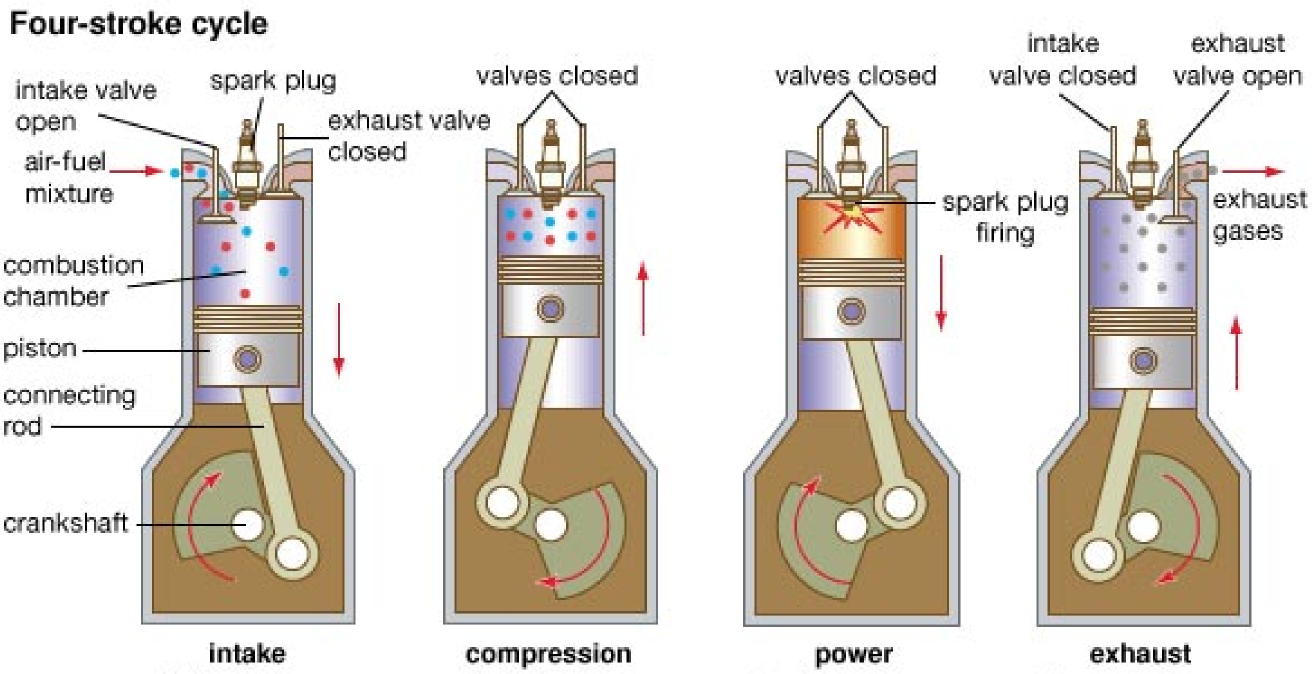
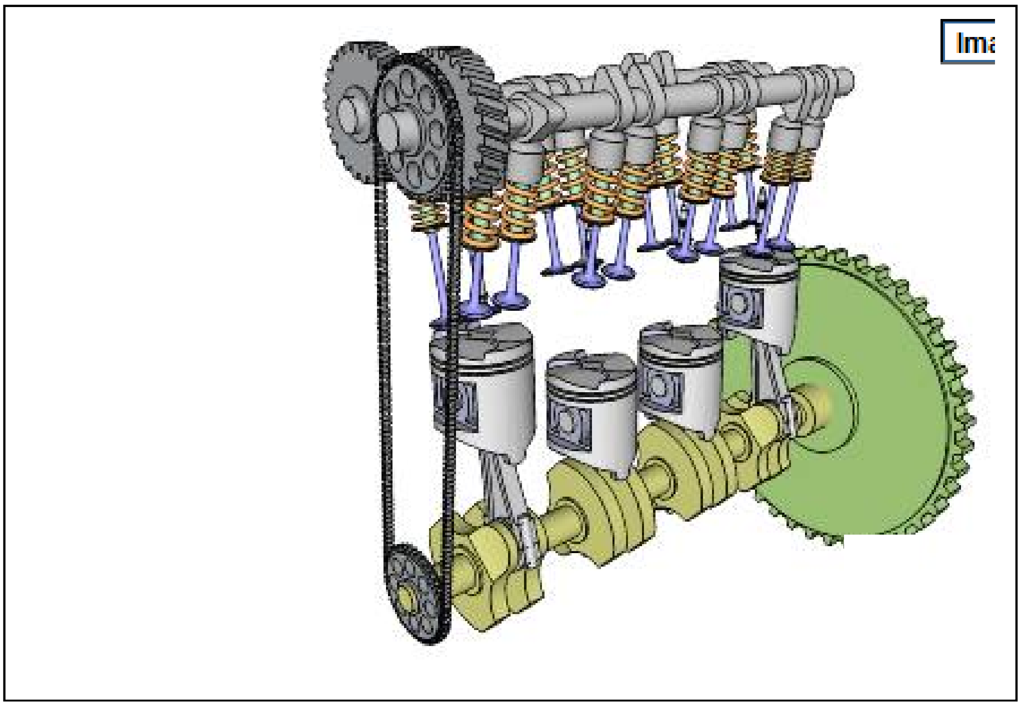
Internal Combustion engine

DR. EMAD TOMA BANE KARASH & TARAQ SHABAN





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Preface

Thorough in its presentation, this essential resource illustrates the latest level of knowledge in engine development, paying particular attention to the presentation of theory and practice in a balanced ratio.

This book remains the indispensable guide to internal combustion engines. It serves as valuable reference for both students and professional engineers needing a practical overview of the subject. Thoroughly updated, clear, comprehensive, well-illustrated, with a wealth of worked examples and problems, its combination of theory, and applied practice is sure to help you understand internal combustion engines, from thermodynamics and combustion to fluid mechanics and materials science. Co-published by Technical of Education, Mosul Institute, Mosul – Iraq.

The Arthur hopes that this book will continue to serve well at the undergraduate level and the advanced topics will prove useful to student at the postgraduate level.

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CONTENTS

Chapter four

AIR - STANDARD CYCLES

Chapter five

ENGINES SYSTEMS

Chapter six

FUEL AND COMBUSTION

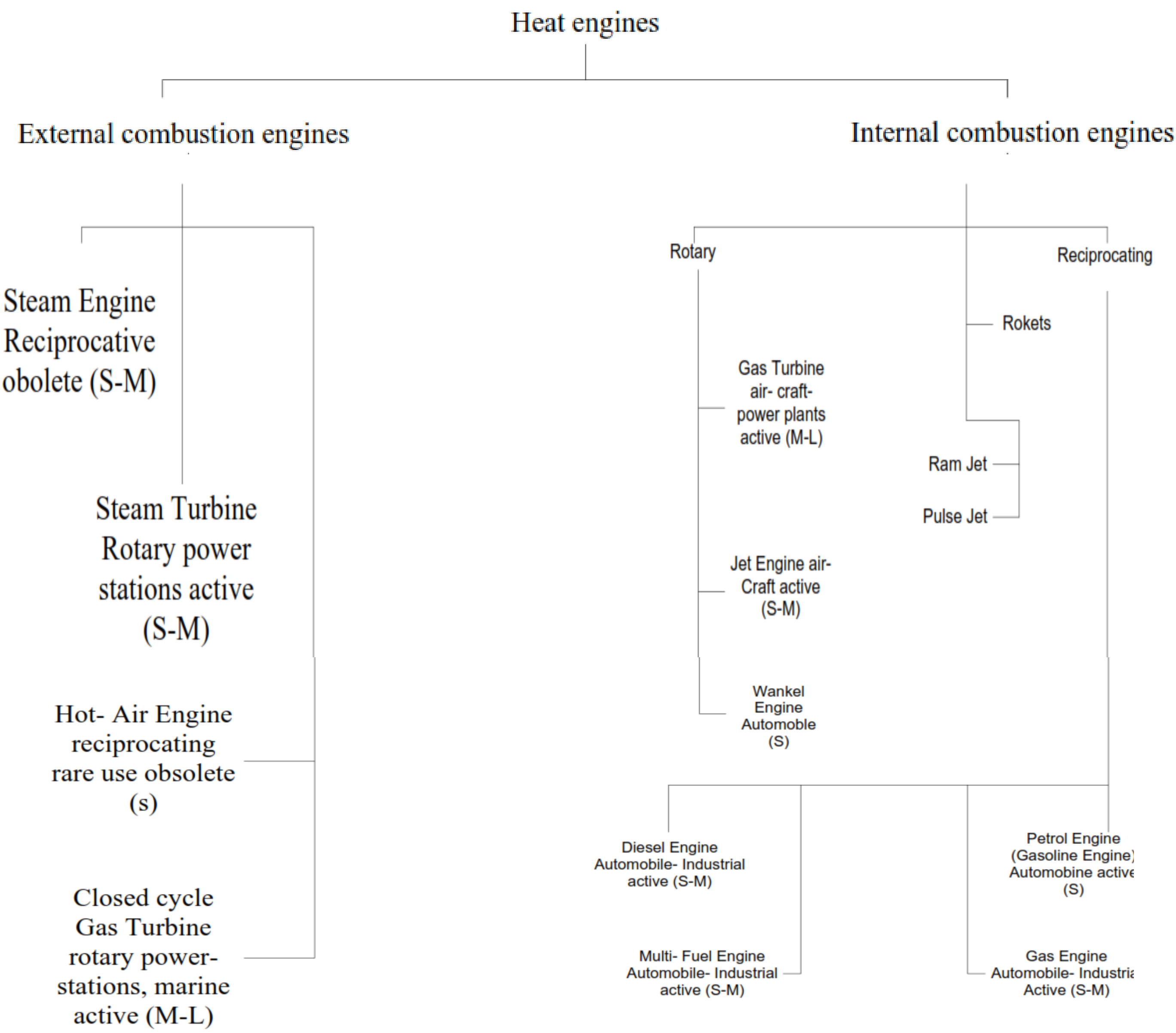
Chapter 1

Engines classification

1- INTERNAL COMBUSTION ENGINES

Internal combustion engine more popularly known as I.C. engine is a heat engine, which converts the heat energy released by the combustion of the fuel inside the engine cylinder, into mechanical work. Its versatile advantages such as high efficiency lightweight, compactness, easy starting, adaptability, comparatively lower cost has made its use as a prime mover universal.

1-1. Classification of Heat Engines:



NOTES:

L: Large over 10000 KW

M: Medium between 1000- 10000 KW

S: Small under 1000 KW

1-2. Engine Development

Year Engine	Designer/developer
1680 Gunpowder	Christian Huygens
1698 Savory Pump	Thomas Saverly
1712 Newcomen Steam	Thomas Newcomen
1763 Watt Double-acting steam	James Watt
1801 Coal gas/electric ignition	Eugene Lebon
1802 High pressure steam	Richard Trevithick
1859 Pre-mixed fuel and air	Etienne Lenoir
1862 Gasoline	Nikolaus Otto
1876 Four cycle gasoline	Nikolaus Otto
1892 Diesel	Rudolf Diesel
1953 Die-cast aluminum	B&S

1-3. Comparison between the different kinds

1. The Reciprocation Piston Engine:

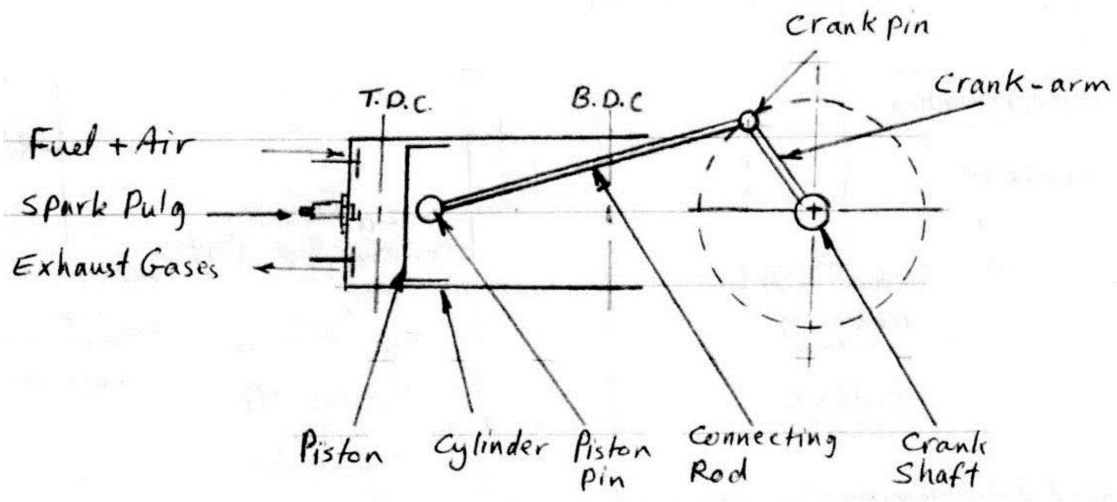


Figure (1): *Diagrammatic representation of reciprocating piston engine*

2. Open Cycle Gas Turbine:

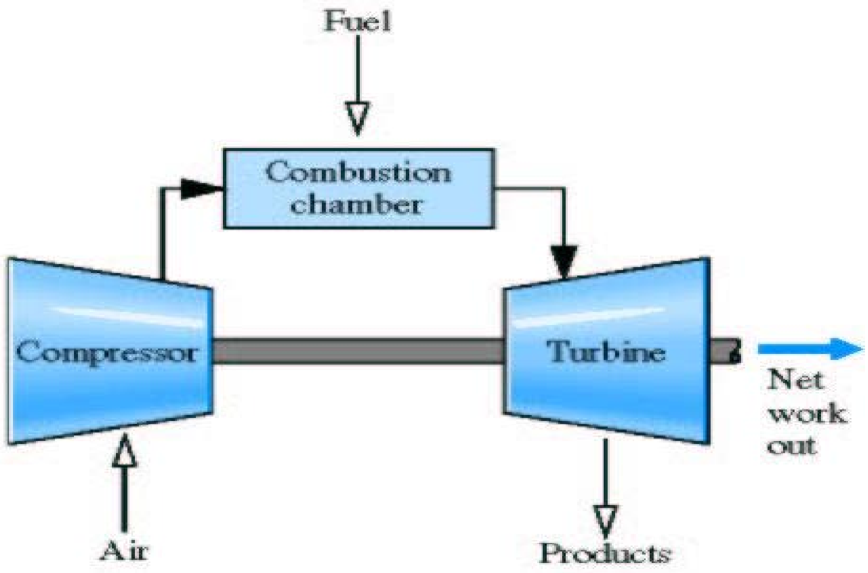
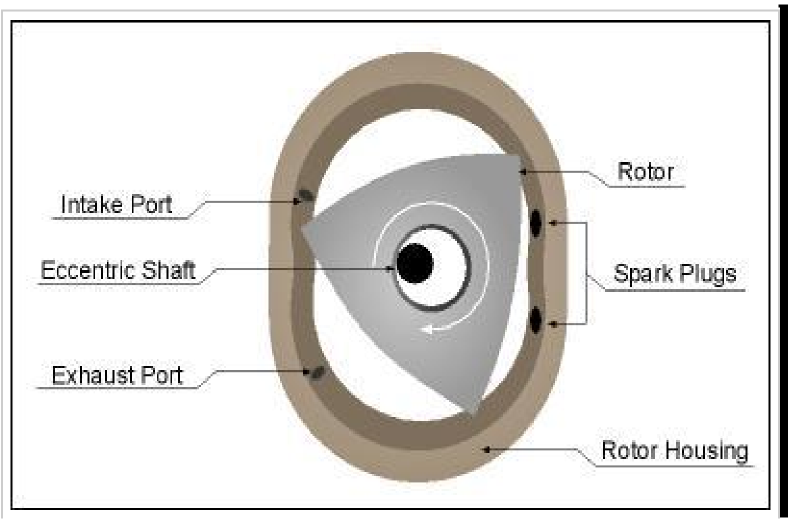


Figure (2): *Diagrammatic representation of gas turbine*

3. The Wankel engine:



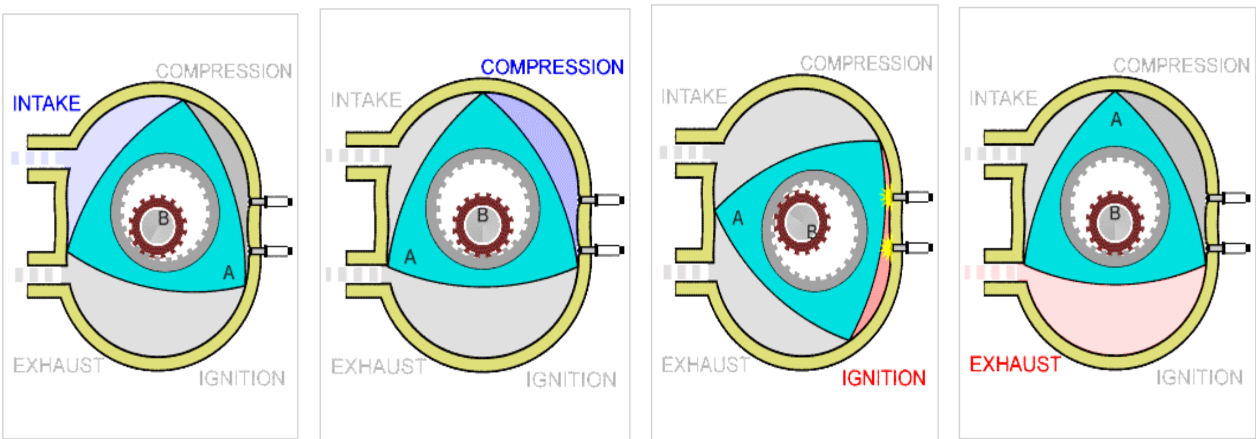


Figure (3): *Wankel four- process cycle*

1. German scientist **Felix Wankel** was the first to put the idea into a working design.
2. Wankel perfected his design and sold the rights for the design to several car companies.
3. Mazda produced its first rotary power car in 1961 and created their Rotary Engine Division in 1963.
4. Popularity for the rotary powered vehicles increased rapidly until the gas crisis in the mid 70's
   a. Rotary engines were not very fuel efficient compared to piston engines
   b. Strict emissions standards could not be met with current rotary technology
5. These two factors severely hurt the sale and development of rotary engines
6. Mazda was the only car company that continued to produce cars with rotary engines through the 90's.

Advantages

1. **Vibration**
   1. No unbalanced reciprocating masses
2. **Power/Weight**
   1. For similar displacements, rotaries are generally 30% lighter and produce twice as much power
3. **Simplicity**
   1. Contain half as many moving parts
   2. Have no connecting rods, crankshaft, or valve trains

Disadvantages

1. **Fuel Efficiency and Emission**
   1. The shape of the combustion chamber, which is long instead of small and concentrated, makes the combustion travel longer than a piston engine

2. Due to the longer combustion chamber, the amount of unburned fuel is higher which is released into the environment

2. **Cost**

1. The lack of infrastructure and development for the rotary engine has caused their production and maintenance costs generally to be more

4. Steam Power Plant:

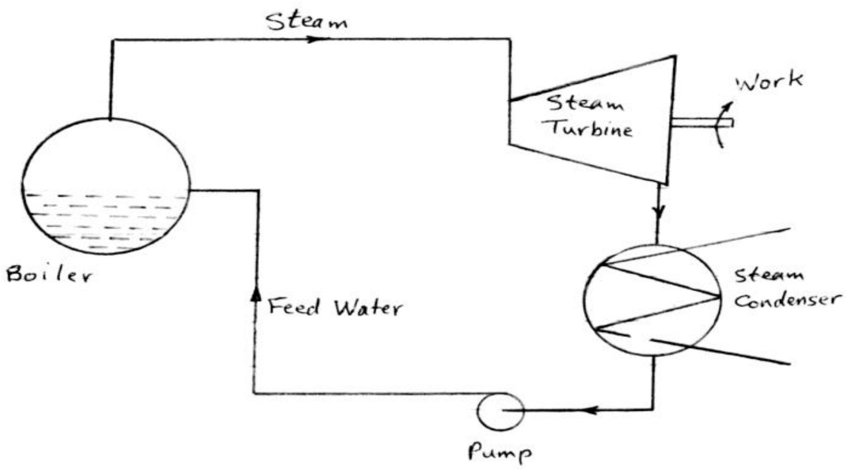


Figure (4): *Diagrammatic representation of steam power plant*

1-4. Classification of I.C. Engines

1. **Engine designs can be classified by:**

2. Size
3. Ignition system
4. Strokes per cycle
5. Cylinder orientation
6. Crankshaft orientation
7. Control system
8. Cooling system

3. I.C engines are classified according to:

1. Nature of thermodynamic cycles as:

1. Otto cycle engine;
2. Diesel cycle engine
3. Dual combustion cycle engine

2. Type of the fuel used:

- **gas fuels**

1 -natural gas

2 -gasification (pirolysis)

3 -biogas, waste gas

4 -other

- **liquid fuels**

1. crude oil fractions (distillation fuels)

- Crude-oil (Diesel fuel)
- Benzine
- Kerosene (JET-A)
- Heavy (ends) oils, etc

2. Renewable fuels

- Rape-, sunflower-seed oil, RME
- Alcohols, Bioethanole, etc

3. Other

3. Number of strokes as

1. Four stroke engine
2. Two stroke engine

4. Method of ignition as:

1. Spark ignition engine, known as SI engine

2. Compression ignition engine, known as C.I. engine

5. Number of cylinder as:

1. Single cylinder engine
2. Multi cylinder engine

6. Position of the cylinder as:

1. Horizontal engine
2. Vertical engine.
3. Vee engine
4. In-line engine.
5. Opposed cylinder engine

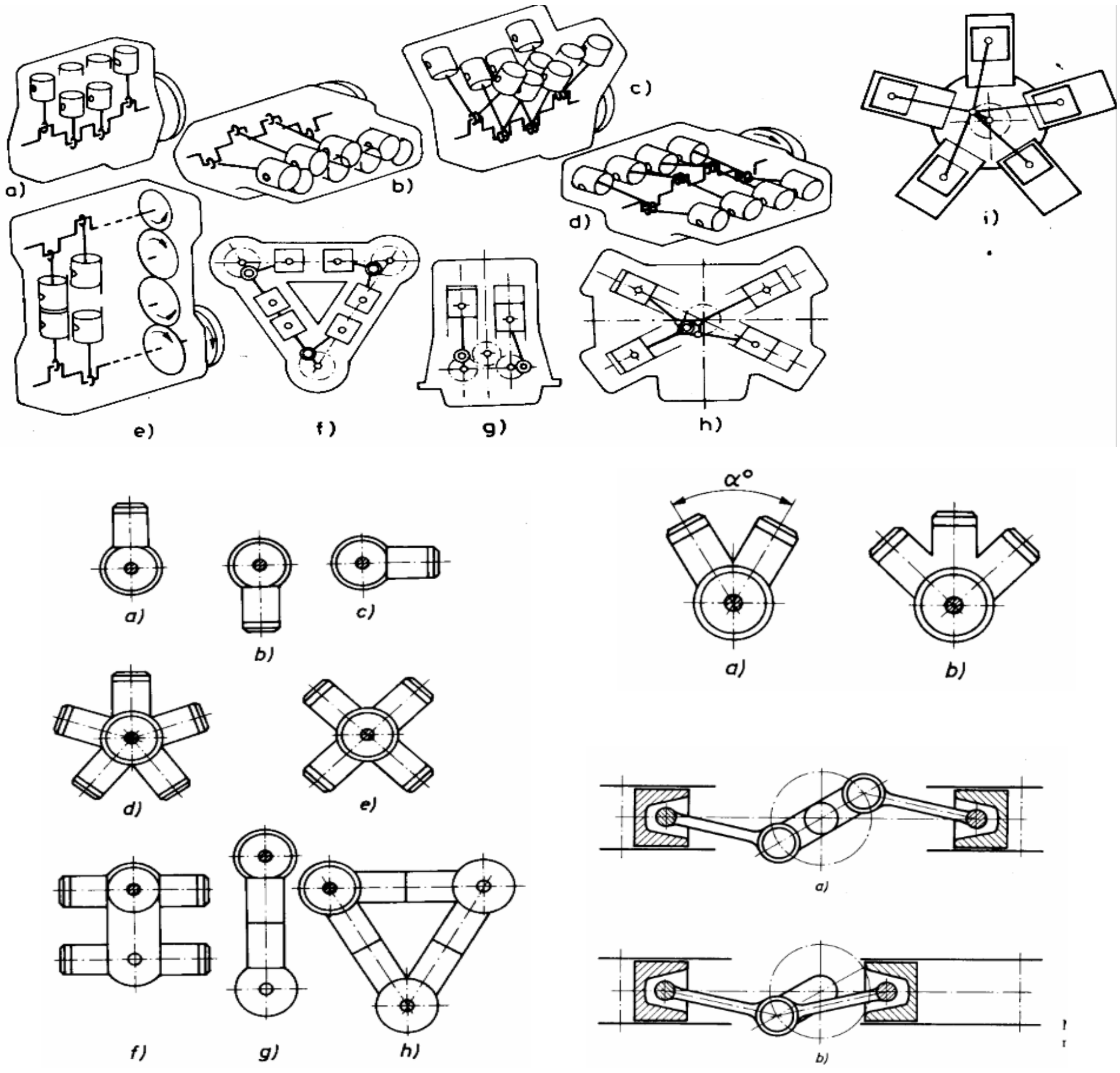


Figure (5): *Cylinders Arrangement*

7. Method of cooling as:

1. Air cooled engine
2. Water cooled engine

8. Air-fuel mixing methods

1. Internal (CIE, GDI (SIE))
2. External (SIE)

1-5. Classification of Internal Combustion (IC) engines

There are several methods of classification of IC engines:

One of the most important is the principle of operation.

It can be four stroke engine or two stroke engine (one stroke is half revolution of the crankshaft)

The four stroke engine operation:

(one cycle is two crankshaft revolution)

Strokes:

I. **Induction**: piston is moving down, inlet valve is open, and air, or air and fuel mixture flow into the cylinder

II. **Compression**: piston is moving up, both valve are closed fluid inside the cylinder is being compromised At TDC: Ignition and after it combustion.

III. **Expansion**: piston is moving down both valve are closed

IV. **Exhaust**: piston is moving up and exhaust valve is open flue gas flow out

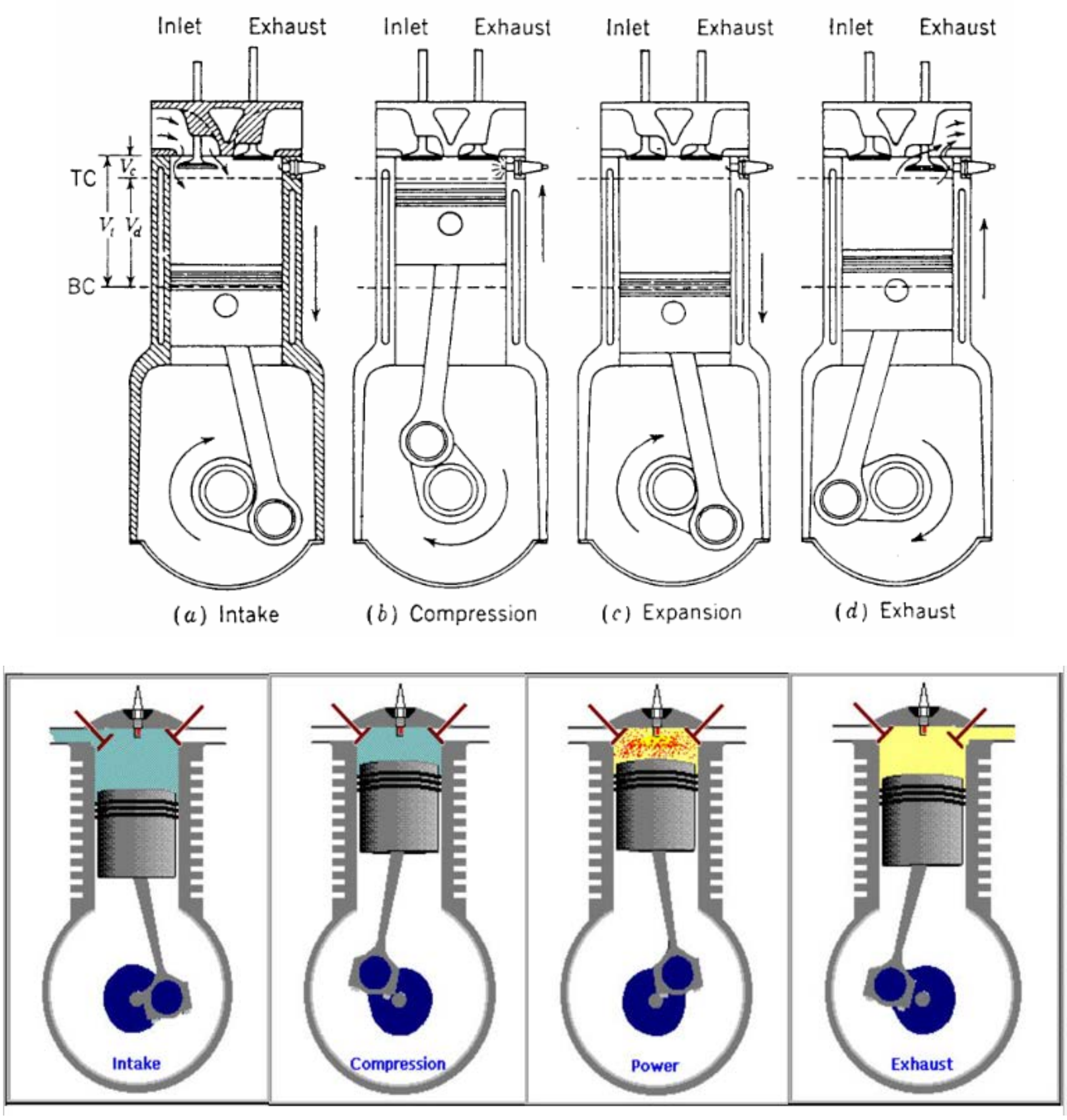


***Figure (6):** The four stroke engine operation*

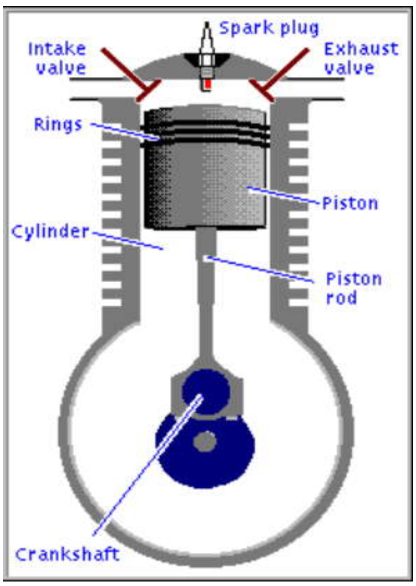


***Figure (7):** The main parts engine*

Advantages

1. More torque

This is the most important reasons why people choose a **4-stroke engine**. The two-stroke boasts its speed and power, but the four-stroke shows extra torque. It is more reliable and quitter.

2. Last longer

3. Run much cleaner than 2 strokes

4. More efficient use of gas

Disadvantages

1. Complicated

2. Half as powerful as two stroke engines

3. More expensive than 2 stroke

Two-Stroke Engine

1. It's called a two-stroke engine because there is a **compression stroke** and then a **combustion stroke**.
2. In a four-stroke engine, there are separate intake, compression, combustion and exhaust strokes.
3. Mix special two-stroke oil in with the gasoline
4. Mix oil in with the gas to lubricate the crankshaft, connecting rod and cylinder walls
5. Note: If you forget to mix in the oil, the engine isn't going to last very long!

Advantages

1. Two-stroke engines do not have valves, which simplifies their construction and lowers their weight.
2. Two-stroke engines fire once every revolution, while four-stroke engines fire once every other revolution. This gives two-stroke engines a significant power boost.

3. Two-stroke engines can work in any orientation, which can be important in something like a chainsaw. A standard four-stroke engine may have problems with oil flow unless it is upright, and
4. These advantages make two-stroke engines lighter, simpler and less expensive to manufacture.
5. Two-stroke engines also have the potential to pack about twice the power into the same space because there are twice as many power strokes per revolution.

Disadvantages

1. Two-stroke engines don't last nearly as long as four-stroke engines. The lack of a dedicated lubrication system means that the parts of a two-stroke engine wear a lot faster.
2. Two-stroke oil is expensive, and you need about 4 ounces of it per gallon of gas. You would burn about a 3.7 litres of oil every 1600km if you used a two-stroke engine in a car.
3. Two-stroke engines are not fuel efficient, so you would get fewer miles per gallon.
4. Two-stroke engines produce a lot of pollution

   1) from the combustion of the oil.

   2) Each time a new charge of air/fuel is loaded into the combustion chamber, part of it leaks out through the exhaust port.

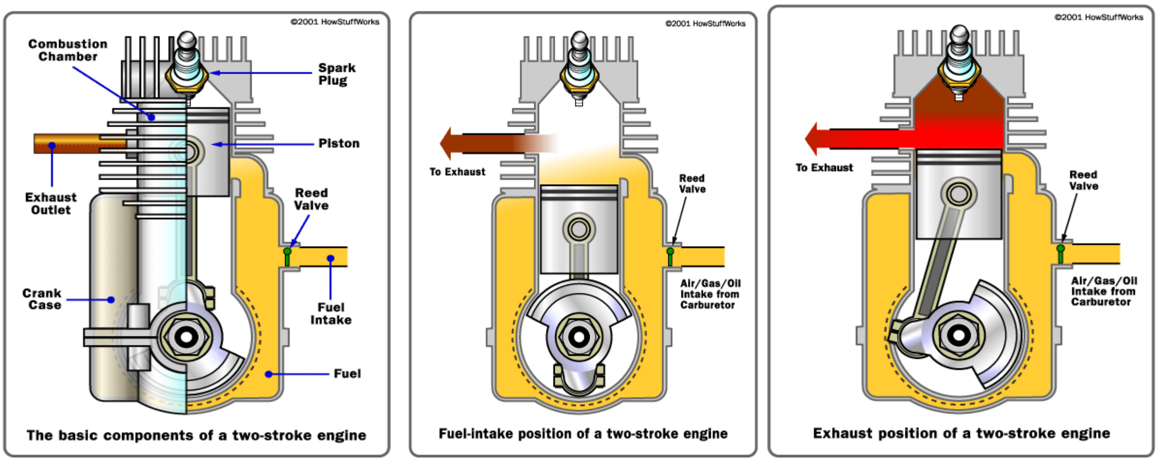


***Figure (8):** The two-stroke engine operation and parts engine*

1-6. Comparison between two stroke and four stroke engines

NO.	Four stroke engine	Two stroke engine
1	One cycle completed in every two revolution of crankshaft	One cycle completed in every revolution of crankshaft
2	More moving parts	Less moving parts
3	More maintenance	Less maintenance
4	Heavy in weight	Light in weight
5	More expensive	Less expensive
6	Produce more pollution	Less pollution
7	Long engine life	Short engine life
8	Not required	Required a mix of oil to lubricate the crankshaft
9	Complex design	Simpler design

Questions

1. What do you mean by I. C. Engine?

2. List down versatile advantages I. C. Engine ?

3. Draw the diagrammatic representation of heat engines ?

4. Draw the Wankel four – process cycle ?

6. Who is the first put the idea into a working design engines ?

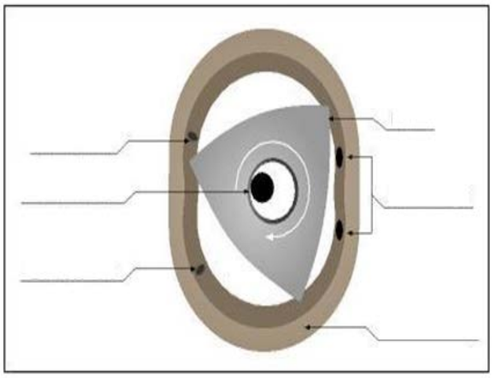
7. Which company produced first rotary power car in 1961 ?

