The internal combustion engine (I.C.E.)

مكائن الأحتراق الداخلي

Chemical energy الطاقة الكيميائية of the fuel الوقود is first أولا converted تتحول to thermal energy طاقة حرارية by means ما يعرف of combustion الأحتراق . This thermal energy raises تزيد the temperature درجة الحرارة and pressure الضغط of the gases الغازات then بعدئذ expands يتمدد against ضد the mechanical الميكانيكية mechanisms الأجزاء of the engine. This expansion is converted by the mechanical linkages حلقات of the engine to a rotating crankshaft عمود المرفق الدوار

Heat engine can be one of the following : الماكنة الحرارية تكون على الأنواع التالية

1- *External خارجي combustion engine (E.C.E.)*
2- *Internal = = (I.C.E.)*

Its important to know من المهم معرفة that the combustion process أجراء in a heat engine in both (E.C.E. & I.C.E.) is actually الحقيقة a chemical reaction تفاعل between air (oxidant) and fuel

** In (E.C.E.) the energy is supplied تجهز from an external source مصدر*
In (I.C.E.) = = = created تخلق inside داخل the system النظام by burning أحتراق fuel .

Comparison مقارنة

** I.C.E.*

1- *High maximum efficiency كفاءة*
2- *Low first cost كلفة*
3- *Absence of large heat exchangers*
   عدم أحتوائه مبادلات حرارية كبيرة
4- *Efficient cooling system*
   نظام تبريد كفوء
5- *Effective cycle temperature control*
   سيطرة فعالة لدرجة حرارة الدورة
6- *Practical in mobile متنقلة application*
7- *Exhaust عادم heat energy utilization أستخدام*

** E.C.E.*

1- *Wide واسع variety تنوع fuel used*
2- *High starting أبتدائي torque عزم*
3- *Almost free vibration engine*
   محرك أهتزاز حر تقريبا
4- *Practical in a very large power unit*
   عمليا يستخدم في وحدات القدرة الكبيرة
5- *Practical in stationary application*
   عمليا يستخدم في التطبيقات الثابتة

<u>*ENGINS CLASSIFICATIONS*</u> *تصنيفات*

<u>*I.C. engines can be classified in a number of different مختلفة ways طرق:*</u>

1. <u>Types of ignition</u> أنواع الأشتعال

(a) Spark القدح Ignition (SI): An SI engine starts يبدأ the combustion الأحتراق process أجراء in each cycle by use of a spark plug شمعة. The spark plug gives a high-voltage electrical

(b) Compression أنضغاط Ignition (CI): The combustion process in a C.I. engine starts when the air-fuel mixture خليط self-ignites يشتعل ذاتيا due نتيجة to high temperature in the combustion chamber حجرة caused المتسببة by high compression.

2. <u>Types of engine cycles</u>

(a) Four-Stroke شوط Cycle: A four-stroke cycle has four piston مكبس movement يتحرك over two engine revolutions دورة for each cycle.

(b) Two-Stroke Cycle: A two-stroke cycle has two piston movements over one revolution for each cycle.

3.<u>Types of basic design</u> التصميم الأساس

(a) <u>Reciprocating</u>. ترددي

(b) <u>Rotary</u>. دوراني Engine is made of a block قطعة (stator ثابت) built يبنى around a large Rotor دوار and crankshaft

4. <u>Types of Cooling</u>

(a) Air Cooled.

(b) Liquid Cooled (Water Cooled)

5. <u>Types of fuel used</u>

(a) Gasoline.

(b) Diesel Oil or Fuel Oil زيت الغاز.

(c) Gas, Natural Gas, Methane.

(d) Alcohol-Ethyl, Methyl.

(e) Dual Fuel الوقود المتعدد: There are a number of engines that use a combination of two or more fuels, some of CI engines use a combination مزيج of methane and diesel fuel

6.<u>Types of applications</u> التطبيقات

(a) Automobile, Truck شاحنة, Bus. *(b) Locomotiv قاطرة*

(c) Stationary ثابت *(d) Marine بحرية* *(e) Aircraft طائرة.*

(f) Small Portable محمول, Chain Saw منشار, Model Airplane

7. Types of valve location موقع الصمامات

(a) Valves in head الرأس (overhead valve), also called (I Head engine) .
(b) Valves in block (flat head), also called (L Head engine).
(c) One valve in head (usually intake الدخول) and one in block, also called (F Head engine) this is much less common شيوع

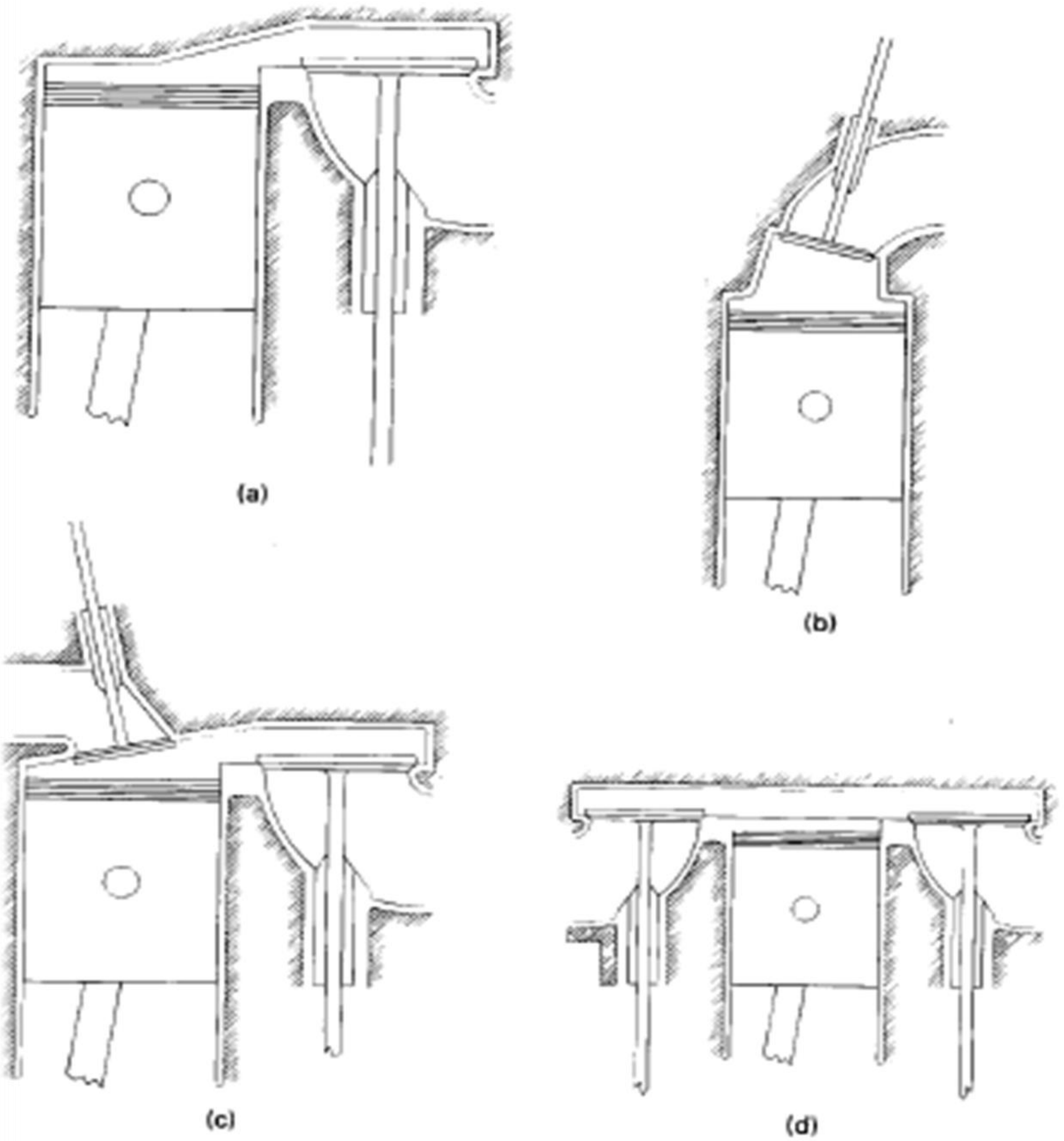
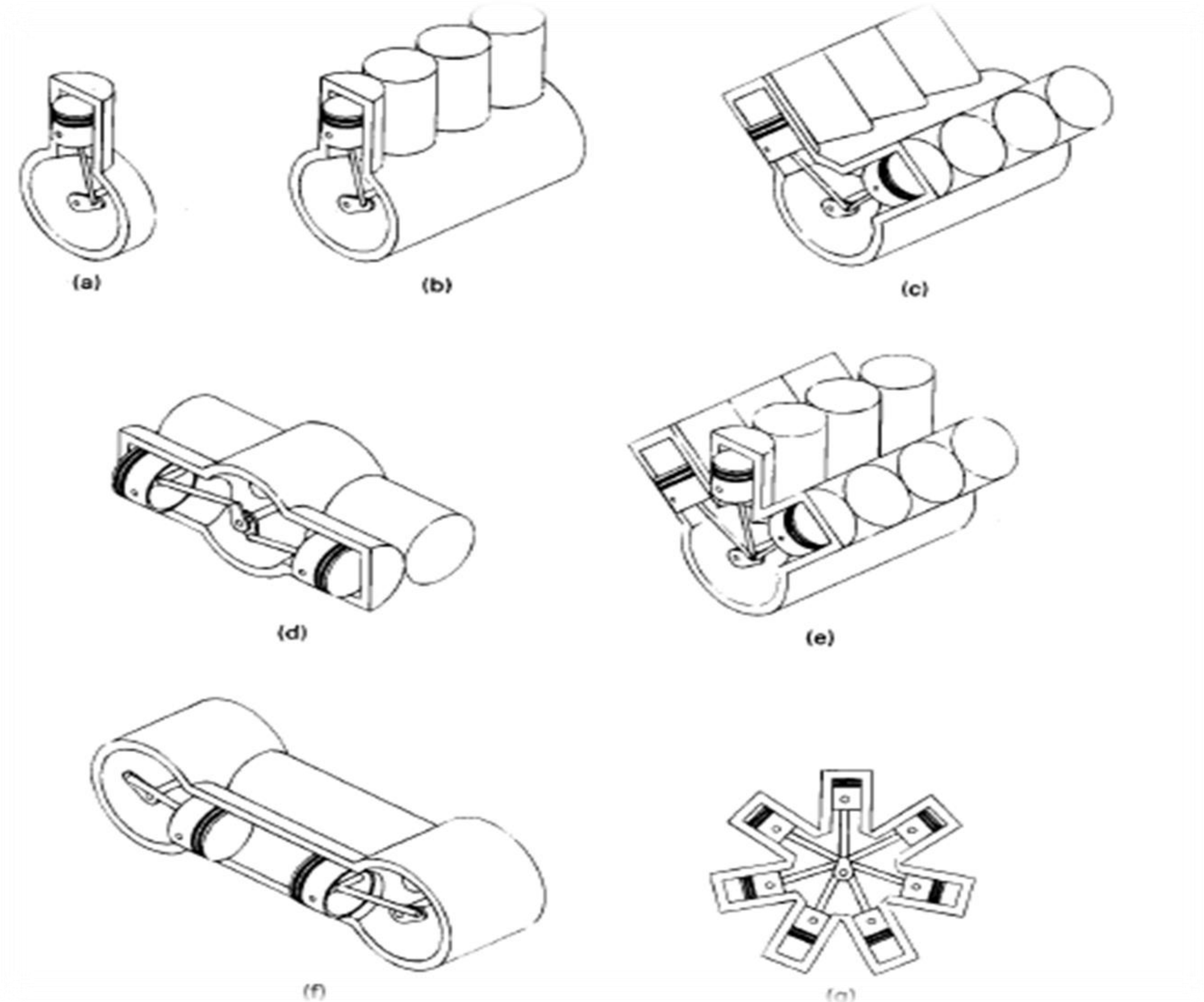


Figure 1-4 Engine Classification by Valve Location. **(a)** Valve in block, L head. Older automobiles and some small engines. **(b)** Valve in head, I head. Standard on modern automobiles. **(c)** One valve in head and one valve in block, F head. Older, less common automobiles. **(d)** Valves in block on opposite sides of cylinder, T head. Some historic automobile engines.

8. Position موقع and Number of Cylinders

(a) Single مفرد Cylinder.
(b) In-Line.
(c) V Engine.
(d) Opposed متقابل Cylinder Engine.
(e) W Engine.



