therefore$ volumetric A/F= 9.52:1

By mass A/F = $\dfrac{2x32 + 7.52x28}{12 + 4x1}$ = 17.16:1

3.4 Calorific value of fuel:

- **Gas fuels**: the calorific value of gas fuels is defined as the quantity of heat to generate when 1 m^3 of gas at N.T.P is completely burned [N.T.P is the normal temp and pressure 0^0C , 760 mm Hg, while S.T.P. is the standard temperature and pressure 25^0C , 760 mm Hg]

- **Liquid fuels**: the calorific value of solid and liquids is defined as the quantity of heat generated when one kg of fuel is completely burned

Higher (gross) and lower (Net) calorific value

Any hydrocarbon fuel contains a certain ratio of H_2 which upon burning in ICE will give water vapor according to the following ratio

$$2H_2 + O_2 \rightarrow 2\ H_2O$$

$$1\ kg\ H_2 + 8\ kg\ O_2 \rightarrow 9\ kg\ H_2O$$

Higher (gross) and lower (Net) calorific value

The lower calorific value, is the quantity, of heat generated when a unit volume of gas or unit mass of liquid or solid of the fuel is completely burned, while the water vapor formed due to the combustion of H_2 on the fuel is in the vapor form.

The higher calorific value is defined in a similar way with the exception that the water vapor formed is in the condensed form.

$$\textbf{H.C.V. = L.C.V. + } (m_s + 9\,H_2)\textbf{ 2240 KJ/Kg}$$

Where m_s = mass of moisture / Kg fuel and 2440 is the latent heat of steam.

Calorific values of some important elements found in fuel. The following table gives the H.C.V. of important elements (KJ/Kg)

$C \rightarrow CO_2$	$C \rightarrow CO$	H_2	$S \rightarrow SO_2$
35000	10200	143000	91600

Example: Find the higher and lower C.V. of petrol having composition of 87% C , 13% H_2

H.C.V. = 35000x0.87 + 143000x0.13= 49040 Kj/Kg

L.C.V. = H.C.V. – (m_s+9H_2)x2240

=49040 – (0+9x0.13)2240= 46419.2

3.5 **Self ignition temp**.:

The self ignition temperature of fuel whether liquid or solid or gas is the min. temperature at which the fuel burns when at contact with air.

fuel	CH_4	CO	kerosene	Petrol	Diesel gas
S.I.T. ^{0}C	530	630	290	550	340

From the table it is clear that the Diesel burns at a lower temp. than petrol thus in C.I.D. engine smaller compression ratio is needed to burn Diesel fuel than required to burn petrol fuel spontaneously.