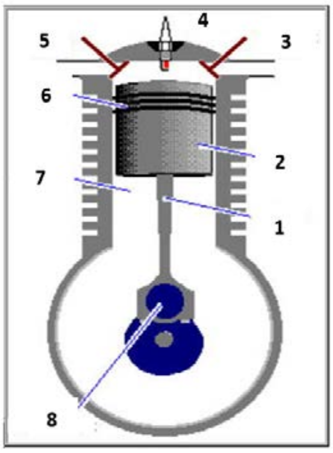
8. What are the two factors severely hurt Wankel engine ?

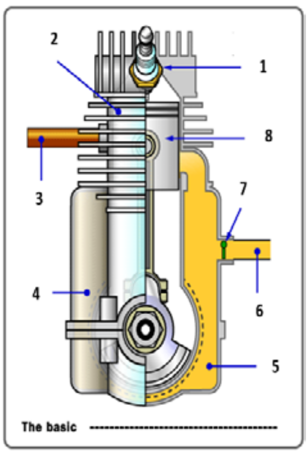
9. What are the advantages of Wankel engines ?

10. What are the disadvantages of Wankel engines ?

11 - What is the basis of classification engine design?
12 - What are the IC engines classification according to:
A - Type of natural of thermodynamic cycles ?
B - Type of fuel used?
C – Number of strokes ?
D – Method of ignitions ?
E – position of the cylinder with drawing ?
F – Number of cycles ?
G –Method of cooling ?
H – Air fuel mixing methods ?
13 – Dissuasion four stroke engine with drawing ?
14 – What are the advantages and disadvantages of four stroke engines ?
15 – Why called two stroke engines ?
16 – What are the advantages and disadvantage of two stroke engines ?
17 – Comparison between the two stroke engines and the four stroke engines ?
18- Put the terms on this figures ?







Chapter 2

Engines Geometry

2. Engine Geometry

2-1. Engine Geometry

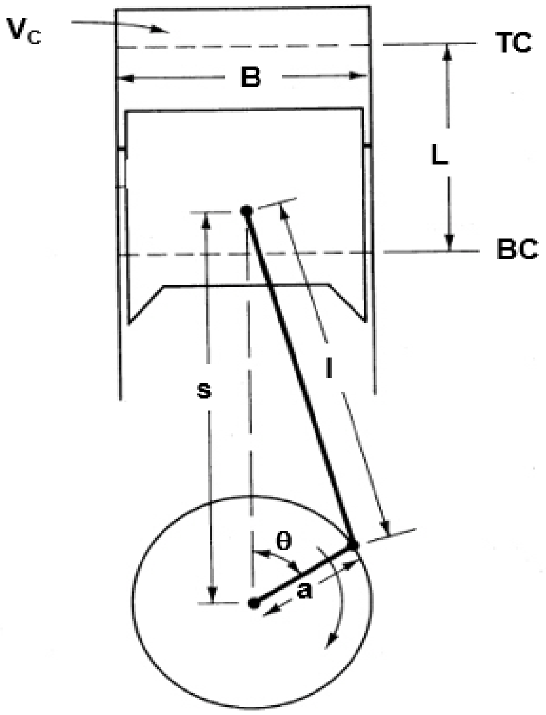


Figure (1): *Engine geometry*

$$s(\theta) = a\cos\theta + \left(l^2 - a^2\sin^2\theta\right)^{1/2}$$

The distance traveled by the piston from its topmost positions (also called as **Top dead center *TDC***), to its bottom most position (or **bottom dead center *BDC***) is called stroke it will be two times the crank radius.

2-1-1. Swept volume

It is denoted by letter ***h***. Units ***mm*** or inches. Now we can calculate the swept volume as follows: **(*L* = 2*r*)**

$$V_S = \left[\frac{\pi . D^2}{4}\right] . L$$

If ***D*** is in **cm** and ***L*** is also in ***cm*** than the units of ***V*** will be cm^3 which is usually written as cubic centimeter or ***c.c***.

2-1-2. Bore

The inner diameter of the engine cylinder is known as bore. It can be measured precisely by a **Vernier caliper** or **bore gauge**. As the engine cylinder wears out with the passage of time, so the bore diameter changes to a larger value, hence the piston becomes lose in the cylinder, and power loss occurs. To correct this problem reboring to the next standard size is done and a new piston is placed. Bore is denoted by the letter ***'B'***. It is usually measured in mm (S.I. units) or inches (metric units). It is used to calculated the engine capacity (**cylinder volume**).

2-1-3. Clearance Volume

The volume above the *T.D.C* is called as clearance volume, this is provided so as to accommodate engine valves etc. this is referred as **(V_c)**. Then total volume of the engine cylinder

$$V = V_S + V_C$$

2-2. Compression Ratio

It is calculated as follows

$$r_k = \frac{Total\,volume}{Clearnce\,volume} = \frac{V_S + V_C}{V_C}$$

2-3. Air-Fuel Ratio

For combustion to take place, the proper ratio of air and fuel must be present in the cylinder.

The **air-fuel ratio** is defined as

$$AF = m_a / m_f$$

The ideal **AF** is about 15:1, with homogenous combustion possible in the range of 6 to 19.

For a **SI** engine the **AF** is in the range of 12 to 18 depending on the operating conditions.

For a **CI** engine, where the mixture is highly non-homogeneous and the AF is in the range of 18 to 70.

2-4. Air standard cycles

Most of the power plant operates in a thermodynamic cycle i.e. the working fluid undergoes a series of processes and finally returns to its original state. Hence, in order to compare the efficiencies of various cycles, a hypothetical efficiency called air standard efficiency is calculated.

If air is used as the working fluid in a thermodynamic cycle, then the cycle is known as "Air Standard Cycle".

To simplify the analysis of *I.C.* engines, air standard cycles are conceived.

Assumptions

1. The working medium is assumed to be a perfect gas and follows the relation

$$P.V = m.R.T \qquad \Rightarrow \ \rho = \frac{m}{V} \quad \Rightarrow \ P = \rho.R.T$$

2. There is no change in the mass of the working medium.
3. All the processes that constitute the cycle are reversible.
4. Heat is added and rejected with external heat reservoirs.
5. The working medium has constant specific heats.

2-5. Power and Mechanical Efficiency

The main purpose of running an engine is to obtain mechanical power.

• Power is defined as the rate of doing work and is equal to the product of force and linear velocity or the product of torque and angular velocity.

• Thus, the measurement of power involves the measurement of force (or torque) as well as speed. The force or torque is measured with the help of a dynamometer and the speed by a tachometer.

The power developed by an engine and measured at the output shaft is called the brake power (***bp***) and is given by,

$$b.p = \frac{2\pi NT}{60}$$

Where, ***T*** is torque in N-m and *N* is the rotational speed in revolutions per minute.

The total power developed by combustion of fuel in the combustion chamber is, however, more than the ***bp*** and is called indicated power (***ip***). Of the power developed by the engine, i.e. ***ip***, some power is consumed in overcoming the friction between moving parts, some in the process of inducting the air and removing the products of combustion from the engine combustion chamber.

2-6. Indicated Power

It is the power developed in the cylinder and thus, forms the basis of evaluation of combustion efficiency or the heat release in the cylinder.

where,

$$IP = \frac{P_{im}\, LANK}{60}$$

im = Mean effective pressure, N/m^2,

L = Length of the stroke, m,

A = Area of the piston, m^2,

N = Rotational speed of the engine, rpm (It is N/2 for four stroke engine), and

k = Number of cylinders.

Thus, we see that for a given engine the power output can be measured in terms of mean effective pressure.

The difference between the **ip** and **bp** is the indication of the power lost in the mechanical components of the engine (due to friction) and forms the basis of mechanical efficiency; which is defined as follows :

$$Mechanical\ efficiency = \frac{bp}{ip}$$

The difference between ***ip*** and ***bp*** is called friction power (***fp***).

$$fp = ip - bp$$

$$\therefore Mechanical\ efficiency = \frac{bp}{(bp + fp)}$$

2-7. Break Mean Effective Pressure (P_{bm})

Mean effective pressure is defined as a hypothetical/average pressure which is assumed to be acting on the piston throughout the power stroke. Therefore,

$$P_{im} = \frac{60000 \times ip}{L.A.N.K}$$

Where;

ip = indicated power (kW)

bp = Break Powder (kW)

P_{im} = indicated mean effective pressure (N/m^2)

P_{bm} = Break mean effective Pressure (N/m^2)

L = length of the stroke ; *A* = area of the piston (m^2)

N = number of power strokes = ***rpm*** for 2-stroke engines

= ***rpm/2*** for 4-stroke

K = no. of cylinder.

An indicated diagram is a graph between pressure and volume. The former being taken on vertical axis and the latter on the horizontal axis. This is obtained by an instrument known as indicator. The indicator diagram are of two types;

(*a*) Theoretical or hypothetical (*b*) Actual.

The theoretical or hypothetical indicator diagram is always longer in size as compared to the actual one. Since in the former losses are neglected. The ratio of the area of the actual indicator diagram to the theoretical one is called diagram factor.

2-8. Mean Effective Pressure (P_m or P_{mef})

Mean effective pressure is that hypothetical constant pressure which is assumed to be acting on the piston during its expansion stroke producing the same work output as that from the actual cycle.

Mathematically,

$$P_M = \frac{Work\ output}{Swept\ volume} = \frac{W_{net}}{(V_1 + V_2)}$$

It can also be shown as

$$P_M = \frac{Area\ of\ Indicator\ diagram}{Length\ of\ diagram} \times Const.$$

The constant depends on the mechanism used to get the indicator diagram and has the units ***bar/m***.

2-9. Indicated Mean Effective Pressure (P_{im})

Indicated power of an engine is given by

$$P_m = \frac{P_{im}\ L.A.N.K}{60000} \quad \Rightarrow \quad P_{im} = \frac{60000 \times ip}{L.A.N.K}$$

2-10. Combustion Efficiency

The time for combustion in the cylinder is very short so not all the fuel may be consumed or local temperatures may not support combustion . A small fraction of the fuel may not react and exits with the exhaust gas. The **combustion efficiency** is defined as actual heat input divided by theoretical heat input:

$$\eta_c = \frac{Q_{in}}{m_f\ .Q_{HV}}$$

Where Q_{in} = heat added by combustion per cycle

m_f = mass of fuel added to cylinder per cycle

Q_{HV} = heating value of the fuel (chemical energy per unit mass)

2-11. Thermal Efficiency

η_t = work per cycle / heat input per cycle

$\eta_t = W / Q_{in} = W / (\eta_c \, m_f \, Q_{HV})$

or in terms of rates…

η_t = power out/rate of heat input

$$\eta_t = P/\dot{Q}_{in} = P/(\eta_c \, \dot{m}_f \, Q_{HV})$$

Thermal efficiencies can be given in terms of brake or indicated values.

Indicated thermal efficiencies are typically 50% to 60% and brake thermal efficiencies are usually about 30% .

2-12. Arbitrary Efficiency

$$\eta_f = \frac{W_b}{m_f \,.\, Q_{HV}} = \frac{P_b}{m'_f \, Q_{HV}}$$

Note: h_f is very similar to h_t, the difference is that h_t takes into account only the actual fuel combusted in the engine.

Recall that $sfc = \dot{m}_f / P_b$

Thus $\eta_f = 1 / (sfc \, Q_{HV})$

2-13. Volumetric Efficiency

Due to the short cycle time and flow restrictions less than ideal amount of air enters the cylinder.

The effectiveness of an engine to induct air into the cylinders is measured by the volumetric efficiency which is the ratio of actual air inducted divided by the theoretical air inducted:

$$\eta_v = \frac{m_a}{\rho_a . V_d} = \frac{n_R . m_a}{\rho_a . V_d . N} \quad .$$

where r_a is the density of air at atmospheric conditions P_o, T_o for an ideal gas $r_a = P_o / R_a T_o$ and R_a = *0.287 kJ/kg-K* (at standard conditions r_a = 1.181 kg/m^3)

Typical values for WOT are in the range 75%-90%, and lower when the throttle is closed.

2-14. Engine performance measurement.

1. **Volumetric efficiency** - The amount of air/fuel mixture taken into the cylinder on the intake stroke. The ratio is determined by the amount of air/fuel mixture that actually enters the cylinder to the amount that could possibly enter.

Example: A cylinder can hold 0.034 ounces of air. The engine is running at a high speed and 0.027 ounces get in so the volumetric efficiency is 0.027/0.034 or 80%. The volumetric efficiency should be at least 50% at high speeds.

2. Ways to increase volumetric efficiency

a. Widen intake ports and passages and keep ports and passages as straight as possible.

b. Smooth the inside surfaces of the intake ports.

c. Use more carburetors or carburetors with a larger air passages.

L. **Brake horsepower (bhp)** - Horsepower output or power delivered in the engine.

M. **Indicated horsepower (ihp)** - The power that develops inside the combustion chamber of the engine during the combustion process.

N. **Friction horsepower (fhp)** - The power required by the engine to overcome the friction of the moving parts in the engine (the greatest loss occurs when the rings scrape on the cylinder walls).

The relationship is bhp = ihp - fhp.

O. **Engine efficiency** - The relationship between power delivered and power that could be obtained.

1. **Mechanical efficiency** - The relationship between bhp and ihp.

Mechanical efficiency = bhp / ihp

Example: At a certain speed the bhp of an engine is 116 and the ihp is 135.

The mechanical efficiency is $\frac{116}{135}$ = .86 or 86%.

The remaining 14% is loss due to fhp.

2. **Thermal efficiency** - The relationship between power output and the energy of the fuel burned.

   a. Losses due to:

      1) Combustion carried away by the cooling system.

      2) Exhaust gases.

EXAMPLES

WORKED EXAMPLE No.1

A 4 stroke carburetted engine runs at 2 500 rev/min. The engine capacity is 3 litres. The air is supplied at 0.52 bar and 15^oC with an efficiency ratio of 0.4. The air fuel ratio is 12/1. The calorific value is 46 MJ/kg. Calculate the heat released by combustion.

SOLUTION

Capacity = 0.003 m^3
Volume induced = 0.003 x (2 500/60)/2 = 0.0625 m^3/s
Using the gas law pV = mRT we have
Ideal air
m = pV/RT = 0.52 x 10^5 x 0.0625/(287 x 288) = 0.03932 kg/s

Actual air
m = 0.03932 x 0.4 = 0.01573 kg/s.

Mass of fuel
m_f = 0.01573/12 = 0.00131 kg/s

Heat released

Φ = calorific value x m_f = 46 000 kJ/kg x 0.00131 kg/s = 60.3 KW

WORKED EXAMPLE No.2

A 4 cylinder, 4 stroke engine gave the following results on a test bed.

Shaft Speed N = 2 500 rev/min
Torque arm R = 0.4 m
Net Brake Load F = 200 N
Fuel consumption m_f = 2 g/s
Calorific value = 42 MJ/kg
Area of indicator diagram A_d = 300 mm^2
Pressure scale S_p = 80 kPa/mm
Stroke L = 100 mm
Bore D = 100 mm
Base length of diagram Y = 60 mm.

Calculate the B.P., F.P., I.P., MEP, η_{BTh}, η_{ITh}, and η_{mech},

SOLUTION

$$N = 2500 \ rev./\min. \quad ; \quad R = 0.4\,m \quad ; \quad F = 200\,N \ \Rightarrow \ T = \frac{F}{R} = \frac{200}{0.4} = 500 \ N.m$$

$$m_f = 2\,g/s = \frac{2}{1000} = 0.002\,kg/s$$

$$C.V = 42\,MJ/kg = 42000 \ kJ/kg \quad ; \quad A_d = 300 \ mm^2 \quad ; \quad S_p = 80 \ kPa/mm$$

$$L = 100 \ mm = 0.1 \ m \quad , \quad D = 100 \ mm = 0.01 \ m \ \Rightarrow \ r = \frac{D}{2} = \frac{0.1}{2} = 0.03 \ M$$

$$A = \pi.r^2 = 3.14 \times 0.05^2 = 0.00785 \ m^2 \quad ; \quad Y = 60 \ mm$$

$$BP = \frac{2\pi.N.T}{60} = \frac{2 \times 3.14 \times 2500 \times 500}{60} = 20.94\,KW$$

$$\phi = m_f \times C.V = 0.002 \times 42000 = 84 \;\; KW \;\; heat \; released$$

$$IP = \frac{PLAN}{60}$$

$$P = MEP = \frac{A_d}{Y} \times S_P = \frac{300}{60} \times 80 = 400 \;\; KW$$

$$IP = \frac{400 \times 0.1 \times 0.00785 \times 2500}{60} \times \frac{1}{2} = 6.54\,KW \;\; per \; cylinder$$

$$Fourc \; cylinders \;\; IP = 6.54 \times 4 = 26.18 \;\; KW$$

$$FP = IP - BP = 26.18 - 20.94 = 5.24 \; KW$$

$$\eta_{BTh} = \frac{BP}{\phi} \times 100\,\% = \frac{20.94}{84} \times 100\,\% = 24.9\,\%$$

$$\eta_{rTh} = \frac{IP}{\phi} \times 100\,\% = \frac{26.18}{84} = 31.1\,\%$$

$$\eta_{mech} = \frac{BP}{IP} 100\,\% = \frac{20.94}{26.18} \times 100\% = 80\,\%$$

The remaining power = 100% - 80% = 20 % is loss due to ***fhp***.

Questions

Q 1 / Draw the engine geometry with equation to calculate S(ɵ) ?

Q 2 / define swept volume with writing the equation?

Q 3 / What is meant by bore in I.C. engines?

Q 4 / Define the clearance volume with writing the equation?

Q 5 / Write the following equations:

a. Compression ratio
b. Air – fuel ratio
c. Perfect gas equation
d. Brake horse power
e. Indicated horse power
f. Friction power
g. Indicated mean effective pressure
h. Mean effective pressure
i. Combustion efficiency
j. Thermal efficiency
k. Arbitrary Efficiency
l. Volumetric Efficiency

Q 6 / Define the following

a. Compression ratio
b. Air – fuel ratio
c. Brake horse power
d. Indicated horse power
e. Friction power
f. Indicated mean effective pressure
g. Mean effective pressure
h. Combustion efficiency
i. Thermal efficiency
j. Volumetric Efficiency

Chapter 3

Structural Components

3. STRUCTURAL COMPONENS

3-1. Fixed parts engine

3-1-1. Cylinder Block

Engine blocks are generally manufactured from Cast Iron or Aluminum Alloy.

a. Part of engine frame that contains cylinders in which piston moves
b. Supports liners & head

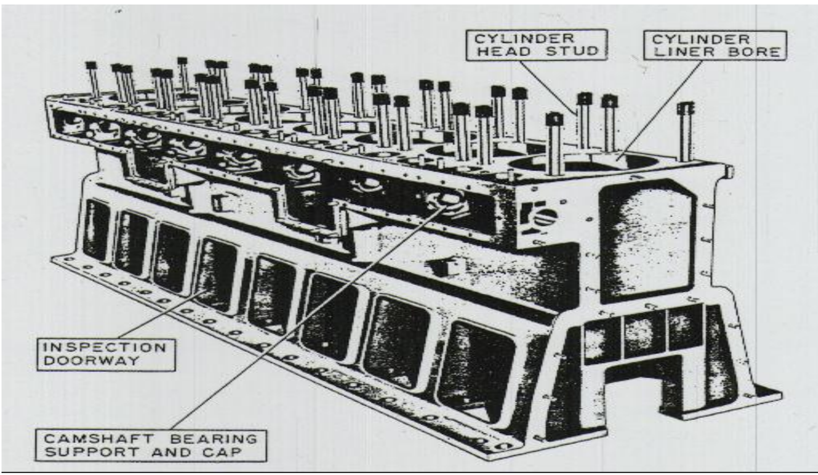


Figure (1): *The cylinder block in the engine*

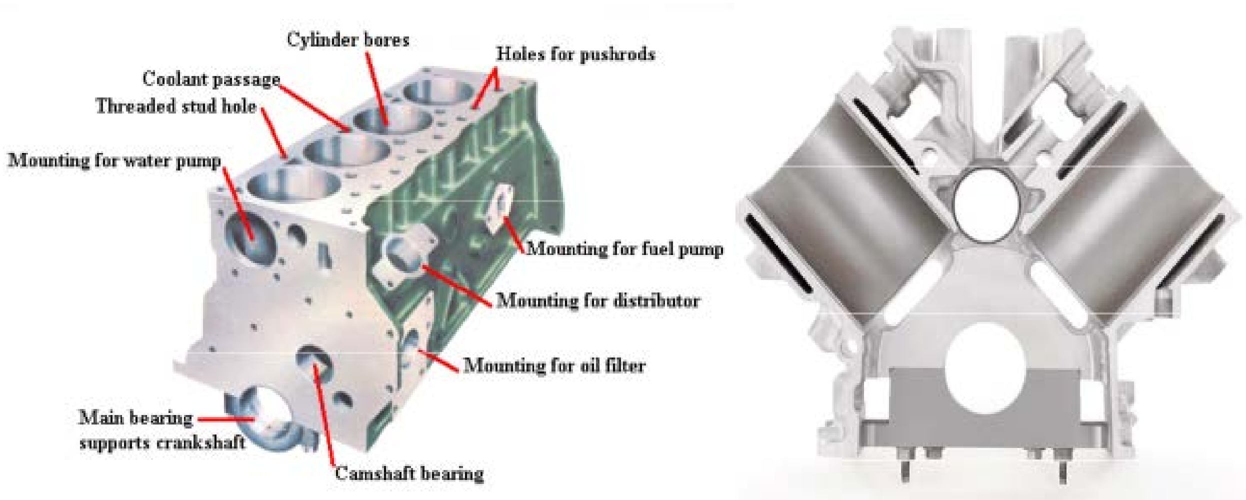


Figure (2): *A typical inline four cylinder and V – block*

3-1-2. Cylinder Head/Assembly

Cylinder heads are produced from Cast Iron , from Cast Iron or Aluminum Alloy . It carries Valve sit and Valve mechanisms, inlet and exhaust manifolds.

Part that covers and encloses the Cylinder. It contains cooling fins or water jackets and the valves.

Some engines contains the camshaft in the cylinder head.

1. Serves to admit, confine, and release fuel/air
2. Cover to cylinder block
3. Supports valve train

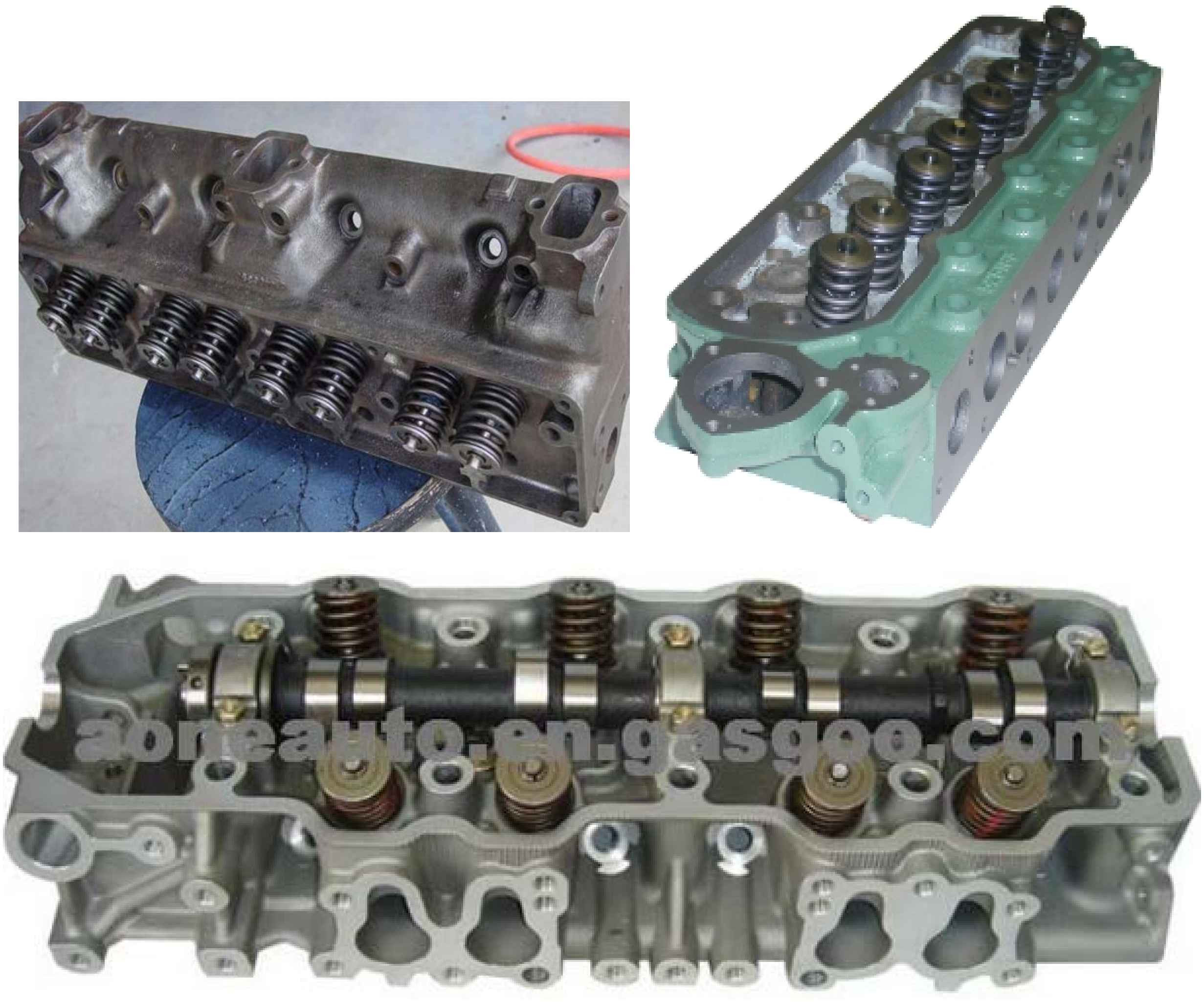


Figure (3): *A Cylinder head in the engine*

Different cylinder head design

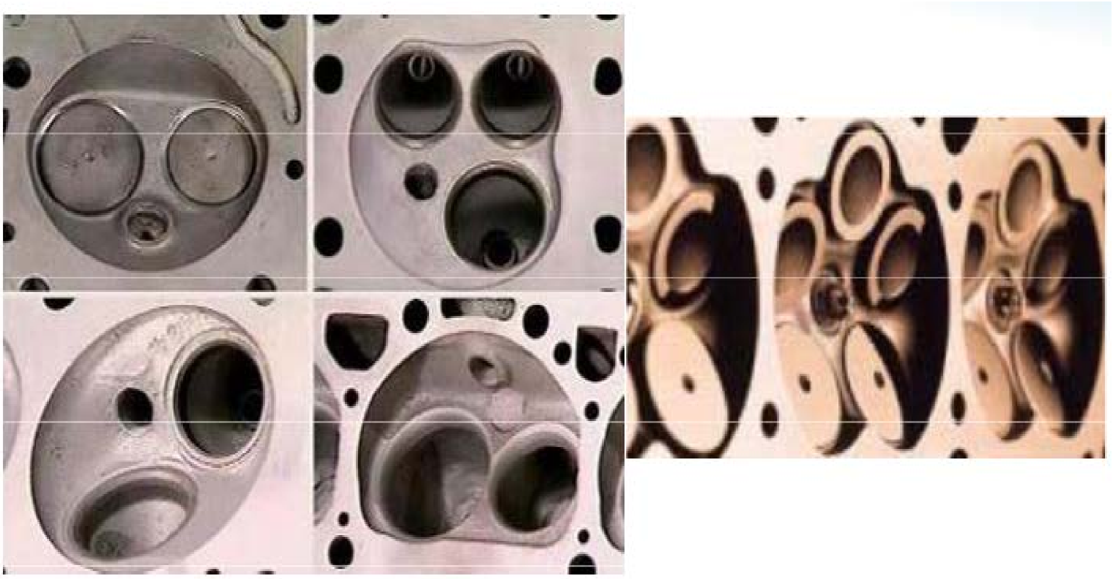


Figure (4): Different cylinder head design

- Modern designs incorporate:
  - Squish area – the un-concaved area in the combustion chamber designed to promote turbulence.
  - Quench area – an area in the combustion chamber designed to cool the air/fuel mixture.

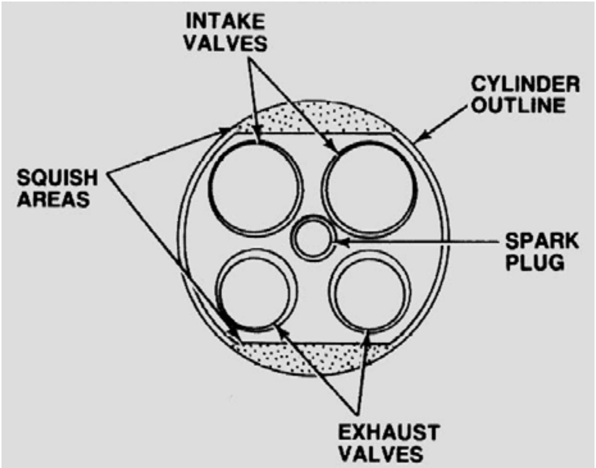


Figure (5): *Shown Squish area and Quench area*

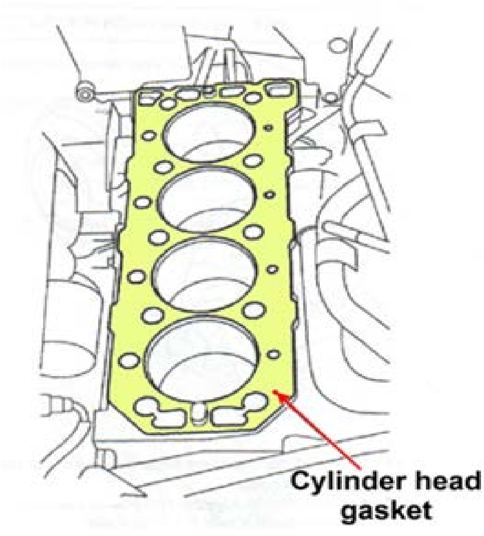
3-1-3. Gasket

The head gasket forms a seal between the engine block and the cylinder head. This seals both the combustion chamber and the coolant passages in your engine. This means your head gasket has to seal both extremely hot high pressure combustion gases as well as engine coolant which can be anywhere from cold ambient temperatures to the normal operating temperature of your engine. Do to the wide range of temperatures and relatively large surface area, it is not unusual for head gaskets to develop leaks over time.

It is important to know the other symptoms so you can accurately diagnose a head gasket problem.

Blown Head Gasket Symptoms:

1. Coolant leaking externally from bellow the exhaust manifold
2. White smoke from the exhaust pipe
3. Overheating engine
4. Bubbles in the radiator or coolant overflow tank
5. White milky oil
6. Significant loss of coolant with no visible leaks



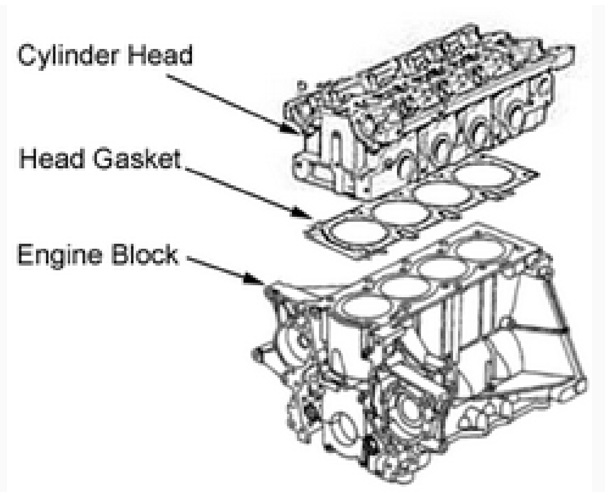


Figure (6): *Shown cylinder head gasket*

3-1-4. Manifolds

There are two types of manifold which are installed on cylinder head

1. Inlet manifold
2. Exhaust manifold

Figure (7): Shown inlet manifold and exhaust manifold

3-1-5. Spark Plug

It provides the means of ignition when the gasoline engine's piston is at the end of compression stroke, close to Top Dead Center(TDC) .

Figure (8): Shown Spark plug

The difference between a "hot" and a "cold" spark plug is that the ceramic tip is longer on the hotter plug

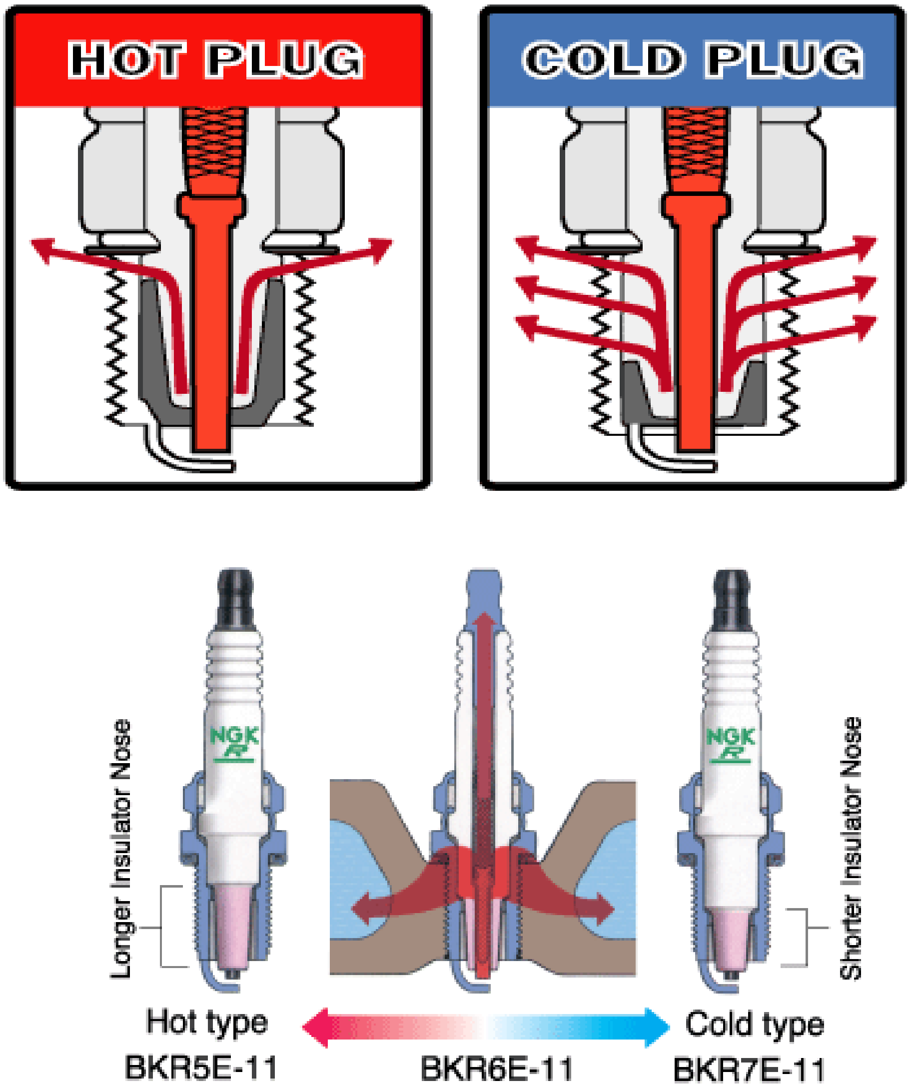


Figure (9): *Shown different between hot and cold Spark plug*

Causes of Carbon Fouling:

1. Continuous low speed driving and/or short trips
2. Spark plug heat range too cold
3. Air-fuel mixture too rich
4. Reduced compression and oil usage due to worn piston rings / cylinder walls
5. Over-retarded ignition timing
6. Ignition system deterioration

3-2-6. Engine carter

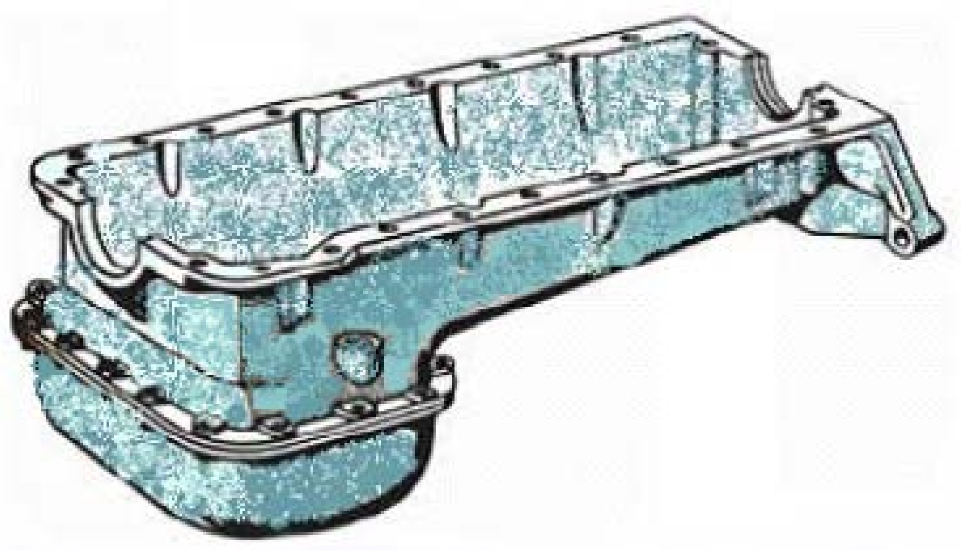


Figure (10): *Engine carter*

3-1-7. Cylinder head cover

Figure (11): *Cylinder head cover*

3-2. Moving parts engine

Three Groups – according to motion

1. Reciprocating only (pistons and valves)

2. Reciprocation & rotary (connecting rods)
3. Rotary only (crankshafts and camshafts)

3-2-1. Crankshaft

Definition: The main driving shaft of an engine that receives reciprocating motion from the pistons and converts it to rotary motion. Together, the crankshaft and the connecting rods transform the pistons' reciprocating motion into rotary motion.