<u>GENERAL DEFINITIONS</u> تعاريف عامة

<u>Top-Dead-Center (T.D.C.)</u> : *Position of the piston when it stops at the furthest* الأبعد *point away from the crankshaft.*

<u>Bottom-Dead-Center (B.D.C.)</u> : *Position of the piston when it stops at the point closest* الأقرب *to the crankshaft.*

<u>Direct Injection (D.I.)</u> : *Fuel injection* ضخ *into the main combustion chamber of an engine.*

<u>Indirect Injection (I.D.I.)</u> : *Fuel injection into the secondary* الثانوية *chamber of an engine with a divided combustion chamber.*

<u>Bore (B)</u> : *Diameter of the cylinder or diameter of the piston face* وجه

<u>Stroke (S)</u> : *Movement* حركة *distance of the piston from TDC to BDC or BDC to TDC.*

<u>Clearance Volume (V_C)</u> : *Minimum volume* الحجم الأدنى *in the combustion chamber with piston at TDC.*

<u>Displacement Volume or swept volume (V_d)</u> : *Volume displaced* المزاح *by the piston as it travels* يقطع *through one stroke. Displacement can be given for one cylinder or for the entire* الكلي *engine (one cylinder times* ضرب *number of cylinde)*

<u>ENGINE COMPONENTS</u> :

1-Block	2- Cylinder
3- Head	4- Piston
5- Head gasket حشوة	6- Camshaft عمود الحدبات
7- Piston ring حلقة	8- Exhaust system
9- Crankshaft	10- Carburetor الخلاط
11- Exhaust manifold متفرع	12- Flywheel
13- Fuel injector حاقن	14- Combustion chamber
15- Fuel pump مضخة	16- Connecting rod
17- Connecting rod bearing	18- Cooling fins زعانف
19- Crankcase غلاف	20- Fan مروحة

Basic Engine Cycles

4 - Stroke S.I. Engine Cycle

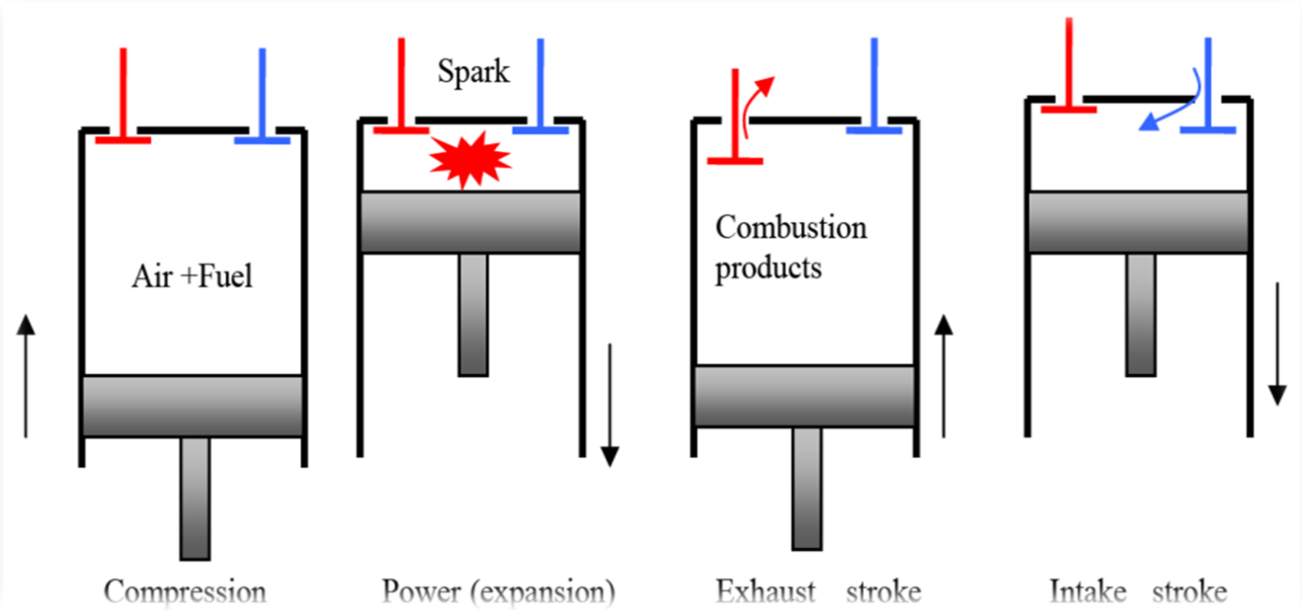
1. *Intake Stroke or Induction :* *The piston travels from T.D.C. to B.D.C. with the intake valve open and exhaust valve closed.*

2. *Compression Stroke :* *When the piston reaches يصل B.D.C. the intake valve closes and the piston travels back يعود to T.D.C. with all valves closed.*
(combustion of the air- fuel mixture occurs يحدث in a very short but finite محدود length Of time with the piston near T.D.C.)

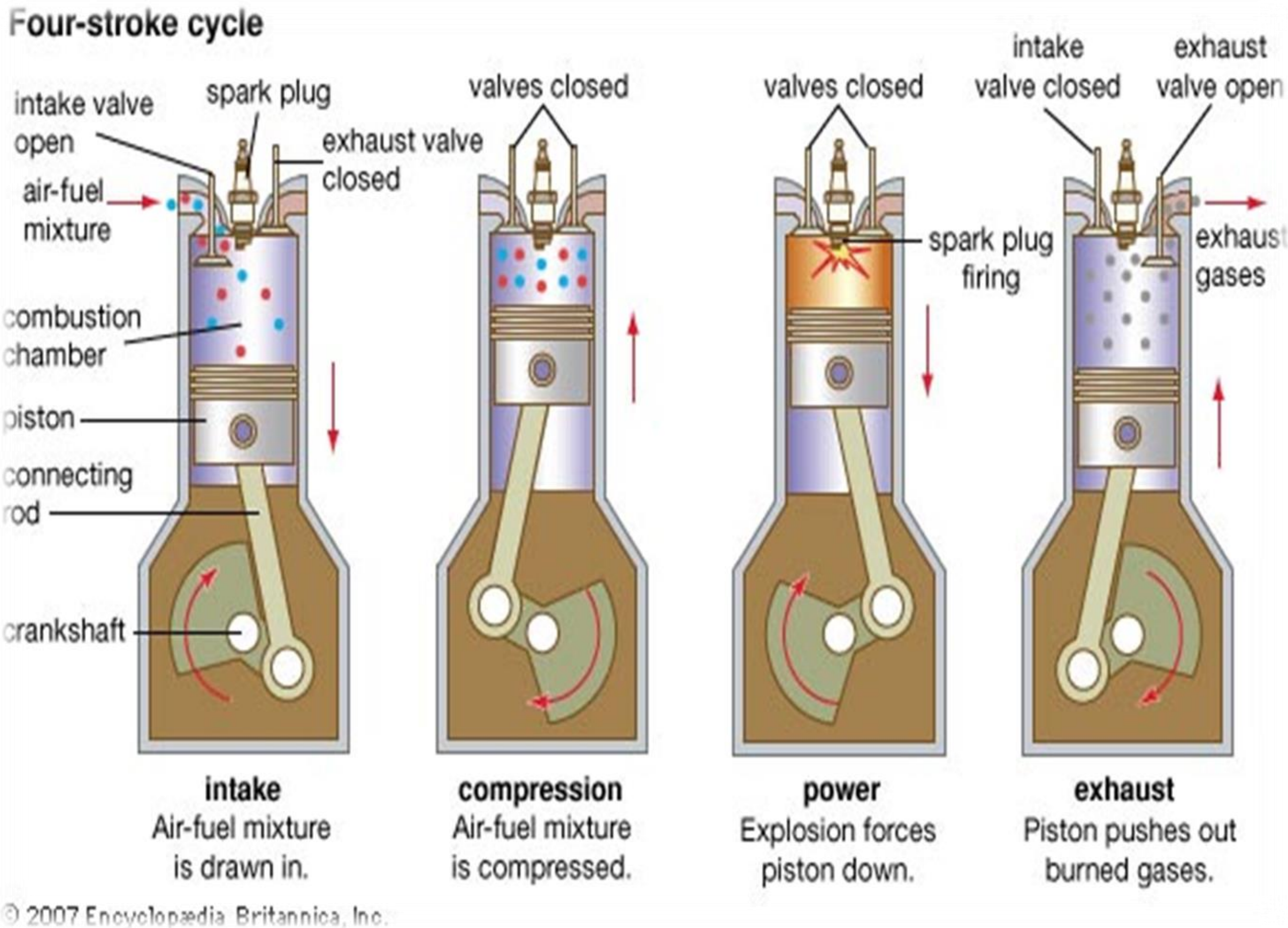
3. *Expansion Stroke or Power Stroke :* *With all valves closed, the high press. created by the combustion process pushes يدفع the piston away from T.D.C.*

4. *Exhaust Stroke :* *By the time the piston reaches B.D.C. exhaust blow يهب down is complete , but the cylinder is still يبقى full ممتلئ of exhaust gases at approximately تقريبا atmospheric pressure الضغط الجوي .*

When petrol / gasoline is used , a spark plug ignites the compressed petrol vapor بخار. It expands and pushes the piston away , which in turn pushes and rotates يدور a crankshaft.



Spark
Air +Fuel
Combustion products
Compression
Power (expansion)
Exhaust stroke
Intake stroke



Four-stroke cycle
intake valve open
spark plug
exhaust valve closed
air-fuel mixture
combustion chamber
piston
connecting rod
crankshaft
valves closed
valves closed
spark plug firing
intake valve closed
exhaust valve open
exhaust gases
intake
Air-fuel mixture is drawn in.
compression
Air-fuel mixture is compressed.
power
Explosion forces piston down.
exhaust
Piston pushes out burned gases.
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4 - Stroke C.I. Engine Cycle

1. Intake Stroke . same as an S.I. engine with one major difference أختلاف رئيسي:
no fuel is adde يضاف to the incoming الداخل air.

2. Compression Stroke . same as an SI engine except ماعدا that only air is compressed and compression is to higher pressures and temperature.

3. Power Stroke . The power القدرة stroke continues يستمر as combustion ends and the piston travels towards بأتجاه B.D.C.

4. Exhaust Stroke . Same as with an S.I. engine

Diesel I.C.E.

A diesel is slightly قليلا different. It has no spark plug, but relies يعتمد on air compression alone to heat the fuel to ignition temperature.The piston has a higher compression ratio so the gases can be compressed to a higher temperature .

(((Diesel fuel is less easily أصعب flammable ألتهاب)))

Comparision between S.I and C.I. engine

Factor	*S.I.*	*C.I.*
1- dynamic heat cycle	*Auto*	*Diesel*
2- combustion	*spark ignition*	*compression ignition*
3- compression ratio نسبة	*6/12*	*12/22*
4- mean effect المؤثر pressure	*low*	*high*
5- engine speed (r.p.m.)	*2000-6000 and more*	*400-3500*
6- piston speed	*16 m/s*	*11 m/s*
7- exhaust heat	*high*	*low*
8- starting	*easy*	*difficul*
9- fuel economic أقتصاد	*high cost*	*low cost*
10- fuel safety أمان	*high volitality*	*little volitality*
11- operation cost كلفة التشغيل	*high*	*low*
12- maintenance الصيانة cost	*low*	*high*
13- noise الضوضاء	*little*	*high*
14- fuel	*gasoline*	*diesel*

2 - stroke S.I. engine cycle

a. Power or expansion stroke : high cylinder pressure pushed piston from T.D.C. towards BDC with all valves closed . Air in crankcase is compressed by downward motion of piston.

b. Exhaust blowdown : when exhaust valve opens near end of power stroke

c. Cylinder scavenging : when intake valve opens and air+fuel is forced into cylinder under pressure. intake mixture pushes some of the remaining exhaust out the open exhaust valve . Scavenging كنس lasts until piston passes B.D.C. and closes intake and exhaust valve

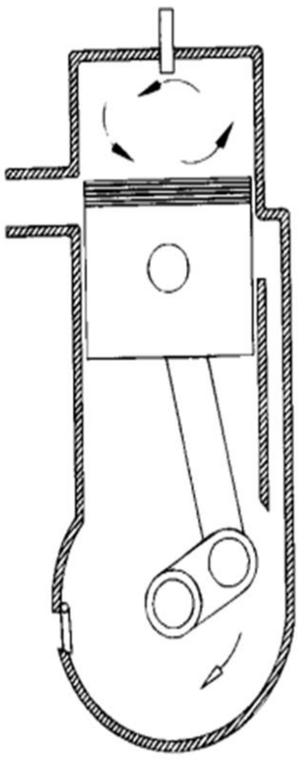
d. Compression stroke : piston moves from BDC to T.D.C. with all valves closed. Intake air + fuel fills crankcase. Spark ignition occurs near end of compression stroke.

e. Combustion : combustion occurs at almost constant volume near T.D.C.

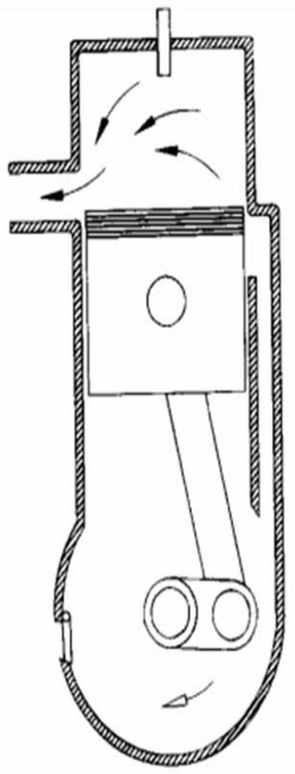
The calorific value of a fuel (C.V.) القيمة الحرارية

It is quantity كمية of heat produced by its combustion at constant pressure and under "normal" conditions (i.e. 0^o C and under a pressure of 1,013 mbar)

The combustion process generates water vapor and certain techniques تقنيات may be used to recover أزالة the quantity of heat contained in this water vapor by condensing it



(a)



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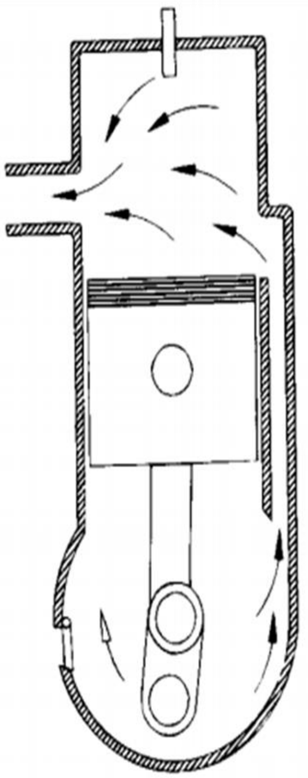

