INTERNAL COMBUSTION ENGINES

(I.C.) Internal Combustion engines can be divided into two classes

a) Spark Ignition engines (S.I.) (Mostly petrol engines)

b) Compression Ignition engines (C.I.) (Mostly diesel engines)

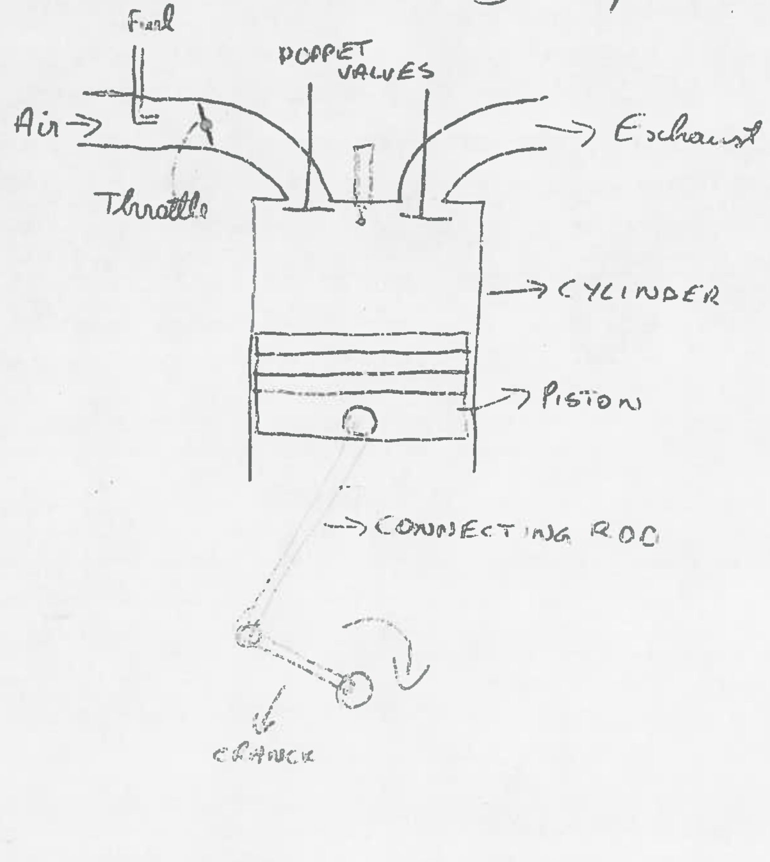
The process involved in either of the above two types of Internal combustion engines can be performed in.

a) Four strokes , i.e. 2 revolutions

b) Two strokes , i.e. 1 revolution.

One stroke being the movement of the piston between it's extremeties of travel.

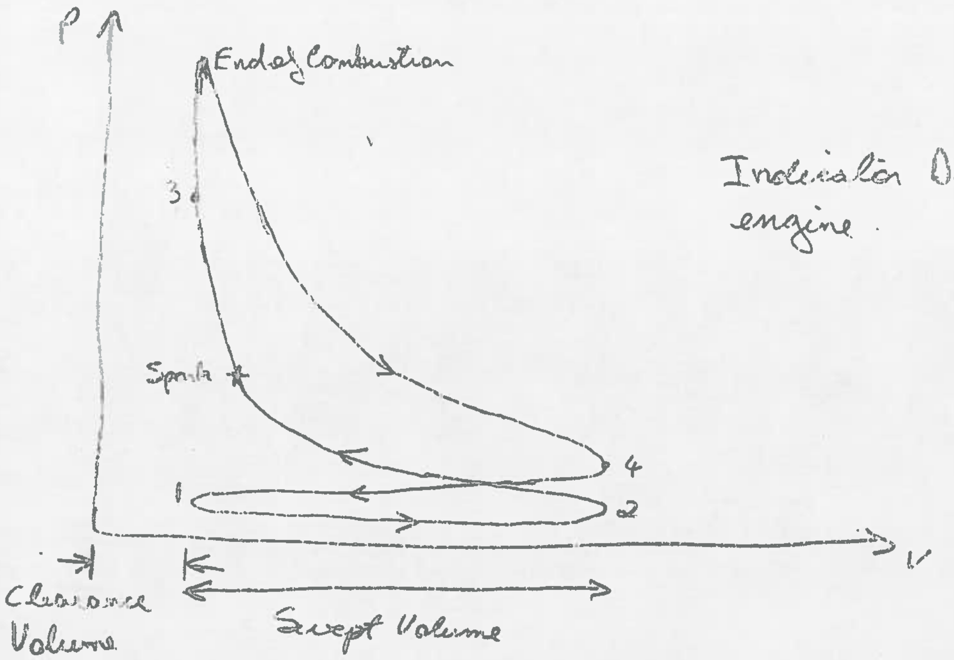
The normal setup for an I.C. engine is to have a piston move in a cylinder with connecting-rod, crank and valves.