The crankshaft converts the linear (reciprocating) motion of the piston into a rotary motion that can be transmitted through the driveline.

Crank throws are position around the centerline in a manner that provides smooth power output..

The firing order of the engine is determined by the crankshaft as well as the camshaft.

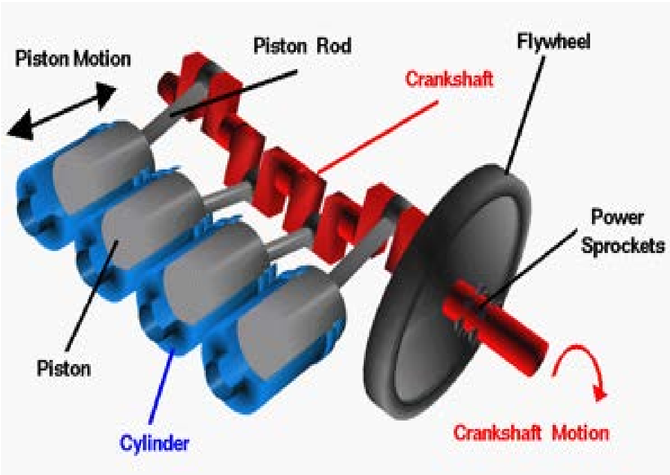
Crankshaft Materials

1. Cast iron
2. Cast steel
3. Forged steel
4. Nodular iron
5. Malleable iron
6. Billet steel
7. Titanium

Crankshaft Steels

1. 1010 --Standard alloy steel, one step above nodular iron.
2. 1053 --One strength-level
3. better alloy, used in high-performance crankshafts.
4. 5140 --Excellent alloy steel, a compromise between strength and price.
5. 4150 --Much more durable alloy, yet not quite as strong as 4340 alloy.

6. 4340 --Premium-grade alloy steel used for ultimate-performance cranks in both forgings and billet. Standard for aerospace and diesel industries



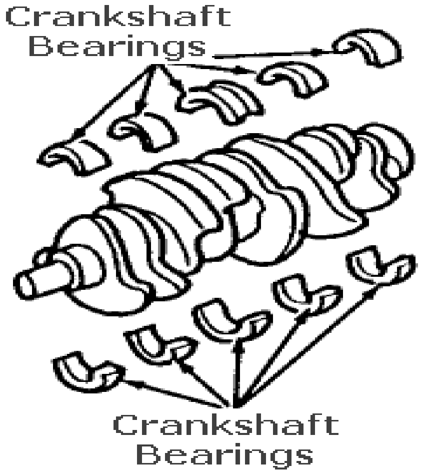
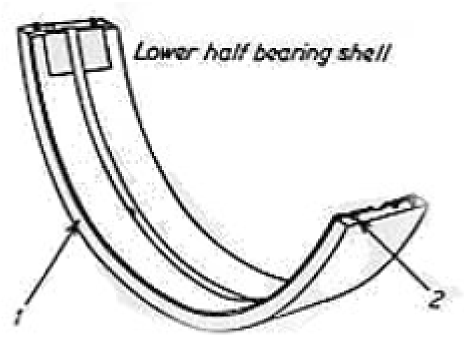


Figure (12): *Crankshaft in the engine*

3-2-2. Bearing



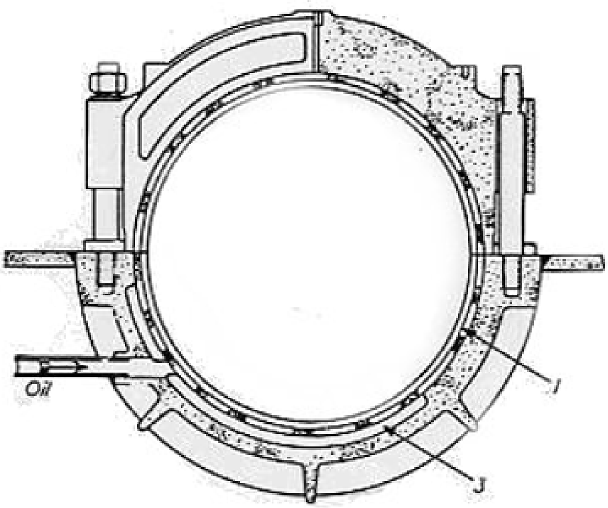


Figure (13): *Bearing Crankshaft*

3-2-3. Connecting Rod

Connecting rods are produced from Steel , Aluminum or Titanium by casting or forging technics . They carries pistons and connecting rod on crank from crank journals.

.

Figure (14): *Connecting rod in the engine*

3-2-4. Piston

A movable part fitted into a cylinder, which can receive and transmit power. Through connecting rod, forces the crankshaft to rotate.

- **Piston Design Considerations**

Pistons must

1. Contain cylinder pressure
2. Transmit the pressure created by combustion to force on the connecting rod

3. Provide a place for oil control and compression rings to be located

4- Be rigid enough to not deform under the tremendous pressures and forces encountered

5- Be ductile enough to absorb pressure peaks and not shatter

6- Retain the proper shape under the extreme temperatures encountered

7- Piston Construction

Materials

7-2- Cast iron (used in very old engines)

7-3- Cast aluminum (most common)

7-4- Forged aluminum

7-5- Hypereutectic alloys (high silicon content aluminum)

7-6- Carbon Graphite (being tested)

Piston Construction

1. Piston head
   a. Round
   b. Approx. .040 undersized
2. Ring grooves
3. Ring lands
4. Drain holes and slots
5. Wrist pin boss
6. Reinforcing struts – cast pistons contain steel struts to control expansion and aid in wrist pin support
7. Lock ring grooves – for full-floating piston pins
8. Piston skirt
9. Full skirt

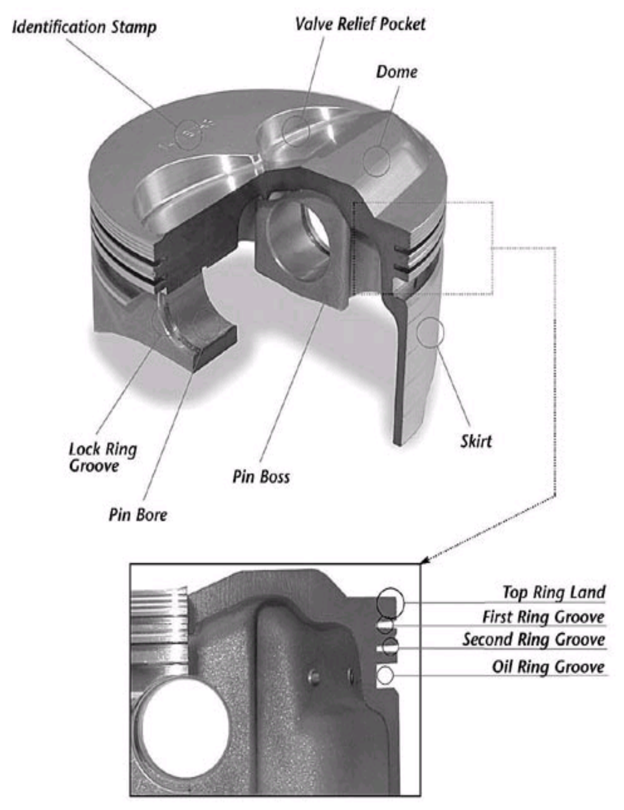


***Figure (15)**: Piston Construction*

10.Partial skirt

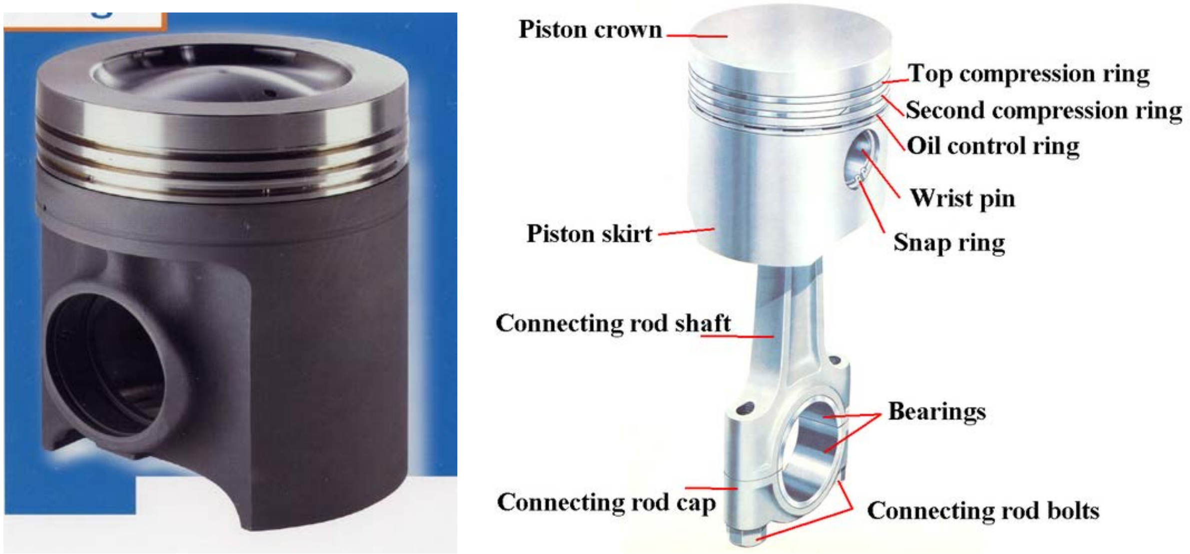


Figure (16): *Parts of the piston with connecting rod*

3-2-5. Piston Rings

Piston Ring End Gap Recommendations

Most piston ring manufacturers recommend a minimum end gap of .004 inches times the bore diameter for the top piston compression ring. So for a 4 inch bore, the standard end gap would be .016 inches.

For the 2nd compression ring, the standard end gap recommendation for most stock engines is typically .005 in. x the bore diameter. So for a 4 inch bore, the minimum end gap on the 2nd ring would be .020 inches.

For a modified street performance engine that generates more horsepower and heat, the end gap should be opened up a bit to compensate for increased thermal expansion. The recommendation would be a minimum top compression piston ring end gap of.0045 to .005 inches times the bore diameter. For a 4 inch bore, the ring end gap on the top ring should be increased to .018 to .020 inches.

The 2nd compression ring on a modified street performance engine, the recommendation is typically open up the end gap to .0055 inches times the bore diameter. For a 4 inch bore, the 2nd ring would be gapped to .022 inches.

For a nitrous or blown racing engine, the top ring end gap should be opened up to as much as .006 or .007 inches times the bore diameter. Now we're looking at a 2nd ring end gap of .024 to .028 inches in an engine with 4 inch bores.

The 2nd ring on a nitrous or blown motor, the recommended ring end gap is even wider: .0063 to .0073 inches times the bore (or 0.025 to 0.029 inches with a 4 inch bore).

The recommended ring end gap for oil rings regardless of the engine application is typically .015 inches.

Some racers believe that opening up the 2nd end gap even more (say an additional 10%) can improve overall ring sealing by allowing trapped gases to escape before they blow past the top ring and cause ring flutter at high rpm (say above 5000 to 6000 rpm).

NOTE: These recommendations are rules of thumb only. Always follow the end gap specifications recommended by the piston ring supplier or engine manufacturer.

Four stroke*:* Three rings Top two are compression rings (sealing the compression pressure in the cylinder) and the third is an oil ring (scrapes excessive oil from the cylinder walls) .

Two Stroke*:* Two Rings Both the rings are Compression rings

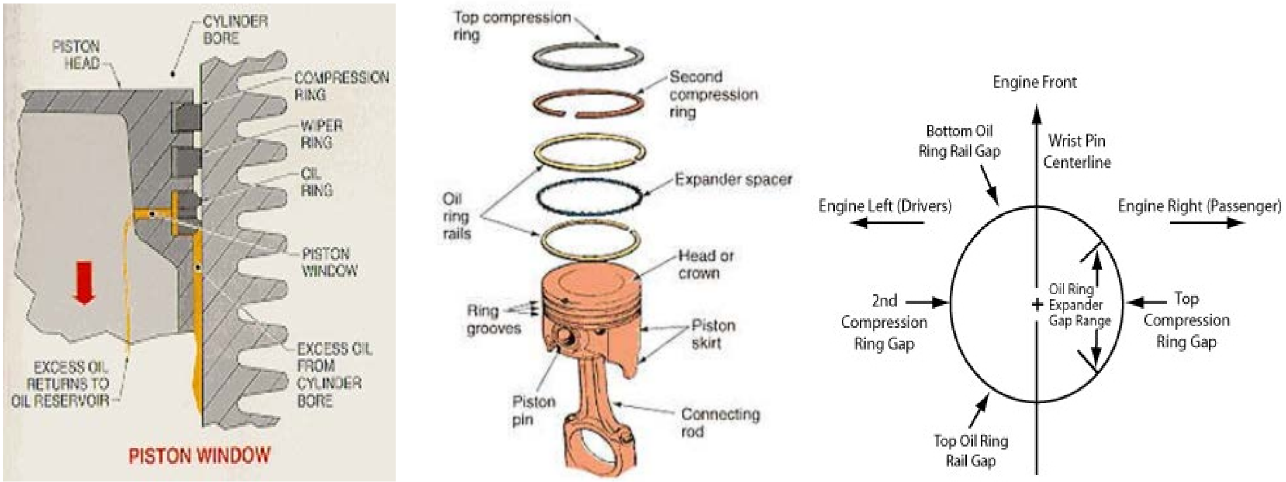


Figure (17): *Ring orientation diagram*

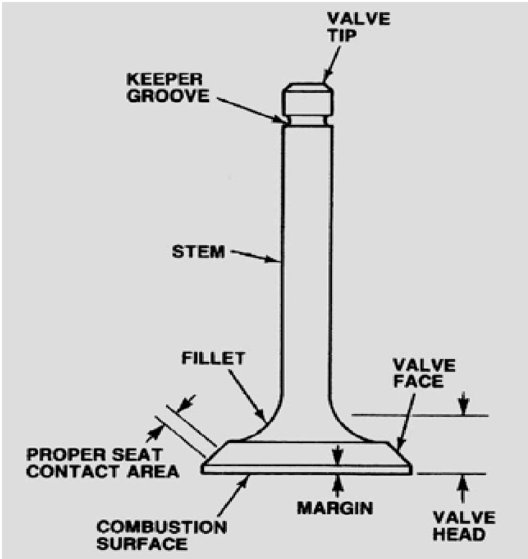
3-2-6. Valves

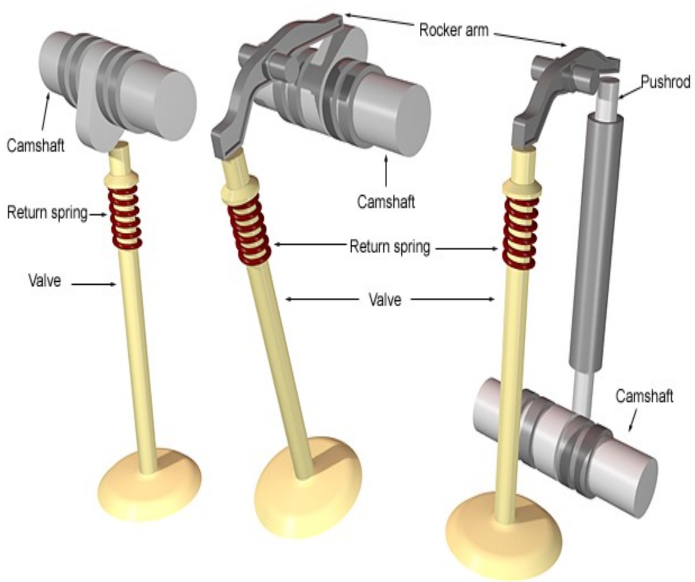
Valves are produced from produced from forged steel.

There are two types:

1. Exhaust valves
2. Intake valves

- **Exhaust Valve** lets the exhaust gases escape the combustion Chamber. (Diameter is smaller than Intake valve).
- **Intake Valve** lets the air or air fuel mixture to enter the combustion chamber. (Diameter is larger than the exhaust valve.





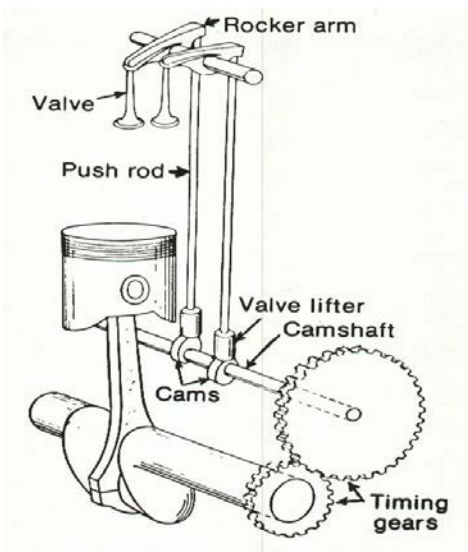


Figure (18): *Valves in the engine*

a. Valve Springs: Keeps the valves close

b. Valve Lifters: Rides the cam lobe and helps in opening the valves.

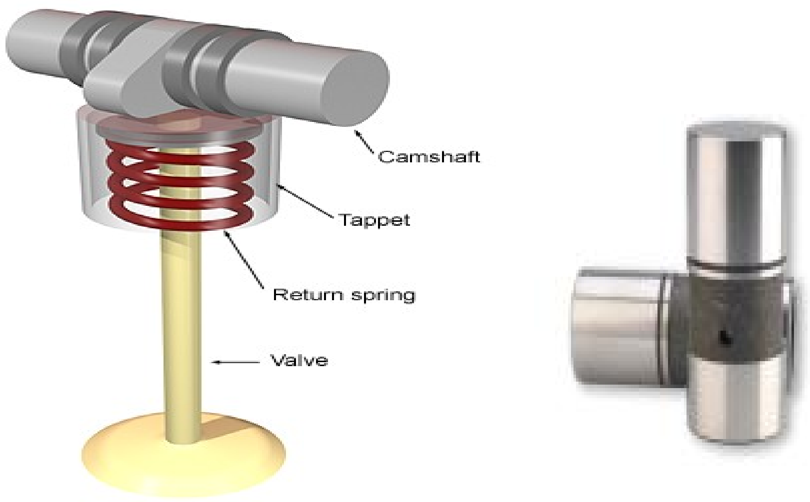


Figure (19): *Valve springs and valve lifters in the engine*

Different arrangement of valve and camshaft

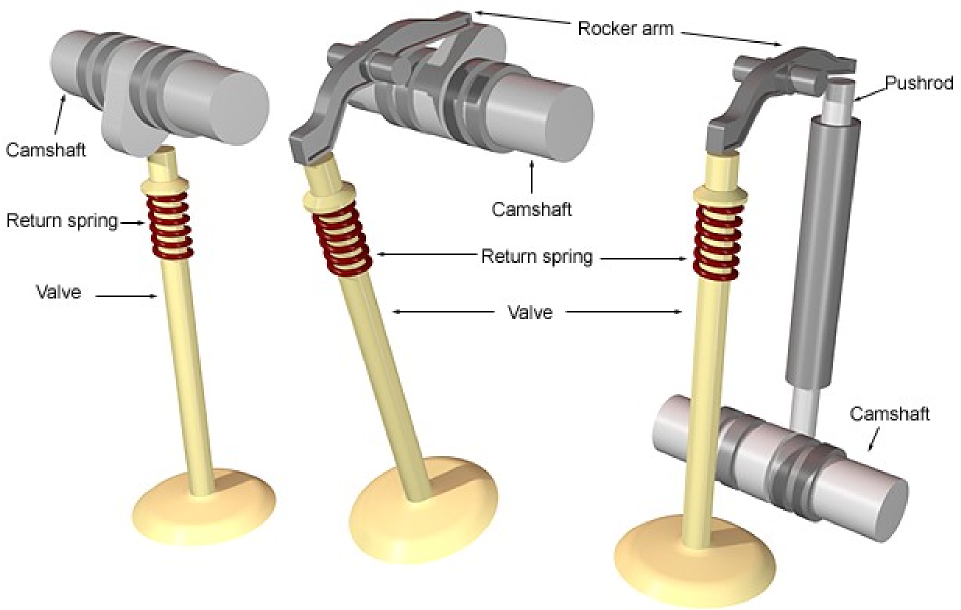


Figure (20): *Different arrangement of valve and camshaft*

3-2-7. Camshaft

Camshafts are produced from forged steel. There is a lobe for each valve for each valve on the camshaft.
The "brain" of the engine

a. Controls valve train operation
b. Rotates at ½ crankshaft speed
c. Along with the crankshaft it determines firing order
d. Along with
e. the induction and exhaust systems it determines the useful rpm range of the engine

Camshaft design

- Features
  1. Max lift or nose
  2. Flank
  3. Opening clearance ramp
  4. Closing clearance ramp
  5. Base circle
  6. Exhaust opening timing figure
  7. Exhaust closing timing figure
  8. Intake opening timing figure
  9. Intake closing timing figure
  10. Intake to exhaust lobe separation

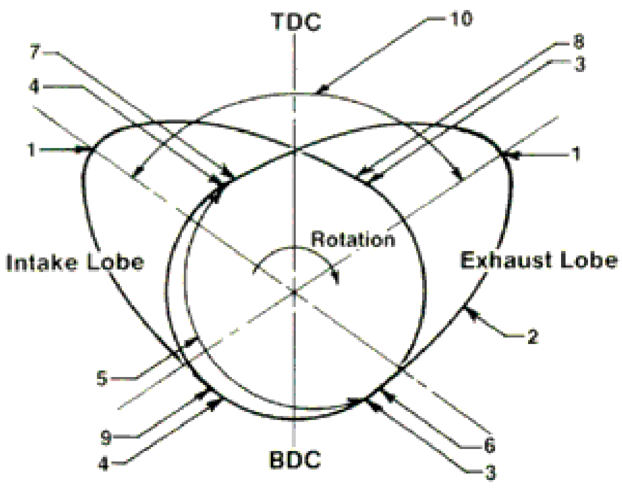


Figure (21): *Camshaft design*

Camshaft Measurements

1. Lift
2. Duration
3. Lobe separation angle
4. Valve overlap
5. Intake valve opening (IVO)
6. Intake valve closing (IVC)
7. Exhaust valve opening (EVO)
8. Exhaust valve closing (EVC)

Lift

1. Lobe lift is the distance the lifter moves in one direction
2. Lobe lift is the difference in measurement between the nose of the lobe and the base circle of the lobe
3. Valve lift is what most people are taking about when they refer to lift and is simply lobe lift multiplied by the rocker arm ratio

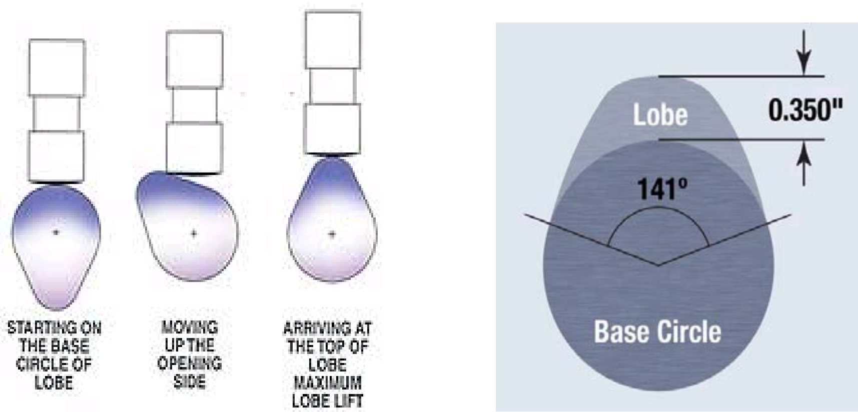


Figure (22): *Lobe lift camshaft*

a) Increasing the lift opens the valve further. This reduces the restriction to airflow at the valve and allows air to flow more freely into the cylinder.
b) At some point the valve can be opened to a point at which the port is the valve

c) is no longer the greatest restriction to airflow, and at that point opening the valve further will not increase airflow.

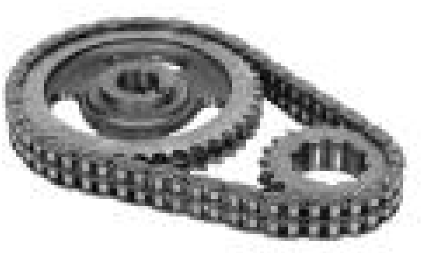
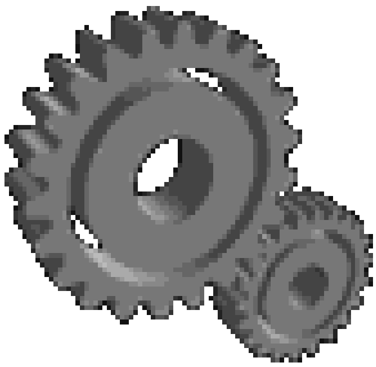
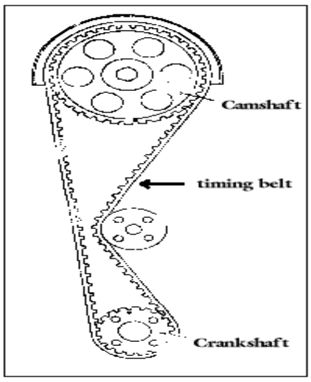
d) The distance a valve can be opened is limited by duration, rocker arm ratio, lifter design, camshaft design and valve to piston clearance.

3-2-8. Valve Timing

a. The ratio of cam to crank sprocket is 2:1

b. For every two revolutions of

c. Crankshaft, the Camshaft turns once.

Chain driven ***Gear drive*** ***Belt drive***

Figure (23): *The valve timing in the engine*

3-2-9. Flywheel

Energy stored in a high velocity composite wheel. When desired, energy is transferred to the axle via clutch

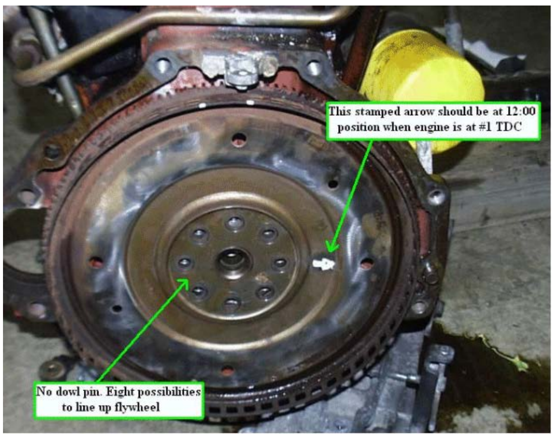



Figure (24): *Shown flywheel in engine*

Questions

Q 1 / What is the cylinder block ?

Q2/ What are the head assembly ?

Q3/ What are the meaning by:

a. Squish area b. Quench area

Q4/ What is the Gasket ?

Q5/ List head Gasket symptoms ?

Q6/ What are the Manifolds ?

Q7/ What is the Spark plug ?

Q8/ What are the three groups moving parts engine according to motion ?

Q9/ Define the crankshaft?

Q10/ Mention materials types used manufacturing Crankshaft?

Q11/ List standard crankshaft steels?

Q12/ Mention parts crankshaft?

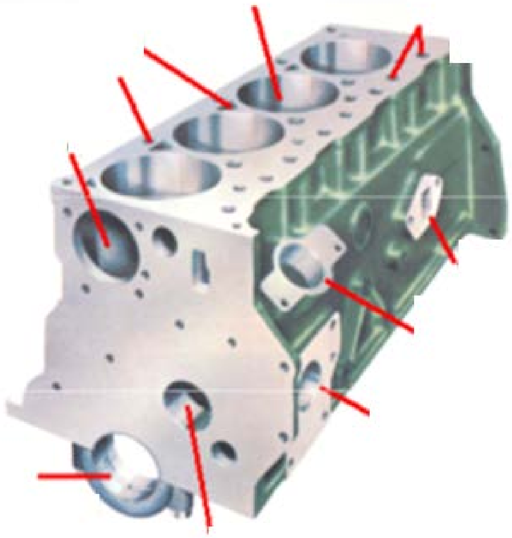
Q13/ Define the piston that is used in engine?

Q14/List down materials types used manufacturing Piston ?

Q15/ What are the piston construction?

Q16/ How many rings used in two stroke engine and four stroke engine?

Q17/ Put the terms in in the following figures?



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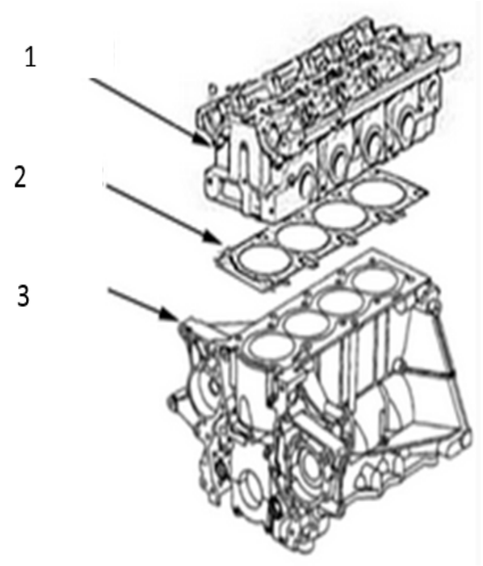

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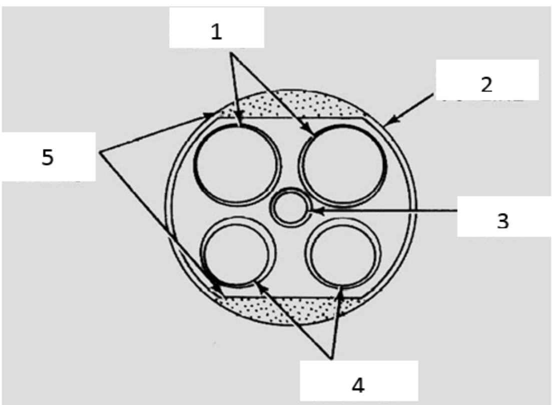

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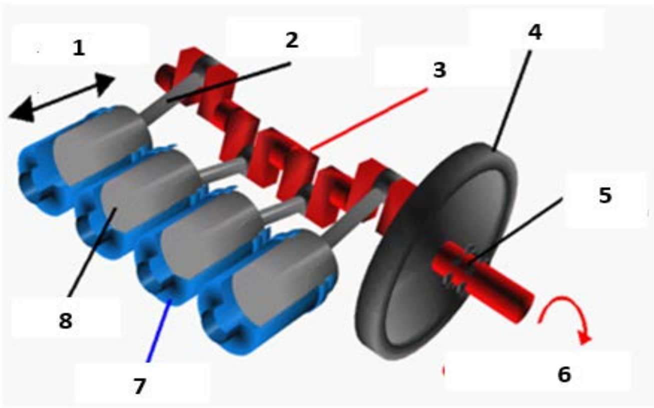

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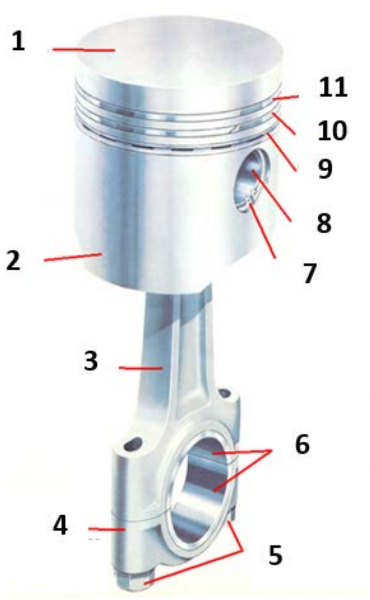

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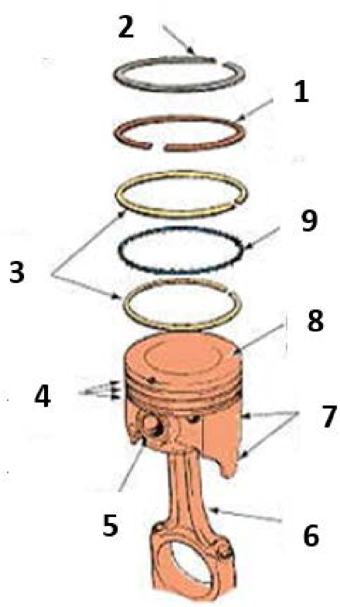

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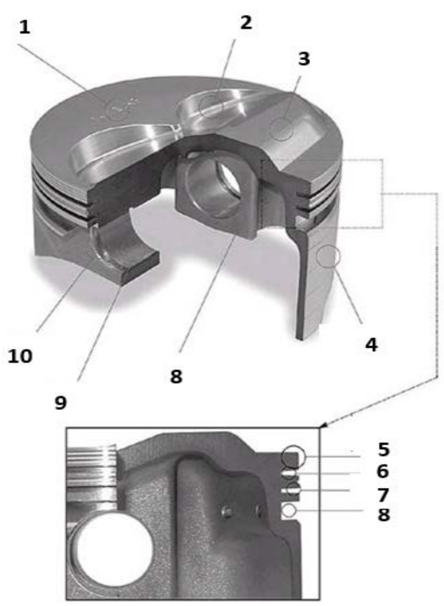


g)

Chapter 4

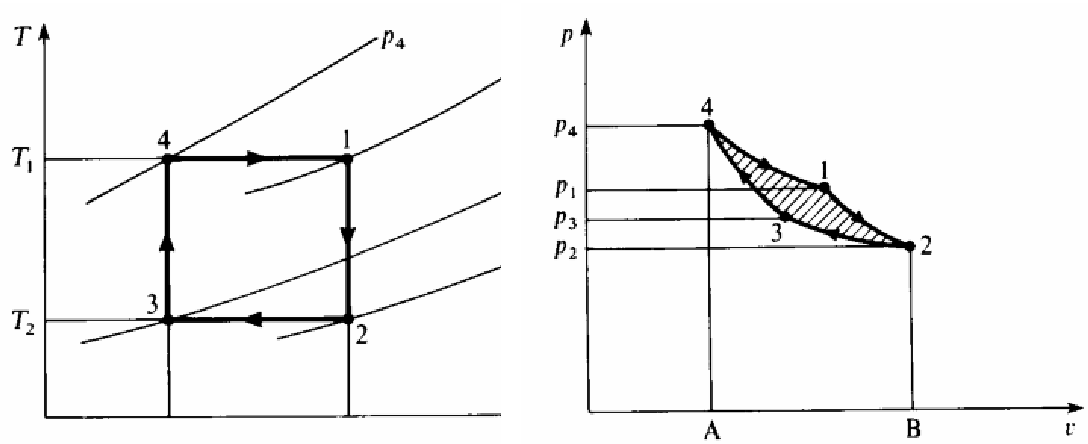
AIR - STANDARD CYCLES

4. AIR - STANDARD CYCLES

4-1. Ideal cycles.