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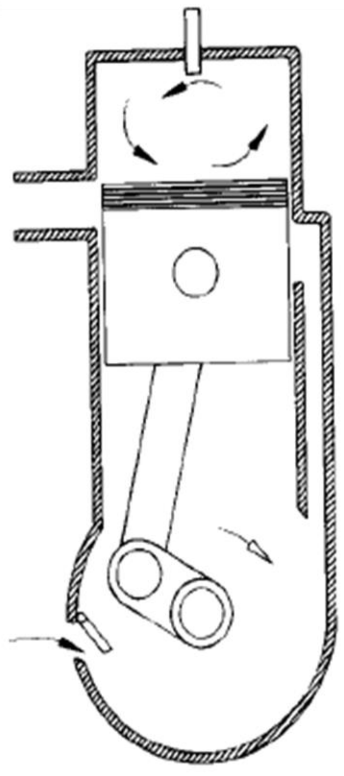
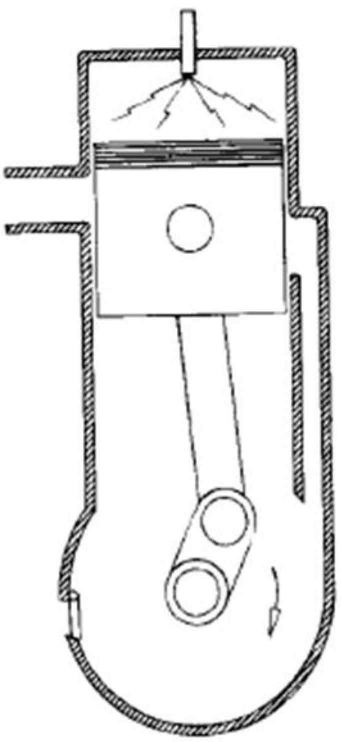
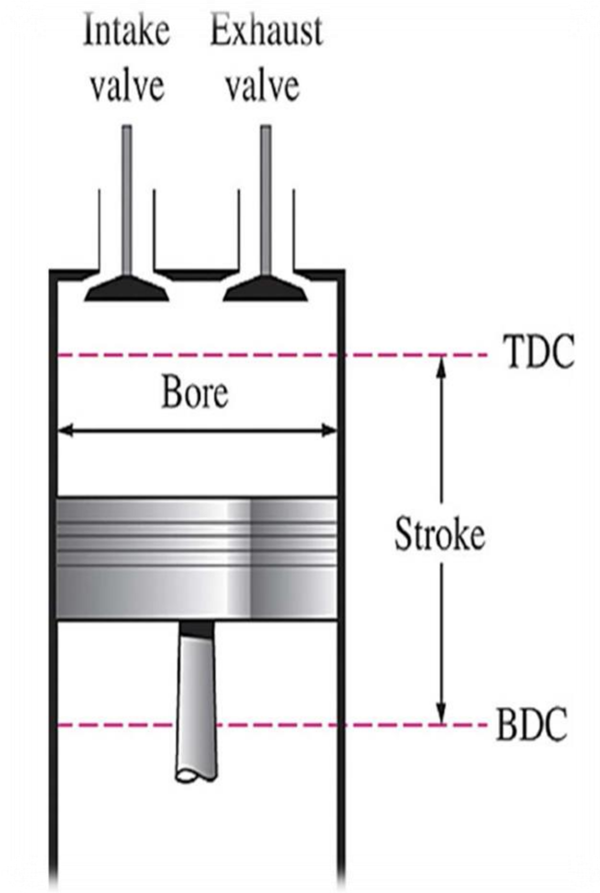


(d)



(e)

<u>Engine Parameters</u> محددات



$V_d = N_c\,(\pi/4)\,B^2 S$

V_d : displacment volume (m^3)

N_c = number of engine cylinders

B : cylinder bore (m) , S : stroke (m)

V_c = clearance volume = V_{TDC} (m^3)

= minimum cylinder volume occurs when the piston is at TDC

$V_{BDC} = V_c + V_d$ (m^3)

Indicated البيانية Power (I.P.) (kw)

$$= \frac{M.E.P.*S*A*N*Nc}{60} \quad \text{for 2- stroke}$$

$$= \frac{M.E.P.*S*A*N*Nc}{120} \quad \text{for 4- stroke}$$

M.E.P. = mean معدل effect pressure (KN/m^2)

$A = (\pi/4)\,B^2$ section area of cylinder (m^2)

N = engine speed (r.p.m.)

Power output الخارجة $(p) = \dfrac{W\ N}{Dynamometer\ constant}$ = I.P

W: the load الحمل (kg)

1- Break الكبح Power (B.P.) $= \dfrac{2\pi\ N\ T}{60}$ (kw) , T= torque العزم (KN.m)

2- Friction Power (F.P.) = I.P. – B.P. = $m_f \times C.V.$ (kw)

3- Mechanical efficiency (η_m) = B.P. / I.P.

4- Indicated thermal efficiency (η_{Ith}) = I.P. / ($\dot{m}_f$ * C.V.)

5- Brake thermal efficiency (η_{bth}) = B.P. / ($\dot{m}_f$ * C.V.)

$\dot{m}_f$ = fuel mass flow rate (kg / sec)

C.V. = calorific value القيمة الحرارية (kj / kg)

6- Indicated specific fuel consumpsion أستهلاك (I.S.F.C.) = $\dot{m}_f$ / I.P. (kg/kw.hr)

7- Brake specific fuel consumption (B.S.F.C.) = $\dot{m}_f$ / B.P. (=)

IC ENGINE ENERGY FLOW جريان

Fuel equivalent power ⟶ ENGINE ⟶ Heat losses

Indicated power ⟶ ↓

Output shaft ⟶ Friction losses

Brake power ⟶ ↓

Ex1/ An engine consumes 0.01537kg/s of air.The air fuel ratio is 12/1. The calorific value is 46 Mj/kg .Calculate the friction power (F.P.)

Solution/ air consumes $m_a = 0.01537$ kg/s , $m_a / m_f = 12/1$

mass of fuel $m_f = 0.01537 / 12 = 0.00131$ kg/s

$F.P. = m_f \times C.V. = 0.00131 \times 46000 = 60.3$ kw

Ex2/ Find : (F.p. , η_m , B.S.F.C. and η_{bth}) of (16 cm dia.) 4 cylinder engine , Piston stroke = 20 cm , develops يعطي a tourqe of 7 KN.m, M.E.P.= 7.5 bar at 2000 r.p.m. , $\acute{m}_f = 0.001$ kg/s and calorific value of fuel = 42000 kj/kg .

Solution/ $A = (\pi/4) B^2 = 0.02\ m^2$

$I.P = M.E.P. \times S \times A \times N \times N_c / 120 = 40$ Kw

$B.P.= 2\,\pi\, N\, T / 60 = 24.4$ Kw

$F.P.= I.P. – B.P. = 15.6$ Kw

$\eta_m = B.P. / I.P. = 0.61 = 61\%$

$B.S.F.C. = \dot{m}_f / B.P. = 0.000041$ Kg/Kj

$\eta_{bth} = B.P. / (\dot{m}_f \times C.V.) = 0.58 = 58\%$

Ex3/ A single (0.01 m^2 sectional area) cylinder cycle engine tested تختبر at 1000 r.p.m. Calculate :

M.E.P. and T , for the following data : Stroke = 15 cm , fuel consumption = 0.1 kg/min , I.S.F.C. = 0.0015 kg/kw.min , $\eta_m = 0.5$

Solution/ $I.S.F.C. = \dot{m}_f / I.P. \longrightarrow I.P. = \dot{m}_f / I.S.F.C. = 66.67$ Kw

$I.P = M.E.P. \times S \times A \times N \times N_c / 120$

$M.E.P. = 120 \times I.P. / S \times A \times N \times N_c = 5333.6\ KN/m^2$

$\eta_m = B.P. / I.P. \longrightarrow B.P. = \eta_m \times I.P. = 33.3$ Kw

$B.P.= 2\,\pi\, N\, T / 60 \longrightarrow T = 60\, B.P. / 2\,\pi\, N = 0.3$ KN.m

<u>Basic measurement</u> قياسات

1- Air consumption

Air consumption rate can be measured by any of the followings :

a- Air box method

b- Viscous لزوجة flow air meter

2- Engine speed

a- Revolution counter

b- Mechanical tachometer

c- Electrical tachometer

3- Fuel consumption

a- Fuel flow method

b- Gravimetric method

c- Continuous مستمر flow meter

4- Smoke density كثافة الدخان

a- Bosch smoke meter

b- Hatridge smoke meter

c- PHS smoke meter

5- Brake power

a- Apsorption dynamometer

b- Transmission dynamometer

c- Fan dynamometer

6- Indicated power

a- Indicated diagram (on P – V diagram)

b- Morse test

c- Calculation of I.P.

Cycle selection أختيار

Many working cycles have been proposed تقترح for internal combustion engine analysis تحليل, and many have been tried محاولة and tested أختيار.

1- Otto cycle (constant volume)

2- Diesel cycle (constant pressure)

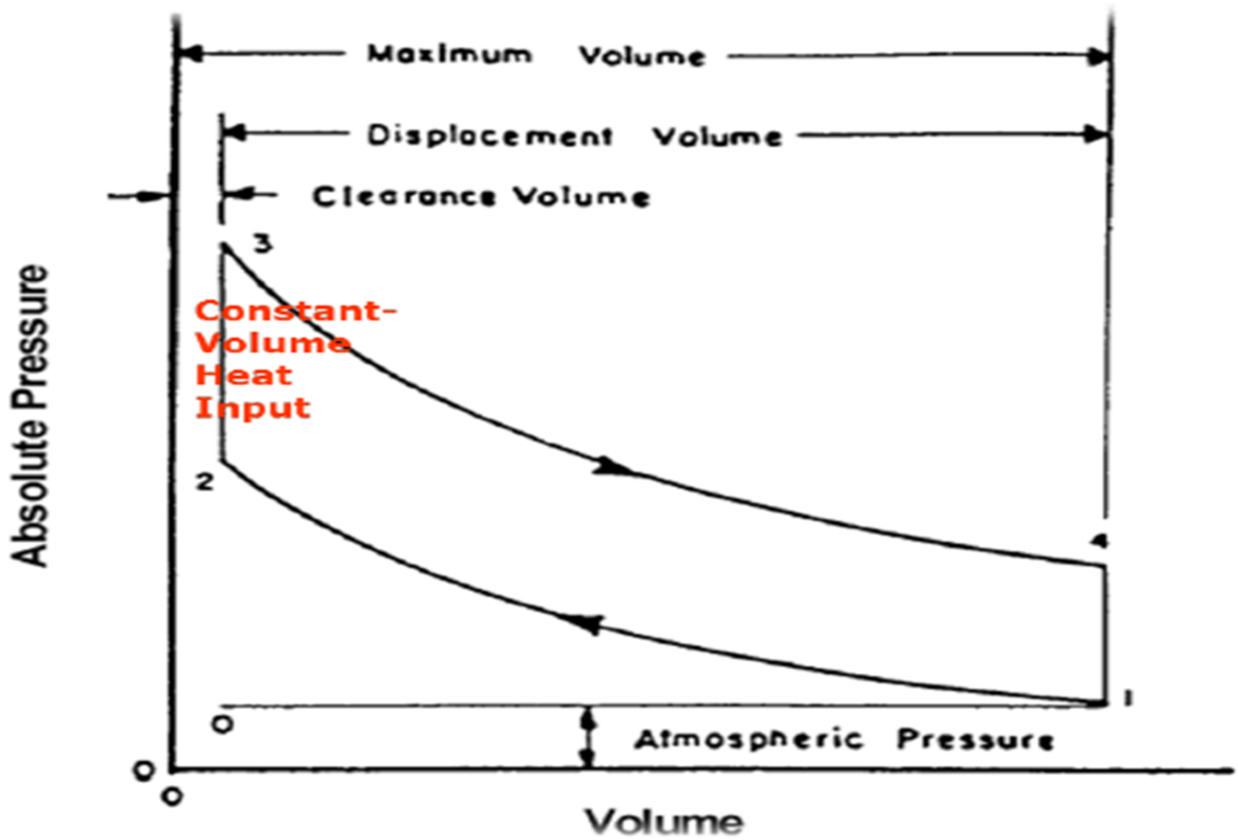
3- Dual cycle (mixed or combination)

Otto Cycle

The otto cycle is also called a constant volume cycle

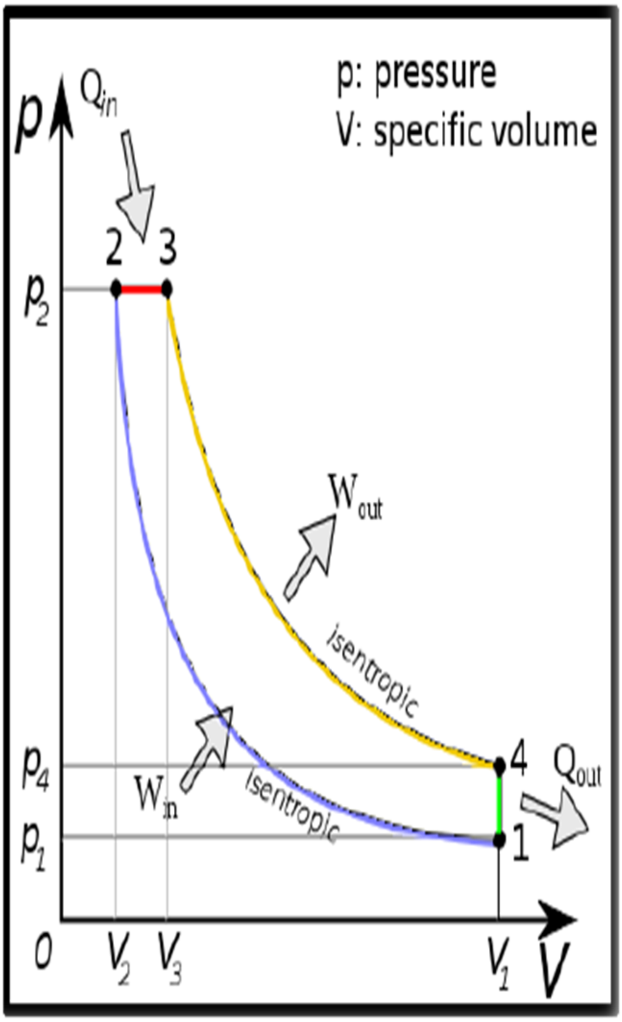
The processes :

- *1- 2: Isentropic compression*
- *2- 3: Costant volume heat addition*
- *3- 4: Isentropic expansion*
- *4- 1: Constant volume heat rejection*