THE 4 STOKE ENGINE

The four processes required for an internal combustion engine are
1 Induction 2 Compression 3 Power 4 Exhaust

In a four stroke engine, the above 4 processes are done in two revolutions. Thus each process takes approximately one complete stroke.



Indication Diagram for a SI engine.

Process 1 to 2 is the Induction stroke. A mixture of air and petrol, premixed in the carburettor are drawn into the cylinder as the piston moves down. The pressure in the cylinder is slightly less than atmospheric due to the pressure drop in carburettor, manifold, valve port etc. The inlet valve closes at the end of the stroke.

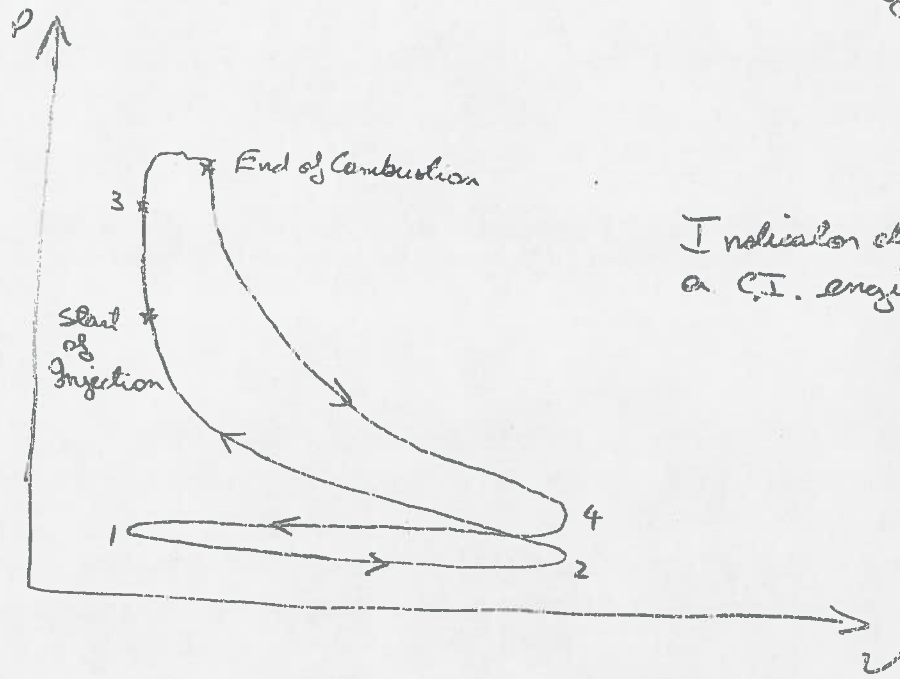
Process 2 to 3 is compression stroke. Both inlet & exhaust valves are closed, while the piston moves up towards top dead center (TDC), the air fuel mixture gets compressed. At some point before TDC the spark occurs. Combustion has a finite time for completion, since the piston moves very little in vertical direction when close to TDC, the combustion is practically at constant volume.

Process 3 to 4 is the power stroke. The high pressure combustion gases push on the piston and make it move downwards thus expanding into a larger volume. When the piston is very close to bottom dead centre, the exhaust valve opens and the expanded combustion gases are allowed to escape.