To produce mechanical power from heat power, a cycle process is needed.
Carnot cycle would be ideal, but there is no machine which is working according to the Carnot cycle.

<u>At the Carnot cycle:</u>



Where:

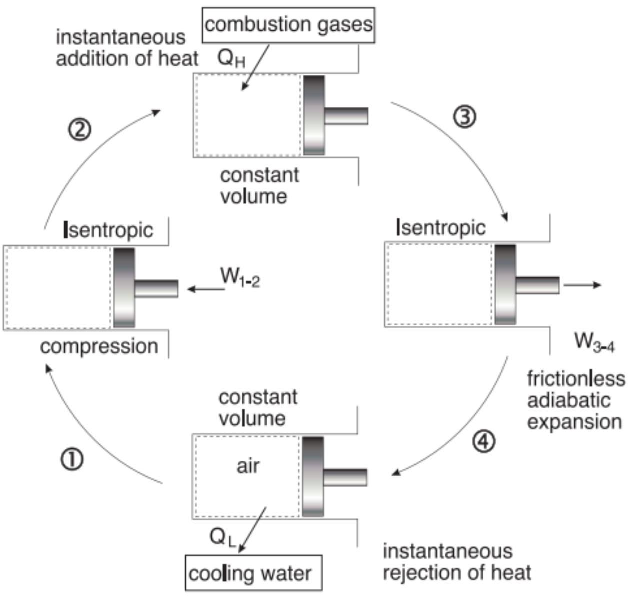
Process 1 to 2 - isentropic expansion

Process 2 to 3 is isothermal heat rejection

Process 3 to 4 is isentropic compression

Process 4 to 1 is isothermal heat supply

Efficiency of the cycle:



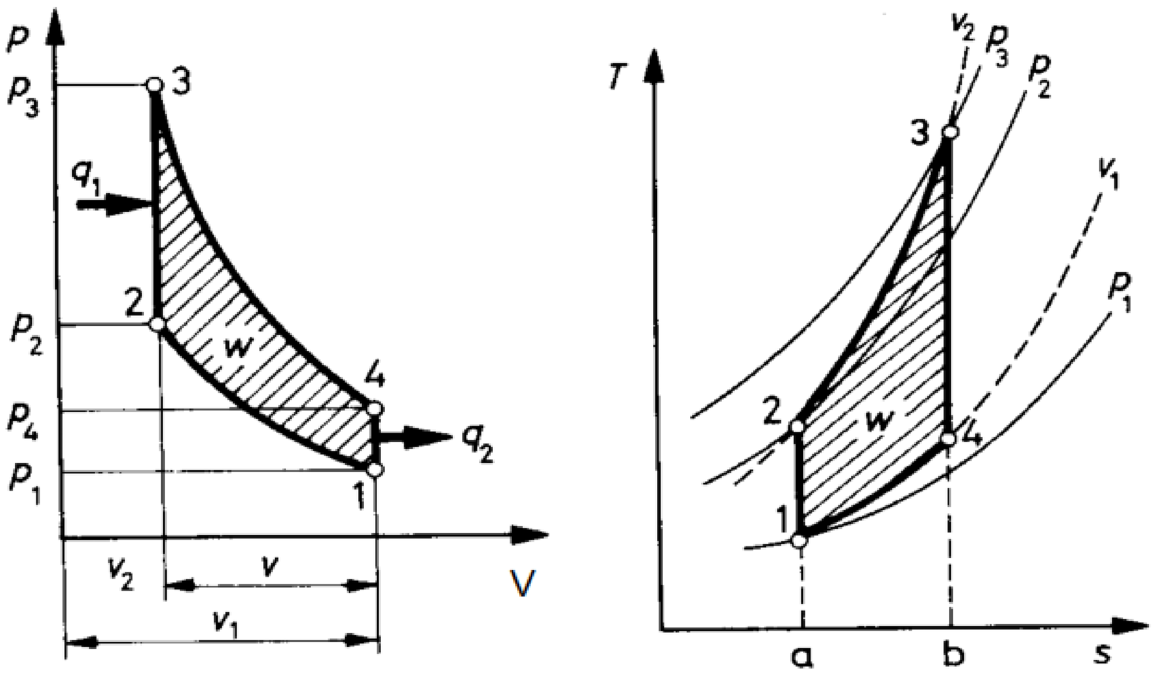
$$\eta = \frac{-\sum W}{Q_1} = \frac{\sum Q}{Q_1} = \frac{(T_1 - T_2)\cdot(s_B - s_A)}{T_1 \cdot (s_B - s_A)} = 1 - \frac{T_2}{T_1}$$

There are other types of cycles and machines which are connected with each other. These are called Reciprocating Internal Combustion Engines.

4-2. Otto cycle.

This cycle is named after Nicholas August Otto, who invented his first engine in 1876.

The ideal air standard Otto cycle:



Where:

Process 1 to 2 is isentropic compression

Process 2 to 3 is reversible constant volume heating

Process 3 to 4 is isentropic expansion

Process 4 to 1 is reversible constant volume cooling

Efficiency of the cycle:

$$\eta = \frac{-\sum W}{Q_1} = \frac{\sum Q}{Q_1} = \frac{c_v(T_3 - T_2) - c_v(T_4 - T_1)}{c_v(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{1}{\varepsilon^{\kappa - 1}}$$

where: $\varepsilon = \frac{V_1}{V_2} = \frac{\text{swept volume(V)} + \text{clearance volume}(V_2)}{\text{clearance volume}(V_2)}$ - the compression ratio

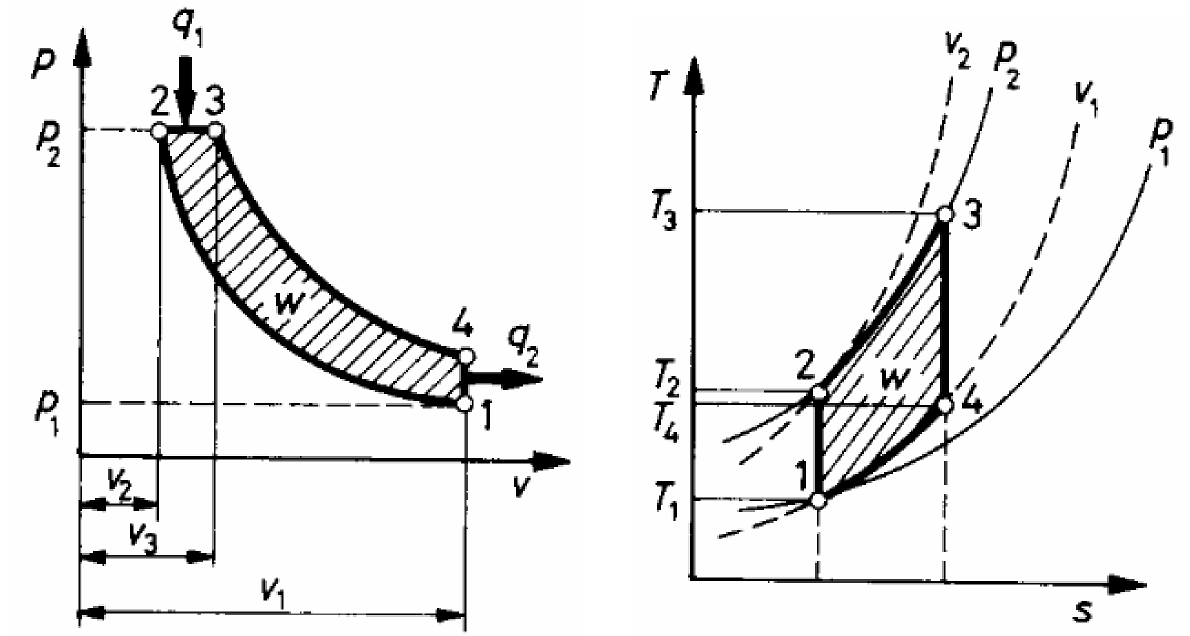
and since processes 1-2 and 3-4 are isentropic:

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\kappa-1} = \left(\frac{v_4}{v_3}\right)^{\kappa-1} = \frac{T_3}{T_4} = \varepsilon^{\kappa-1}$$

4-3. The Diesel (or Constant Pressure) Cycle

The original engine was invented by Rudolf Diesel in 1892.

4-3-1. The Ideal air standard Diesel cycle:



Where:

Process 1 to 2 is isentropic compression

Process 2 to 3 is reversible constant pressure heating

Process 3 to 4 is isentropic expansion

Process 4 to 1 is reversible constant volume cooling

Efficiency of the cycle:

$$\eta = \frac{-\sum W}{Q_1} = \frac{\sum Q}{Q_1} = \frac{c_p(T_3 - T_2) - c_v(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{1}{\varepsilon^{\kappa-1}} \cdot \frac{\rho^\kappa - 1}{\kappa \cdot (\rho - 1)}$$

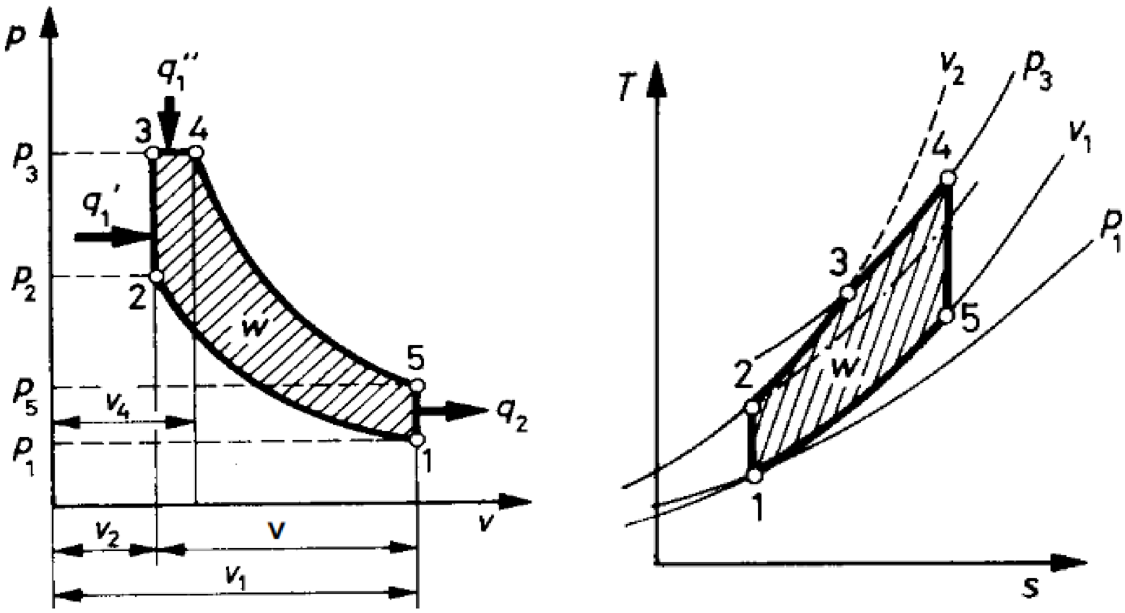
where: $\varepsilon = \frac{V_1}{V_2} = \frac{\text{swept volume(V) + clearance volume(}V_2\text{)}}{\text{clearance volume(}V_2\text{)}}$ - the compression ratio

swept volume: $V = V_1 - V_2$

$\rho = \frac{v_3}{v_2}$ - cut off ratio

4-3-2. The Dual-combustion cycle:

In this process, heating divided in two parts, a constant volume, and a constant pressure part:



Where:

Process 1 to 2 is isentropic compression

Process 2 to 3 is reversible constant volume heating

Process 3 to 4 is reversible constant pressure heating

Process 4 to 5 is isentropic expansion

Process 5 to 1 is reversible constant volume cooling

Efficiency of the cycle:

$$\eta = \frac{-\sum W}{Q_1} = \frac{\sum Q}{Q_1} = \frac{c_v(T_3 - T_2) + c_v(T_4 - T_3) - c_v(T_5 - T_1)}{c_v(T_3 - T_2) + c_v(T_4 - T_3)} = 1 - \frac{1}{\varepsilon^{\kappa - 1}} \cdot \frac{\rho^{\kappa} \cdot \lambda - 1}{(\lambda - 1) + \kappa \cdot \lambda \cdot (\rho - 1)}$$

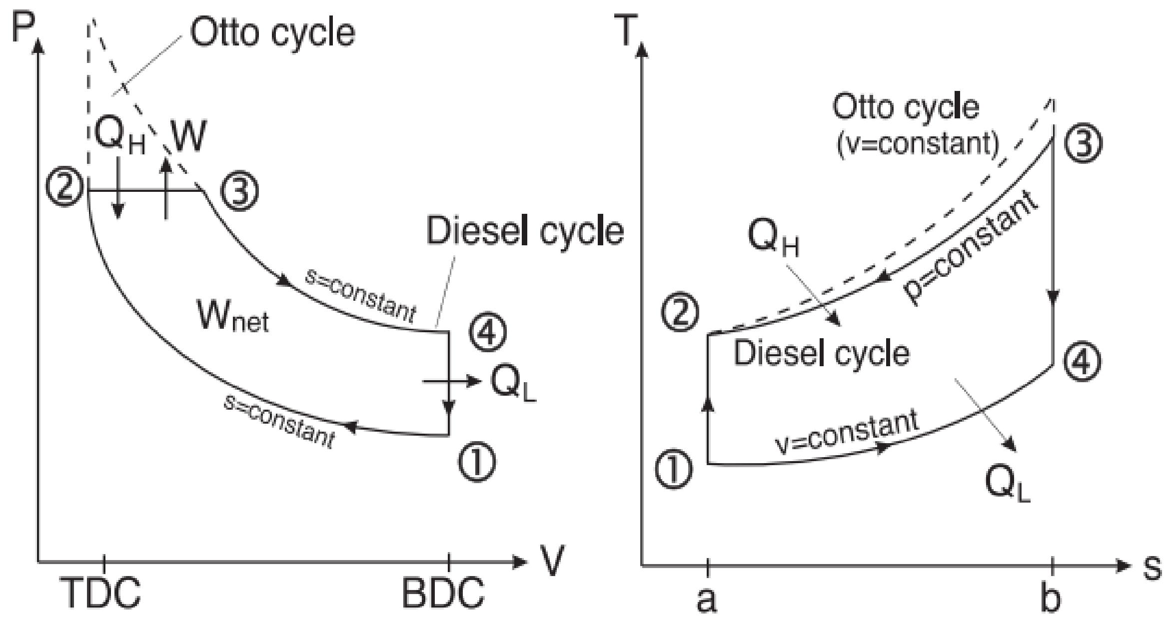
where: $\boldsymbol{\varepsilon} = \frac{V_1}{V_2} = \frac{\text{swept volume(V)} + \text{clearance volume}(V_2)}{\text{clearance volume}(V_2)}$ - the compression ratio

$\boldsymbol{\lambda} = \frac{p_3}{p_2}$ - pressure ratio

$\boldsymbol{\rho} = \frac{v_4}{v_3}$ - cut off ratio

4-4. Comparison of the Otto and the Diesel Cycle

1. $\eta_{Otto} > \eta_{Diesel}$ for the same compression ratio
2. but a diesel engine can tolerate a higher ratio since only air is compressed in a diesel cycle and spark knock is not an issue
3. direct comparisons are difficult



Solution examples

Example (1)

Calculate the thermal efficiency and compression ratio for an automobile working on otto cycle. If the energy generated per cycle is thrice that of rejected during the exhaust. Consider working fluid as an ideal gas with $\gamma = 1.4$ *(May–01)*

Sol.: Since we have

$$\eta_{otto} = (Q_1 - Q_2)/Q_1$$

Where

$$Q_1 = \text{Heat supplied}$$
$$Q_2 = \text{Heat rejected}$$

Given that

$$Q_1 = 3Q_2$$
$$\eta_{otto} = (3Q_2 - Q_2)/3Q_2 = 2/3 = 66.6\%$$

We also have;

$$\eta_{otto} = 1 - 1/(r)^{\gamma - 1}$$
$$0.667 = 1/(r)^{1.4 - 1}$$
$$\boldsymbol{r = (3)^{1/0.4} = 15.59}$$

Example (2)

A 4 stroke diesel engine has length of 20 cm and diameter of 16 cm. The engine is producing indicated power of 25 KW when it is running at 2500 RPM. Find the mean effective pressure of the engine. *(May–03)*

Sol.: Length or stroke = 20 cm = 0.2 m

Diameter or Bore = 16 cm = 0.16 m

Indicating power = 25 KW

Speed = 2500 RPM

Mean effective pressure = ?

$$K = 1$$

Indicated power = $P_{ip} = (P_{mef}.L.A.N.K)/60$

Where $N = N/2$ = 1250 RPM (for four stroke engine)

$$25 \times 10^3 = \{P_{mef} \times 0.2 \times (\pi/4)(0.16)^2 \times 1250 \times 1\}/60$$
$$\boldsymbol{P_{mef} = 298.415 KN/m^2}$$

Example (3)

A 4 stroke diesel engine has L/D ratio of 1.25. The mean effective pressure is found with the help of an indicator equal to 0.85MPa. The engine produces indicated power of 35 HP. While it is running at 2500 RPM. Find the dimension of the engine. ***(Dec–03)***

$$L/D = 1.25$$

$$P_{mef} = 0.85 \text{ MPa} = 0.85 \times 10^6 \text{ N/m}^2$$

$$P_{IP} = 35 \text{ HP} = 35/1.36 \text{ KW (Since 1KW = 1.36HP or 1HP = 1/1.36 KW)}$$

N = 2500 RPM = 1250 RPM for four stroke engine ($N = N/2$ for four stroke)

Indicated power = $P_{ip} = (P_{mef}.L.A.N.K)/60$

$$(35/1.36) \times 10^3 = \{0.85 \times 10^6 \times 1.25D \times (\pi/4)(D)^2 \times 1250 \times 1\}/60$$

$$D = 0.11397\ m = 113.97 \text{ mm}$$

$$L = 1.25\ D = 142.46 \text{ mm}$$

D = 113.97 mm, L = 142.46 mm **.......ANS**

Example (4)

: An engine of 250 mm bore and 375 mm stroke works on otto cycle. The clearance volume is 0.00263 m³. The initial pressure and temperature are 1 bar and 50°C. If the maximum pressure is limited to 25 bar. Find

(1) The air standard efficiency of the cycle.

(2) The mean effective pressure for the cycle. ***(Dec–00)***

Sol.: Given that:

Bore diameter d = 250mm

Stroke length L = 375mm

Clearance volume V_C = 0.00263m³

Initial pressure P_1 = 1bar

Initial temperature P_3 = 25 bar

We know that, swept volume

$$V_s = \frac{\pi}{4} d^2 \cdot L = \frac{\pi}{4} \times (0.25)^2 \times 0.375 = 0.0184077 \text{ m}^3$$

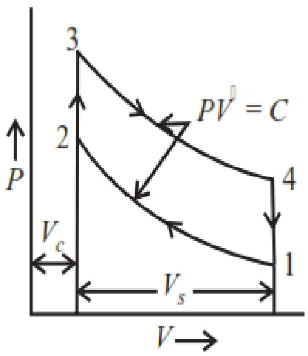


Fig. 4.9

Compression ratio 'r' $= \dfrac{V_c + V_s}{V_c} = \dfrac{0.0184077 + 0.0263}{0.00263} = 8$

∴ The air standard efficiency for Otto cycle is given by

$$\eta_{otto} = 1 - \frac{1}{(r)^{\gamma-1}} = 1 - \frac{1}{(8)^{1.4-1}} = 0.5647 \text{ or } 56.57\%$$

$$\frac{T_2}{T_1} = (r)^{\gamma - 1} = (8)^{1.4 - 1} = 2.297;\ T_2 = (50 + 273) \times 2.297 = 742.06 \text{ K}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} = (8)^{1.4} = 18.38; \; P_2 = 1 \times 18.38 = 18.38 \text{ bar}$$

Process (2 – 3)

$$V_2 = V_3; \; \frac{P_2}{T_2} = \frac{P_3}{T_3}$$

$$T_3 = \frac{25}{18.38} \times 742.06 = 1009.38$$

$$q_s = C_p \, (T_3 - T_2) = 1.005 \, (1009.38 - 742.06) = 268.65 \text{ kJ/kg}$$

$$\eta_{\text{otto}} = \frac{w}{q_s}; \; w = q_s \times \eta_{\text{otto}} = 268.65 \times 0.5647 = 151.70 \text{ kJ/kg}$$

Mean effective pressure $P_m = \dfrac{W}{V_2 - V_2}; \; P_m = \dfrac{151.70 \times m}{0.021 - 0.00263}$

$$m = \frac{P_1 V_1}{RT_1} = \frac{1 \times 10^5 \times 0.021}{0.287 \times 10^3 \times (50 + 273)} = 0.02265$$

$$P_m = \frac{151.70 \times 0.02265}{0.021 - 0.00263} = 187 \text{ kPa} = 1.87 \text{ bar}$$

Example (5)

An Air standard otto cycle has a compression ratio of 8. At the start of compression process the temperature is 26°C and the pressure is 1 bar. If the maximum temperature of the cycle is 1080K. Calculate

(1) Net out put

(2) Thermal efficiency. Take C_V = 0.718 ***(Dec–04)***

Sol.: Compression Ratio $(R_c) = 8$

T_1 = 26°C = 26 + 273 = 299K = 1 bar

T_3 = 1080 k

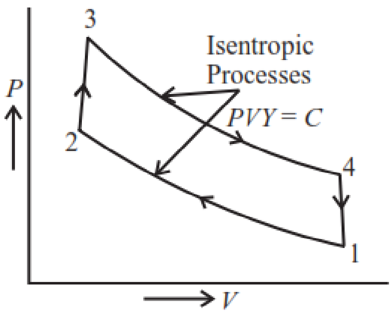


Fig. 4.10

(*i*) Net output = work done per kg of air $= \oint \delta w = \oint \delta q$

Process (1 – 2) Isentropic compression process $\dfrac{T_2}{T_1} = \left(\dfrac{V_1}{V_2}\right)^{\gamma-1}$

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

$$T_2 = T_1 (R_c)^{\gamma - 1} \qquad \left(\because Rc = \frac{P_2}{P_1}\right)$$

$$T_2 = 299 \, (8)^{1.4 - 1} = 299 \, (8)^{0.4} = 299 \times 2.29 = 686.29 \; K$$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}; \; T_4 = \frac{T_3}{R_C^{\gamma-1}} = \frac{10.30}{8^{1.4-1}} = \frac{1080}{(8)^{0.4}}; \; T_4 = \frac{1080}{2.29} = 471.62 \; k$$

Net output = work done per kg of air $= \oint \delta w$

$$\oint \delta w = C_v (T_3 - T_2) - Cv (T_4 - T_1)$$
$$= 0.718 (1080 - 686.92) - 0.718 (471.62 - 299)$$
$$= 0.718 \times 393.08 - 0.718 \times 172.62 = 282.23 - 123.94$$

Net Output = 158.28 KJ/Kg **.......ANS**

(*ii*) $$\eta_{thermal} = \frac{\oint \delta w}{qs} \times 100 = \frac{\text{work done per kg of air}}{\text{heat suplied per kg of air}}$$

$$q_s = Cv (T_3 - T_2) = 0.718 (1080 - 686.29) = 282.23 \text{ KJ/kg}$$

$$\eta \text{ thermal} = \frac{\oint \delta w}{q_s} \times 100 = \frac{158.28}{282.23} \times 100$$

η thermal =56.08% **.......Ans**

Example (6)

A diesel engine operating on Air Standard Diesel cycle operates on 1 kg of air with an initial pressure of 98kPa and a temperature of 36°C. The pressure at the end of compression is 35 bar and cut off is 6% of the stroke. Determine (*i*) Thermal efficiency (*ii*) Mean effective pressure. ***(May–05)***

Sol.: Given that :

$$m = 1 \text{ kg},$$
$$P_1 = 98 \, kPa = 98 \times 10^3 \, Pa;$$
$$T_1 = 36°C = 36 + 273 = 309 \, K,$$
$$P_2 = 35 \text{ bar} = 35 \times 10^5 \, Pa$$
$$V_3 - V_2 = 0.06 V_S$$

For air standard cycle $P_1 V_1 = mRT_1$

$$98 \times 103 \times V_1 = 1 \times 287 \times 309$$
$$V_1 = 1.10 \text{ m3}; \; V_1 = V_2 + V_3 = 1.10$$

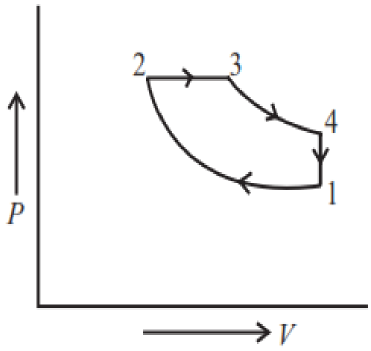


Fig. 4.11

As process 1-2 is adiabtic compression process,

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

$$\frac{T_2}{309} = \left(\frac{35 \times 10^5}{98 \times 10^3}\right)^{\frac{1.4-1}{1.4}} \quad \Rightarrow \quad T_2 = 858.28 \text{ K}$$

$$P_2V_2 = \text{mRT}_2$$

$$35 \times 10^5 \times V_2 = 1 \times 287 \times 858.28;$$

$$V_C = V_2 = 0.07\text{m}^3$$

$$V_s = V_1 = 1.10\text{m}^3$$

However, $$V_3 - V_2 = 0.06\ V_s$$

$$V_3 - 0.07 = 0.06 \times 1.10;\ V_3 = 0.136\text{m}^3$$

Compression ratio $$R_c = \frac{V_1}{V_2} = \frac{1.10}{0.07} = 15.71$$

$$\rho = \frac{V_1}{V_2} = \frac{0.136}{0.07} = 1.94$$

$$\gamma_{\text{thermal}} = 1 - \frac{1}{(R_c)^{\gamma-1}}\left[\frac{(\rho^\gamma - 1)}{\gamma(\rho - 1)}\right]$$

$$= 1 - \frac{1}{(15.71)^{1.4-1}}\left[\frac{(1.94)^{1.4} - 1}{1.4(1.94 - 1)}\right] = 1 - \frac{1}{(15.71)^{0.4}}\left[\frac{253 - 1}{1.4 \times 0.94}\right]$$

$$= 1 - \frac{1}{3.01}\left[\frac{153}{1.32}\right] = 1 - \frac{1}{3.01}(1.16) = 1 - 0.39 = 0.61$$

$$= 1 - \frac{1}{(15.71)^{1.4-1}}\left[\frac{(1.94)^{1.4} - 1}{1.4(1.94 - 1)}\right] = 1 - \frac{1}{(15.71)^{0.4}}\left[\frac{253 - 1}{1.4 \times 0.94}\right]$$

$$= 1 - \frac{1}{3.01}\left[\frac{153}{1.32}\right] = 1 - \frac{1}{3.01}(1.16) = 1 - 0.39 = 0.61$$

P_{mef} is given by $= P_1 \cdot R_c\left[\frac{\gamma(R_c)^\gamma(\rho - 1) - (\rho^\gamma - 1)}{(R_c - 1)(\gamma - 1)}\right]$

$$= 98 \times 10^3 \times 15.71\left[\frac{1.4(15.71^{1.4-1}(1.94 - 1) - (1.94^{1.4} - 1)}{(15.71 - 1)(1.4 - 1)}\right]$$

$$= 98 \times 103 \times 15.71\left[\frac{1.4(15.71)^{0.4}(0.94) - (1.94^{1.4} - 1)}{14.71 \times 0.4}\right]$$

$$= 1539580\left[\frac{1.32 \times 3.01 - (253 - 1)}{5.88}\right]$$

$$= \left[\frac{3.97 - 1.53}{5.88}\right] = 1539580\left[\frac{2.44}{5.88}\right]$$

= 1539580 × 0.415 Pa = 6389257 Pa = 6389.3 KPa ....ANS

Example (7)

Air enters at 1bar and 230°C in an engine running on diesel cycle whose compression ratio is 18. Maximum temperature of cycle is limited to 1500°C. Compute

(1) Cut off ratio

(2) Heat supplied per kg of air

(3) Cycle efficiency. ***(Dec–05)***

Sol.: Given that:

$$P_1 = 1\text{bar}$$
$$T_1 = 230 + 273 = 503\text{K}$$
$$T_3 = 1500 + 273 = 1773\text{K}$$

Compression ratio $r = 18$

Since $T_2/T_1 = (r)^{\gamma-1}$

$$T_2 = T_1 \times (r)^{\gamma-1}$$
$$= 503(18)^{1.4-1} = 1598.37\text{K}$$

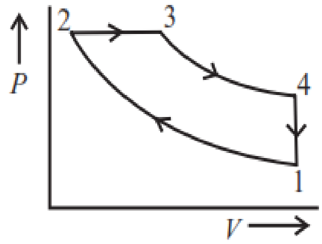


Fig. 4.12

(1) Cut off ratio (ρ) = $V_3/V_2 = T_3/T_2$

$$T_3/T_2 = \rho$$
$$\rho = 1773/1598.37$$
$$\boldsymbol{\rho = 1.109}$$ **.......ANS**

(2) Heat supplied per kg of air

$$Q = C_P\,(T_3 - T_2) = 1.005\,(1773 - 1598.37)$$
$$\boldsymbol{Q = 175.50\ \text{KJ/kg}}$$ **.......ANS**

(3) Cycle efficiency

(3) Cycle efficiency

$$\eta_{diesel} = \{1 - 1/[\gamma(r)^{\gamma-1}]\}\{(\rho^{\gamma} - 1)/(\rho - 1)\}$$
$$\eta_{diesel} = \{1 - 1/[1.4(18)^{1.4-1}]\}\{(1.109^{1.4} - 1)/(1.109 - 1)\}$$
$$\eta_{diesel} = \{1 - 0.225\}\{(0.156)/(0.109)\}$$
$$\eta_{diesel} = 0.678$$

or $$\boldsymbol{\eta_{diesel} = 67.8\%}$$ **.......ANS**

Chapter 5

ENGINES SYSTEMS

5. Engine systems

All engine parts and functions can divided into five (5) systems.

1. Compression system
2. Fuel Supply system
3. Lubrication system
4. Ignition system
5. Cooling system

If an engine will not start, which one of the five system(s) is most likely the problem?

If an engine has a lot of operating time, is hard to start and doesn't seem to be producing as much power as it once did, which one of the five system(s) is most likely the problem?

5-1. COMPRESSION SYSTEM

The compression system includes all of the parts that create, contain and manage the engine compression.

5-1-1. Parts compression system

6) Valves
7) Valve springs
8) Connecting rod
9) Crankshaft
10) Gaskets

1) Block
2) Piston
3) Piston rings
4) Cylinder head
5) Bearings

5-1-2. Compression Problems

Two possible problems:

1. Inadequate compression

Symptoms: Poor starting, less power – **Cause:** Leaks

2. Excessive compression

Symptoms; Harder to crank Detonation Pre-ignition

Cause: Carbon buildup in combustion chamber

5-1-3. Detonation

1. An undesirable engine condition in which pockets of fuel start to burn at about the same time as the spark plug fires

2. Multiple pressure fronts collide

3. Sometimes called knocking, spark knock or pinging

4. Causes large pressure differentials in the combustion chamber

5. Will cause engine damage


Causes

1. Increased compression
2. High temperatures
3. Lean fuel/air mixture
4. Advanced ignition timing
5. Low octane fuels

How do you prevent detonation?

5-1-4. Pre-ignition

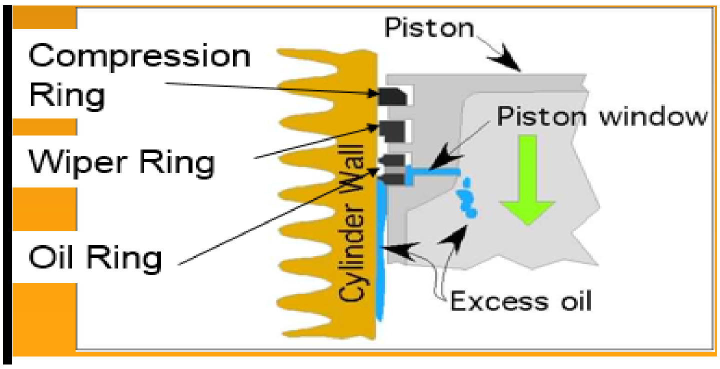
1) Fuel starts to burn before the spark plug fires.
2) Increases the peak combustion pressure in the cylinder.
3) Increases internal temperature.
4) Decreases engine performance and produces and audible pinging or knocking sound in the engine.
5) Will cause engine pistons, connecting rods, crankshafts and other compression system parts to fail.

Causes

1. An overheated spark plug
2. Glowing carbon deposits
3. Overheated exhaust valve
4. A sharp edge in the combustion chamber or on top of the piston
5. Sharp edges on valves that were reground improperly
6. A lean fuel mixture.

5-1-5. Piston Rings

- **Compression ring**
  - Subject to greatest amount of chemical corrosion and highest temperatures.
  - Transfers 70% of combustion heat from piston to cylinder walls.
- **Wiper ring**
  - Meters oil film on cylinder walls
  - Must be installed correctly.
- **Oil ring**
  - Constructed of two thin rails with holes or slots cut in-between.
  - Has the highest pressure against the cylinder wall of the three rings.



5-1-6. Crankcase Breather

- Maintains pressure in the crankcase at less than ambient pressure to assist in the control of oil consumption.
- Excessive blow by renders the breather useless.

- Old engines vent to the atmosphere.
- New engines vent to the carburetor.

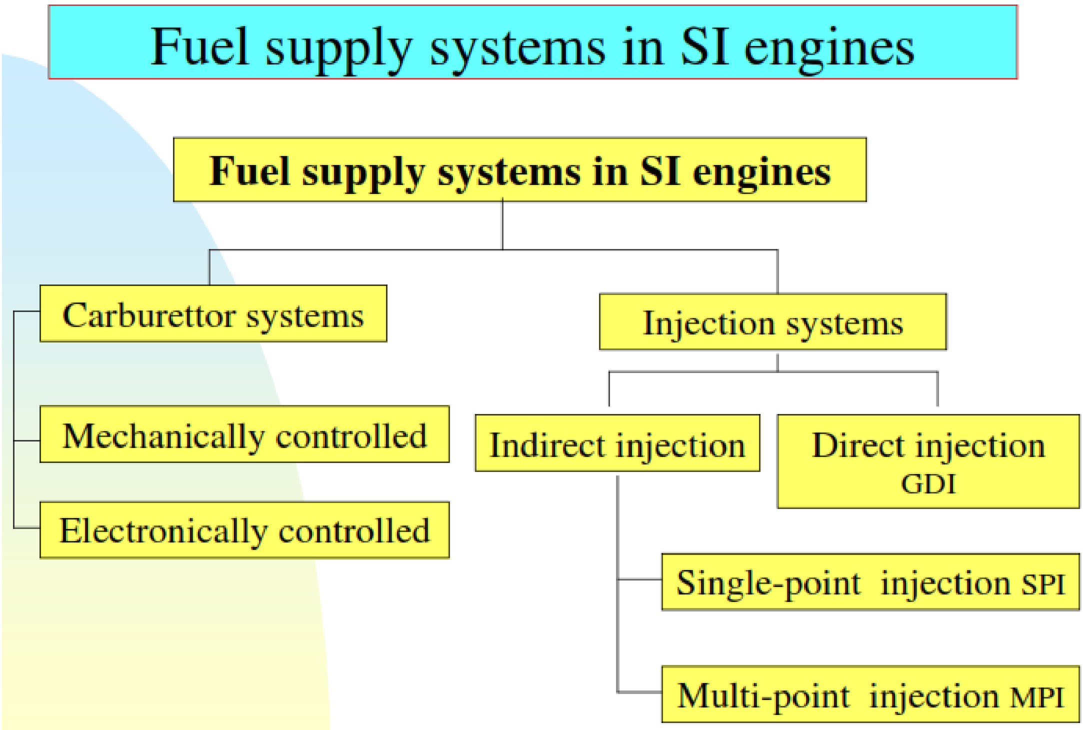
5-1-7. Compression Release

- Compression release systems are used to decrease effort required to start engine.
- Holds the exhaust valve slightly open during starting, and then allows it to fully close once engine starts.