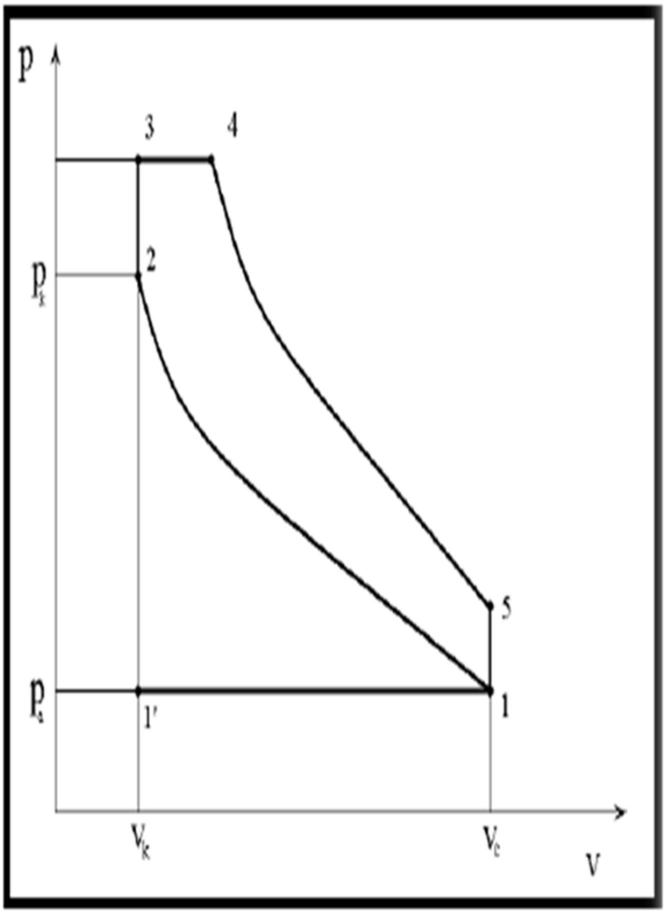
Diesel cycle

- *This cycle, proposed by a German engineer, Dr. Rudolph Diesel , is also called the constant pressure cycle.*
- it is equivalent to air cycle for the reciprocating slow speed compression ignition engine.
- it has processes similar to that of the Otto cycle except that the heat is added at constant pressure.
- 1-2 : isentropic compression.
- 2-3 : constant pressure heat addition.
- 3-4 : isentropic expansion.
- 4-1 : constant volume heat rejection.



Dual cycle

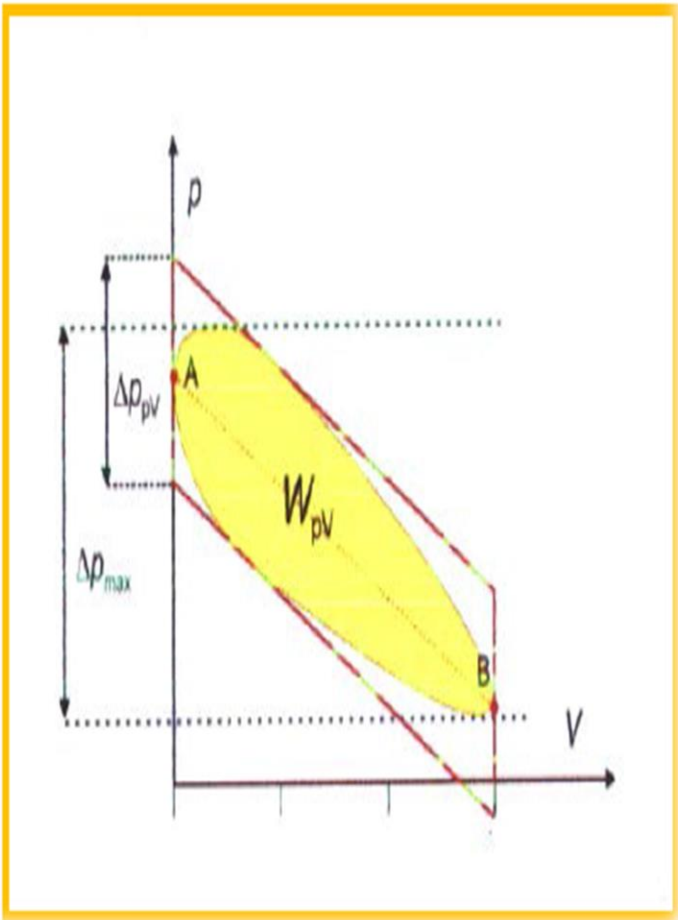
- It is also called “limited pressure cycle”
- better represent most high speed engines.
- In this cycle part of the combustion accruing at constant volume, and the rest at constant pressure.
- 1-2 : isentropic compression
- 2-3 : constant (V) heat added
- 3-4 : constant (P) heat added
- 5-1 : constant (V) heat rejected



Actual cycle

Using the air standard cycle to represent a given real cycle is called the equivalent cycle having the following characteristics in common with the real cycle.

1. Similar sequence of process
2. Same (V_{max}/V_{min}) ratio.
3. Same (P&T) at chosen ref. point.
4. App. Value of heat added per unit mass



عند مقارنة دورة الهواء القياسية مع الدورة الفعلية نلاحظ أنها تشترك معها بالخواص التالية :

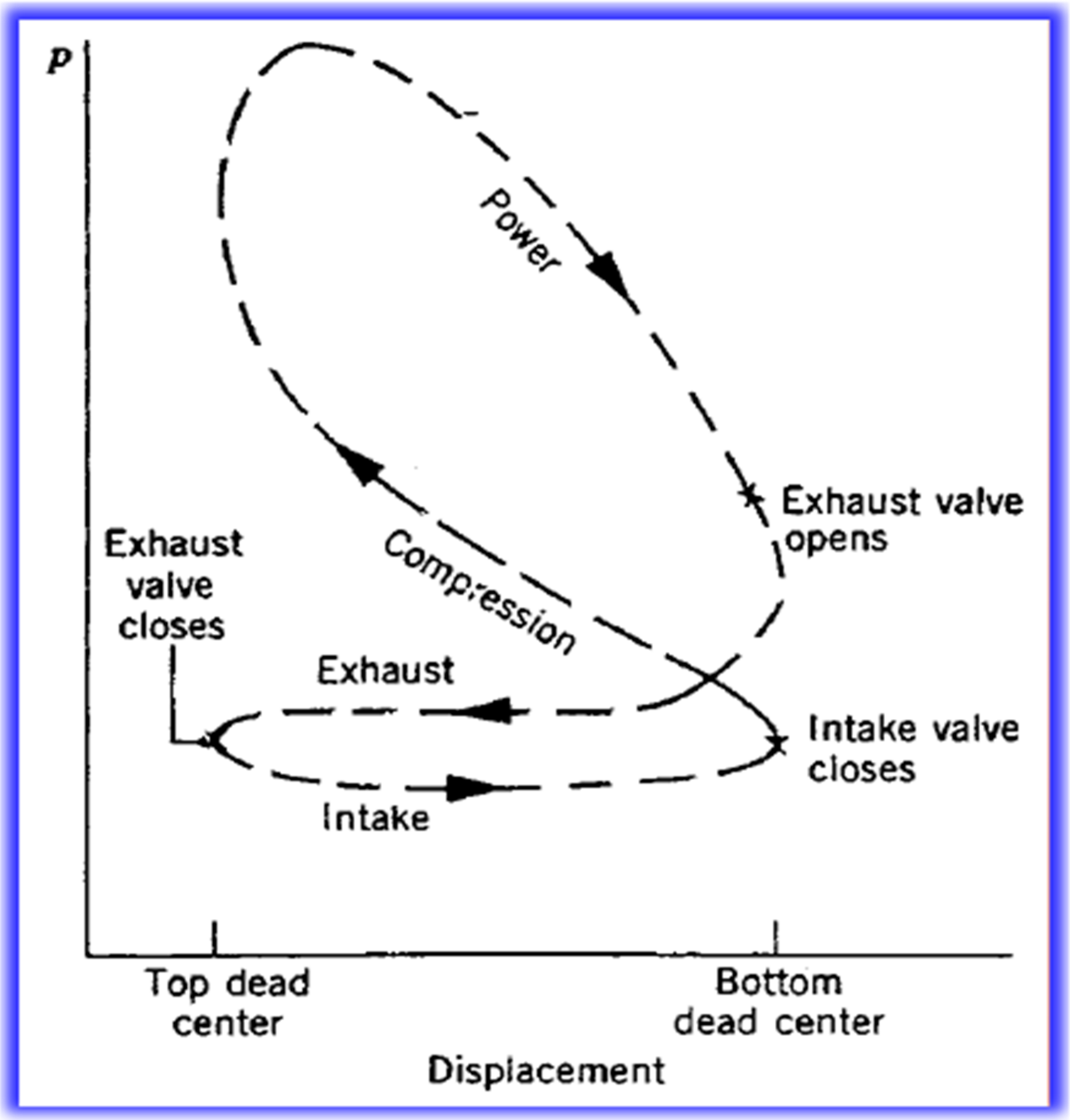
1- نفس تتابع الأجراءات

2- نفس النسبة بين الحجم الأقصى و الأدنى للدورة

3- تستند لنفس الضغط و درجة الحرارة المختارين

4- نفس كمية الحرارة المضافة لوحدة الكتلة تقريبا

<u>From all of the above the PV-diagram for both the actual and the ideal cycles looks as shown here.</u>

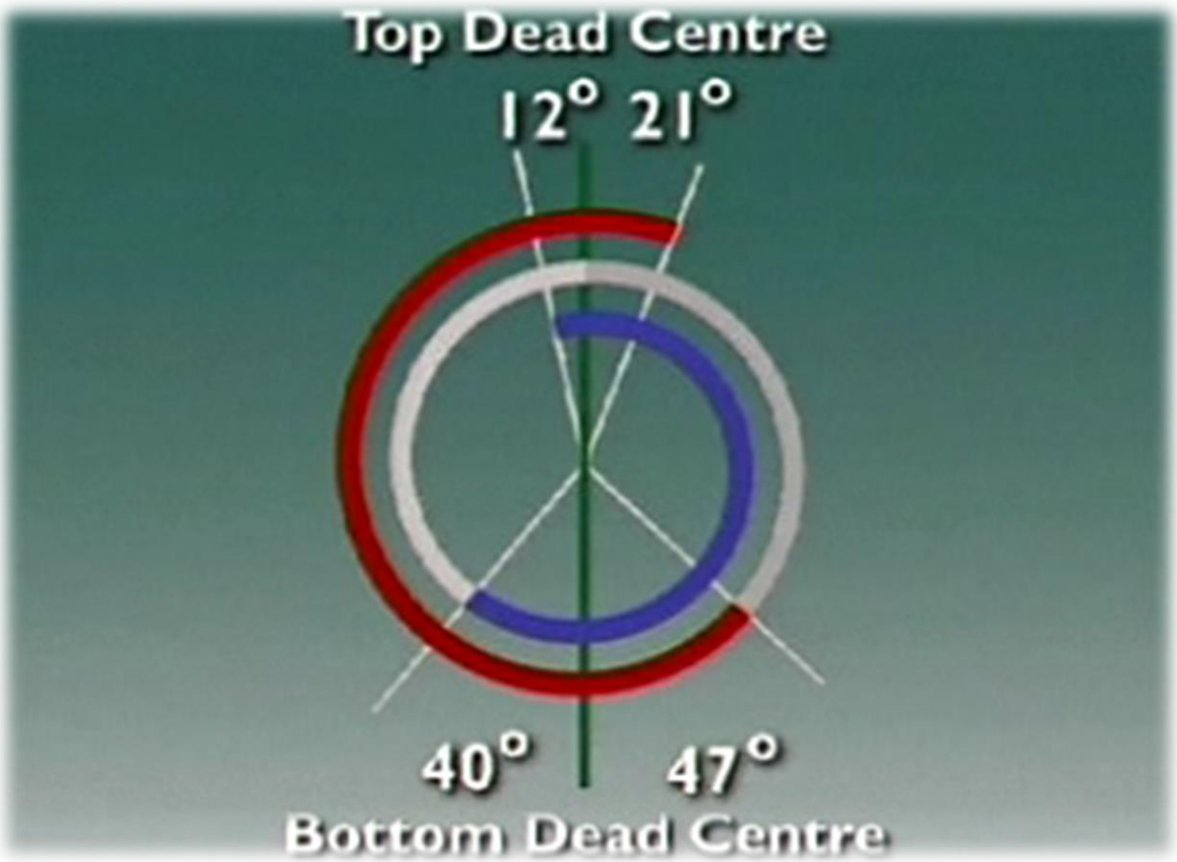


Valve timing of 4-strok SI engine

intake valve opens 12° before the piston reaches TDC and it closes 40° after BDC.

The exhaust valve opens 47° before BDC - and stays open - until 21° past TDC , this gives exhaust gases more time to leave.

By the time the piston is at 47° before BDC on the power stroke, combustion pressures have dropped considerably كثيرا *and little power is lost* تفقد *by letting the exhaust gases have more time to exit.*



4-strok CI engine

intake valve opens 30° before TDC. And it closes 50° after BDC.

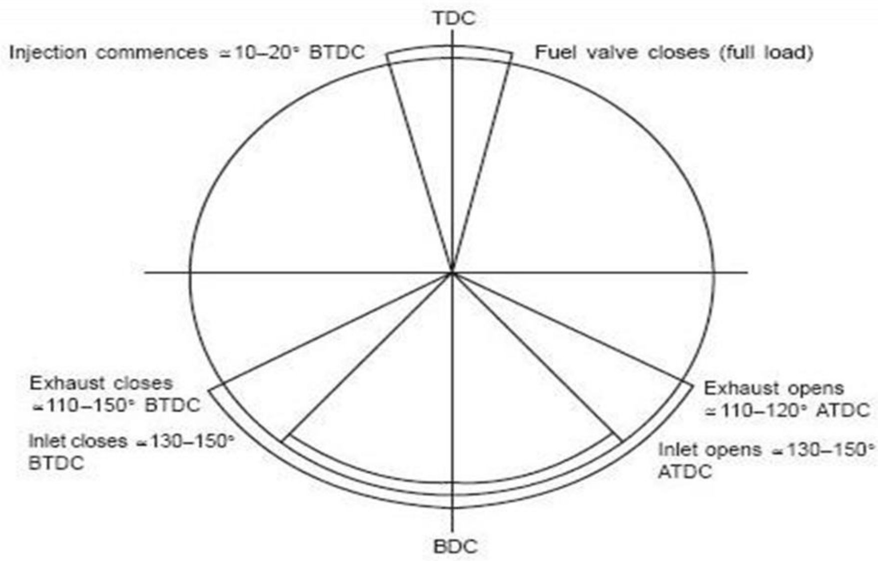
The exhaust valve opens 45° before BDC - and closed 10 before TDC. This gives exhaust gases more time to leave.