Process 4 to 1 is the exhaust stroke. The gases that remain in the cylinder after the initial escape are forced out of the cylinder when the piston is moved up to TDC. At the end of the exhaust stroke the exh valve closes and inlet valve opens for the next induction process.

The above was discription was for a four stroke SI engine

For a four stroke C.I. engine the events are slightly different



Indicator diagram for a C.I. engine.

1-2 Induction stroke, only air is admitted to the cylinder.

2-3 Air is compressed (to higher pressures than SI engine) and hence air temperature gets high enough that when fuel is sprayed in the compressed air, it ignites.

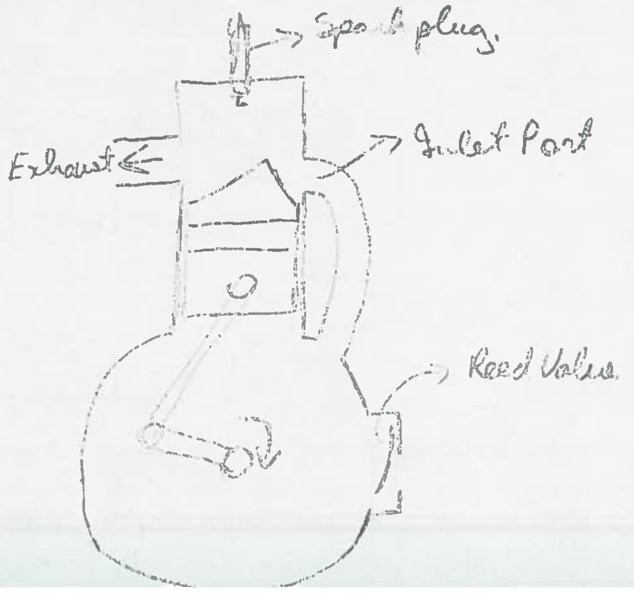
3-4 Power stroke, fuel is sprayed for a prolonged period and keeps on being sprayed for a part of the downward stroke of the piston.

Two Stroke Cycle

In a two stroke cycle the complete cycle is performed in one revolution of the crank. The induction and compression processes are grouped together in one single stroke, while the power and exhaust strokes are grouped together in the other stroke.

Starting from TDC, the gases have just been ignited and combustion is underway. The gases push the piston down and during the first part of expansion, we have a power process. When the piston has moved a considerable part of the stroke downwards the exhaust valve opens and allows the gases to escape. Very close to BDC, the inlet valve opens and allows a fresh charge to come into the cylinder. Note that the fresh charge has to be pushed in, that is two stroke engines always have some form or other of supercharging. The piston then moves upwards and compresses the fresh charge for another repetition.

For one cylinder engines, the volume underneath the piston can be effectively used as a compressor to supercharge the cylinder. In such engines, we usually have inlet & exhaust ports which are covered / uncovered by the piston itself, reed valve on crankcase, no oil in crankcase.



∴ "Two stroke are not only used on small motor cycle S.I. engines but also on very large C.I. engines. Two stroke also used on large truck engines, marine engines and power plant engines.

For small two stroke engines, it is normal that these can go to higher rpm than a similar size four stroke engine because the need for a camshaft is eliminated. However, the two stroke mentioned for marine or power plant are usually slow speed engines, less than 1000 rpm and have poppet valves not slide valves.

- Note that a four stroke engine always requires a camshaft running at ½ crank shaft speed.

For the same size and speed, a two stroke produces more power than a four stroke because power is developed in every revolution.
For a SI two stroke engine, economy is less because some air/fuel mixture is lost through exhaust port which is open at the same time as the inlet port.

SOME COMPARISONS BETWEEN S.I & C.I.

- C.I. engines are said to be quality governed as power control is by means of varying the amount of fuel.

S.I. engines are said to be quantity governed as power is controlled by varying the amount of air/fuel mixture. Mixture is always close to the stoichiometric value of 14.5.

Generally the C.I. engine is more efficient (in terms of specific fuel consumption), because it has higher compression ratios and is quality governed. Compression ratios for S.I. is say around 10, for C.I. engine it is say around 20.