5-2. FUEL SUPPLY SYSTEM

5-2-1. Fuel supply systems of SI engines

1. Carburetor systems
2. Injection systems



5-2-2. function of the fuel system

1 storing
2 metering
3 atomizing
4 vaporizing
5 mixing fuel and air
6 delivering fuel air mixture to intake manifold

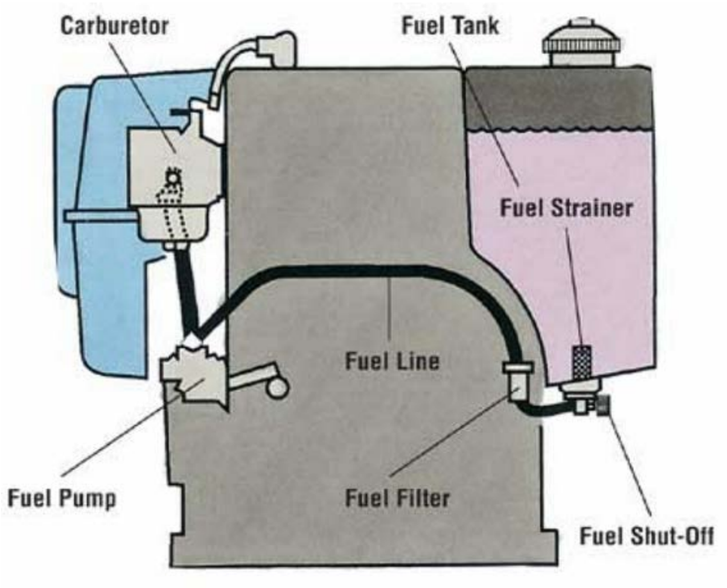
5-2-3. Common Small Engine Fuels

1) Gasoline
2) Diesel

3) LPG
4) LNG
5) CNG

5-2-4. Fuel system parts

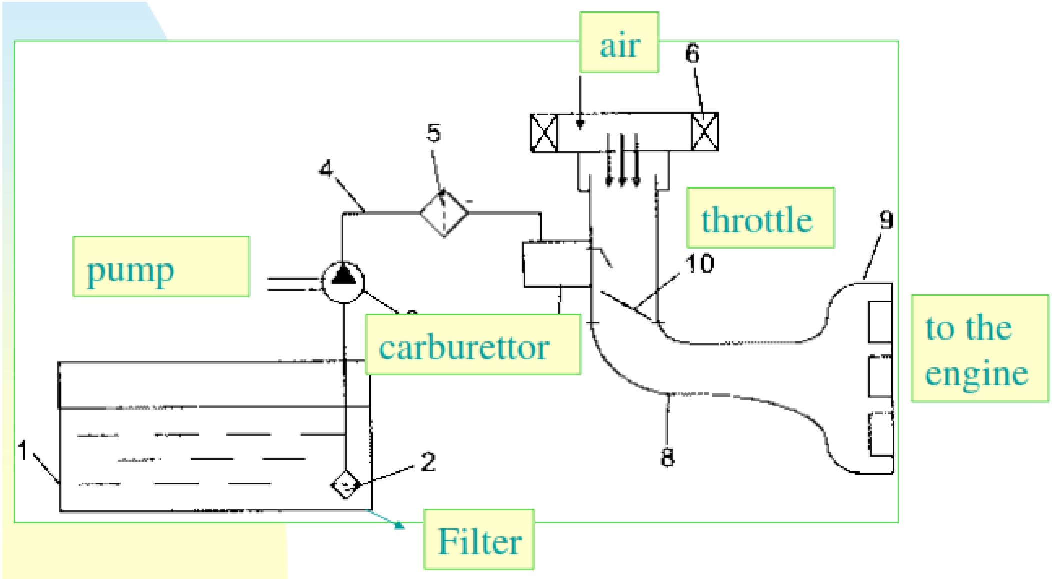
1. Supply (tank)
2. Lines
3. Shut off valves
4. Filter
5. Pump
6. Carburetor

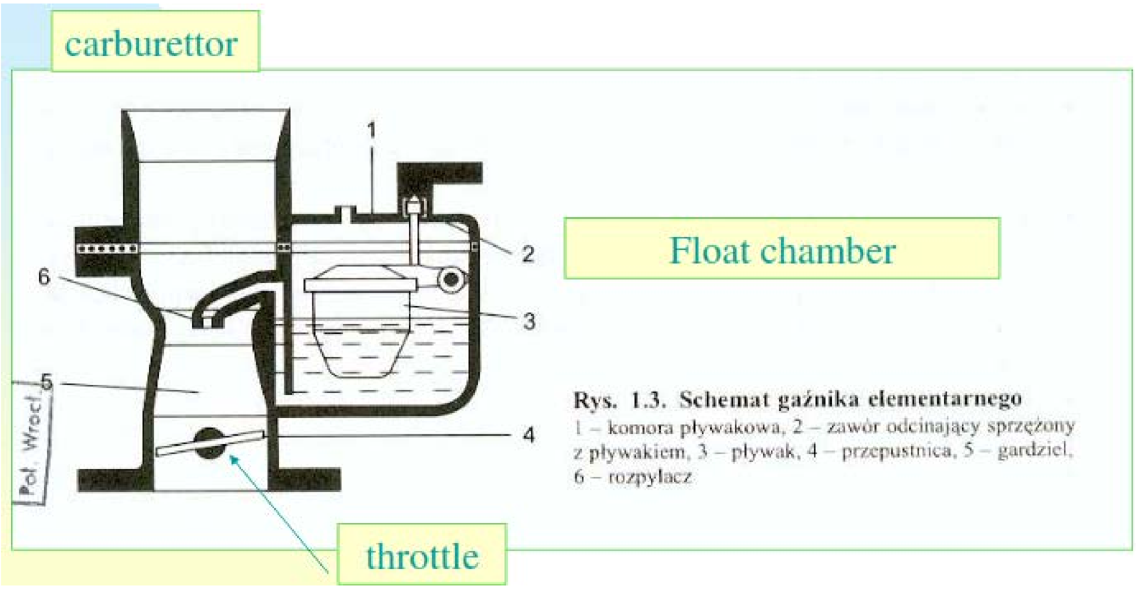


- Additional facts about the fuel system:
  1. Fuel must be clean and good quality
  2. Air fuel mixture must be richer for starting
  3. Excess fuel washes lubrication off the cylinder walls and accelerates wear.
  4. Excess fuel dilutes the oil and accelerates wear.
  5. Air fuel mixture that is too lean will cause pre-ignition.

Carburetor

The process of preparing air-fuel mixture away from the engine cylinder is called carburetion. and the device in which this process takes is called carburetor.



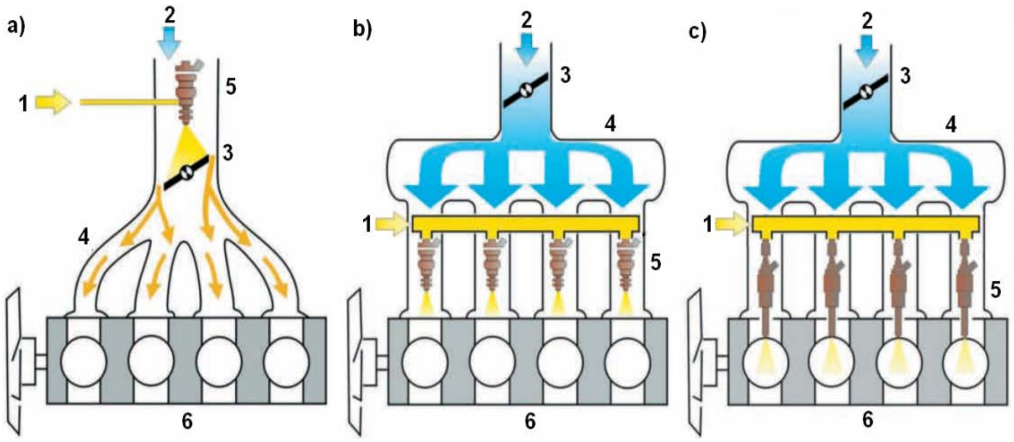


Rys. 1.3. Schemat gaźnika elementarnego
1 – komora pływakowa, 2 – zawór odcinający sprzężony z pływakiem, 3 – pływak, 4 – przepustnica, 5 – gardziel, 6 – rozpylacz

Functions of carburetor

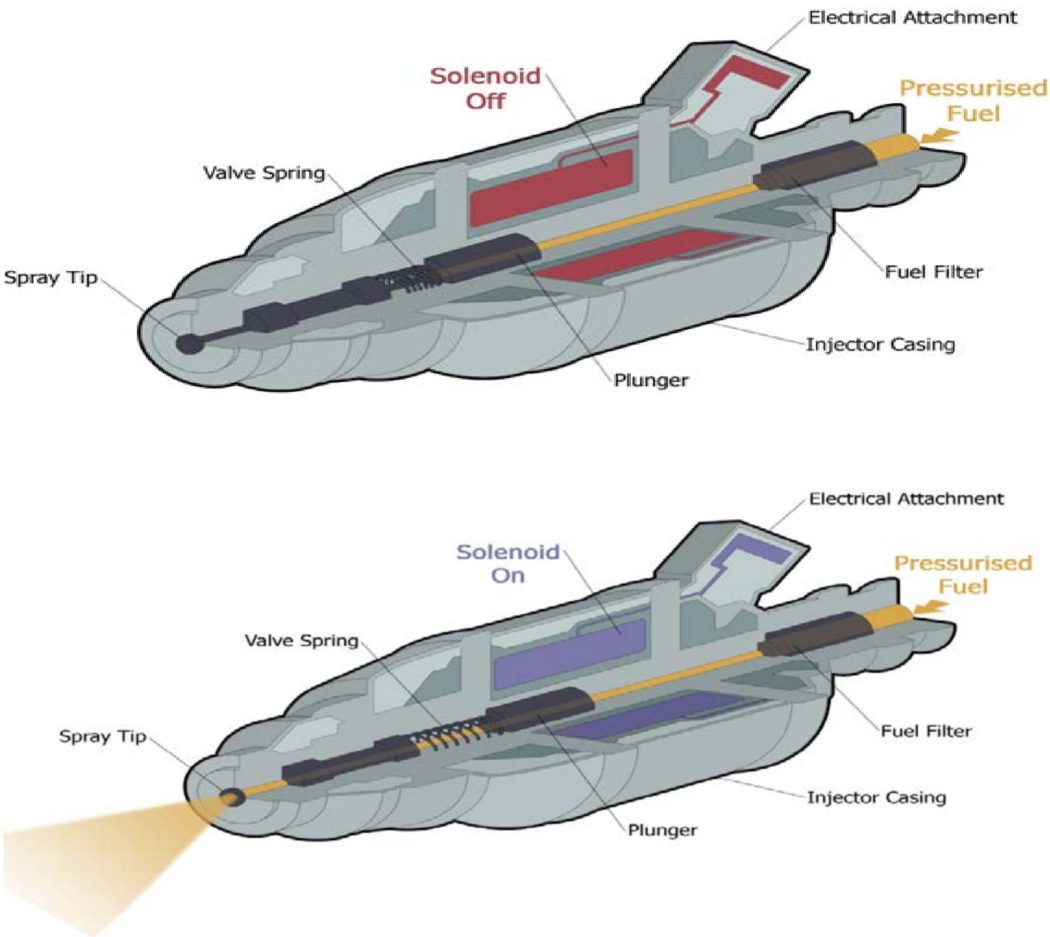
1. To mix the air and fuel thoroughly
2. To atomize the fuel
3. To regulate the air- fuel ratio at different speeds and loads on the engine.
4. to supply correct amount of mixture at different speeds and loads

5-2-5. Types of injection systems



a) single-point, b) multi-point, c) direct injection

1 – Fuel supply, 2 – Air intake, 3 – Throttle, 4 – Intake manifold, 5 – Fuel injector (or injectors), 6 – Engine.



Animated cut through diagram of a typical fuel injector

Fuel system

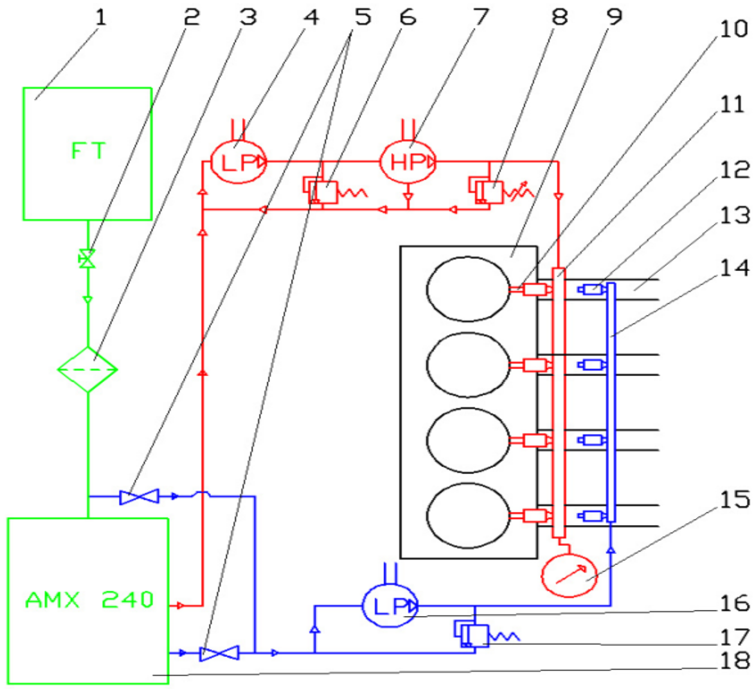


Figure. The scheme of the fuel system; 1 – Fuel Tank, 2 – Shutoff valve, 3 – Fuel filter, 4 – DI priming pump, 5 – Electro valves for measurement of fuel flow in DI-circuit, 6 – Regulator of low-pressure of DI-circuit, 7 – High pressure pump, 8 – Regulator of high-pressure of DI-circuit, 9 – Engine, 10 – Direct fuel injector, 11 – Rail of the direct fuel injectors, 12 – Indirect fuel injector, 13 – Intake pipe, 14 – Rail of the indirect fuel injectors, 15 – DI pressure gauge, 16 – MPI fuel pump, 17 – Regulator of pressure of MPI-circuit, 18 – Fuel flow meter.

Fuel tank

It is a storage tank for diesel. A wire gauge strainer is provided under the cap to prevent foreign particles entering the tank

Fuel lift pump

It transfers fuel from fuel tank to inlet gallery of fuel injection pump

Preliminary filter (sediment bowl assembly)

This filter is mostly fitted on fuel lkift pump. It prevents foreign materials from reaching

inside he fuel line. It consists of a glass cap with a gasket.

Fuel filter

Mostly two stage filters are used in diesel engines

1. Primary filter 2. Secondary filter

Primary filter removes coarse materials, water and dust. Secondary filter removes fine dust particles.

Fuel injection pump

It is a high pressure pump which supplies fuel to the injectors according to the firing order of the engine. It is used to create pressure varying from 120 kg/cm
supplies the required quantity of fuel to each cylinder at appropriate time.

Air venting of fuel system

When air has entered the fuel lines or suction chamber of the injection pump, venting should be done properly.. Air is removed by the priming pump through the bleeding holes of the injection pump.

Fuel injector

It is the component which delivers finely atomized fuel under high pressure to combustion chamber of the engine. Modern tractor engines use fuel injectors which have multiple holes. Main parts of injectors are nozzle body, and needle valve. The needle valve is pressed against a conical seat in the nozzle body by a spring. The injection pressure is adjusted by adjusting a screw.

5-3. LUBRICATION SYSTEM

IC engine is made of moving parts. Duo to continuous movement of two metallic surfaces over each other, there is wearing of moving parts, generation of heat and loss of power in engine. Lubrication of moving parts is essential to prevent all these harmful effects.

5-3-1. Purpose of lubrication

1. Reducing frictional effect
2. Cooling effect
3. Sealing effect
4. Cleaning effect

5-3-2. Types of lubricants

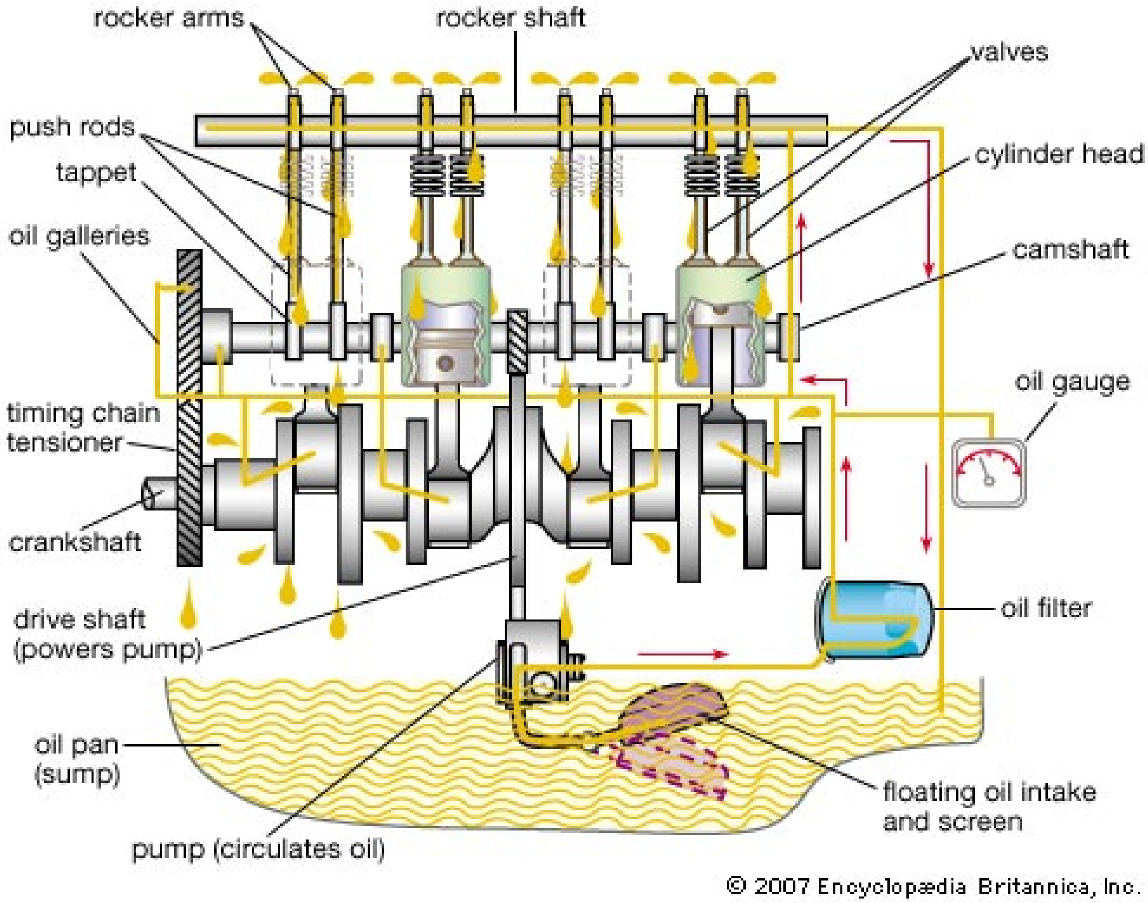
Lubricants are obtained from animal fat, vegetables and minerals. Vegetable lubricants are obtained from seeds, fruits and plants. Cotton seed oil, olive oil, linseed oil, castor oil are used as lubricants. Mineral lubricants are most popular for engines and machines. It is obtained from crude petroleum found in nature. Petroleum lubricants are less expensive and suitable for internal combustion engines .

The lubricating system of an engine is an arrangement of mechanisms which maintains the supply of lubricating oil to the rubbing surfaces of an engine at correct pressure and temperature.

The parts which require lubrication are

1. Cylinder walls and piston
2. Piston pin
3. crankshaft and connecting rod bearings
4. Camshaft bearings
5. Valve operating mechanism
6. Cooling fan
7. Water pump and

8. Ignition mechanism



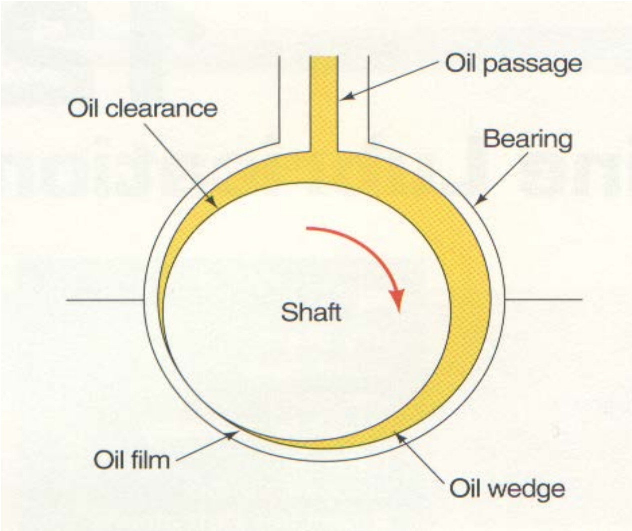
5-3-3. Types of lubricating systems

1. Splash system
2. Forced feed system

5-3-4. Purpose of Lubrication System

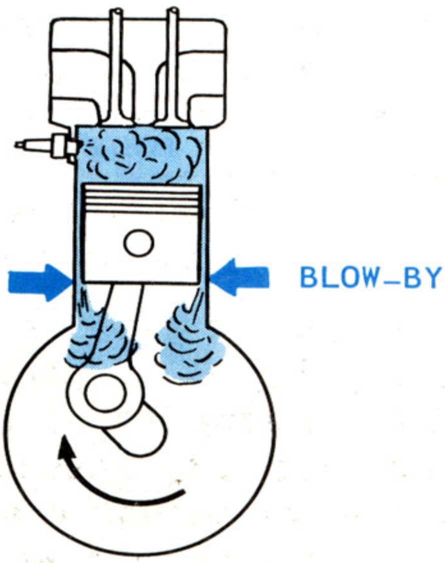
1. Lubricate

Reduces *Friction* by creating a thin **film** *(Clearance)* between moving parts (*Bearings and journals)*



2. Seals

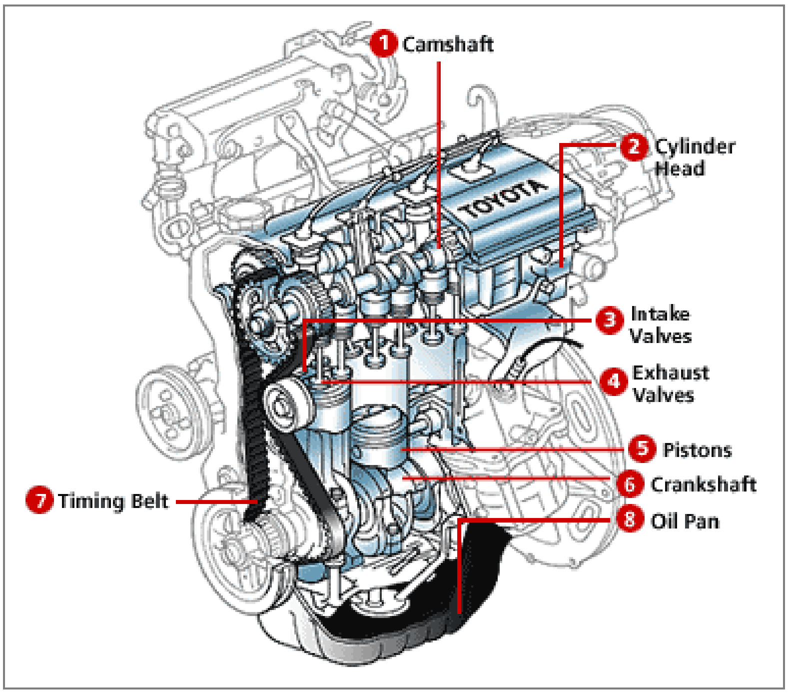
The oil helps form a gastight seal between piston rings and cylinder walls (*Reduces Blow-By)*



Internal oil leak (blow-by) will result in *BLUE SMOKE* at the tale pipe.

3. Cleans

As it circulates through the engine, the oil picks up metal particles and carbon, and brings them back down to the pan.



4. Cools

Picks up heat when moving through the engine and then drops into the cooler oil pan, giving up some of this heat.

5. Absorbs shock

When heavy loads are imposed on the bearings, the oil helps to cushion the load.

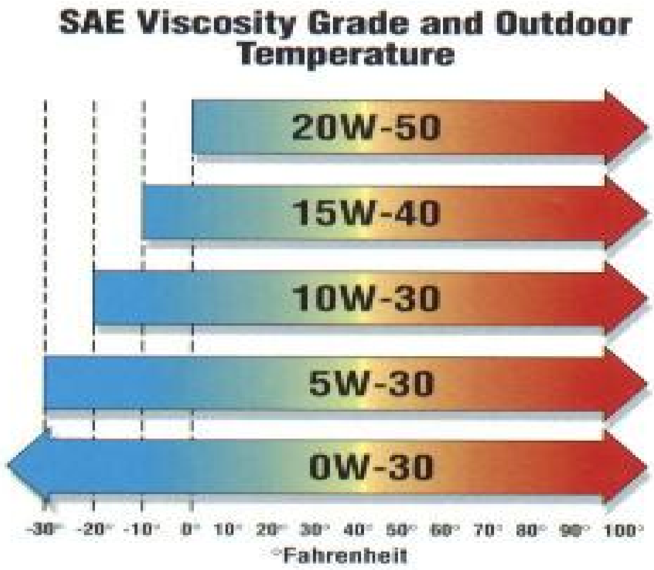
6. Absorbs Contaminants

The additives in oil helps in absorbing the contaminants that enter the lubrication system.

5-3-5. VISCOSITY

Viscosity is a measure of oil's resistance to flow.

- A low viscosity oil is thin and flows easily
- A high viscosity oil is thick and flows slowly.
- As oil heats up it becomes more viscous (*Becomes thin)*



- If the oil is too thin(*has very low viscosity)* it will be forced out from between the moving parts, resulting in rapid wear.
- If the oil is too thick(*has very high viscosity)* it will flow very slowly to engine parts, especially when the engine and the oil are cold, resulting in rapid wear.

5-3-5-1. Viscosity Index

is the measure of how much the viscosity of an oil changes with temperature. (20 W)

Viscosity number is set by **SAE** *(Society of Automotive Engineers)*

- **Single viscosity oils** SAE 5W, SAE 10W (Winter) and SAE 20, SAE30 … (Summer)
- **Multiple viscosity oils** SAE 10W-30.

This means that the oil is same as SAE 10W when cold and SAE30 when hot.

The higher the number the higher the viscosity(*thickness)* of oil.

5-3-5-2. Properties of oil

- **Corrosion and Rust Inhibitor:** Displaces water from metal surfaces, to prevent corrosion.
- **Foaming Resistance:** Rotating crankshaft tends to cause bubbles (*Foam)* in the oil and bubbles in oil will reduce the effectiveness of oil to lubricate.
- **Synthetic Oils:** Made by chemical process and do not necessarily come from petroleum.

5-4. IGNITION SYSTEM

The ignition system provides a high voltage spark in the combustion chamber at the proper time.

5-4-1. Ignition System Function

1. Ignite the fuel and air mixture at the proper time.
2. Advance and retard the ignition timing as needed.
3. "Ground-out" the ignition system so the engine will stop running.

5-4-2. Ignition function

1. Produces 30,000 volt spark across spark plug
2. Distributes high voltage spark to each spark plug in correct sequence
3. Times the spark so it occurs as piston is nearing top dead center
4. Varies spark timing with load, speed, and other conditions

5-4-3. Ignition Principles

1. M Electromagnetic Induction
2. How does the Ignition Coil work?
3. Primary winding: creates a magnetic field by running current through it.
4. When we open the circuit current stops, and the electromagnetic field collapses.

5-4-4. Ignition Coil Parts

1. Primary Winding
2. Secondary Winding
3. Iron Core

5-4-5. Switching current in Primary

1. Breaker Points and condenser

2. Points: Mechanical switch
3. Condenser: makes the switch last longer so the points don't " burn out"

m Parts

5-4-6. Basic ignition system components Battery

1. Ignition coil
2. Ignition switch
3. Low voltage wires (battery volts)
4. Ignition Pick-up (points or electronic)
5. High Voltage wire(s)
6. Spark Plug

5-4-7. Basic ignition system

Battery supplies power to entire system

1. Ignition Switch turns engine on or off
2. Coil transforms volts
3. Switching device triggers ignition coil
4. Spark Plug and wires distribute spark

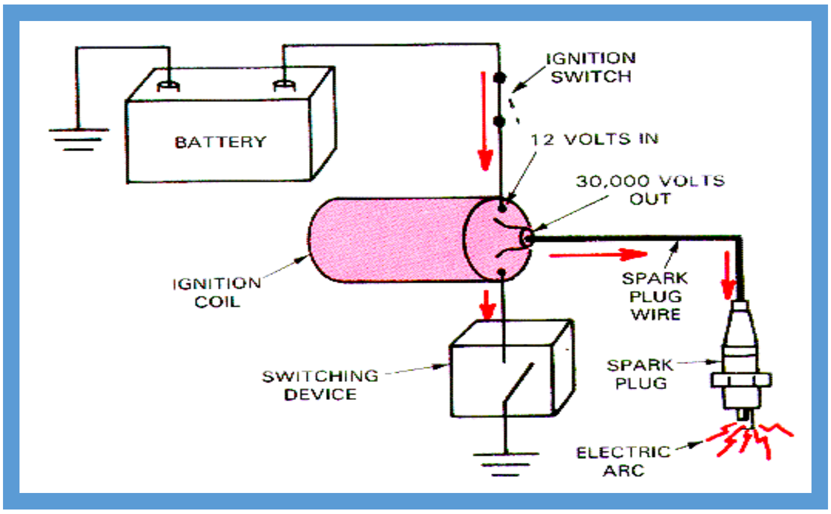


***Figure (1)** – Basic ignition system*

5-4-8. Primary circuit

Consists of low voltage wiring and components

1. Uses conventional type automotive primary wires
2. Controls when ignition will take place. (When coil fires)

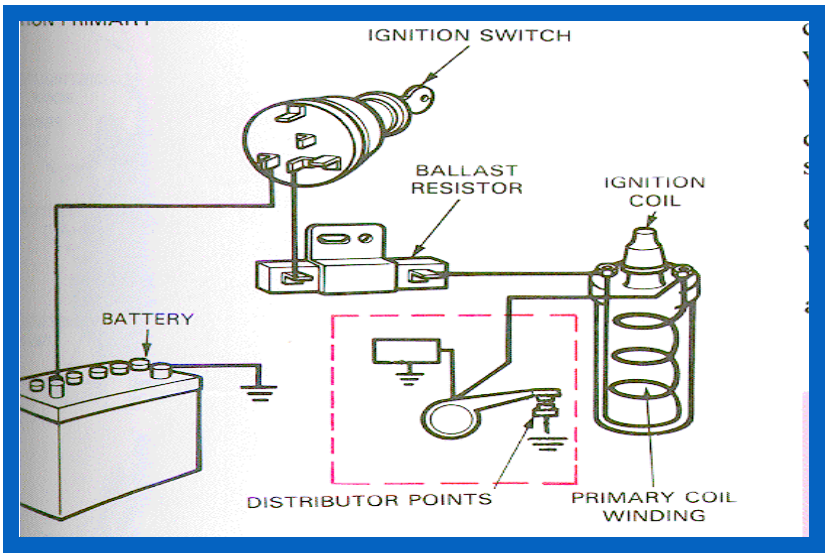


***Figure (2)** – Primary circuit*

5-4-9. Secondary circuit

1. Distributes current to individual cylinders to jump spark plug gap
2. Must have thicker, heavier insulation on wires
3. Typical voltage to jump gap - 10K Volts

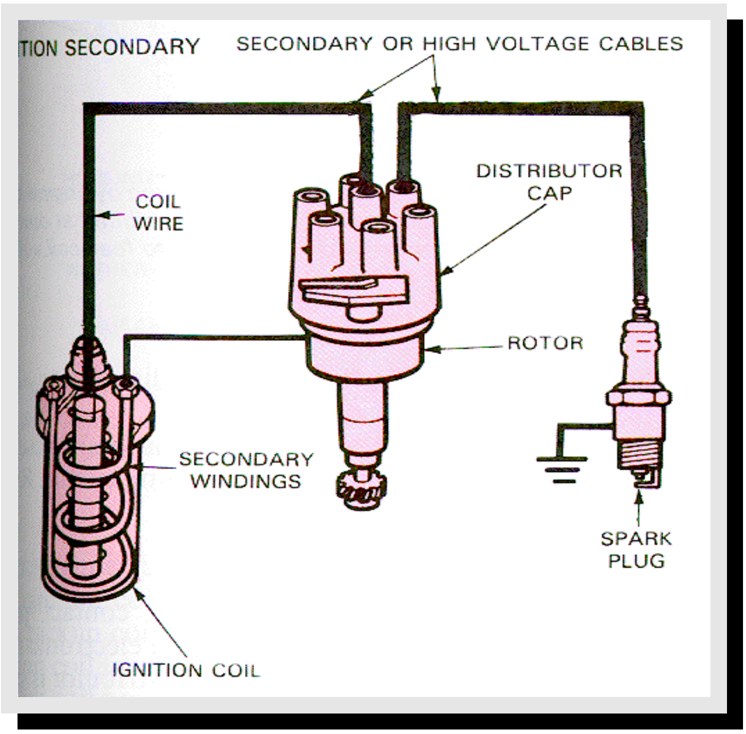


***Figure (3)** – Secondary circuit*

5-4-10. Ignition coil

1. transformer
2. 2 sets of windings
    - primary windings
    - secondary windings
3. iron core
4. produces magnetic field

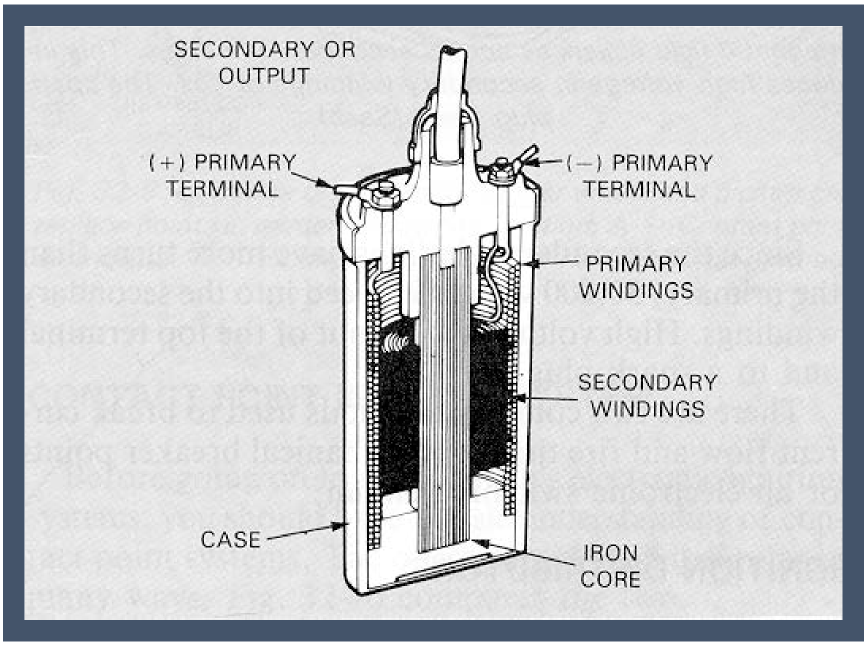


Figure (4) *– Ignition coil*

5-4-11. Ignition system types

1. contact point ignition system
2. electronic ignition system
3. distributorless ignition system