When an intake valve opens before TDC and the exhaust valve opens before bottom dead center, it is called lead.

When an intake valve closes after BDC, and the exhaust valve closes after TDC, it is called lag.

On the exhaust stroke, the intake and exhaust valve are open at the same time for a few degrees around TDC. This is called valve overlap.

2-strok SI engine



The above timing diagram is a general one, of a two stroke engine design
having inlet and exhaust ports in the cylinder liner or inlet port in the liner and valve exhaust in a cylinder cover.

Slightly before TDC around 10 degrees injection of atomized fuel begines it burns , ignited by the high temperature , ignition last about 30 degrees , this varies dependly on load . The fuel continues to burn and expands which increases the pressure and temperature , whithin the cylinder .

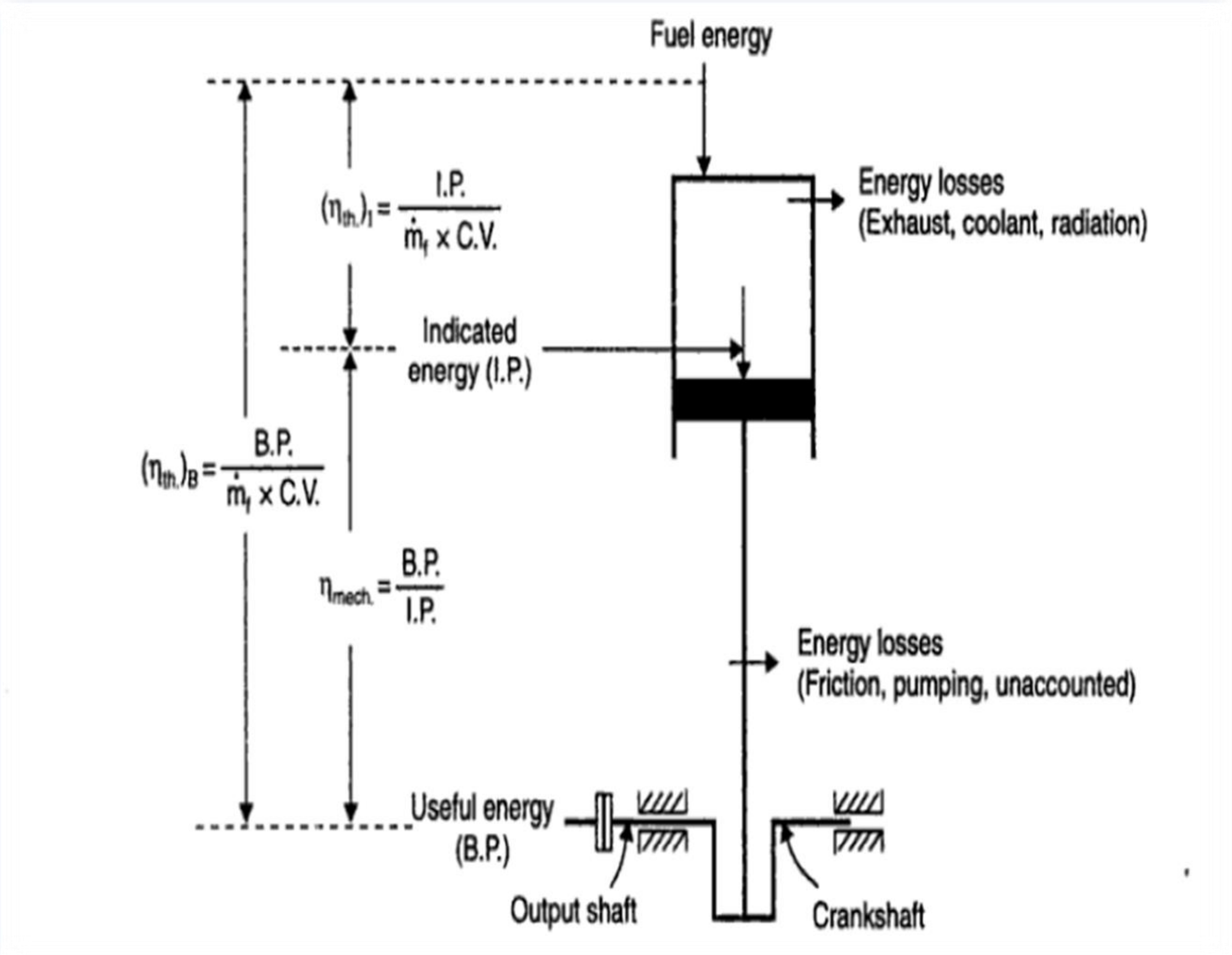
Around 15 degrees after TDC , combustion is complete and maximum pressure is reached within the cylinder .

Thermal Energy Of Engines

The thermal energy produced by the combustion of fuel in an engine is not completely utilized ينتفع for the production of the mechanical power. The thermal efficiency of I.C. engines is about 33 %. of the available heat energy in the fuel, about 1/3 is lost through the exhaust system, and 1/3 is absorbed يمتص by the cooling system

The heat energy balance

1. *Heat equivalent المكافئة to brake power of the engine.*
2. *Heat carried away المطروحة by the cooling water*
3. *Heat carried away by the exhaust gases*
4. *Unaccounted غير المحسوبة heat losses*



<u>Engine knock</u> *الصفع*

Is a sound صوت that is made when the fuel ignites <u>too early</u> مبكر جدا in the compression stroke , severe شديد knock causes severe engine damage , such as

1- broken تحطم connected rods أذرع التوصيل

3- melted صهر or broken valves and other components

The octane rating is a measure of how likely a gasoline or liquid petroluim fuel is to self ignite

The higher the O.N. the less likely an engine is to pre سبق ignite and suffer يحدث damage

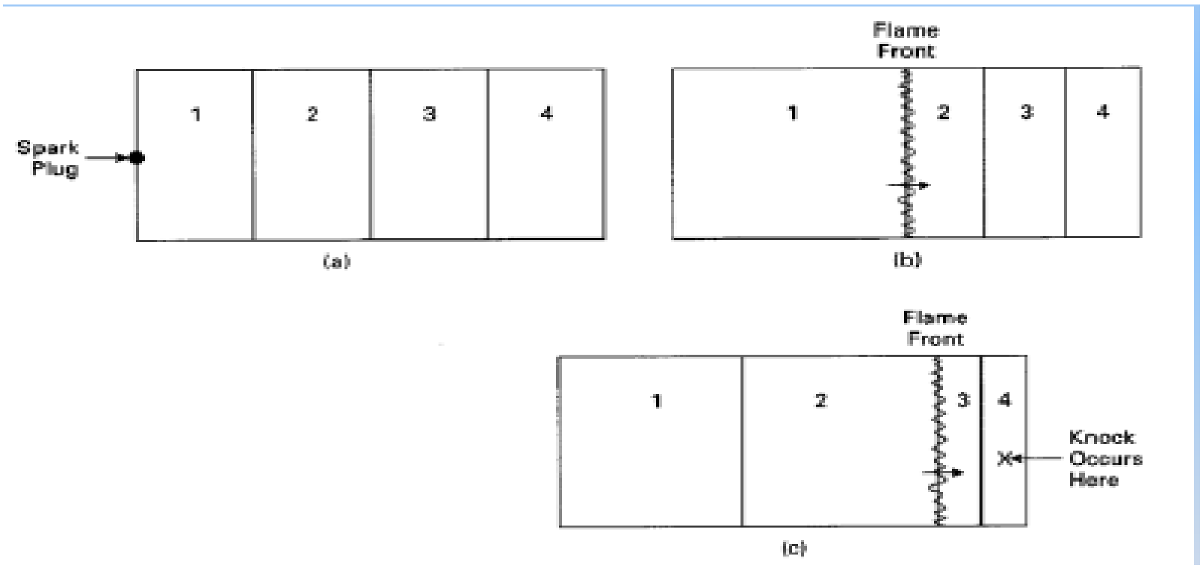
For figure below :

a – mass of air fuel is equally distributed as spark plug is fired to start combustion

b- as flame front moves across chamber , unburned mixture in front of flame is compressed into smaller volume

c- flame front continues to compress unburned mixture into smaller volume , which increases its temperature and pressure

If compression raises temperature of end gas above SIT , self ذاتي ignition and knock can occur يحدث



Stages مراحل of combustion in compression ignition engines :

The combustion in a compression ignition engine is considered to be taken place in four phases أطوار . it is divided into :

a- the ignition delay تأخير period فترة

b- the period of rapid سريع combustion

c- the period of control سيطرة combustion

d- the period of after-burning .

a- Ignition delay period

The ignition delay period is also called the preparatory تحضير phase during which some fuel has already been admitted الداخل but has not yet ignited . this period is counted تحسب from the start of ignition to the point where the pressure – time curve separates ينفصل from the motoring curve indicated as start of combustion .

The delay period in the compression ignition engine exerts يولد a very great influence تأثير on both engine design and performance أداء . it is of extreme قصوى importance أهمية because of its effect on both combustion rate and knocking and also its influence on engine starting ability قابلية and the presence وجود of smoke in the exhaust .

(i) Physical delay

The physical delay is the time between the beginning of injection and the attainment أحراز of chemical reaction تفاعل conditions شروط . During this period the fuel is atomized يذرر , vapourized يتبخر , mixed with air and raised to its self – ignition temperature . this physical delay depend تعتمد on type of fuel i.e.:

for light fuels physical delay is small while for heavy viscous fuel the physical delay is high .

(ii) Chemical delay

During the chemical delay , reaction start slowly and then accelerate يتعجل until inflammation يلتهب or ignition take place .

Generally chemical delay is larger than physical delay .

it depends on the temperature of surroundings المحيط and high temperatures , the chemical reactions are faster أسرع and physical delay become longer than chemical delay.

Effect تأثير of variables المتغيرات on the delay period

Increase in variable	*effect on delay period*
1- cetane number of fuel	*reduces*
2- injection pressure	*=*
3- compression ratio	*=*
4- intake temperature	*=*
5- water temperature	*=*
6- fuel temperature	*=*
7- intake pressure	*=*
8- speed	*increase*
9- engine size	*decrease*
10- injection timing advance تقدم	*increase*

CN (Cetan number) & ID (Ignition delay) :

1- Low CN – causes ID to be too long , as more fuel will be ignited before combustion , and so when combusted results in :

a- high initial pressure rise
b- large initial force on piston
c- rough خشن engine operation

2- High CN – causes ID will be shorter , causing :

a- combustion start too early before TDC
b- resulting in power loss

(Normal CN (40 – 60))

Ignition delay :

Ignition delay period of about (0.4 – 3) ms will be considered يعتبر normal when :

1- A/F mixture in the combustion ratio

2- temperature of the mixture in the SIT range

*** Ignition delay decreases when any of the following parameters increass :*

(temperature – pressure – engine speed – compression ratio – high RPM)

3- Ignition rate has no real effect on ignition delay, but ignition timing has a marked ملحوظ effect as when ignition starts :

a- too early – ignition delay time increases due to (T & P)

b- too late – also ignition delay time increases , and piston moves well past TDC during the uncontrolled غير المسيطر combustion stage

4- Due to many reasons , ignition delay period may be :

a- Long ID b- Short ID c- Normal ID

Conditions of combustion in S.I. engines :

The angular speed in SI engines is in the range of 500 – 5000 r.p.m. so the whole كامل cycle is 10 – 100 ms . during this time the mixture must be ignited , burnt and reburnt .

Laminar خطي flame is too slow , however the mixture in the cylinder is turbulized يضطرب and flame is turbulent , which makes the rate of combustion very high .

In the process of combustion in SI can be divided into three phases :

a- Ignition أشتعال

b- Combustion أحتراق

c- reburning أعادة حرق

Reduction تخفيض of knock in S.I. engine

To prevent منع knock in S.I. engine the end gas should have :

1- a low temperature

2- a low density

3- a long ignition delay

4- a non – reactive تفاعل composition

Where engine condition are changed , the effect of the change may be reflected تنعكس by more than one of the above variables , for example , an increase in compression ratio will increase both the temperature and density of unburned mixture .