FUELS FOR I.C. ENGINES

In S.I. engines the air fuel mixture is prepared before induction into the cylinder. Thus the fuel is better mixed with the air. Since the fuel/air mix can be ignited if a high temperature exists, the compression ratio cannot be larger than say 12, otherwise any fuel would ignite by the temperature reached due to the compression process.
For this reason, a good fuel for S.I. engines is one which could be used at higher compression ratios. It is important that ignition & combustion start only as a result of the spark, and not due to any hot spot or high temperature due to the compression. Such a "self-ignition" can lead to "knocking" sound. Other terms used are "pre-ignition" and/or "detonation". It should be noted that when "pre-ignition" or "pinking" happens the system is self deteriorating because, pinking leads to a less efficient engine => more energy goes to heat => an increase in temperature of the hot spots => even more pinking. Pinking is the more pronounced uphills at full throttle and higher gears than appropriate. This is because engine breaths well (full throttle) and hence the pressure reached after compression is high => susceptibility to pink.

Fuels for S.I. engines are rated by their octane number. High octane fuels are less prone to self ignition, ∴ they could be used for higher compression ratios. Recall that from theory of OTTO cycle, higher compression ratios => more efficiency.
The octane rating of a fuel is obtained by comparing to a mixture of iso-octane (high rating) and normal heptane (low rating). The octane number of the fuel is the percentage of octane in the reference mixture which knocks under the same conditions as the fuel.
High octane fuels can be produced by the use of anti-knock additives such as tetraethyl lead.

Fuels for C.I. engine need to be able to self-ignite, i.e. the opposite requirement to S.I. engine. This is because in C.I. engine, only air is induced in the cylinder, a sufficiently high temperature is reached by the compression process that when the fuel is injected into the combustion chamber, there is self-ignition. Higher compression ratios than S.I. engines is used so that a high enough temperature is reached, the minimum being 12. The higher the compression ratio the greater the efficiency (from theory of the Diesel Cycle and Mixed combustion cycle), however compression ratios higher than 25 are impractical.

A delay period exists between the start of diesel injection and the first combustion as the fuel has to vapourise first, hence delays are longer than for S.I. engines. If the delay period becomes too long and a large combustion front occurs simultaneously, we could have "diesel knock". The delay period is dependent on the fuel and hence a fuel with a short delay or high ignitability is preffered.
Reference mixtures of cetane (high ignitability) and α-methyl-naphthalene are used to establish the so called cetane number scale by comparison of performance to the fuel being tested.
The knocking point of diesel fuel also depends on droplet size, the rate at which droplets are introduced into the cylinder and the heat transferred between droplets and their environment.

CRITERIA OF PERFORMANCES FOR I.C. ENGINES

BRAKE POWER: (b.p.) is the power that is measured by a dynamometer. The dynamometer is a means of braking or loading the engine hence brake power.

INDICATED POWER: (i.p.) is the actual rate of work done by the working fluid on the piston, and the difference between the i.p. and the b.p. is the power absorbed by mechanical friction. The i.p. can be determined from an indicator diagram

MEAN EFFECTIVE PRESSURE: m.e.p. is defined as the height of a rectangle having the same length and area as the cycle plotted on a p-v diagram.

the indicated i.m.e.p is found by subtracting the area of the pumping loop from the power loop of an indicator diagram. the brake bmep is as the imep but based on the measured output of the engine.

SPECIFIC FUEL CONSUMPTION: s.f.c. is the rate of fuel consumption per unit of brake power i.e.

$$s.f.c. = \frac{m_f}{b.p.}$$

MECHANICAL EFFICIENCY: η_m is the ratio of b.p. to i.p. i.e.

$$\eta_m = \frac{b.p.}{i.p.}$$ Normally between 80 & 90%

VOLUMETRIC EFFICIENCY η_v is the ratio of the volume of air induced, measured at the free air conditions to the swept volume of the cylinder

$$\eta_v = \frac{V}{V_s}$$ usually less than 80%

THERMAL EFFICIENCY we can have either brake or indicated thermal efficiency

$$\eta_b = \frac{b.p.}{m_f \times Q_{net\,p}} \qquad \eta_I = \frac{i.p.}{m_f \times Q_{net\,p}}$$

$Q_{net\,p}$ is the net calorific value of the fuel at constant pressure.