5-4-12. Firing Order

- 1,3,4,2
- 1,2,5,4,3,2
- 1,5,6,3,4,2,7,8

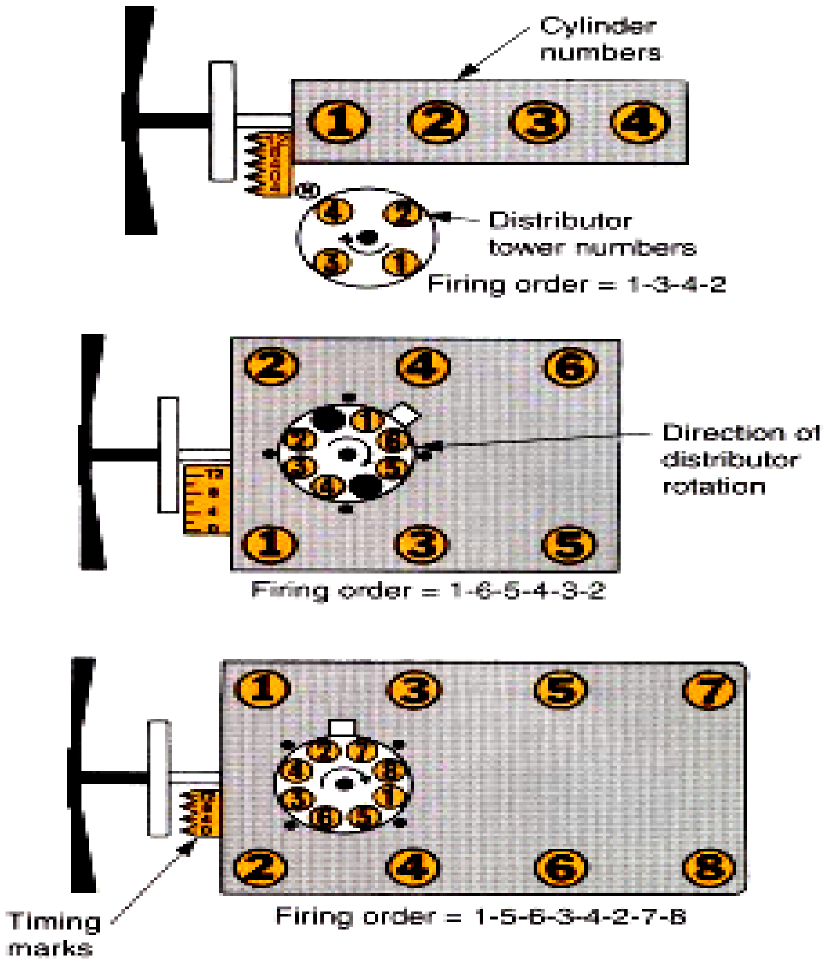


Figure (5) – Firing order

5-4-13. Ignition system

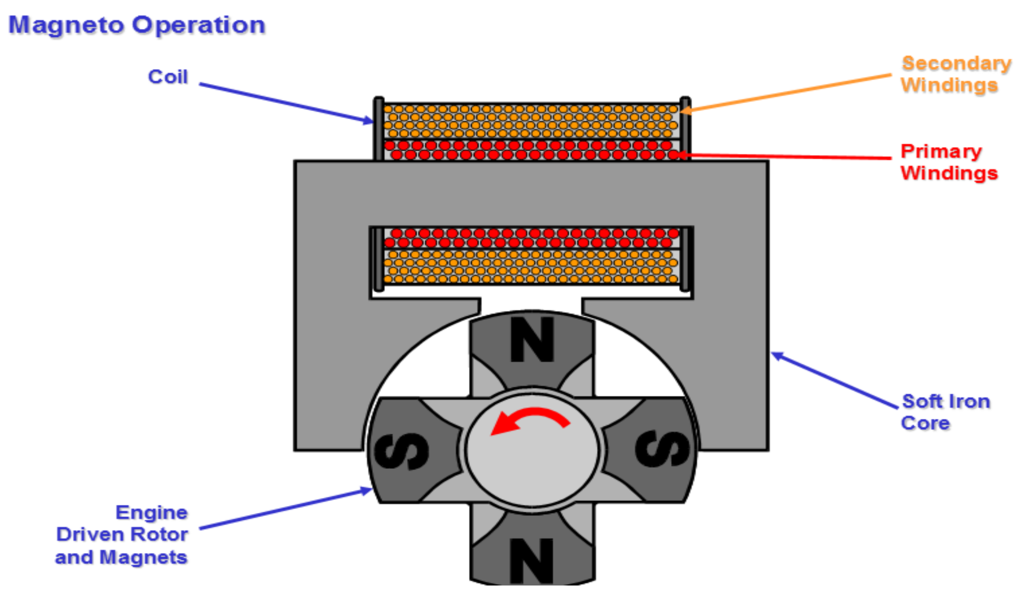


Figure (5) – Ignition system , magneto operation

5-4-13-1. No magnetic field in soft iron core

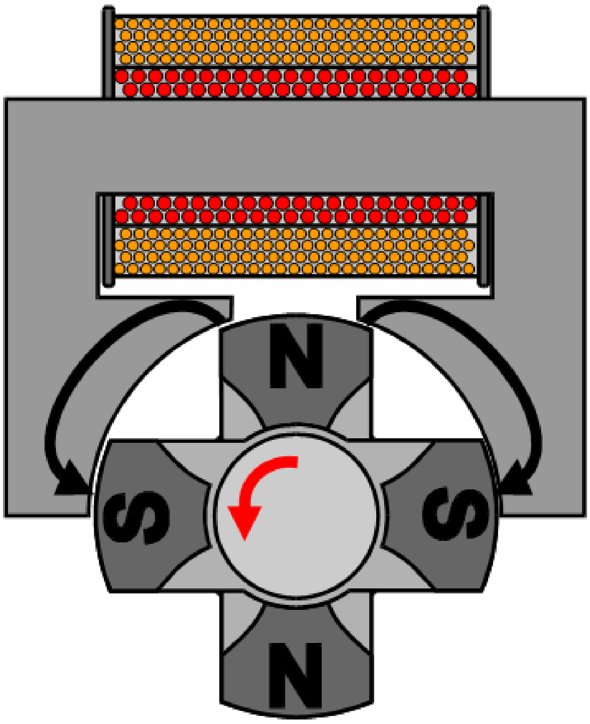


***Figure (6)** – No magnetic field*

5-4-13-2. The magnetic field passes through soft iron core again

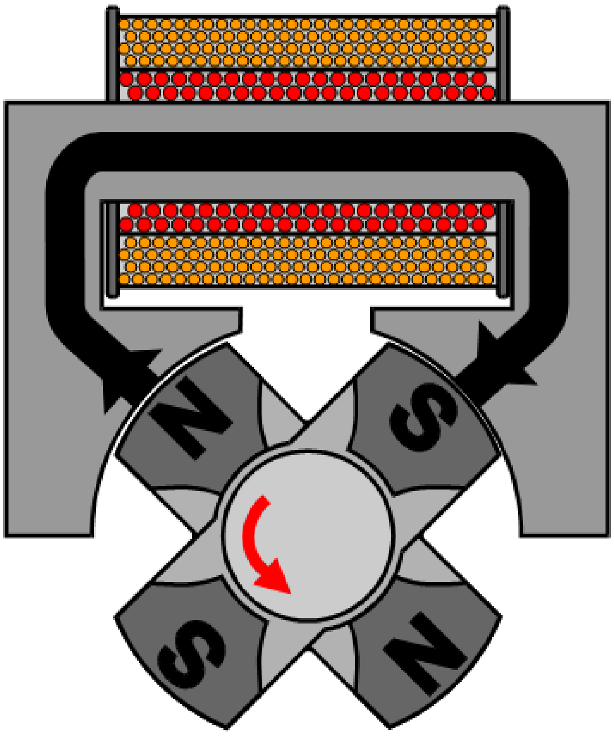


***Figure (6)** – magnetic field passes*

5-4-13-3. Magneto System

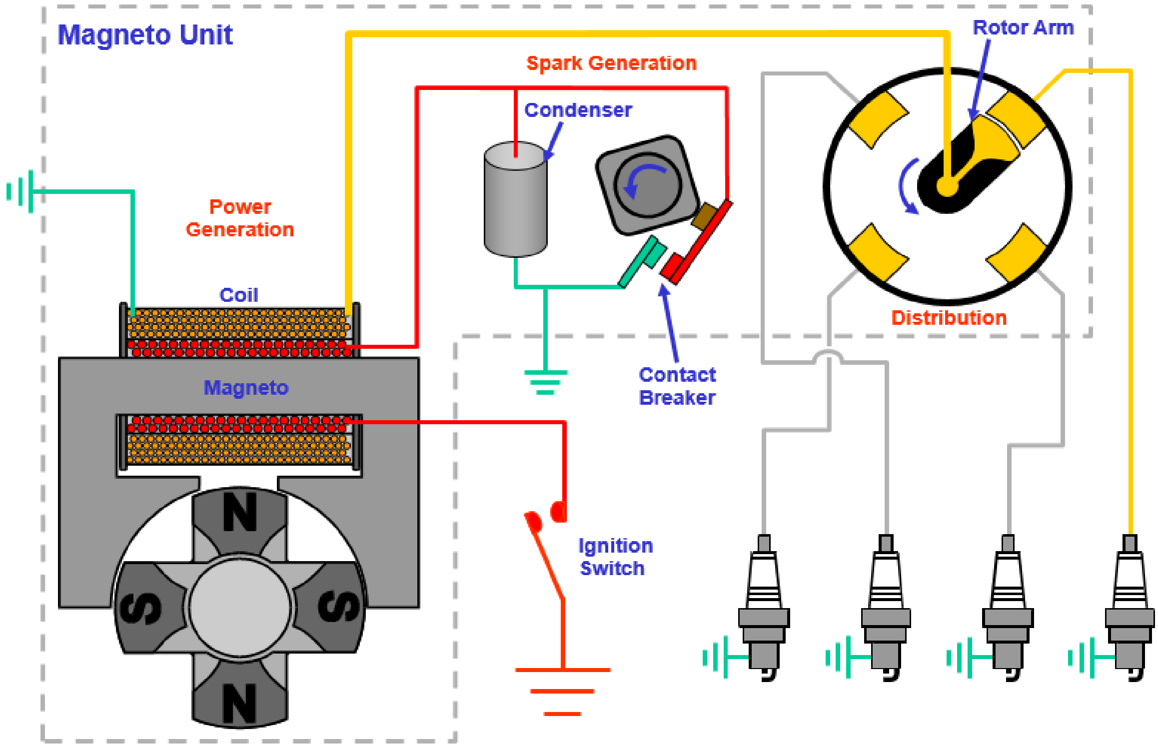


Figure (7) – Magneto System

5-4-13-4. Dynamo/Alternator System

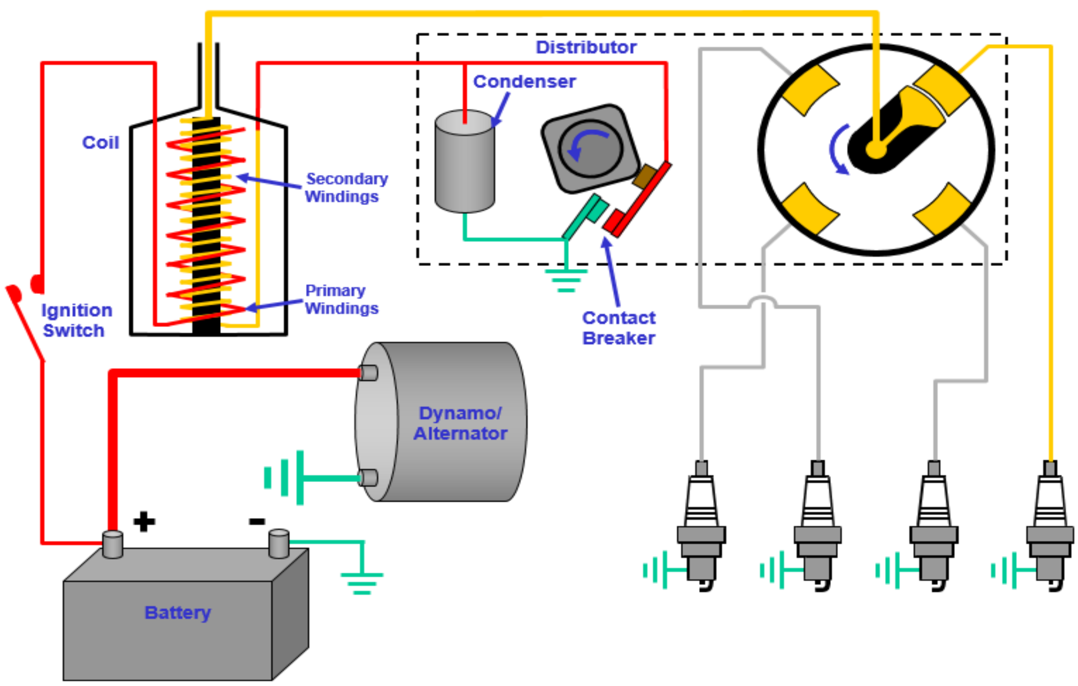


Figure (8) – Dynamo/Alternator System

5-4-14. Distributor

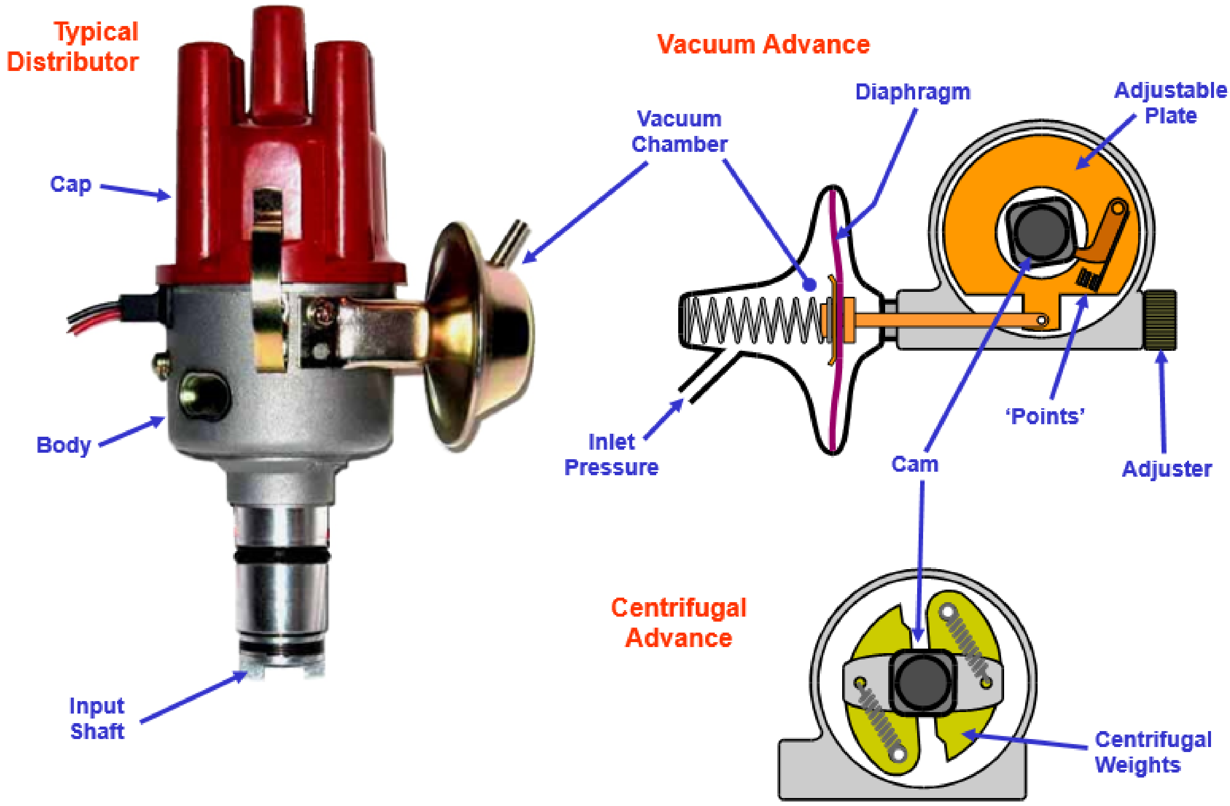


Figure (9) – Ddistributor

5-4-15. Electronic Systems

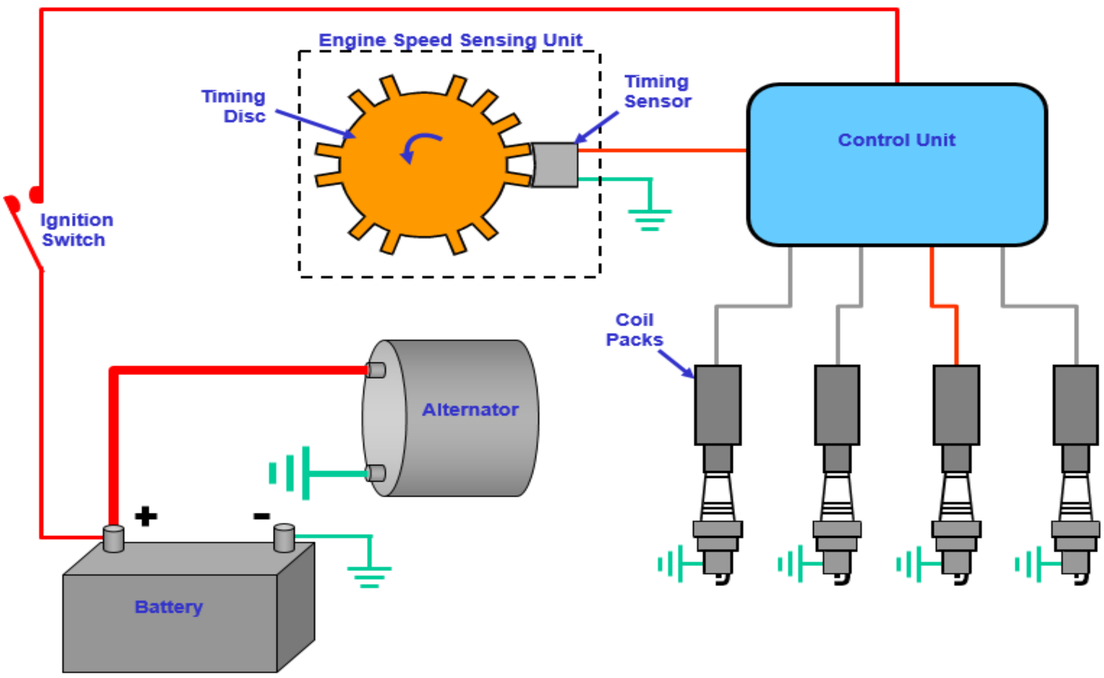


Figure (10) – Electronic system

5-4-16. Spark Plug

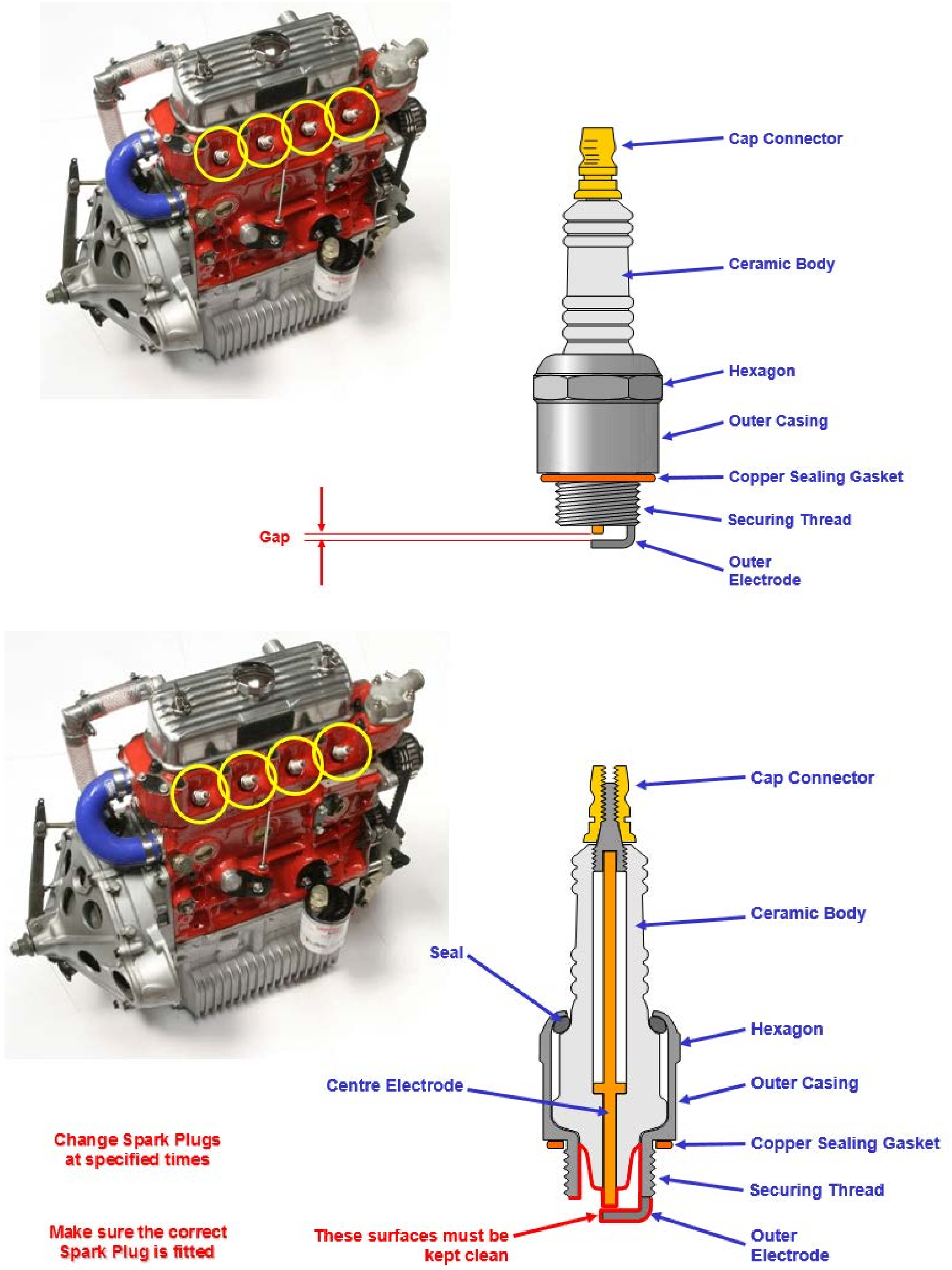


Figure (11) – Spark plug

5-5. COOLING SYSTEM

Fuel is burnt inside the cylinder of an internal combustion engine to produce power. The temperature produced on the power stroke of an engine can be as high as 1600 °C and this is greater than melting point of engine parts.. The best operating temperature of IC engines lie between 140 F and 200 °F and hence cooling of an IC engine is highly essential. . It is estimated that about 40% of total heat produced is passed to atmosphere via exhaust, 30% is removed by cooling and about 30% is used to produce power.

5-5-1.Purpose of cooling

1. To maintain optimum temperature of engine for efficient operation under all conditions.

2. To dissipate surplus heat for protection of engine components like cylinder, cylinder head, piston, piston rings, and valves
3. To maintain the the lubricating property of oil inside engine

5-5-2. Methods of cooling

1. Air cooled system
2. Water cooled system

5-5-2-1. Air cooling system

Air cooled engines are those engines in which heat is conducted from the working Components of the engine to the atmosphere directly.

Principle of air cooling-

The cylinder of an air-cooled engine has fins to increase the area of contact of air for speedy cooling. The cylinder is normally enclosed in a sheet metal casing called cowling. The flywheel has blades projecting from its face, so that it acts like a fan drawing air through a hole in the cowling and directed it around the finned cylinder.

For maintenance of air-cooled system, passage of air is kept clean by removing grasses etc. by a stiff brush of compressed air

Advantages of air-cooled engine

1. It is simple in design and construction
2. Water jackets, radiators, water pump, thermostat, pipes, hoses are not required
3. It is more compact
4. Lighter in weight

Disadvantages

1. There is uneven cooling of engine parts
2. Engine temperature is generally high during working period

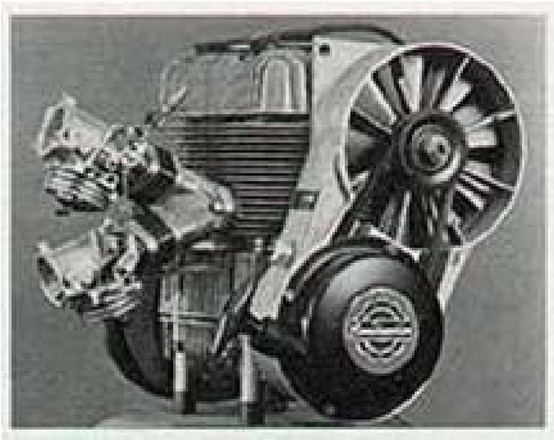


Figure (1) – Air-cooled engine

5-5-2-2. Water cooling system

Engines using water as cooling medium called water-cooled engines. Water circulated round the cylinders to absorb heat from the cylinder walls. The heated water conducted through a radiator to remove the heat and cool the water.

5-5-2-2-1. Methods of water-cooling

1. Open jacket or hopper method
2. Thermo siphon method
3. Forced circulation method

1. Open jacket method

There is a hopper or jacket containing water which surrounds the engine cylinder. So long as the hopper contains water the engine continues to operate satisfactorily. As soon as the water starts boiling it is replaced by cold water.. The hopper is large enough to run for several hours without refilling. A drain plug is provided in a low accessible position for draining water as and when required.

2. Thermo siphon method

It consists of a radiator, water jacket, fan, temperature gauge and hose connections. The system is based on the principle that heated water which surrounds the cylinder becomes lighter and it rises upwards in liquid column. Hot water goes to the radiator where it passes through tubes surrounded by air. Circulation of water takes place due to the reason that water jacket and radiator are connected at both sides i.e. at top and bottom. A fan is driven with the help of a V belt to suck air through tubes of the radiator unit, cooling radiator water.

The disadvantage of the system is that circulation of water is greatly reduced by accumulation of scale or foreign matter in the passage and consequently causing over heating of the engine.

3. Forced Circulation system

In this method, a water pump is used to force water from radiator to the water jacket of the engine. After circulating the entire run of water jacket, water comes back to the radiator where it loses its heat by the process of radiation. To maintain the correct engine temperature , a thermostat valve is placed at the outer end of cylinder head. Cooling liquid is by-passed through the water jacket of th3e engine until the engine attains the desired temperature. The thermostat valve opens and the by-pass is closed, allowing the water to go to the radiator. The system consists of the following components

1. Water pump	2. Radiator
3. Fan	4. Fan-belt

5. Water jacket
6. Thermostat valve
7. Temperature gauge
8. Hose pipe

Water pump

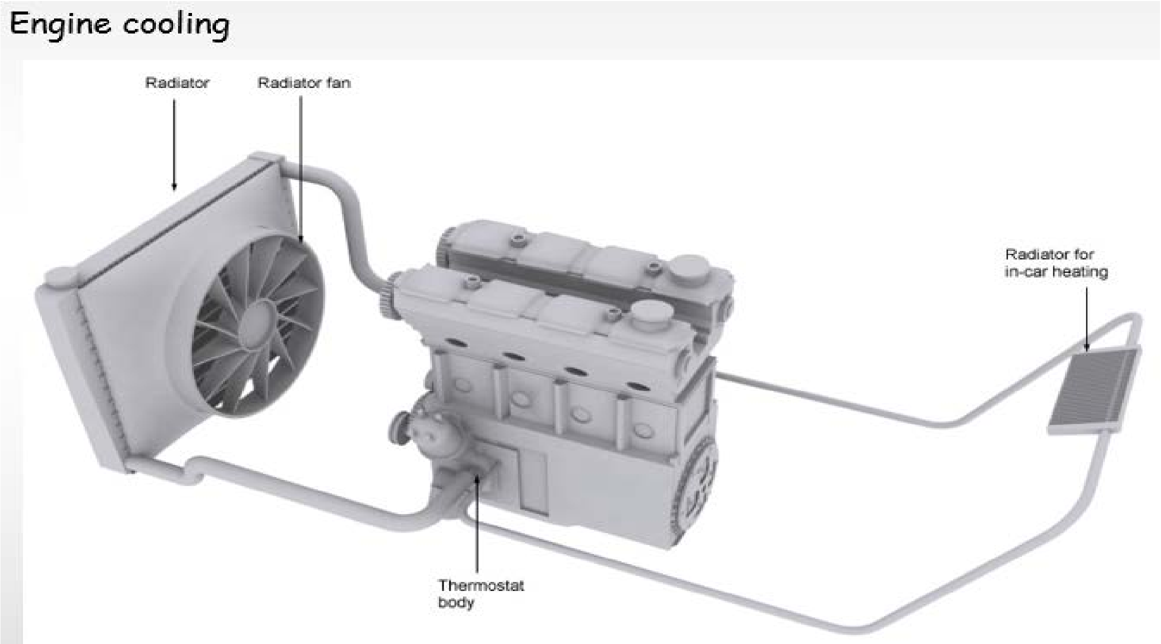
It is a centrifugal pump. It draws the cooled water from bottom of the radiator and delivers it to the water jackets surrounding the engine.

Thermostat valve

It is a control valve used in cooling system to control the flow of water when activated by a temperature signal**.**

Fan

The fan is mounted on the water pump shaft. It is driven by the same belt that drives the pump and dynamo. The purpose of radiator is to provide strong draft of air through the radiator to improve engine cooling Water jacket - Water jackets are passages cored out around the engine cylinder as well as around the valve opening



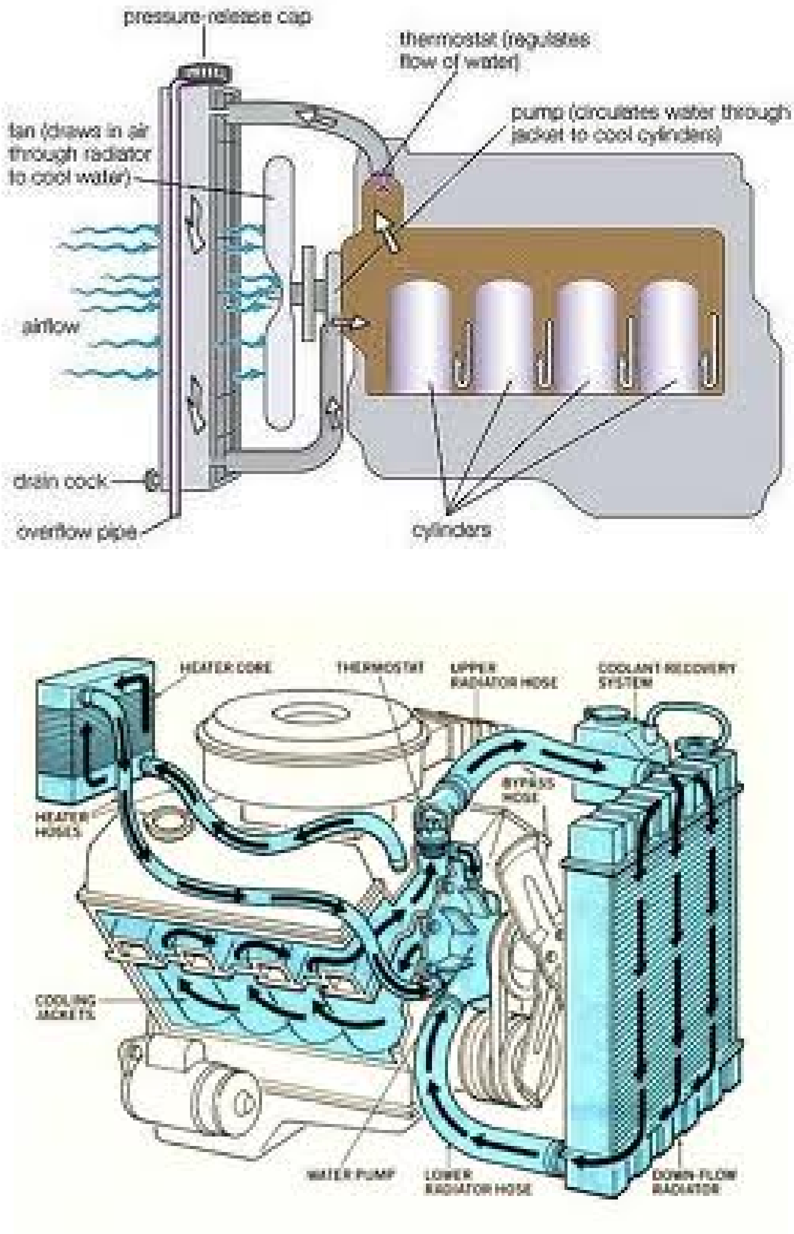


***Figure (2)** - Forced Circulation cooling system- Water-cooled engine*

5-5-3. Governor

Governor is mechanical device, designed to control the speed of the engine with in Specified limit. Used on tractor or stationary engine for

1. Maintaining a nearly constant speed of engine under different load conditions
2. Protecting the engine and attached equipment against high speeds, when the load is removed or reduced

Types of governors

1. Centrifugal governor
2. Pneumatic governor
3. Hydraulic governor

Governor regulation

The governor is fitted on an engine for maintaining a constant speed , even then some variation in speed is observed at full load and no load conditions. In normal working , a variation of about 100 rev/min is observed between full load and no-load conditions for a good governor.

Hence it is possible to regulate the governor to maintain a higher or lower speed by changing the tension of the spring . The extent of regulation done , is expressed in terms of percentage called percentage regulation. This is also called speed drop. It is the variation in the engine speed between full load and no load condition. It is usually expressed as percentage of rated speed. This is given by

$$R = \frac{N_1 - N_2}{(N_1 + N_2)/2} \times 100$$

Where ,

R – % regulation,

N_1 – Speed at no load, rpm

N_2 – Speed at full load, rpm

Problem- Find the percentage regulation in a governor if speed at no load is 1600 rev/min and at full load is 1500 rev/min

Governor hunting

Governor hunting is the erratic variation of the speed of the governor when it over compensates for speed changes. When the governor produces a periodic effect on the engine speed like too fast and then too slow, then too fast and so on it is a sign of governor hunting. In such cases it is observed that when the engine speeds up quickly, the governor suddenly responds, the speed drops quickly, the governor again responds and this process is repeated.

The reason for governor hunting may be due to incorrect adjustment of fuel pump or carburetor, improper adjustment of the idling screw and excessive friction. Hunting may be due to governor being too stiff or due to some obstruction in free movement of governor components.