Temperature factor in S.I. knock reducation :

Increasing the temperature of the unburned mixture by any of the following factors will increase the possibility أمكانية of S.I. engine knock :

1- raising زيادة the compression ratio

2- raising the inlet air temperature

3- raising the coolant temperature

4- raising the temperature of the cylinder and chamber walls

5- advancing تقدم the spark timing

- *the temperature of the exhaust valve is relatively high and therefore it should be located near the spark plug and not in the end – gas region*

Density factors in S.I. knock reduction :

Increasing the density of the unburned mixture by any of the following factors will increase the possibility of S.I. engine knock :

1- opening the throttle الخنق (increasing the load)

2- supercharching الشحن الفائق the engine

3- advancing the spark timing

- *Opening the throttele doesnt appreciably معتبر change the gas temperatures when the air – fuel ratio is constant . However, total energy release تحرر is proportional متناسب to the mass of the mixture in the cylinder , and therefore opening the throttle tends تميل to raise wall temperature and raise mixture & end – gas temperatures .*

Compression factors in S.I. knock reducation :

The properties of the fuel and fuel – air ratio are the primary means for controlling knock , once the compression ratio and engine dimensions are selected . The possibility of knock is decreased by :

1- *increasing the octane rating of the fuel*
2- *either rich or lean mixtures*
3- *stratifying* تقسيم *the mixture so that the end – gas is less reactive*
4- *increasing the humidity of the entering air*

- *A rich / lean mixture is effective in reducing :*
  1- *the longer delay*
  2- *the lower combustion temperature .*

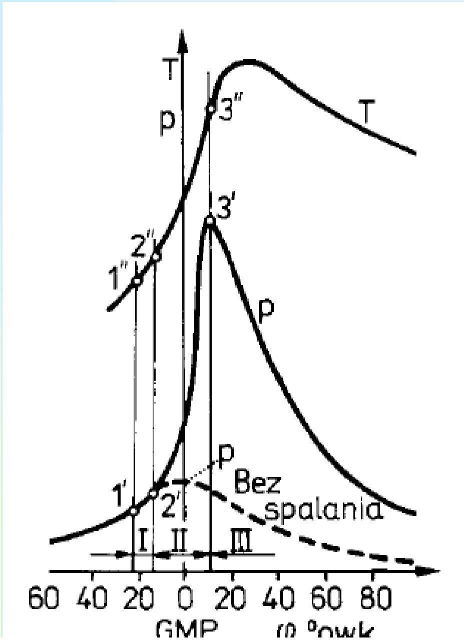
Time factors in S.I. knock reducation :

Increasing the time of exposure تعرض *of the unburned mixture to autoigniting conditions by any of the following factors will increase the possibility of S.I. engine knock :*

1- *increasing the distance the flame has to travel in order to traverse* طريق مختصر *the combustio chamber*
2- *decreasing the turbulence* أضطراب *of the mixture and thus decreasing the flame speed*
3- *decreasing engine speed : thus*
   a- *decreasing the turbulence of the mixture*
   b- *increasing the time available for preflame reactions*

** If the chamber width is great , the end – gas may have time to reach a self – ignition temperature and pass through the ignition delay period before the flame has completed its travel .*

Phases of combustion in SI engines



Changes of the pressure in the cylinder of SI engine

Phases of combustion:

I – ignition,

II – combustion,

III – reburning.

1 – ignition, 2 – start of combustion, 3 –maximum of pressure (end of combustion)

Optimisation الأمثل of combustionin S.I. engines

There is dominating تحكم tendency ميل to burn lean فقير mixtures (ג >> 1) , because it improves تحسين efficiency of the engine and reduces pollutant تلوث emission أنبعاث

Combustion of lean mixtures in S.I. engines causes some problems :

A – speed of laminar flame propagation دعم is lower

B – ignition is more difficult صعوبة

Pre-ignition سبق

Increase in the rate of heat transfer أنتقال to the cylinder walls جدران may cause local محلي hot spots نقاط, i.e overheating projected يجعل parts such as ""spark plug electrodes قطب كهربائي; exhaust valve head ; metal معدن corners زوايا in the combustion chamber; carbon deposits ترسبات … etc"",

which may reach a temperature high enough to ignite the charge الشحنة before the occurrence of the actual timed spark . Such local pre - ignition spots may occur in the spark plug , overheated exhaust valves, or may be on a glowing توهج carbon deposits in the combustion chamber

Self-ignition

If the temperature of A/F mixture is raised high enough, the mixture will ignite itself without the need الحاجة of a spark or external igniter شاعل. the temperature above which this occurs is called the " self ignition temperature .

Auto-ignition

Is the initiation الشروع of combustion without the necessity of a flame, and therefore it is one the causes that leads تقود to the occurrence of engine knock.
In this case the flame speed is assumed المفترضة normal before the onset بداية of auto-ignition, whereby بواسطة gas vibration أهتزاز created تتكون by number of end gas elements auto-ignites almost instantaneously فورا.

Therefore, auto-ignition does not occur immediately مباشرة as the self-ignition temperature is reached, where some ignition delay period is required before the mixture becomes يصبح explosive أنفجار

<u>*Fuel supply systems in S.I. engines*</u>

1- Carburettor خلاط systems :

a- Mechanically controlled

b- Electronically controlled

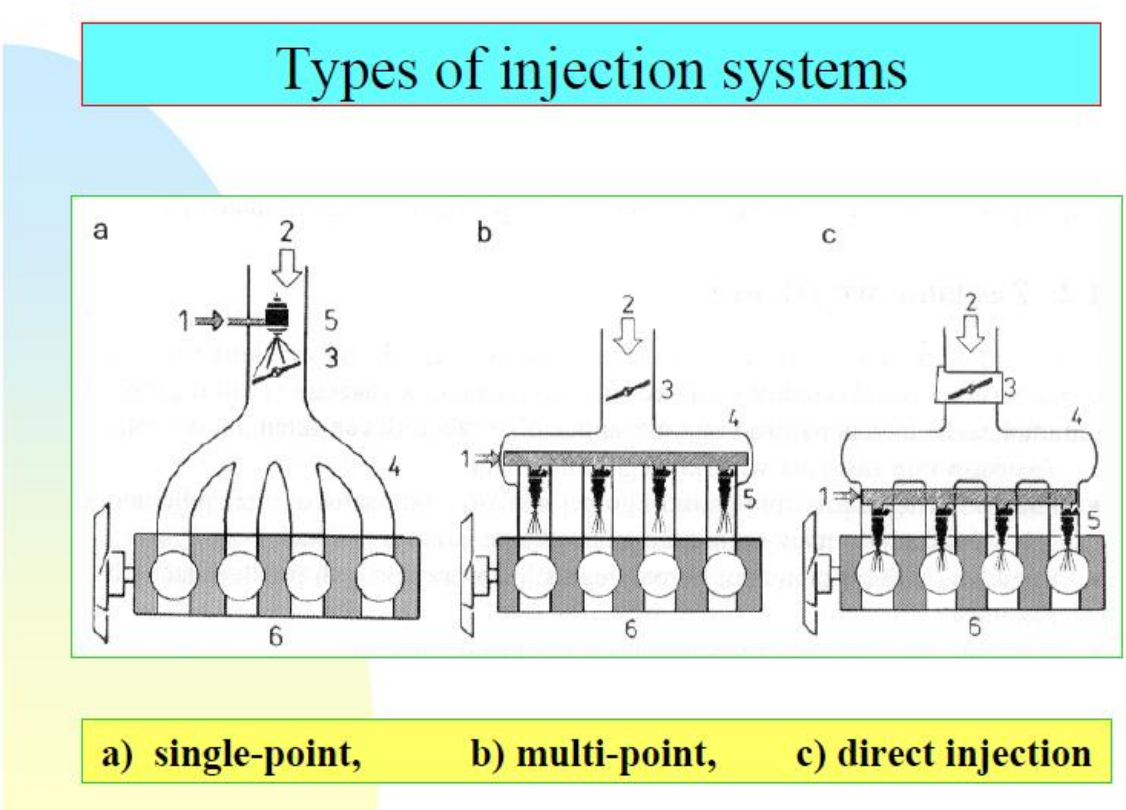
2- Injection ضخ systems :

a- IDI : indirect غير مباشر injection system :

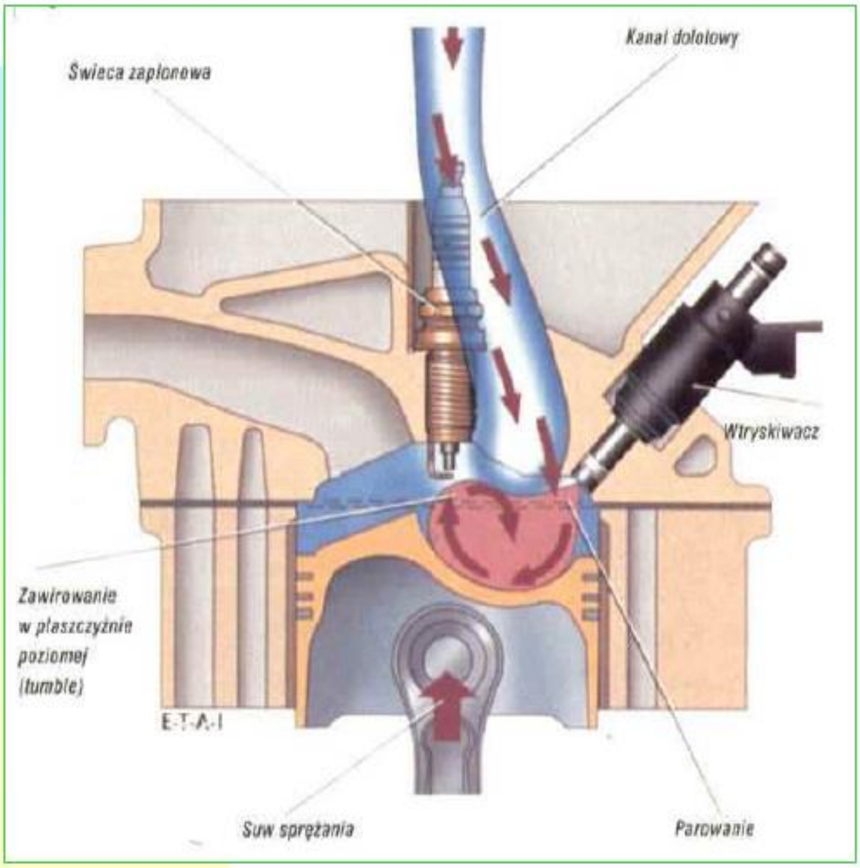
- SPI : single - point injection (to the carburettor)

- MPI : multi – point injection system (to the inlet channel قناة)