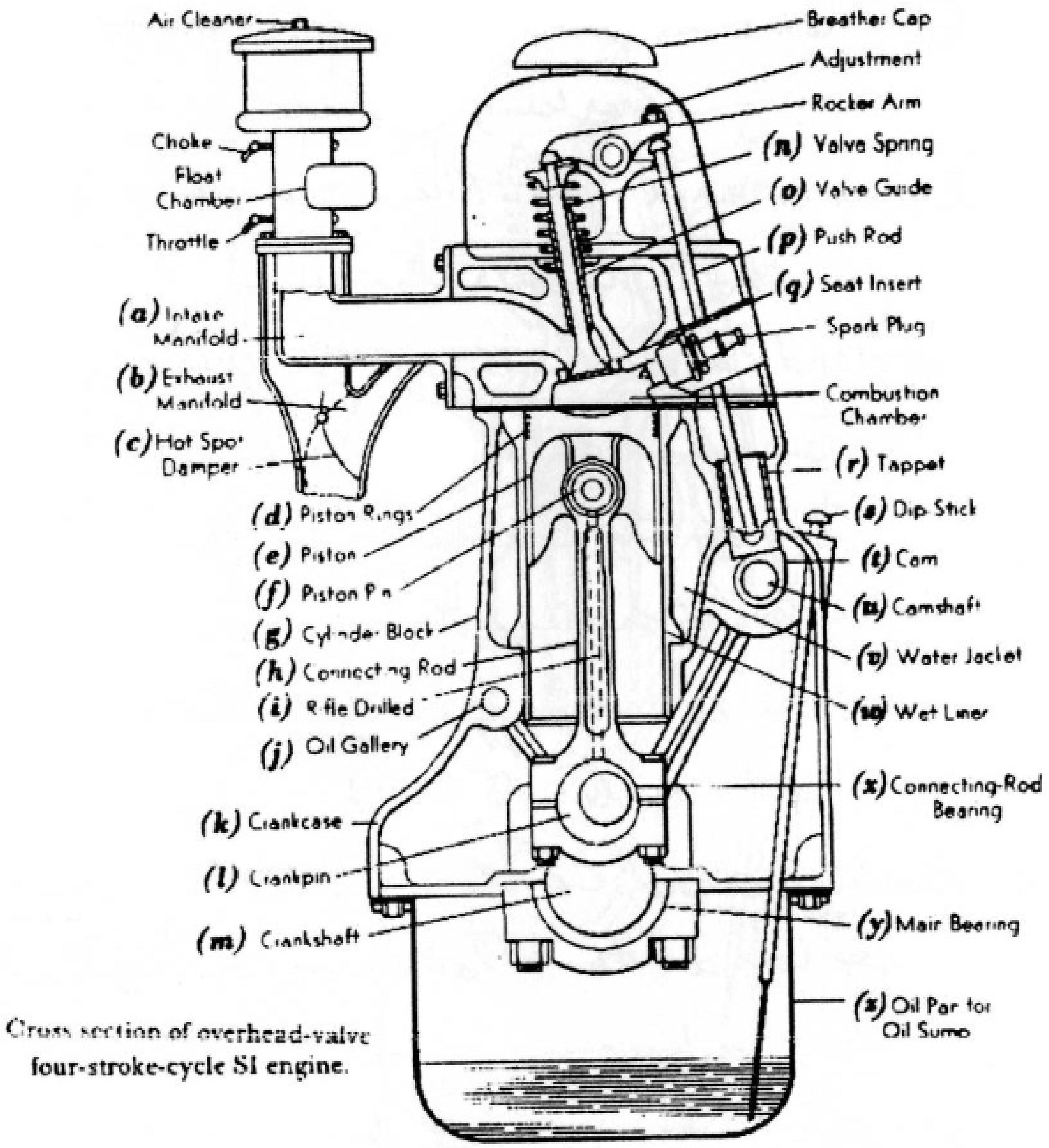


Figure (3) *– Shown parts engine*

Chapter 6

FUEL AND COMBUSTION

6. Fuel and Combustion

6-1. Types of fuels

1. Fossil fuels

a. solid fuels (coal)

b. liquid fuels (oil)

c. gaseous fuels (natural gas)

2. Nuclear fuels

3. Renewable fuels (biomass)

4. Waste fuels (municipal wastes)

Fuel is any material when burnt will produce heat energy. Various fuels commonly used are as follows:

6-2. Solid Fuels:

Coal is the most important solid fuel; there are other types of solid fuels, such as: nuclear fuels, solid wastes (wood, sugar-cane). Coal is divided into groups according to their chemical and physical properties. An accurate chemical analysis for the fuel by mass is called the "ultimate analysis", which gives the percentage of the important elements present in the fuel. Another approximate analysis of fuel called the "proximate analysis" gives the percentage of moisture, volatile matter, and combustible solid (fixed carbon) and ash.

Table 1. Ultimate Analysis of Coals

Coal	**C**	**H**	**O**	**N + S**	**Ash**
Anthracite	90.27	3.00	2.32	1.44	2.97
Bituminous	74.00	5.98	13.01	2.26	4.75
Lignite	56.52	5.72	31.89	1.62	4.25

6-2-1. Coal classification

Coal is classified into three major types namely anthracite, bituminous, and lignite. However, there is no clear demarcation between them. Coal is further classified as semi-anthracite,semi-bituminous, and sub-bituminous. Anthracite is the oldest coal from a geological perspective. It is a hard coal composed mainly of carbon with little volatile content and practically no moisture. Lignite is the youngest coal from a geological perspective. It is a soft coal composed mainly of volatile matter and moisture content with low fixed carbon. Fixed carbon refers to carbon in its free state, not combined with other elements. Volatile matter refers to those combustible constituents of coal that vaporize when coal is heated. The common coals used in for example Indian industry are bituminous and sub bituminous coal. The gradation of Indian coal based on its calorific value is as follows:

Grade	Calorific Value Range (in kCal/kg)
A	Exceeding 6200
B	5600 – 6200
C	4940 – 5600
D	4200 – 4940
E	3360 – 4200
F	2400 – 3360
G	1300 – 2400

Normally D, E and F coal grades are available to Indian industry. The chemical composition of coal has a strong influence on its combustibility. The properties of coal are broadly classified as physical properties and chemical properties.

6-2-2. Physical and chemical properties of coal

Physical properties of coal include the heating value, moisture content, volatile matter and ash.

The chemical properties of coal refer to the various elemental chemical constituents such as carbon, hydrogen, oxygen, and sulphur. The heating value of coal varies from coal field to coal field. The typical GCVs for various coals are given in the Table below.

Table 2. GCV for various coal types

Parameter	Lignite (Dry Basis)	Indian Coal	Indonesian Coal	South African Coal
GCV (kCal/kg)	4,500*	4,000	5,500	6,000

*GCV of lignite on '*as received basis*' is 2500 –3000

6-2-3. Analysis of coal

There are two methods to analyze coal: ultimate analysis and proximate analysis. The ultimate analysis determines all coal component elements, solid or gaseous and the proximate analysis determines only the fixed carbon, volatile matter, moisture and ash percentages. The ultimate analysis is determined in a properly equipped laboratory by a skilled chemist, while proximate analysis can be determined with a simple apparatus. (It may be noted that proximate has no connection with the word "approximate").

Measurement of moisture.

The determination of moisture content is carried out by placing a sample of powdered raw coal of size 200-micron size in an uncovered crucible, which is placed in the oven kept at 108 +2 ^{o}C along with the lid. Then the sample is cooled to room temperature and weighed again. The loss in weight represents moisture.

Measurement of volatile matter

A fresh sample of crushed coal is weighed, placed in a covered crucible, and heated in a furnace at 900 + 15 ^{o}C. The sample is cooled and weighed. Loss of weight represents moisture and volatile matter. The remainder is coke (fixed carbon and ash). For detailed methodologies (including for determination of carbon and ash content).

Measurement of carbon and ash

The cover from the crucible used in the last test is removed and the crucible is heated over the Bunsen burner until all the carbon is burned. The residue is weighed, which is the incombustible ash. The difference in weight from the previous weighing is the fixed carbon.

In actual practice Fixed Carbon or FC derived by subtracting from 100 the value of moisture, volatile matter and ash.

Proximate analysis

The proximate analysis indicates the percentage by weight of fixed carbon, volatiles, ash, and moisture content in coal. The amounts of fixed carbon and volatile combustible matter directly contribute to the heating value of coal. Fixed carbon acts as a main heat generator during burning. High volatile matter content indicates easy ignition of fuel. The ash content is important in the design of the furnace grate, combustion volume, pollution control equipment and ash handling systems of a furnace. A typical proximate analysis of various coal types is given in Table 3.

Table 3. Typical proximate analysis of various coals (percentage)

Parameter	Indian Coal	Indonesian Coal	South African Coal
Moisture	5.98	9.43	8.5
Ash	38.63	13.99	17
Volatile matter	20.70	29.79	23.28
Fixed Carbon	34.69	46.79	51.22

These parameters are described below

Fixed carbon

Fixed carbon is the solid fuel left in the furnace after volatile matter is distilled off. It consists mostly of carbon but also contains some hydrogen, oxygen, sulphur and nitrogen not driven off with the gases. Fixed carbon gives a rough estimate of the heating value of coal.

Volatile matter

Volatile matters are the methane, hydrocarbons, hydrogen and carbon monoxide, and incombustible gases like carbon dioxide and nitrogen found in coal. Thus the volatile matter is an index of the gaseous fuels present. A typical range of volatile matter is 20 to 35%.

Volatile matter

Proportionately increases flame length, and helps in easier ignition of coal

Sets minimum limit on the furnace height and volume

Influences secondary air requirement and distribution aspects

Influences secondary oil support

Ash content

Ash is an impurity that will not burn. Typical range is 5% to 40%. Ash

Reduces handling and burning capacity

Increases handling costs

Affects combustion efficiency and boiler efficiency

Causes clinkering and slagging

Moisture content

Moisture in coal must be transported, handled and stored. Since it replaces combustible matter, it decreases the heat content per kg of coal. Typical range is 0.5 to 10%. Moisture

Increases heat loss, due to evaporation and superheating of vapour

Helps to a certain extent with binding fines

Aids radiation heat transfer

Sulphur content

Typical range is 0.5 to 0.8% normally. Sulphur

Affects clinkering and slagging tendencies

Corrodes chimney and other equipment such as air heaters and economizers

Limits exit flue gas temperature

Ultimate analysis

The ultimate analysis indicates the various elemental chemical constituents such as carbon, hydrogen, oxygen, sulphur, etc. It is useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. This information is required for the calculation of flame temperature and the flue duct design etc. Typical ultimate analyses of various coals are given in the table below.

Table 4. Typical ultimate analysis of coals

Parameter	Indian Coal, %	Indonesian Coal, %
Moisture	5.98	9.43
Mineral Matter (1.1 x Ash)	38.63	13.99
Carbon	41.11	58.96
Hydrogen	2.76	4.16
Nitrogen	1.22	1.02
Sulphur	0.41	0.56
Oxygen	9.89	11.88

Table 5. Relationship between ultimate analysis and proximate analysis

%C	=	0.97C+ 0.7(VM - 0.1A) - M(0.6-0.01M)
%H	=	$0.036C + 0.086 (VM - 0.1xA) - 0.0035M^2 (1-0.02M)$
$\%N_2$	=	2.10 -0.020 VM
Where		
C	=	% of fixed carbon
A	=	% of ash
VM	=	% of volatile matter
M	=	% of moisture

Note: the above equation is valid for coal with a greater than 15% moisture content

6-2-4. Storage, handling and preparation of coal

Uncertainty in the availability and transportation of fuel necessitates storage and subsequent handling. Storing coal has its own disadvantages like build-up of inventory, space constraints, deterioration in quality and potential fire hazards. Other minor losses associated with the storage of coal include oxidation, wind and carpet loss. A 1% oxidation of coal has the same effect as 1% ash in coal. Wind losses may account for nearly 0.5 – 1.0 % of the total loss. The main goal of good coal storage is to minimize carpet loss and the loss due to spontaneous combustion. Formation of a soft carpet, comprising of coal dust and soil, causes carpet loss. On the other hand, if the temperature gradually rises in a coal heap, then oxidation may lead to spontaneous combustion of coal stored. Carpet losses can be reduced by:

1. Preparing a hard solid surface for coal to be stored

2. Preparing standard storage bays of concrete and brick In industry, coal handling methods range from manual and conveyor systems. It would be advisable to minimize the handling of coal so that further generation of fines and segregation effects are reduced.

The preparation of coal prior to feeding into the boiler is an important step for achieving good combustion. Large and irregular lumps of coal may cause the following problems:

1. Poor combustion conditions and inadequate furnace temperature
2. Higher excess air resulting in higher stack loss
3. Increase of unburnts in the ash
4. Low thermal efficiency

Note: A detailed description for the preparation of coal is given under the section "Energy Efficiency Opportunities".

6-3. Liquid Fuels:

Liquid fuels are widely used for I.C.E. Practically all liquid fuels have two basic combustible elements; carbon and hydrogen, present separately or in a combination called hydrocarbons, there are principal commercial types of liquid fuels.

Liquid fuels like furnace oil and LSHS (low sulphur heavy stock) are predominantly used in industrial applications.

The various properties of liquid fuels are given below.

6-3-1. Density

Density is defined as the ratio of the mass of the fuel to the volume of the fuel at a reference temperature of 15°C. Density is measured by an instrument called a hydrometer. The knowledge of density is useful for quantitative calculations and assessing ignition qualities. The unit of density is kg/m^3.

6-3-2. Specific gravity

This is defined as the ratio of the weight of a given volume of oil to the weight of the same volume of water at a given temperature. The density of fuel, relative to water, is called specific gravity. The specific gravity of water is defined as 1. Since specific gravity is a ratio, it has no units. The measurement of specific gravity is generally made by a hydrometer. Specific gravity is used in calculations involving weights and volumes.

The specific gravity of various fuel oils are given in Table below:

Table 6. Specific gravity of various fuel oils

Fuel Oil	L.D.O (Light Diesel Oil)	Furnace oil	L.S.H.S (Low Sulphur Heavy Stock)
Specific Gravity	0.85 - 0.87	0.89 - 0.95	0.88 - 0.98

6-3-3. Viscosity

The viscosity of a fluid is a measure of its internal resistance to flow. Viscosity depends on the temperature and decreases as the temperature increases. Any numerical value for viscosity has no meaning unless the temperature is also specified. Viscosity is measured in Stokes / Centistokes. Sometimes viscosity is also quoted in Engler, Saybolt or Redwood. Each type of oil has its own temperature - viscosity relationship. The measurement of viscosity is made with an instrument called a Viscometer. Viscosity is the most important characteristic in the storage and use of fuel oil. It influences the degree of pre- heating required for handling, storage and satisfactory atomization. If the oil is too viscous, it may become difficult to pump, hard to light the burner, and difficult to handle. Poor atomization may result in the formation of carbon deposits on the burner tips or on the walls. Therefore pre-heating is necessary for proper atomization.

6-3-4. Flash Point

The flash point of a fuel is the lowest temperature at which the fuel can be heated so that the vapour gives off flashes momentarily when an open flame is passed over it. The flash point for furnace oil is 66^{0}C.

6-3-5. Pour Point

The pour point of a fuel is the lowest temperature at which it will pour or flow when cooled under prescribed conditions. It is a very rough indication of the lowest temperature at which fuel oil is ready to be pumped.

6-3-6. Specific Heat

Specific heat is the amount of kCals needed to raise the temperature of 1 kg of oil by 10C. The unit of specific heat is kcal/kg0C. It varies from 0.22 to 0.28 depending on the oil specific gravity. The specific heat determines how much steam or electrical energy it takes to heat oil to a desired temperature. Light oils have a low specific heat, whereas heavier oils have a higher specific heat.

6-3-7. Calorific Value

The calorific value is the measurement of heat or energy produced, and is measured either as gross calorific value or net calorific value. The difference is determined by the latent heat of condensation of the water vapour produced during the combustion process. Gross calorific value (GCV) assumes all vapour produced dur ing the combustion process is fully condensed. Net calorific value (NCV) assumes the water leaves with the combustion products without fully being condensed. Fuels should be compared based on the net calorific value. The calorific value of coal varies considerably depending on the ash, moisture content and the type of coal while calorific value of fuel oils is much more consistent. The typical GCVs of some of the commonly used liquid fuels are given below:

Table 2. Gross calorific values for different fuel oils

Fuel Oil	Gross Calorific Value (kCal/kg)
Kerosene -	11,100
Diesel Oil -	10,800
L.D.O -	10,700
Furnace Oil -	10,500
LSHS -	10,600

6-3-8. Sulphur

The amount of sulphur in the fuel oil depends mainly on the source of the crude oil and to a lesser extent on the refining process. The normal sulfur content for the residual fuel oil (furnace oil) is in the order of 2 - 4 %. Typical figures for different fuel oils are shown in Table 3.

Table 3. Percentages of sulphur for different fuel oils

Fuel Oil	Percentage of Sulphur
Kerosene -	0.05 - 0.2
Diesel Oil -	0.05 - 0.25
L.D.O -	0.5 - 1.8
Furnace Oil -	l 2.0 - 4.0
LSHS -	< 0.5

The main disadvantage of sulphur is the risk of corrosion by sulphuric acid formed during and after combustion, and condensation in cool parts of the chimney or stack, air pre-heater and economizer.

6-3-9. Ash Content

The ash value is related to the inorganic material or salts in the fuel oil. The ash levels in distillate fuels are negligible. Residual fuels have higher ash levels. These salts may be compounds of sodium, vanadium, calcium, magnesium, silicon, iron, aluminum, nickel, etc.

Typically, the ash value is in the range 0.03 - 0.07 %. Excessive ash in liquid fuels can cause fouling deposits in the combustion equipment. Ash has an erosive effect on the burner tips, causes damage to the refractories at high temperatures and gives rise to high temperature corrosion and fouling of equipments.

6-3-10. Carbon Residue

Carbon residue indicates the tendency of oil to deposit a carbonaceous solid residue on a hot surface, such as a burner or injection nozzle, when its vaporizable constituents evaporate. Residual oil contains carbon residue of 1 percent or more.

6-3-11. Water Content

The water content of furnace oil when it is supplied is normally very low because the product at refinery site is handled hot. An upper limit of 1% is specified as a standard.

Water may be present in free or emulsified form and can cause damage to the inside surfaces of the furnace during combustion especially if it contains dissolved salts. It can also cause spluttering of the flame at the burner tip, possibly extinguishing the flame, reducing the flame temperature or lengthening the flame.

Typical specifications of fuel oils are summarized in the Table below.

Table 4. Typical specifications of fuel oils

Properties	Fuel Oils		
	Furnace Oil	L.S.H.S	L.D.O
Density (Approx. g/cc at 150C)	0.89 - 0.95	0.88 - 0.98	0.85 - 0.87
Flash Point (0C)	66	93	66
Pour Point (0C)	20	72	18
G.C.V. (kCal/kg)	10500	10600	10700
Sediment, % Wt. Max.	0.25	0.25	0.1
Sulphur Total, % Wt. Max.	Up to 4.0	Up to 0.5	Up to 1.8
Water Content, % Vol. Max.	1.0	1.0	0.25
Ash % Wt. Max.	0.1	0.1	0.02

6-3-12. Storage of Fuel oil

It can be potentially hazardous to store furnace oil in barrels. A better practice is to store it in cylindrical tanks, either above or below the ground. Furnace oil that is delivered may contain dust, water and other contaminants.

The sizing of the storage tank facility is very important. A recommended storage size estimate is to provide for at least 10 days of normal consumption. Industrial heating fuel storage tanks are generally vertical mild steel tanks mounted above the ground. It is prudent for safety and environmental reasons to build bund walls around tanks to contain accidental spillages.

As a certain amount of settlement of solids and sludge will occur in tanks over time, tanks should be cleaned at regular intervals: annually for heavy fuels and every two years for light fuels. Care should be taken when oil is decanted from the tanker to the storage tank. All leaks from joints, flanges and pipelines must be attended to at the earliest. Fuel oil should be free from possible contaminants such as dirt, sludge and water before it is fed to the combustion system.

6-4. Gaseous Fuel Gas fuels

Are the most convenient because they require the least amount of handling and are used in the simplest and most maintenance-free burner systems. Gas is delivered "on tap" via a distribution network and so is suited for areas with a high population or industrial density. However, large individual consumers do have gasholders and some produce their own gas.

6-4-1. Types of gaseous fuel

The following is a list of the types of gaseous fuel:

1. Fuels naturally found in nature: - Natural gas

- Methane from coal mines

2. Fuel gases made from solid fuel

- Gases derived from coal

- Gases derived from waste and biomass

- From other industrial processes (bla st furnace gas)

3. Gases made from petroleum

- Liquefied Petroleum gas (LPG)

- Refinery gases

- Gases from oil gasification

4. Gases from some fermentation process Gaseous fuels in common use are liquefied petroleum gases (LPG), Natural gas, producer gas, blast furnace gas, coke oven gas etc. The calorific value of gaseous fuel is expressed in Kilocalories per normal cubic meter (kCal/Nm_3) i.e. at normal temperature (20 ^{0}C) and pressure (760 mm Hg).

6-4-2. Properties of gaseous fuels

Since most gas combustion appliances cannot utilize the heat content of the water vapour, gross calorific value is of little interest. Fuel should be compared based on the net calorific value. This is especially true for natural gas, since increased hydrogen content results in high water formation during combustion. Typical physical and chemical properties of various gaseous fuels are given in Table 6.

Table 5. Typical physical and chemical properties of various gaseous fuels

Fuel Gas	Relative Density	Higher Heating Value kcal/Nm^3	Air/Fuel ratio- m^3 of air to m^3 of Fuel	Flame Temp. ^{o}C	Flame Speed m/s
Natural Gas	0.6	9350	10	1954	0.290
Propane	1.52	22200	25	1967	0.460
Butane	1.96	28500	32	1973	0.870

6-4-3. LPG

LPG is a predominant mixture of propane and Butane with a small percentage of unsaturated (Propylene and Butylene) and some lighter C2 as well as heavier C5 fractions. Included in the LPG range are propane (C_3H_8), Propylene (C_3H_6), normal and iso-butane (C_4H_{10}) and Butylene(C_4H_8).

LPG may be defined as those hydrocarbons, which are gaseous at normal atmospheric pressure, but may be condensed to the liquid state at normal temperature, by the application of moderate pressures. Although they are normally used as gases, they are stored and transported as liquids under pressure for convenience and ease of handling. Liquid LPG evaporates to produce about 250 times volume of gas. LPG vapour is denser than air: butane is about twice as heavy as air and propane about one and a half time as heavy as air. Consequently, the vapour may flow along the ground and into drains sinking to the lowest level of the surroundings and be ignited at a considerable distance from the source of leakage. In still air vapour will disperse slowly. Escape of even small quantities of the liquefied gas can give rise to large volumes of vapour / air mixture and thus cause considerable hazard. To aid in the detection of atmospheric leaks, all LPG’s are required to be odorized. There should be adequate ground level ventilation where LPG is stored. For this very reason LPG cylinders should not be stored in cellars or basements, which have no ventilation at ground level.

6-4-4. Natural gas

Methane is the main constituent of natural gas and accounting for about 95% of the total volume. Other components are: Ethane, Propane, Butane, Pentane, Nitrogen, Carbon Dioxide, and traces of other gases. Very small amounts of sulphur compounds are also present. Since methane is the largest component of natural gas, generally properties of methane are used when comparing the properties of natural gas to other fuels. Natural gas is a high calorific value fuel requiring no storage facilities. It mixes with air readily and does not produce smoke or soot. It contains no sulphur. It is lighter than air and disperses into air easily in case of leak. A typical comparison of carbon contents in oil, coal and gas is given in the table below.

Table 7. Comparison of chemical composition of various fuels

	Fuel Oil	Coal	Natural Gas
Carbon	84	41.11	74
Hydrogen	12	2.76	25
Sulphur	3	0.41	-
Oxygen	1	9.89	Trace
Nitrogen	Trace	1.22	0.75
Ash	Trace	38.63	-
Water	Trace	5.98	-

Performance evaluation of fuels

This section explains the principles of combustion, how fuel performance can be evaluated using the stoichiometric calculation of air requirement, the concept of excess air, and the draft system of exhaust gases.

COMBUSTION

6-5. Principles of Combustion

6-5-1. Introduction

All conventional fossil fuels, whether, solid, liquid or gaseous, contain basically carbon and hydrogen which invariably react with the oxygen in the air forming carbon dioxide, carbon monoxide or water vapour. The heat energy released as a result of combustion can be utilized for heating purposes or for generation of high pressure steam in a boiler or as power from an engine or a gas turbine.

The solid fuels are burned in beds or in pulversied from suspended in the air stream. The liquid fuels are burned either by vaporising and mixing with air before ignition, when they behave like a gaseous fuel. The gaseous fuels are either burned in burners when the fuel and air are premixed or the fuel and air flow separately in to a burner or a furnace and simultaneously mix together as combustion proceeds.

The Kg-mole or gram-mole is widely used in combustion calculations as a unit of weight.

The molecular weight of any substance in kg represents one kilogram mole or 1K mole. 1Kmol of hydrogen has a mass of 2.016Kg and 1Kmol of carbon has a mass of 12Kg.

Consider a reaction

$$\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O} \qquad \mathbf{(1)}$$
$$\mathbf{(12+4.032) + 64 \rightarrow 44 + 2\,(2.032 + 16)}$$

16.032kg of methane reacts with 64Kg of oxygen to form 44kg of carbon dioxide and 36.032kg of water. We can also simply state that 1Kmol of methane reacts with 2Kmol of oxygen to form 1Kmol of carbon dioxide and 2K mol of water, this has advantage of permitting easy conversion between the mass and volumetric quantities for the gaseous fuel and the product of combustion. If the gases are considered ideal then according to Avogadro hypothesis, all gases contain the same number of molecules per unit volume. It implies that 1K mole of any gaseous substance occupies the volume of 22.4m^3 at NTP i.e., 1.013bar and 273K.

$$\mathbf{CH_4 + 2\,O_2 \rightarrow CO_2 + 2H_2O} \qquad \mathbf{(2)}$$

1 volume of methane reacts with 2 volume of oxygen to form one volume of CO_2 and two volumes of H_2O. Therefore in any reactions, the mass in confirmed but the no. of mol or volumes may not be considered.

(i) $C + O2 \rightarrow CO2$

On mass basis (12) + (32) → (44)

1 Mol (C) + 1 Mol (O_2) → 1 Mol (CO_2)

(ii) $2C + O_2 \rightarrow 2CO$

On mass basis (24) + (32) → (56)

Volume basis 2 Mol (C) + 1 Mol (O_2) → 2Mol (CO)

(iii) $2C + O_2 \rightarrow 2CO_2$

On mass basis (56) + (32) → (88)

2 Mol (CO) + 1 Mol (O_2) → 2 Mol (CO_2)

6-5-2. Combustion Stoichometry

A balanced chemical equation for complete Combustion of the reactions with no excess air in the product is known as a stiochiometric equation. A stiochiometric mixture of the reactants is one in which the molar proportions of the reactants are exactly as given by the stoichiometric coefficients, so that no excess of any constituent is present. In general a chemical reaction may be written as

$$\mathbf{aA + bB \rightarrow cC + dD} \qquad (3)$$

Where the reactants A and B react to form the products C and D. The small letters a, b, c and d are known as the stiochiometric coefficients.

For the combustion of any fuel the most common oxidizer is air which is a mixture of 21% O_2 and 79% N_2 (on volume basis). One mol of oxygen is accompanied by 79/21 (3.76) mol of Nitrogen. The Chemical equation for the stiochiometric combustion of carbon with air is written as

$$\mathbf{C + O_2 + 3.76N2 \rightarrow CO_2 + 3.76N_2} \qquad (4)$$

The minimum amount of air required for the complete combustion of a fuel is known as theoretical air. However in practice it is difficult to achieve complete combustion with theoretical air. Therefore fuel requires some excess air for different application and may vary from 5% ~ 20% and in gas turbine it may go up to 400% of theoretical quantity.

6-5-3. Theoretical air required for complete combustion.

If the fuel composition is known, the requirement of oxygen or air can be calculated either by mass balance or by mole method.

Consider a equation

$$\mathbf{C \ + \ O2 \ \rightarrow \ CO_2} \qquad \mathbf{(5)}$$
$$\mathbf{(12) \ + \ (32) \ \rightarrow \ (44)}$$

Or

$$1 + 8/3 \rightarrow 11/3$$

Or

$$1\ Kg\ C + 8/3\ Kg\ O2 \rightarrow\ 11/3\ kg\ CO2$$

Similarly

$$\mathbf{2\,C \ + \ O_2 \ \rightarrow \ 2CO} \qquad \mathbf{(6)}$$
$$\mathbf{2(12) \ + \ (32) \ \rightarrow \ 2(28)}$$

Or

$$1\ Kg\ C\ +\ 32/24\ Kg\ O2\ \rightarrow\ 56/24\ kg\ CO$$
$$Or\ 1\ Kg\ C\ +\ 4/3\ Kg\ O2 \rightarrow\ 7/3\ kg\ CO$$

Similarly

$$\mathbf{1\ Kg\ CO\ +\ 4/7\ Kg\ O_2\ \rightarrow\ 11/7\ kg\ CO_2} \qquad \mathbf{(7)}$$

On molal basis

$$1K\ mol\ C + 1K\ mol\ O_2 \rightarrow\ 1K\ mol\ CO_2$$
$$1K\ mol\ C + ½\ K\ mol\ O_2 \rightarrow\ 1K\ mol\ CO$$
$$1K\ mol\ C + ½\ K\ mol\ O_2 \rightarrow\ 1K\ mol\ CO_2$$

6-5-4. Conversion of Gravimetric analysis to volumetric basis and vice versa

If the composition of fuel is given on gravimetric (or weight) basis it can be converted to volumetric (or mole) basis as follows. Divide the weight of each constituents of the mixture by its molecular weight. This will give the relative volume (or mole) of each constituents. Add all the
relative volumes of the constituents then,

$$\frac{Indivisual\ (relative)\ volume\ of\ the\ constituents}{Total\ volume\ of\ all\ the\ constituents}\times 100,$$

Will give the %age by volume of each constituents in the fuel.

If the volumetric composition of a fuel is given, it can be converted to gravimetric (or weight) basis as follows. Multiply the indivisual volume of each constituent by its molecular weight. This will give relative weight of each constituent. Add all the relative weights of the constituents then Indivisual weight of the constituents X 100 Total (reative)weights of the constituents will give the %age by weight of each constituent in the fuel.

6-5-4-1. Calculation of the minimum amount of air for a fuel of known composition.

Example 1

Calculate the minimum volume of air required to burn one Kg of coal having the following composition by weight

$C = 72.4\%$, H_2 5.3%, $N_2 = 1.81$, $O_2 = 8.5\%$, moisture 7.2%

S = 0.9% and ash 3.9%

On weight basis:

Taking 1kg coal as basis weight of oxygen required to burn 1kg of coal

$$C + O_2 \rightarrow CO_2$$

$$0.724 \times 32/12 = 1.93 \text{ kg}$$

$$0.53 \times 16/2 = 0.424 \text{ kg}$$

$$0.009 \times 32/32 = 0.009 \text{ kg}$$

$$\text{Total } O_2 = 2.363 \text{ kg per kg of coal}$$

But 0.085kg O_2 is available in coal, therefore O_2 required = 2.363 – 0.085 = 2.278kg per Kg of coal.

Air contains 23% of oxygen by weight. Therefore the weight of the air supplied is 2.278 x 100/23 = 9.9 kg per kg of coal Density of air required at NTP

P v = mRT

P = m/v RT = ρRT,

$$\rho = \frac{Molecular\ weight}{Volume} = \frac{P}{RT} = 1.013 \times \frac{105}{287} \times 273 = 1.29 kg/m^3$$

Therefore volume of air required = 9.9(kg)/1.29(kg) = 7.67 m3

On mole basis

Consider 100kg of coal

$C = 72.4/12 = 6.03$ K mol, $O_2 = 8.5/32 = 0.265$ K mol

$H_2 = 5.3/2 = 2.65$ K mol, $H_2O = 7.2/18 = 0.4$ K mol

$N_2 = 1.8/28 = 0.064$ K mol, $S = 0.9/32 = 0.028$ K mol

1K mol C + 1K mol $O_2 \rightarrow$ 1Km CO_2

Therefore 6.03 K mol of carbon requires

6.03 K mol of oxygen

1 K mol H_2 + ½ K mol $O_2 \rightarrow$ 1K mol H_2O

H_2 - 2.65 x ½ = 1.325K mol

S - 0.028x1 = 0.028

Total O_2 required 6.03 + 1.325 + 0.028 = 7.383

The oxygen present in coal 0.265K mol

Net O_2 required = 7.383 – 0.265 = 7.118K mol

Air required

7.118x100/21 = 33.89K mol / 100kg of coal = 0.3389K mol / 1kg coal

Volume of air supplied

0.3389K mol/kg X 22.4m3 = 7.59m3/kg of coal

Example 2

Calculate the volumetric analysis of the flue gases when coal burns with 20% excess air from the previous calculation the actual air required 33.89K mol/100kg coal. Therefore the actual air is

33.89 x 120/100 = 40.67K mol/ 100 kg coal

The amount of N_2 associated with this

40.67 x 79/100 = 32.13K mol

The amount of O_2 present 40.67 x 21/100 = 8.54K mol

The actual amount of O_2 required was 7.118K mol excess O_2 will appear in exhaust gas = 8.54 –7.118 = 1.422K mol.

Therefore:

CO_2 = 6.03K mol

SO_2 = 0.028K mol

N_2 = 32.13K mol (air) + 0.064 (fuel) = 32.194K mol

O_2 = 1.422K mol os excess oxygen.

Therefore the Total volume = (6.03 + 0.028 + 32.194 + 1.422) = 39.674K mol

The volumetric composition of the gas

CO_2 = (6.03/39.674) x 100 = 15.12%

SO_2 = (0.028/39.674) x 100 = 0.07%

N_2 = (32.13/39.674) x 100 = 81.15%

O_2 = (1.422/39.674) x 100 = 3.58%

6-5-5. Calculation of the composition of fuel and excess air supplied from the exhaust gasanalysis:

Sometimes the composition of fuel is unknown and it becomes necessary to judge whether the amount of air supplied is sufficient or not, or excess. This can be obtained by analyzing the sample of exhaust gases.

Example 3

The composition of dry flue gases obtained by burning a liquid fuel containing only hydrogen and carbon is CO_2 10.7%, O_2 5.1%, N_2 84.2%. Calculate the composition of fuel by weight and excess air used.

Solution:

Consider 100K mol of dry flue gases. They will contain 10.7K mol of O_2 (from CO_2) + 5.1K mole of (as max. oxygen) = 15.8K mol

Using nitrogen balance the actual air used 84.2 x 100/79 = 106.58K mol of dry flue gases and oxygen in the air supplied 106.58 x 21/100 = 22.38K mol. Therefore the amount of O_2 present in the water produced by the combustion of H_2 is 22.38 – 15.8 = 6.58K mol O_2. We know that 1 K mole of H_2 combines with ½ K mol O_2 to produce water. Therefore the amount of hydrogen present is 6.58x2 = 13.16K mol/100K mol of dry flue gases, and the carbon present is 12X10.7 = 128.4kg/100K mol of dry flue gas. Therefore the composition of fuel (by weight) is 128.4kg C and 26.32Kg H_2 on the %age basis.

C = (128.4/(128.4+26.32) × 100 = 82.99%

H = (26.32/(128.4+26.32) × 100 = 17.01%

Excess air supplied

The amount of O_2 required to burn 10.7K mol C is 10.7K mol and to burn 13.16K mol H_2 is 13.16 × ½ = 6.58

Total O_2 required = 10.7 + 6.58 = 17.28K mol/100K mol of dry flue gases

% age of excess air = (22.38 – 17.28)/(17.28) × 100 = 29.5%

6-5-6. Dew point of products:

The product of combustion containing water vapour are known as wet products. The water vapour present in combustion product is cooled down to a point of condensation the vapour turn in to liquid and volume will be reduced. Knowing the partial pressure exerted by the water before condensing, it is possible to find the saturation temp. corresponding to partial pressure from the steam tables.

6-5-7. Flue gas analysis

A fuel has the following % age volumetric analysis

$$H_2 = 48\ CH_4 : 26,\ CO_2 : 11,\ CO : 5,\ N_2 = 10$$

The %age volumetric analysis of the dry exhaust gases in CO_2:8.8, O_2: 5.5, N_2: 85.7

Determine the air/fuel ratio by volume if air contains 21% O_2 by volume

Solution:

The chemical equation for the reaction of 100 moles of fuel gas with air may be written as

$$\mathbf{48H_2 + 26CH_4 + 11CO_2 + 5CO + 10N_2 + x\,(O_2 + 3.76N_2) \rightarrow aCO_2 + bH_2O + CO_2 + dN_2}$$

Carbon balance (C) → 26 + 11 + 5 = a = H2

H2 → 48 + 52 = b = 100

O2 → 11 + 2.5 + x = a + c (i)

N2 → 10 + 3.76x = d (ii)

Solving (i) and (ii) we, have

From (i) 11 + 2.5 + x = 100/2 + a + c

$$13.5 + x = 50 + a + c$$

Adding $$10 + 3.76x = d$$

============================

$$23.5 + 4.76x = 50 + a + c + d$$

Or

$$a + c + d = 4.76x - 26.5$$

% CO2 by volume in dry gas

$$(a/a+c+d) \times 100 = 8.8$$

or $$(42/4.76x - 26.5) = 0.088$$

$$4.76x = 503.77$$

$$AF = \frac{Total\ mol\ air}{Total\ mol\ \ fuel} = \frac{503.77}{100} = 5.038\%$$

Example 4

A blast furnace gas has the following volumetric analysis H_2 CO-24%, CH_4 – 2%, CO_2-6%, O_2-3% and N_2-56%

Determine the Ultimate gravimetric analysis

Given volumetric analysis, H_2 – 9%, CO-24%, CH_4 – 2%, CO_2-6%, O_2-3% and N_2-56%

Solution:

The volumetric analysis may be converted into mass or granite metric analysis by completing the table as follows:

Constituent	Volume in 1m3 of flue gas (a)	Molecular mass (b)	Proportional mass (c)=(a)x(b)	Mass in kg per kg of the gas (d)=(c)/ Σ ©	% by mass = (d)x100
CO	0.24	28	6.72	6.72/18.48 = 0.36	36%
CH_4	0.02	16	0.32	0.32/18.48 = 0.0173	1.73%
CO_2	0.06	44	2.64	264/18.48 = 0.142	14.2%
O_2	0.03	32	0.96	0.96/18.48 = 0.0519	5.19%
N_2	0.56	14	7.84	7.84/18.48 = 0.42	42%
			Σc = 18.48	Σ (d) = 1	100

The volumetric analysis of flue gas components becomes

CO-0.36, CH_4 – 0.0173, CO_2- 0.142, O_2-0.0519 and N_2-0.42

Example 5

Determine the fuel gas analysis and air fuel ratio by weight when fuel oil with 84.9% carbon,11.4% hydrogen, 3.2% sulphur, 0.4% oxygen and 0.1% ash by weight is burnt with 20% excess air, assume complete combustion.

Solution:

Consider 1kg of fuel

Oxygen required / Kg of fuel

For burning of 1kg C - 0.849 x32/12

For burning of 1kg H - 0.114 x16/2

For burning of 1kg S - 0.032 x32/32

Total O_2 required is 3.208 kg.

Amount of O_2 contained in the fuel = 0.004Kg

Net O_2 supplied / kg of fuel = 3.208 – 0.004 = 3.204 kg O_2

Net air supplied = 3.204 x 100/23 = 13.93 kg/kg of fuel

When 20% excess air supplied

Total air supplied = 13.93 x 1.2 = 16.716 kg/kg of fuel.

N_2 actually supplied = 16.716 x 77/100 = 12.871 kg/kg of fuel

O_2 actually supplied = 16.716 x 23/100 = 3.845 kg/kg of fuel

Total free O_2 in fuel gas = 3.845 – 6.204 = 0.641 kg/kg of fuel

Total free N_2 in fuel gas = 12.87 kg/kg of fuel

Flue gas analysis:

C converted to CO_2 = 0.849 x 44/12 = 3.113 kg CO_2

H converted to H_2O = 0.114 x 18/2 = 1.026 kg H_2O

S converted to SO_2 = 0.032 x 64/32 = 0.064 kg SO_2

Flue gas / kg of fuel:

= 3.113 + 1.26 + 0.064 + 0.641 + 12.871 = 17.715kg.

CO_2 H_2O SO_2 O_2 N_2

Therefore:

CO_2 = (3.113/17.715)x100 = 17.573%

SO_2 = (0.064/17.715)x100 = 0.36%

O_2 = (0.641/17.715)x100 = 3.618%

H_2O = (1.026/17.715)x100 = 5.79%

N_2 = (12.871/17.715)x100 = 72.656%

Air fuel mixture ratio is = 16.716 : 1

Example 6

A blast furnace gas has the following volumetric analysis.

H_2 = 9%, CO = 24%, CH_4 = 2%, CO_2 = 6%, O_2 = 3% and N_2 = 56 %

Determine the ultimate gravimetric analysis.

Solution:

Total H2 in the blast furnace gas.

% volumetric analysis = $9H_2 + 2H_4$

Proportional mass = % volumetric analysis X mol. Mass of element

= (9x2) + (2x4) = 18 + 8 = 26 kg.

Total 'C' in the blast furnace gas.

% of volumetric analysis = 24C + 2C + 6C

Proportional mass = (24+2+6) x 12 = 384 kg

Total O_2 in the blast furnace gas

% of volumetric analysis = 24 x O + $6O_2$ + $3O_2$

Proportional mass = (24+16) x 9 (32) = 672 kg

Total N_2 in the blast furnace gas

% of volumetric analysis = 56 N_2

Proportional mass of N_2 = 56 x 28 = 1568 Kg.

Total weight of blast furnace gas:

= 384kg C + 26kg H_2 + 672kg O_2 + 1568kg N_2 = 2650 kgs

Gravimetric %age compositon:

C = (384/2650) x 100 = 14.49%

H_2 = (26/2650) x 100 = 0.98%

O_2 = (672/2650) x 100 = 25.36%

N_2 = (1568/2650) x 100 = 59.17%

Example 7

The analysis of coal used in a boiler trial is as follows. 82% carbon, 6% hydrogen, 4% oxygen, 2% moisture and 8% ash. Determine the theoretical air required for complete combustion of 1kg of coal. If the actual air supplied is 18kg per kg of coal the hydrogen is completely burned & 80% carbon burned to CO_2 ,the reminder is CO, Determine the volumetric analysis of the dry products of combustion.

<u>Solution:</u>

For complete combustion.

O_2 required is

For carbon - 0.82 = 2.186 kg of O2

For hydrogen - 0.006 = 0.48 kg of O2

Total O_2 required = 2.666kg.

Net O_2 supplied = Total O_2 required – O_2 present in the fuel = 2.66 – 0.004

= 2.662 kg/kg of coal

Theoretical minimum air required for complete combustion [C burns to CO_2 totally]

Air supplied = 2.626 x 100/23 = 11.417 kg/kg of coal

Flue gas analysis:

But actually only 80% carbon is burns to CO_2

CO_2 = 0.8 x 0.82 x44/12 = 2.405kg of CO_2

20% carbon is burnt to CO

CO = 0.2 x 0.82 x 28/12 = 0.383 kg of CO

O_2 actually required for 80% carbon burnt to CO_2

= 0.8 x 0.82 x 3232/12 = 1.749 kg of O_2

O_2 actually required for 20% carbon burnt to CO

= 0.2 x 0.82 x 16/12 = 0.219 kg of O_2

O_2 required by Hydrogen:

= 0.06 x 8 = 0.48 kg of O_2.

H_2O produced = 0.06 x 9 = 0.54 kg of H_2O

But actual air supplied = 18 kg

Actually O_2 supplied = 18 x23/100 = 4.14 kg of O_2

Free O_2 in the flue gas = 4.14 + 0.04 – 1.749 – 0.219 – 0.48

= 1.732 kg of O_2/kg of coal

N_2 in the flue gas = 18 x 77/100 = 13.86 kg/kg of coal

Volumetric analysis of the dry products of combustion.

CO_2 = (2.405/44) × 100 = 0.0546 m^3/K. mol

CO = (0.383/28) × 100 = 0.0137 m^3/K.mol

O_2 = (1.732/32) × 100 = 0.0541 m^3/K.mol

N_2 = (13.86/28) × 100 = 0.495 m^3/K.mol

In % of volume:

CO_2 = (0.0546/0.6174) × 100 = 8.84%

CO = (0.0137/0.6174) × 100 = 2.22%

O_2 = (0.0541/0.6174) × 100 = 8.76%

N_2 = (0.495/0.6174) × 100 = 80.70%

6-5-8. Enthalpy of reaction

Enthalpy of a reaction is defined as the difference between the enthalpy of the products at a specified state and the enthalpy of the reactants at the same state for a complete reaction. For combustion process, the enthalpy of a reaction is usually referred to as the "enthalpy of combustion" it is obviously a very useful property for analyzing the combustion processes of fuels.

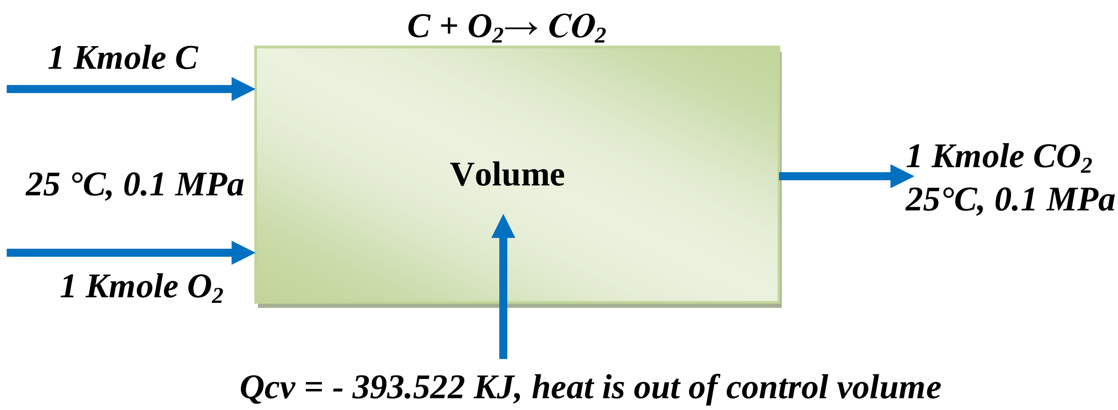
However there are so many different fuels and fuel mixtures that is not practical to list enthalpy of combustion values for all possible cases. Besides, the enthalpy of combustion is not of much use when the combustion is incomplete. Therefore a more practical approach would be have a more fundamentally property to represent the chemical energy of an element or compound at some reference state. This property is the "enthalpy of formation" which can be viewed as the enthalpy of a substance at a specified state due to its chemical composition. To establish a starting point it is assigned the enthalpy of formation for all stable elements such as O_2, N_2, H_2 and C a value of zero at standard reference state of 25^oC and 1 atm. for all stable compounds.

In a chemical reaction bonds are broken in the reactants and new bonds formed in the products.

Energy is required to break bonds and energy is released when bonds are formed. The energy associated with a chemical reaction depends on the number and type of bonds broken and/or formed.

Every chemical species has a certain amount of "heat content," or enthalpy, H, which cannot be measured. However, differences in enthalpy can be measured. The net energy change for a reaction performed at constant pressure is the enthalpy change for the reaction. This enthalpy change, ΔH,

has units kJ/mol and is defined:



[C + H (fuel)] + [O2 + N2 (Air)] -> (Combustion Process) -> [CO2 + H2O + N2 (Heat)]

Where

C = Carbon, H = Hydrogen, O = Oxygen, N = Nitrogen

$$\Delta H = H_{(products)} - H_{(reactants)} \quad (8)$$

If energy is given off during a reaction, such as in the burning of a fuel, the products have less heat content than the reactants and ΔH will have a negative value; the reaction is said to be exothermic. If energy is consumed during a reaction, ΔH will have a positive value; the reaction is said to be endothermic.

The enthalpy change for a chemical change is independent of the method or path by which the change is carried out as long as the initial and final substances are brought to the same temperature.

This observation, known as HESS'S LAW, has important practical utility.

Thermochemical equations may be treated as algebraic equations: they may be written in the reverse direction with a change in the sign of _H – even though the reverse reaction may not actually occur; they may be added and subtracted algebraically; the equation and associated ΔH value may be multiplied or divided by

factors. Hess's Law allows the calculation of enthalpy changes that would be difficult or impossible to determine directly, i.e. by experiment.
The enthalpy change for the reaction:

$$2C\ (s) \quad + \quad O_2\ (g) \quad \rightarrow \quad 2CO\ (g) \qquad (9)$$

Cannot be determined directly because carbon dioxide will also form. However, ΔH can be measured for:

$$C\ (s) + O2\ (g) \rightarrow CO_2\ (g)\ \Delta H = -393.5\ kJ \qquad (10)$$

$$2CO\ (g) + O2\ (g) \rightarrow 2CO_2\ (g)\ \Delta H = -566.0\ kJ \qquad (11)$$

Multiplying equation (10) by (9) gives equation (12), and reversing equation (11) gives equation (13):

$$2C\ (s) + 2O2\ (g) \rightarrow 2CO_2\ (g)\ \Delta H = -787.0\ kJ \qquad (12)$$

$$2CO2\ (g) \rightarrow 2CO\ (g) + O_2\ (g)\ \Delta H = +566.0\ kJ \qquad (13)$$

Adding equations (12) and (13) gives the desired information:

$$2C\ (s) + O_2\ (g) \rightarrow 2CO\ (g)\ \Delta H = -221.0\ kJ \qquad (14)$$

For a reaction in which a compound is formed from the elements, the enthalpy change is called the heat of formation, $\Delta H_f\ ^o$, for the compound. The superscript "^{o}" indicates standard conditions of one atmosphere pressure. Equation (9) and (10) are such reactions. Some others:

$$S\ (s) + O_2\ (g) \rightarrow SO_2\ (g)\ \Delta H = -296.9\ kJ \qquad (15)$$

$$Mg\ (s) + Cl_2\ (g) \rightarrow MgCl_2\ (s)\ \Delta H = -641.8\ kJ \qquad (16)$$

In reactions (9), (10), (14), and (8) ΔH for the reaction is ΔH o for the compound. For the reaction:

$$2S\ (s) + 3O_2\ (g) \rightarrow 2SO_3\ (g)\ \Delta H = -790.4\ kJ \qquad (17)$$

The heat of reaction is associated with the formation of two moles of SO3. But heat of formation o is per mole of compound, so ΔH_f for SO_3 is half of –790.4, or –395.2 kJ.

Extensive listings of heats of formation are available in handbooks. With these values of ΔH^o, you can calculate virtually any heat of reaction. The heat of a reaction is the sum of ΔH_f o values for the products minus the sum of ΔH_f values for the reactants. Expressed as a formula:

$$\Delta H_{rxn} = \Sigma \Delta H^{\circ}_{f})_{products} - \Sigma \Delta H^{\circ}_{f})_{reactants} \qquad (18)$$

Heats of formation for several com pounds are given below. Note that the phase of the compound is important when choosing a ΔHf for a free element is zero.

STANDARD HEATS OF FORMATION, ΔH_f, kJ/mole, at 25° C

AgCl (s)	–127.1	Ca(OH)2 (s)	–986.1	K3PO4 (aq)	–2002.9
AgNO3 (aq)	–100.7	Ca(OH)2 (aq)	–1002.9	K2SO4 (aq)	–1409.2
AlCl3 (s)	–695.4	HCl (g)	–92.3	MgCl2 (aq)	–797.1
AlCl3 (aq)	–1027.2	HCl (aq)	–167.4	Mg(NO3)2 (aq)	–875.1
Al(OH)3 (s)	–1272.8	H2O (g)	–241.8	NaCl (aq)	–407.1
Al2(SO4)3 (aq)	–3753.5	H2O (l)	–285.8	NaHCO3 (s)	–947.7
BaCl2 (aq)	–873.2	H3PO4 (aq)	–1294.1	NaNO3 (aq)	–446.2
Ba(NO3)2 (aq)	–951.4	H2SO4 (l)	–814.0	NaOH (aq)	–469.4
BaSO4 (s)	–1473.2	H2SO4 (aq)	–888.0	Na2SO4 (aq)	–1387.0
CaCl2 (aq)	–877.8	KOH (aq)	–481.2	ZnCl2 (aq)	–487.4

EXAMPLE: Using ΔH_f^o data calculate the heat of reaction for:

$$AgNO_3\,(aq) + NaCl\,(aq)\ \_\ AgCl\,(s) + NaNO_3\,(aq) \qquad (19)$$

$$\Delta H = [\Delta H_f^{\circ}\ AgCl\,(s) + \Delta H_f^{\circ}\ NaNO_3\,(aq)] - [\Delta H_f^{\circ}\ AgNO_3\,(aq) + \Delta H_f^{\circ}\ NaCl\,(aq)]$$

= [(–127.0) + (–446.2)] – [(–100.7) + (–407.1)]
= [–573.2] – [–507.8] = –573.2 + 507.8 = –65.4 kJ

EXAMPLE : Using ΔH_f^o data calculate the heat of reaction for

$$2\,AgNO_3\,(aq) + MgCl_2\,(aq)\ \_\ 2\,AgCl\,(s) + Mg(NO_3)_2\,(aq) \qquad (20)$$

$\Delta H = [2\ \Delta H_f^\circ\ AgCl\ (s) + \Delta H_f^\circ Mg(NO_3)_2\ (aq)] - [2\ \Delta H_f^\circ AgNO_3\ (aq) + \Delta H_f^\circ MgCl_2\ (aq)]$

$= [2(-127.0) + (-875.1)] - [2(-100.7) + (-797.1)]$
$= [-1129.1] - [-998.5] = -1129.1 + 998.5 = -130.6$ kJ

Note: the values off **ΔH_f^o** chemical equation are multiplied by the stiochiometric coefficients from the balanced

$2C\ (s) + O_2\ (g) \rightarrow 2CO\ (g)\ \Delta H = -221.0$ kJ **(21)**

$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)\ \Delta H = -393.5$ kJ **(22)**

$2H_2\ (g) + O_2(g) \rightarrow 2H_2O\ (g)\ \Delta H = -483.6$ kJ **(23)**

$2H_2\ (g) + O_2(g) \rightarrow 2H_2O\ (l)\ \Delta H = -571.8$ kJ **(24)**

$CaO\ (s) + CO2\ (g) \rightarrow CaCO_3\ (s)\ \Delta H = -178.1$ kJ **(25)**

$2Ca\ (s) + O_2\ (g) \rightarrow 2CaO\ (g)\ \Delta H = -1271.0$ kJ **(26)**

Using Hess' Law with appropriate equations from (13)-(18), above, calculate **ΔH** for each of the following reactions:

1) $H_2O\ (l) \rightarrow H_2O\ (g)$
2) $C\ (s) + H_2O\ (g) \rightarrow CO\ (g) + H_2\ (g)$
3) $Ca\ (s) + H_2O\ (g) \rightarrow CaO\ (s) + H_2\ (g)$
4) $CO\ (g) + 1/2\ O_2\ (g) \rightarrow CO_2\ (g)$
5) $2Ca\ (s) + 2C\ (s) + 3O_2\ (g) \rightarrow 2CaCO_3\ (s)$

Using heats of formation values calculate **ΔH** for each of the following reactions:

6) $2Al\ (s) + 3Cl2\ (g) \rightarrow 2AlCl3\ (s)$
7) $2Al\ (s) + 3H_2SO_4\ (aq) \rightarrow Al2(SO_4)_3\ (aq) + 3H_2\ (g)$
8) $2Al\ (s) + 3ZnCl_2\ (aq) \rightarrow 2AlCl_3\ (aq) + 3Zn\ (s)$
9) $3BaCl_2\ (aq) + Al_2(SO_4)_3\ (aq) \rightarrow 3BaSO_4\ (s) + 2AlCl_3\ (aq)$
10) $Na_2SO_4\ (aq) + BaCl_2\ (aq) \rightarrow BaSO_4\ (s) + 2NaCl\ (aq)$
11) $BaCl_2\ (aq) + 2AgNO_3\ (aq) \rightarrow 2AgCl\ (s) + Ba(NO_3)_2\ (aq)$
12) $Ca(OH)_2\ (aq) + 2HCl\ (aq) \rightarrow CaCl_2\ (aq) + 2H2O\ (l)$

13) $2Al(OH)_3$ (s) + $3H_2SO_4$ (aq) $\rightarrow$ $Al_2(SO_4)_3$ (aq) + 6H2O (l)
14) $AlCl_3$ (aq) + 3NaOH (aq) $\rightarrow$ $Al(OH)_3$ (s) + 3NaCl (aq)
15) 3KOH (aq) + H_3PO_4 (aq) $\rightarrow$ K_3PO_4 (aq) + $3H_2O$ (l)

Answers to Problems

1) +44.1 kJ
2) +131.3 kJ
3) –393.7 kJ
4) –283.0 kJ
5) –2414.2 kJ
6) –1390.8 kJ
7) –1089.5 kJ
8) –592.2 kJ kJ
9) –76.9 kJ
10) –19.2 kJ
11) –130.8
12) k–J1 11.7
13) k–J2 58.7
14) k–J5 8.7 kJ
15) –122.6

6-5-9. Internal Energy of Combustion: It is defined as the difference between the internal energy of the products and the internal energy of the reactants when complete combustion occurs at a given temperature and pressure.

$$U_C = U_P - U_R = \Sigma_P n_e(h_f + \Delta h - pv) - \Delta_R n_i(h_f + \Delta h - pv) \qquad (27)$$

6-5-10. Combustion efficiency

It is defined as the ratio of ideal fuel-air to the actual fuel-air ratio

$$\eta_{comb} = \frac{(F/A)_{ideal}}{(F/A)_{actual}} \qquad (28)$$

Example 8

Consider the following reaction, which occurs in a steady state, steady flow processes.

$$\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O}$$

The reactants and products are each at total pressure of 0.1 Mpa and 25°C. Determine the heat transfer for per K mol of fuel entering the combustion chamber.

Solution : using the values of enthalpy of formation

$$\mathbf{Q = h_f = \Sigma_p n_e h_f - \Sigma_R n_i h_f}$$

Σ_R **n_i h_f = (h_f) CH_4 =** -74873KJ

Σ_p **n_e h_f = (h_f) CO_2 + 2 (h_f) H_2O** = - 393522+2 (-2852830) = - 965182KJ

Therefore

$$\mathbf{Q} = -965182 - (-74873) = -890309KJ$$

Example 9

A small gas turbine uses 3-Methylheptane **C_8H_{18}** as fuel and **400%** theoretical air. The air and fuel enters at **25°C** and the products of combustion leaves at **900K**. The output of the engine and the fuel consumption are measured and it is found that the specific fuel consumption is **0.25kg/Sec** of fuel per **MW** output. Determine the heat transfer from the engine per **K mol** of fuel. Assume complete combustion

Solution:

The combustion equation is

$$C_8H_{18} + 4\,(12.5)O_2 + 4\,(12.5)\,(3.76)N_2 \rightarrow 8CO_2 + 9H_2O + 37.5O_2 + 188N_2$$

By first law

$$Q + \Sigma_R\, n_i\,(h_f + \Delta h); \quad = W + \Sigma_p\, n_e\,(h_f + \Delta h)$$

$$\Sigma_R\, n_i\,(h_f + \Delta h) = (h_f)\, C_8H_{18} = 250105 \text{ KJ/K mol fuel at } 25^oC$$

Considering the products

$$\Sigma_p\, n_e\,(h_f + \Delta h) = nCO_2\,(h_f + \Delta h)\,CO_2 + nH_2O\,(h_f + \Delta h)\,H_2O + nO_2\,(\Delta h)O_2 + nN_2\,(\Delta h)N_2$$

h_f of **O_2, N_2 = O Δh =** Enthalpy of formation from 298°K to 900K

Therefore

$$\Sigma_p\, n_e\,(h_f + \Delta h) = 8\,(-393522+288030) + 9(-241826+21892)$$
$$+ 37.5(19249) + 188(18222) = -755769 \text{ KJ/K mol fuel.}$$

$$W = \frac{1000(Kw)}{0.25} \times \frac{114\,Kg}{K\,mol} = 456920\,KJ\,/\,Kmol$$

Therefore

$$\mathbf{Q} = -755769+456920-(-250105) = -48744 \text{ KJ/K mol fuel}$$

Periodic Table of Elements

1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	9	10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1 H 1.01																	2 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
11 Na 23.0	12 Mg 24.3											13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.4	18 Ar 39.9
19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.8	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.7	32 Ge 72.6	33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8
37 Rb 85.5	38 Sr 87.6	39 Y 88.9	40 Zr 91.2	41 Nb 92.9	42 Mo 95.9	43 Tc (98)	44 Ru 101	45 Rh 103	46 Pd 106	47 Ag 108	48 Cd 112	49 In 115	50 Sn 119	51 Sb 122	52 Te 128	53 I 127	54 Xe 131
55 Cs 133	56 Ba 137	57 La 139	72 Hf 178	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	81 Tl 204	82 Pb 207	83 Bi 209	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226	89 Ac 227	104 Rf (261)	105 Ha (262)	106 Unh (263)	107 Uns (262)	108 Uno (265)	109 Une (266)									

Lanthanides	58 Ce 140	59 Pr 141	60 Nd 144	61 Pm (145)	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 162	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175
Actinides	90 Th 232	91 Pa 231	92 U 238	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

Questions

Following Mechanical Engineering Multiple choice objective type questions

Part 1

1.The pressure at the end of compression in the case of diesel engine is of the order of

- 6 kg/cm
- 12kg/cm
- 20 kg/cm
- 27.5 kg/cm
- 35 kg/cm

2.The ratio of indicated thermal efficiency to the corresponding air standard cycle efficiency is called

- net efficiency
- efficiency ratio
- relative efficiency
- overall efficiency
- cycle efficiency.

3.Compression ratio of LC. engines is

- the ratio of volumes of air in cylinder before compression stroke and after compression stroke
- volume displaced by piston per stroke and clearance volume in cylinder
- ratio of pressure after compression and before compression
- swept volume/cylinder volume
- cylinder volume/swept volume.

4.Supercharging is the process of

- supplying the intake of an engine with air at a density greater than the density of the surrounding atmosphere
- providing forced cooling air
- injecting excess fuel for raising more load
- supplying compressed air to remove combustion products fully

- raising exhaust pressure.

5.The specific fuel consumption per BHP hour for diesel engine is approximately

- 0.15 kg
- 0.2 kg
- 0.25 kg
- 0.3 kg

6.The temperature of interior surface of cylinder wall in normal operation is not allowed to exceed

- 80°C
- 120°C
- 180°C
- 240°C
- 320°C.

7.In a diesel engine, the fuel is ignited by

- spark
- injected fuel
- heat resulting from compressing air that is supplied for combustion
- ignitor
- combustion chamber.

8.The air standard efficiency of an Otto cycle compared to diesel cycle for the given compression ratio is

- same
- less
- more
- more or less depending on power rating
- unpredictable.

9.If the compression ratio of an engine working on Otto cycle is increased from 5 to 7, the %age increase in efficiency will be

- 2%

- 4%
- 8%
- 14%
- 27%.

10.All heat engines utilize

- low heat value of oil
- high heat value of oil
- net claorific value of oil
- calorific value of fuel
- all of the above.

11.The maximum temperature in the I.C. engine cylinder is of the order of

- 500- 1000°C
- 1000- 1500°C
- 1500-2000°C
- 2000-2500°C
- 2500-3000°C

12.The calorific value of gaseous fuels is expressed in terms of

- kcal
- kcal/kg
- kcal/m2
- kcal/n?
- all of the above.

13.Pick up the wrong statement

- 2-stroke engine can run in any direction
- In 4-stroke engine, a power stroke is obtained in 4-strokes
- thermal efficiency of 4-strokc engine is more due to positive scavenging
- petrol engines work on to cycle
- petrol engines occupy more space than diesel engines for same power output.

14.The thermal efficiency of a diesel cycle having fixed compression ratio, with

increase in cut-off ratio will

- increase
- decrease
- be independent
- may increase or decrease depending on other factors
- none of the above.

15.In a typical medium speed 4-stroke cycle diesel engine the inlet valve

- opens at 20° before top dead center and closes at 35° after the bottom dead center
- opens at top dead center and closes at bottom dead center
- opens at 10° after top dead center and closes 20° before the bottom dead center
- may open or close anywhere
- remains open for 200°.

16.Fuel oil consumption guarantees for I .C. engine are usually based on

- low heat value of oil
- high heat value of oil
- net calorific value of oil
- calorific value of fuel
- all of the above.

17.The fuel in diesel engine is normally injected at pressure of

- 5-10 kg/cm2
- 20-25 kg/cm2
- 60-80 kg/cm2
- 90-130 kg/cm2
- 150-250 kg/cm2

18.Does the supply of scavenging air at a density greater than that of atmosphere mean engine is supercharged ?

- yes
- no
- to some extent
- unpredictable

- depends on other factors.

19.In case of gas turbines, the gaseous fuel consumption guarantees are based on

- high heat value
- low heat value
- net calorific value
- middle heat value
- calorific value.

20.The pressure and temperature at the end of compression stroke in a petrol engine are of the order of

- 4 - 6 kg/cm2 and 200 - 250°C
- 6 - 12 kg/cm2 and 250 - 350°C
- 12 - 20 kg/cm2 and 350 - 450°C
- 20 - 30 kg/cm2 and 450 - 500°C
- 30 - 40 kg/cm2 and 500 - 700°C.

21.An engine indicator is used to determine the following

- speed
- temperature
- volume of cylinder
- m.e.p. and I.H.P.
- BHP.

22.If the intake air temperature of I.C. engine increases, its efficiency will

- increase
- decrease
- remain same
- unpredictable
- depend on other factors.

23.Scavenging air in diesel engine means

- air used for combustion sent under pres-sure
- forced air for cooling cylinder

- burnt air containing products of com-bastion
- air used for forcing burnt gases out of engine's cylinder during the exhaust period
- air fuel mixture.

24.Combustion in compression ignition engines is

- homogeneous
- heterogeneous
- both (a) and (b)
- laminar
- turbulent.

Part 2

1. The output of a diesel engine can be increased without increasing the engine revolution or size in following way

- feeding more fuel
- increasing flywheel size
- heating incoming air
- scavenging
- Supercharging.

2.The air-fuel ratio of the petrol engine is controlled by

- fuel pump
- governor
- injector
- carburetor
- Scavenging.

3.A 75 cc engine has following parameter as 75 cc

- fuel tank capacity
- lub oil capacity
- swept volume
- cylinder volume

- Clearance volume.

4.Which of the following is not an internal combustion engine

- 2-stroke petrol engine
- 4-stroke petrol engine
- diesel engine
- gas turbine
- Steams turbine.

5.The accumulation of carbon in a cylinder results in increase of

- clearance volume
- volumetric efficiency
- ignition time
- effective compression ratio
- valve travel time.

6.The specific fuel consumption per BH hour for a petrol engine is approximately

- 0.15 kg
- 0.2 kg
- 0.25 kg
- 0.3kg
- 0.35 kg.

7.In diesel engine the diesel fuel injected intc cylinder would burn instantly at about compressed air temperature of

- 250°C
- 500°C
- 1000°C
- 150°C
- 2000°C.

8.It the temperature of intake air in IC engines is lowered, then its efficiency will

- increase
- decrease

- remain same
- increase up to certain limit and then decrease
- decrease up to certain limit and then in-crease.

9.Pick up the false statement

- Thermal efficiency of diesel engine i about 34%
- Theoretically correct mixture of air am petrol is approximately 15 : 1
- High speed compression engines operate on dual combustion cycle
- Diesel engines are compression ignition engines
- S.I. engines are quality-governed engines.

10.The air requirement of a petrol engine during starting compared to theoretical required for complete combustion is

- more
- loss
- same
- may be more or less depending on engine capacity
- unpredictable

11.The rating of a diesel engine, with increase in air-intlet temperature, will

- increase linearly
- decrease linearly
- increase parabolically
- decrease parabolically
- first decrease linearly and then increase parabolically.

12.In a typical medium speed, 4-stroke cycle diesel engine

- fuel injection starts at 10° before to dead center and ends at 20° after tor dead center
- fuel injection starts at top dead center and ends at 20° after top dead center
- fuel injection starts at just before top dead center and ends just after top dead center
- may start and end anywhere
- none of the above.

13.Compression loss in I.C engines occurs duto

- leaking piston rings
- use of thick head gasket
- clogged air-inlet slots
- increase in clearance volume caused by bearing-bushing wear
- all of the above.

14.In a typical medium speed 4-stroke cycle diesel engine

- compression starts at 35° after bottom dead center and ends at top dead center
- compression starts at bottom dead center and ends at top dead center
- compression starts at 10° before bottom dead center and, ends just before top dead center
- may start and end anywhere
- none of the above.

15.If one cylinder of a diesel engine receives more fuel than the others, then for that cylinder the

- exhaust will be smoky
- piston rings would stick into piston grooves
- exhaust temperature will be high
- engine starts overheating
- scavenging occurs.

1.Air fuel ratio for idling speed of a petrol engine is approximately

- 1 : 1
- 5 : 1
- 10:1
- 15 : 1
- 20 : 1.

2.In the opposed piston diesel engine, the combustion chamber is located

- above the piston (/;) below the piston

- between the pistons
- any when
- there is no such criterion.
- opt 5

3.In the crankcase method of scavenging, the air pressure is produced by

- supercharger
- centrifugal pump
- natural aspirator
- movement of engine piston
- reciprocating pump.

4.In loop scavenging, the top of the piston is

- flat
- contoured
- slanted
- depressed
- convex shaped.

5.Scavenging is usually done to increase

- thermal efficiency
- speed
- power output
- fuel consumption
- all of the above.

6.For maximum power generation, the air fuel ratio for a petrol engine for vehicles, is of the order of

- 9 : 1
- 12 : 1
- 15 : 1
- 18 : 1
- 20: 1.

7.Air fuel ratio at which a petrol engine can not work is

- 8 : 1
- 10 : 1
- 15 : 1
- 20 : 1 and less
- will work at all ratios.

8.Which of the following is the lightest and most volatile liquid fuel

- diesel
- kerosene
- fuel oil
- gasoline
- lub oil.

9.A stoichiometric air-fuel ratio is

- chemically correct mixture
- lean mixture
- rich mixture for idling
- rich mixture for over loads
- the ratio used at full rated parameters.

10.Pour point of fuel oil is the

- minimum temperature to which oil is heated in order to give off inflammable vapours in sufficient quantity to ignite momentarily when brought in contact with a flame
- temperature at which it solidifies or congeals
- it catches fire without external aid
- indicated by 90% distillation temperature i.e., when 90% of sample oil has distilled off
- temperature at which it flows easily.

11.Installation of supercharger on a four-cycle diesel engine can result in the following percentage increase in power

- upto 25%
- upto 35%
- upto 50%

- upto 75%
- upto 100%.

12.A hmh flame speed is obtained in diesel engine when air fuel ratio is

- uniform throughout the mixture
- chemically correct mixture
- about 3-5% rich mixture
- about 10% rich mixture
- about 10% lean mixture.

13.The following volume of air is required for consuming 1 liter of fuel by a four stroke engine

- 1 m3
- 5 m3
- 5-6 m3
- 9-10 m3
- 15-18 m3.

14.The air-fuel ratio in petrol engines-is controlled by

- controlling valve opening/closing
- governing
- injection
- carburettion
- scavenging and supercharging.

15.A 5 BHP engine running at full load would consume diesel of the order of

- 0.3 kg/hr
- 1 kg/hr
- 3 kg/hr
- 5 kg/hr
- 10 kg/hr.

16.The theoretically correct air fuel ratio for petrol engine is of the order of

- 6 : 1
- 9 : 1

- 12 : 1
- 15 : 1
- 20 : 1.

17.In a naturally aspirated diesel engine, the air is supplied by

- a supercharger
- a centrifugal blower
- a vacuum chamber
- an injection tube
- forced chamber

18.For the same power developed in I.C. engines, the cheaper system is

- naturally aspirated
- supercharged
- centrifugal pump
- turbo charger
- none of the above.

19.Diesel engine can work on very lean air fuel ratio of the order of 30 : 1. A petrol engine can also work on such a lean ratio provided

- it is properly designed
- best quality fuel is used
- can not work as it is impossible
- flywheel size is proper
- engine cooling is stopped.

20.A diesel engine has

- 1 valve
- 2 valves
- 3 valves
- 4 valves
- no valve.

21.The knock in diesel engine occurs due to

- instantaneous and rapid burning of the first part of the charge

- instantaneous atuo iginition of last part of charge
- delayed burning of the first part of the charge
- reduction of delay period
- all of the above.

22.Volatility of diesel fuel oil is

- minimum temperature to which oil is heated in order to give off inflame mable vapours in sufficient quantity to ignite momentarily when brought in contact with a flame
- temperature at which it solidifies or congeals
- it catches fire without external aid
- indicated by 90% distillation temperature, i.e., when 90% of sample oil has distilled off
- temperature at which it flows easily.

23.Which is more viscous lib oil

- SEA 30
- SAE 40
- SAE 50
- SAE 70
- SAE 80.

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