b- DI : direct injection system

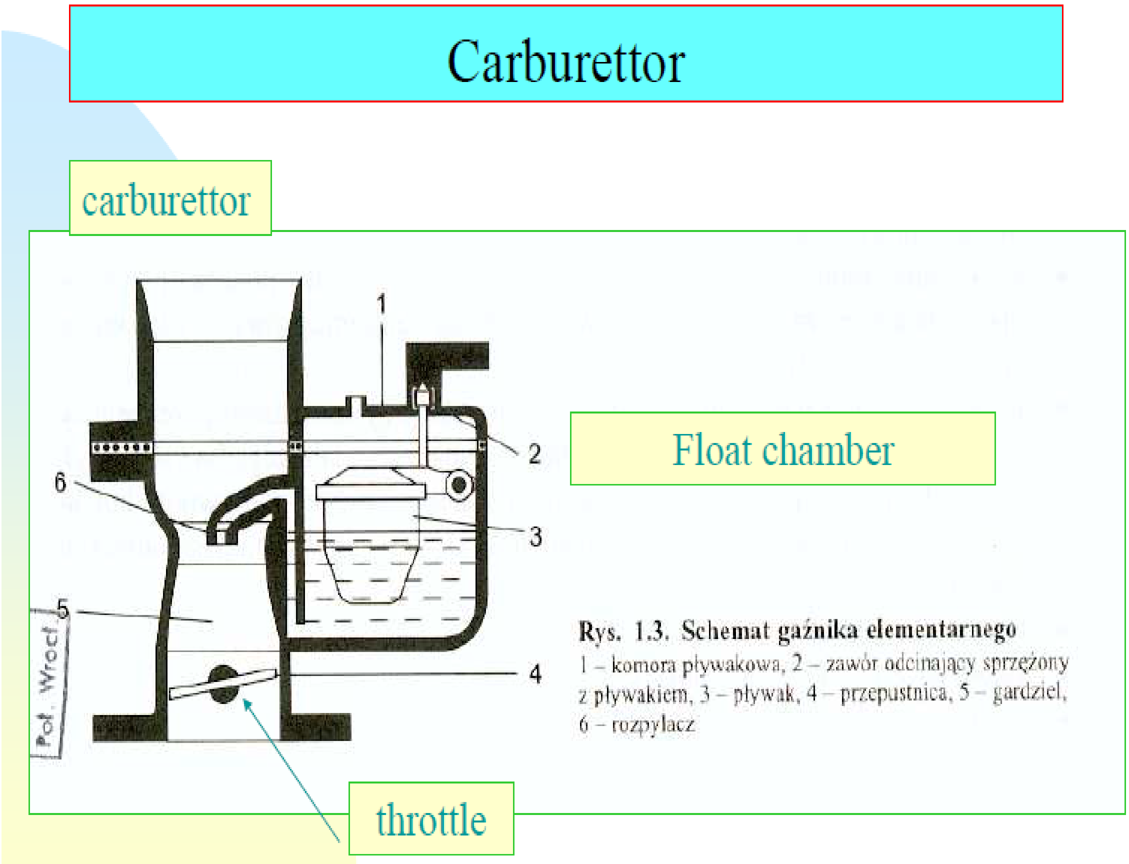


Gasoline Direct Injection

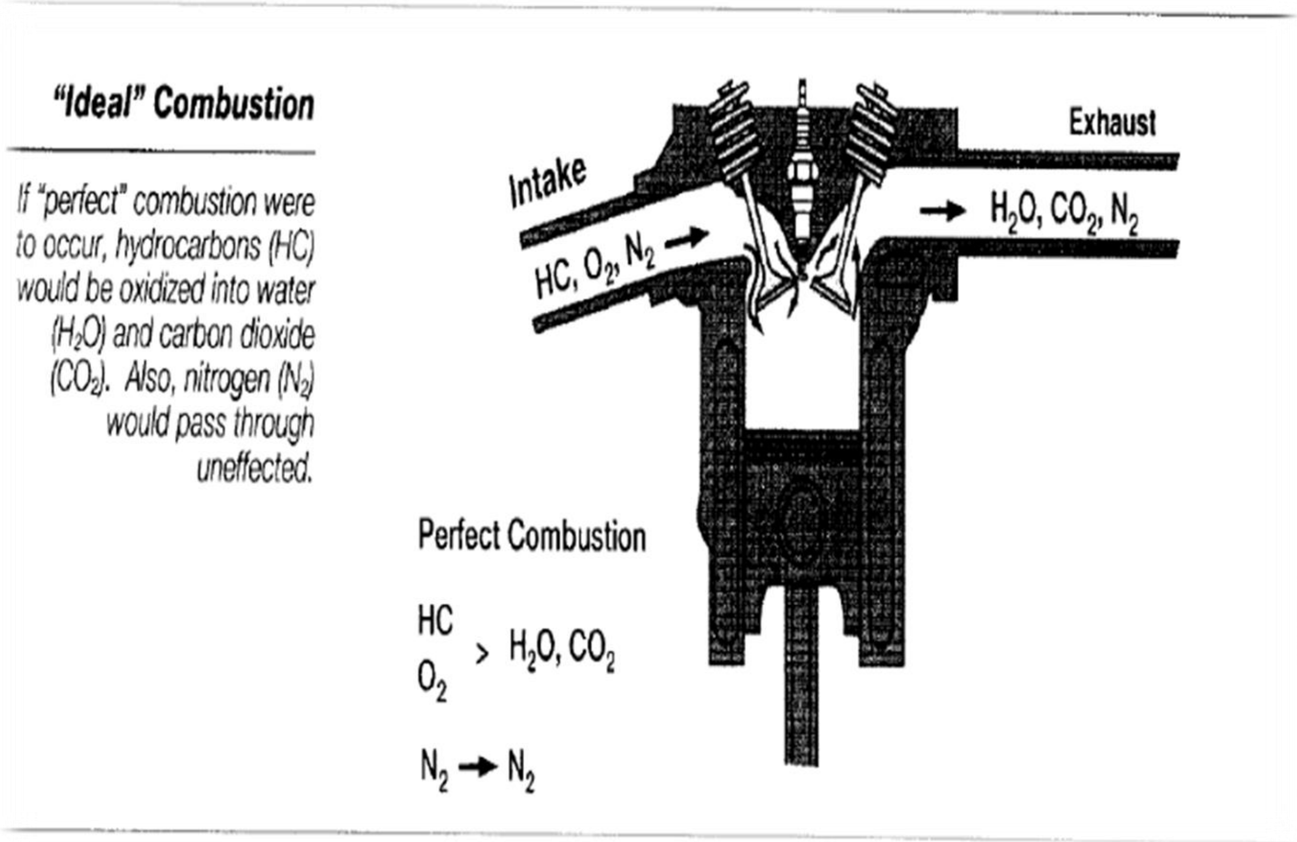


FSI
Fuel
Stratified
Injection

Carburettor الخلاط Fuel Supply System



The cumbustion الأحتراق in S.I. engines



Pollutant emission from SI engines

Flue gas			
Non-toxic compounds		Toxic compounds	
Water	H_2O	Carbon monoxide	CO
Carbon dioxide	CO_2	Hydrocarbons	HC
Nitrogen	N_2	Nitrogen oxides	NO_x
Hydrogen	H_2	Aldehydes	CHO
Noble gases		Solids	PM
		Others	SO_x, Pb

Engine emissions أنبعاثات & air pollution تلوث

Emissions

Four major رئيسي emissions produced by IC engines :

a - unburnt غير المحترقة hydrocarbon (HC)

due to rich mixture of air / fuel

b – carbon monoxides أول أكسيد (CO)

Not enough غير كافي O_2 to form CO_2

c – nitrogen oxides (NO_X)

Excess O_2 and high combustion temperature

d – the solid الصلبة particulates الجسيمات

Carbon particles as black smoke or soot سخام

Several عدة methods are used to control and reduce engines emission such as :

1- Improve تحسين engine and fueh technology to get يعطي better combustion

2- Exhaust gas after – treatment المعالجة by using thermal and catalytic محفز convertor that Promote تروج chemical reaction in the exhaust to convert harmful الضارة emission to Acceptable مقبول CO_2 , H_2O and N_2

3- EGR – exhaust gas recirculation أعادة تدوير to control NO_x formation تشكيل

4- After – burner : the exhaust gases is further أقصى burnt by suppling air and means طرق of ignition

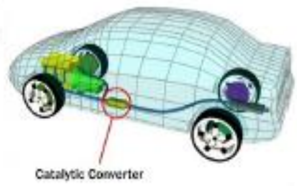
5- Exhaust manifold متفرع reactor مفاعل

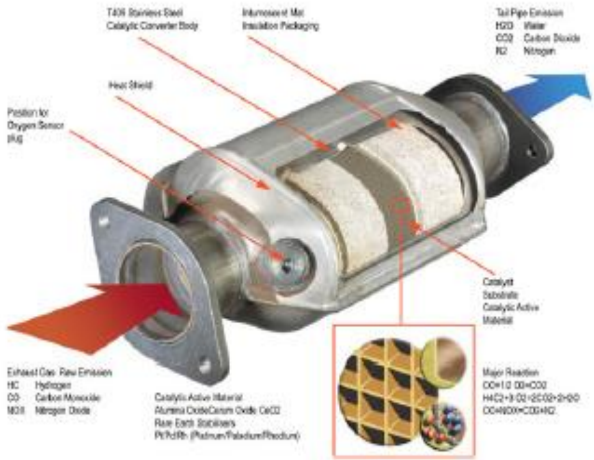
The most effective تأثير after – treatment system for redusing engine emissions is the catalytic convertor.

Catalytic convertors are mostly associated يقترن with automobile where it is located in the engine exhaust pipe as near as possible to engine exhaust manifold.

Catalytic convertor

- The catalytic converter lowers emission levels by changing harmful pollutants into relatively harmless gases.
- The catalytic converter works by using heat, combined with catalyzing agents, to create a chemical process that changes hydrocarbons (HC) and carbon monoxide (CO) into carbon dioxide and water.
- Some catalytic converters are designed to reduce an additional pollutant, oxides of nitrogen (NOx), by breaking it down into base components, nitrogen and oxygen





EGR system

The EGR system (Exhaust Gas Recirculation system) is designed to reduce emissions. To be precise, it lowers the amount of nitrogen oxides (NOx) in the exhaust emissions. Nitrogen oxides are formed at very high combustion temperatures.
What the EGR system actually does is direct part of the exhaust gases back into the intake manifold, which in turn helps reduce the combustion temperature and consequently lower the amount of NOx in the exhaust gases.

Engine heat transfer

1 – heat lost to coolant

- Heat to coolant can be evaluated as follows :

$$Q_{cl} = \dot{m}_w \,.\, Cp_w \,.\, (t_o - t_i)$$

Where

Q_{cl} : heat transferred to coolant (kJ/s = kW)

$\dot{m}_w$: cooling water mass rate (kg/s)

Cp_w : water specific heat (kJ/kg.K)

t_o : cooling water outlet temperature (deg.K)

t_i : cooling water inlet temperature (deg.K)

2 – heat lost to exhaust

- Heat to coolant can be evaluated as follows :

$$Q_{ex} = \dot{m}_{ex} \,.\, Cp_{ex} \,.\, (t_{ex} - t_{amb})$$

Where

Q_{ex} : heat transferred to exhaust (kJ/s = kW)

$\dot{m}_{ex}$: exhaust gas mass rate (kg/s) = $\dot{m}_f + m_a$

Cp_w : exhaust gas specific heat (kJ/kg.K)

t_{ex} : exhaust gas temperature (deg.K)

t_{amb} : ambient temperature (deg.K)

Friction

- Friction refers to :
  i- the forces acting between mechanical components due to their relative motion and to
  ii - forces on and by fluids when they move through the engine

- A percentage of power generated within the engine cylinders are lost to friction, that cause some reduction in the resulting brake power obtained off the crankshaft.

- Engine's accessories that cause some reduction in crankshaft power are also classified as part of engine friction load.

Therefore friction can be defined as

FRICTION is the resistance to motion which takes place when one body is moved upon another. Friction is generally defined as *"that force which acts between two bodies at their surface of contact, so as to resist their sliding on each other"*.

Engine friction (FP)

This can be defined as
""the difference between the indicated power (IP), *which is the power developed inside the cylinder*, and the brake power (BP), *which is the power available at the crank-shaft""*. i.e

FP = IP - BP

Total engine friction

The difference between IP & BP is known as "total engine friction". This includes the following losses:

1. direct frictional losses
2. Pumping losses
3. Blow-by losses
4. Valve throttling loses
5. Combustion chamber pump losses
6. Power loss to drive the auxiliaries

losses

Engine losses can be characterized as follows:

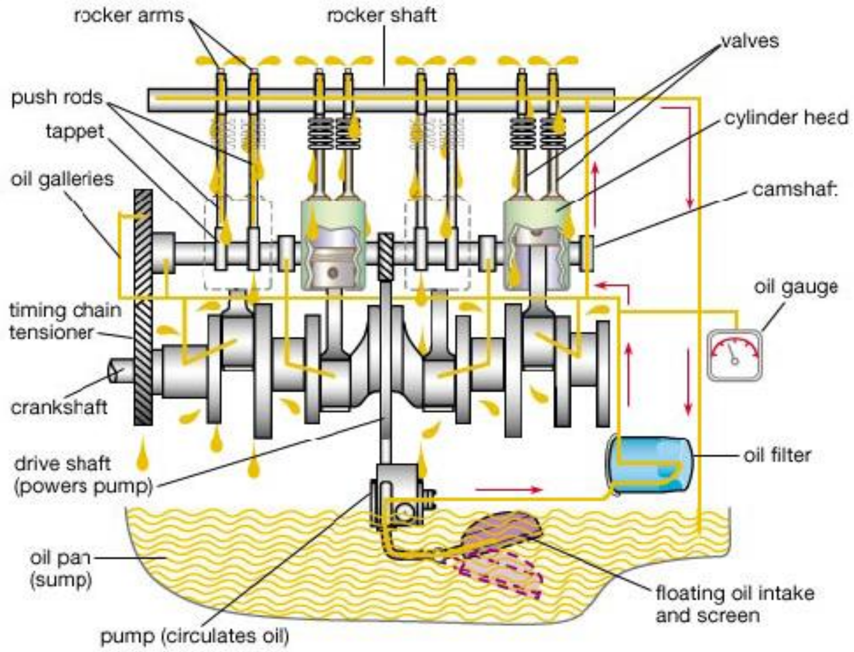
1- friction losses •

these are mechanical losses due to friction between all sliding surfaces; " con rod bearings; crankshaft bearing; camshaft bearings ... etc "

2- parasitic losses •

these are the losses due to loads required to operate engine auxiliaries such; " air conditioner; oil pump; water pump; alternator; supercharger; and all other auxiliaries."

LUBRICATION SYSTEM



<u>Lubricating التزييت Oil Additives</u> *أضافات*

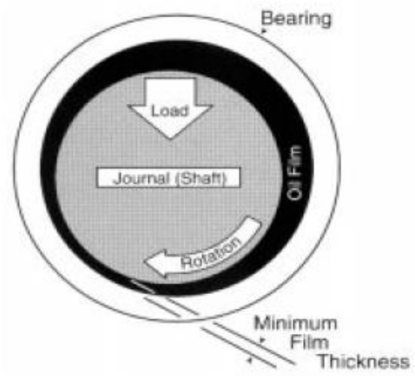
For maximum performance أداء and life span أطالة of the engine , following additives are required :

1- *Antifoam مانع الرغوة agents*
2- *Oxidation inhibitors موانع*
3- *Pour يصب – point depressant أكتئاب*
4- *Antirust مانع الصدأ agents*
5- *Detergents منظفات*
6- *Anti – wear تاكل agents*
7- *Friction reducers*
8- *Viscosity لزوجة index مؤشر improvers*

Purpose of Lubrication System

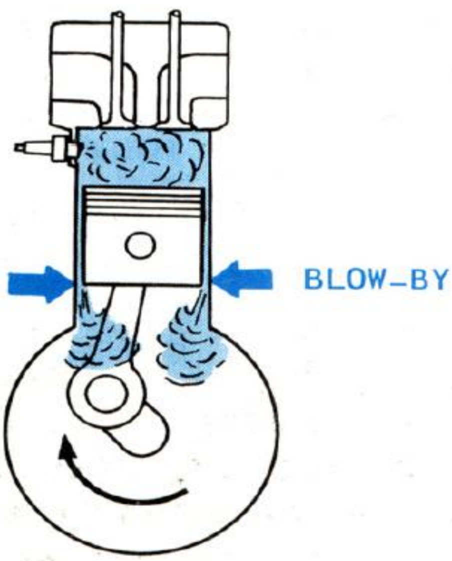
- **1 - Lubricate**

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.

<u>3- Cleans</u>

As it circulates through the engine , the oil picks up يحمل metal particales جسيمات and carbon , and brings يجلب them back down to the pan الوعاء

<u>4- Cools</u>

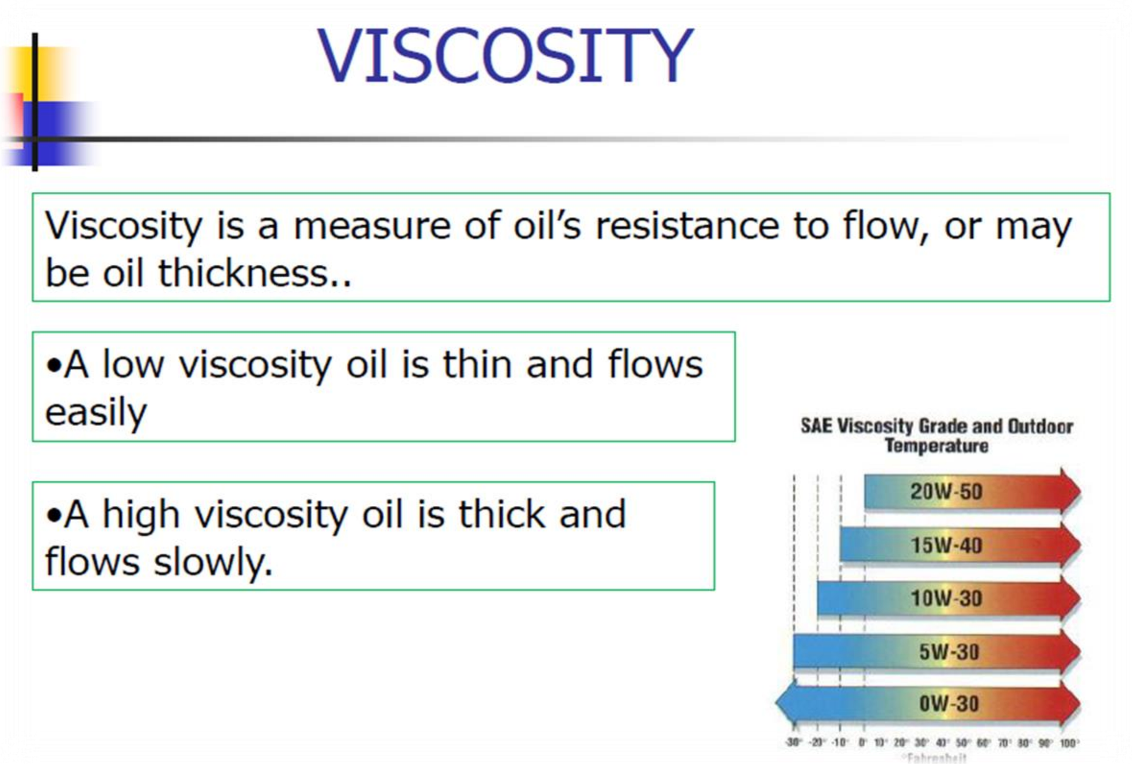
Pick up heat when moving through the engine and then drops قطرات into the cooler oil pan , giving up some of this heat .

<u>5 - Absorbs shock</u> *أمتصاص الصدمة*

When heavy ثقيلة loads are imposed المحملة on the bearings الركائز , the oil helps to cushion وسادة the load .

<u>6 – Absorbs contaminants</u>

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



<u>Parts & components</u>

1- oil pan 2-oil pump 3-pressure relief تخفيف valve 4-oil galleries معارض
5-oil pressure indicator مؤشر 6- oil filter 7- oil cooler

<u>*Oil change*</u> *: a- every 5000 km b- 3 months*

Ignition الأشعال system

** For a spark شرارة to jump تعبر across an air gap فجوة of 0.6 mm in an engine cylinder , having a compression ratio of 8 : 1 , approx. تقريبا 8 KV is required المطلوبة .*

Ignition system has to transform بهيئة battery voltage of 12 to V 8 – 20 KV and has to deliver توصيل the voltage to the right الصحيح cylinder at the right time .

** A bout 0.2 mJ of energy طاقة is required to ignite a stoichiometric المتكافئ mixture خليط at normal engine*

operating التشغيل conditions شروط by means طرق of a spark . Over 3 mJ is required for a rich or lean mixture , in general , ignition systems deliver 30 to 50 mJ of electric energy to the spark .

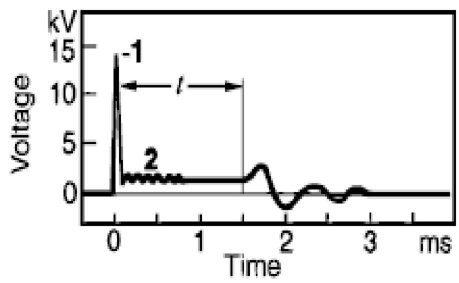
** Fundamental أساسي requirements متطلبات of the ignition source :*

1- a high ignition voltage to break down أنفصال in the spark – gap

2- a low source impedance مقاومة or steep أنحدار voltage rise أرتفاع

3- a high energy capacity سعة to creat خلق a spark kernel نواة of sufficient كافي size

4- sufficient duration مدة of the voltage pulse نبض to ensure ضمان ignition



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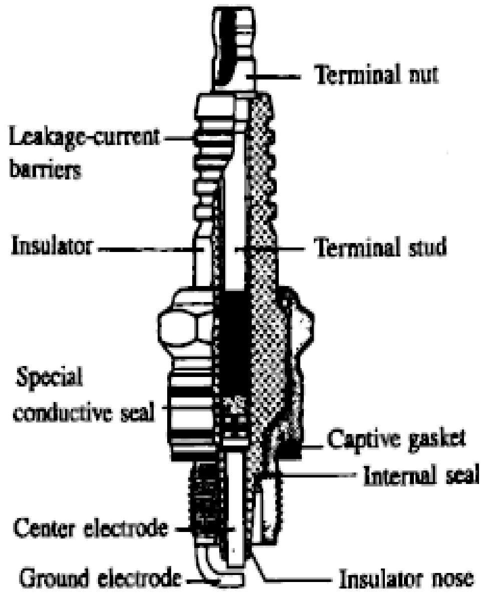
1 *Ignition voltage,* 2 *Spark voltage,* t *Spark duration*



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Types of fuel

Liquid fuel normally used in I.C. engines , however , some engines may be designed to accept قبول gaseous fuels . Also in electricity genaration plant , solid fuel (coal فحم) is used in the boiler furnace فرن .

In general , combusation is actually a chemical reaction process under certain أكيد conditions , where the fuel elements عناصر reacts تفاعل with oxygen present in air to forms oxides of these elements

In doing so , heat of reaction is liberated المحررة

The utilization أستخدام of such heat energy and converting it into other forms of energy (mechanical in this respect) is the whole كاملة idea فكرة behind the theory نظرية of internal combustion engines .

In order to avoid loose واسعة boundaries of this subject , it is useful to limit our considerations within the (hydro – carbon) types of fuel

Hydro – carbon fuel (HC)

In general , most HCs consist mainly of C and H_2 , with some types may include minor قليلة amount of (N_2 , O_2 , S , ... etc) , so

1- Liquid fuel : with chemical formula (C_nH_m)

2- Gaseous fuel : with C.F. ($C_nH_mO_r$)

3- Solid fuel : with C.F. ($C_nH_mS_z$)

Types Of Alternative البديلة Fuels

1- Alcohol

2- Methanol (CH_3OH)

3- Ethanol (C_2H_5OH)

4- Hydrogen

5- Natural gas

6- other

Fuel heating value

The heating value (HV) or calorific value القيمة الحرارية (CV) of a fuel can be defined as : (the magnitude of the heat of reaction , at constant pressure , or at constant volume , released from the complete combustion of a unit mass of fuel)

expressed in KJ/Kg

It is useful to repeat كرر here that the complete combustion means that all (C) is converted to (CO_2) and all (H) to (H_2O)

As most معظم fuels contain (H_2) which forms water when burned . the heating value of a fuel will be different , depending on wether ماأذا the water in combustion products is in the liquid or vapour form .

The heating value may be classified as :

1- Lower heating value (LHV)

When the water produced from the combustion process remains as vapour , and leaves in such form with the other combustion products .

2- Higher heating value (HHV)

When the water in combustion products is completely condensed , whereby حيث the heat of vaporization التبخير is recovered تزال.

It is useful to note that the difference between the two values at room temperature is :

HHV – LHV = mass of water × latent heat of vaporization of water

LHV is usually used in I.C. engine analysis تحليل, as energy released المنبعثة and / or exchanged in the combustion chamber occurs at high temperature , whereby , water in the exhaust mixture almost always remains in the vapour form >

Control السيطرة & Sensors المتحسسات

The control system uses sensors located at various المختلفة engine locations مواقع with programmed مبرمجة electronic controllers and monitors شاشات.

It is used to adjust تعديل combustion for :

1- Optimum أمثل power output

2- Fuel economy أقتصادي

3- Emission control

Input information معلومات from sensors located in appropriate مناسب engine , intake , and exhaust locations .

These sensors measures :

1- throttle الخنق position موقع

2- throttle rate of change

3- intake manifold pressure

4- atmospheric pressure

5- coolant تبريد temperature

6- intake temperature

7- EGR valve position

8- crank angel زاوية

9- O_2 & CO in exhaust

10- knock detection كشف

11- others

Sensor methods of measurment are :

1- mechanical

2- thermal

3- electronic

4- optical بصري

5- chemical

6- combinations مزيج of above

The controlled variables are :

1- ignitin timing

2- valve timing

3- fuel injection duration فترة

4- exhaust air pump

5- air/ fuel ratio

6- transmission النقل shifting تبديل

7- warning التحذير light operation تشغيل

8- repair تصليح diagnostic تشخيص recording تسجيل

9- computer programming

10- Etc الخ

<u>Engine boosting</u> المحرك المعزز

Introduction :

An ordinary أعتيادي four – stroke engine dedicates تكرس one stroke to the process of air intake . There are three steps in the process :

1- *The piston moves down from TDC towards BDC*
2- *This creates a vaccum فراغ*
3- *Air at atmospheric pressure is sucked into the combustion chamber*

Once air is drawn يسحب into the engine , it must be combined with fuel to form the charge , ignition initiation الشروع is essential أساسي for the combustion to takes place تجري.

As the fuel undergoes oxidation يتأكسد, a great deal of energy is released , the force of this explosion الأنفجار, concentrated يتركز a bove the cylinder head , drives the piston down and creates a reciprocating ترددي motion that is eventually في النهاية transferred to the output shaft .

Getting الحصول more fuel into the charge would make for a more powerful explosion , but you cant simply pump more fuel into the engine because an exact دقيق amount of oxygen required to burn a given amount of fuel . This chemically correct mixture 14/1 (14 parts air to 1 part fuel) is essential for an engine to operate effeciently بكفاءة .

(TO PUT IN MORE FUEL YOU HAVE TO PUT IN MORE AIR)

That is <u>ENGINE BOOSTING</u>

Engine boosting therefore is the process of increasing the inlet charge , i.e. increasing of the mass air induced into the cylinder , facilitating thereby تسهل بذلك the possibility of increasing the fuel charge , when burend will produced extra power output for the same engine size .

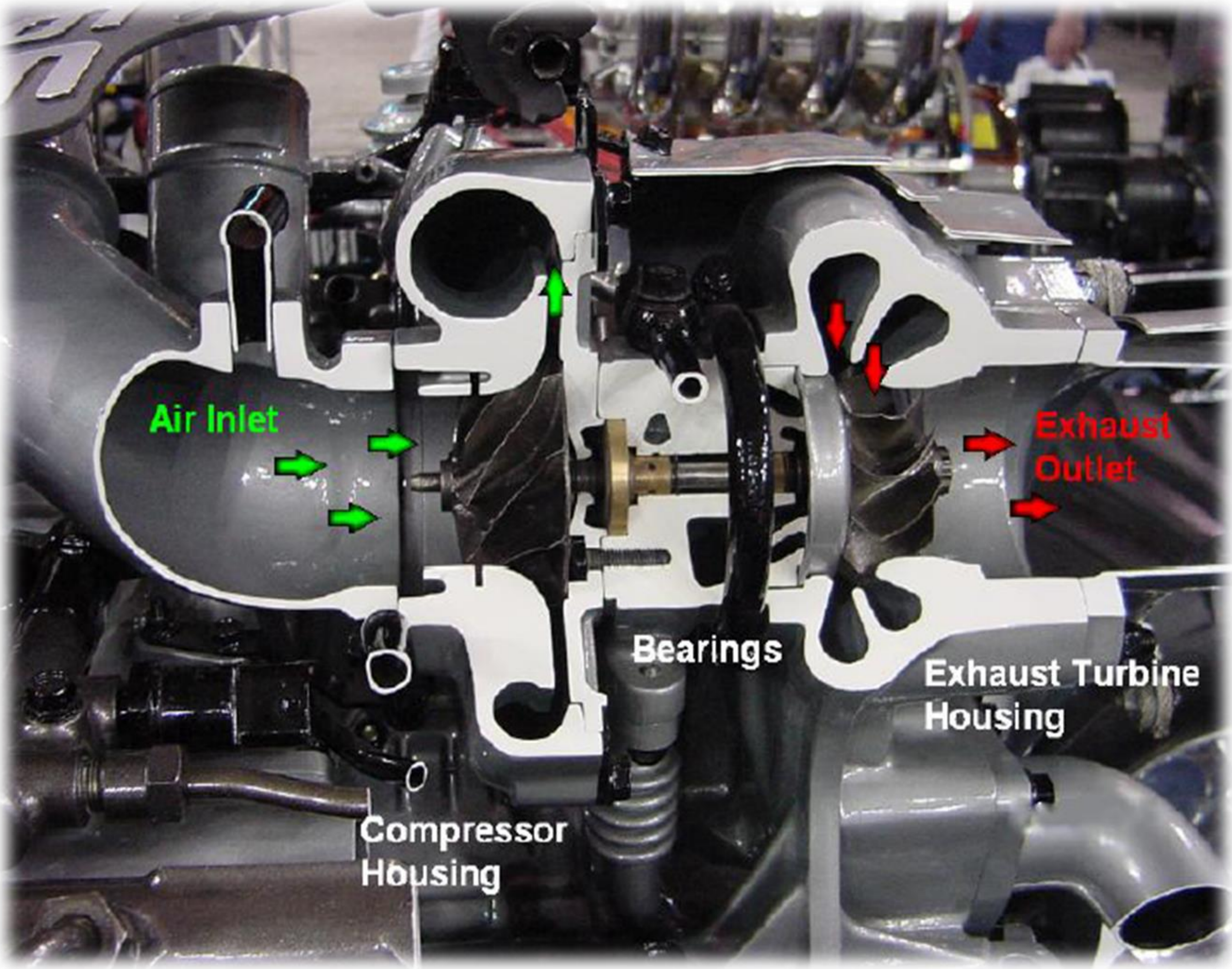
Engine boosting can be achieved by two common well established methods :

1. ***Super - charging***
2. ***Turbo - charging***

Superchargers and Turbochargers are compressors ضواغط *mounted* تقام *in the intake system , and used to raise the pressure of the incoming air . this results in more air and fuel entering each cylinder during each cycle . this added air and fuel creats more power output during combustion , and the net power output of the engine is increased .*

Superchargers increase intake by compressing air above atmospheric pressure , without creating a vaccum . this forces more air into the engine , providing توفير *a (boost) , with the additional air in the boost , more fuel can be added to the charge , and the power of the engine is increased .*

Supercharging adds an average of 46% more horsepower and 31% more torque .



Air Inlet
Exhaust
Outlet
Bearings
Exhaust Turbine
Housing
Compressor
Housing