From the above we can write

$$\eta_b = \left(\frac{i.p.}{\dot{m}_f \times Q_{net,p}}\right)\left(\frac{b.p.}{i.p.}\right) = \eta_i \times \eta_m$$

Also $i.p. = p_{mi} L A N$ where p_{mi} is the imep from the indicator diag.
L is the length of stroke
A is the area of piston, × number of pistons if a multi cylinder engine
N is the number of power strokes per second, which is half rotational speed for 4 stroke.

Similarly
$b.p. = p_{mb} L A N$ where p_{mb} is the bmep, brake mean eff pressure

POWER MEASUREMENT

b.p. is measured by a dynamometer.
dynamometers can be absorption or transmission types
absorption dynamometers
i) friction type, for low power low speed
ii) hydraulic, like torque converter
iii) electrical, produces electrical power output
iv) air-fan types.

If a net load W is acting at a known radius R, the torque is

$$T = WR$$

Then the $b.p. = 2\pi N T$ where N is the revolutions per second, even for a 4 stroke engine.

A type of test for the calculation of the i.p. without the indicator diagram is the MORSE TEST, applicable only to multi cylinder engines.
Engine is run at the req^d speed and the b.p. is measured. One cylinder is cut out, by shorting the plug if an S.I. or disconnecting injector if C.I.. The speed falls, because of the loss of power, but is restored by reducing the load. The b.p. is measured again when the speed is restored.

For a 4 cylinder engine, if I_1, I_2, I_3 and I_4 are the i.p. of all four cylinders and power losses in each cylinder is L_1, L_2, L_3 & L_4.

If the value of b.p. B at the test speed when all four cylinders are working,

$$B = (I_1 - L_1) + (I_2 - L_2) + (I_3 - L_3) + (I_4 - L_4)$$

When cylinder 1 is cut out, I_1 is lost, and if losses remain the same

$$B_1 = (0 - L_1) + (I_2 - L_2) + (I_3 - L_3) + (I_4 - L_4)$$

Subtracting the 2nd eqn from the 1st

$$B - B_1 = I_1$$

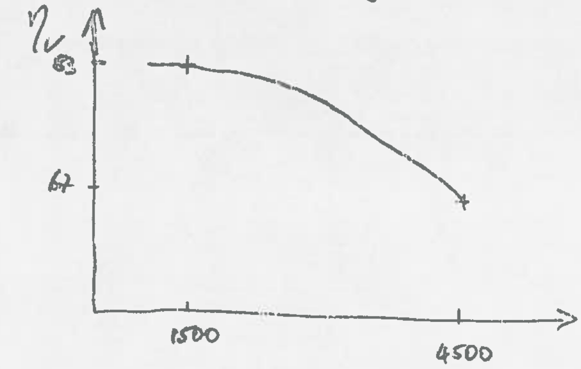
If each cylinder is cut out in turn, values of I_2, I_3 & I_4 are obtained

Then for the whole engine we would have

$$I = I_1 + I_2 + I_3 + I_4$$

SUPERCHARGING.

The volumetric efficiency of an engine falls as the rotational speed increases.



As a consequence the power output of the engine is also affected, that is if the engine continues to breathe as much as at the lower speed, it would develop far more power.

The objective of supercharging is to raise the volumetric efficiency above that obtained with normal aspiration.

Supercharging is especially important in aviation as at high altitude engines find greater difficulties to breath.

Supercharging gives better benefits on C.I engines than S.I. engines. This is because S.I. engines are already limited in compression ratio because of knocking, hence if supercharging is performed, the compression ratio of the engine has to be reduced. Hence the thermal efficiency would be reduced. In C.I. engines, the supercharging may give even better pressure ratio which leads to higher efficiency and wider range of usable fuels.

Supercharging can either be mechanically driven from the shaft or turbine driven from a turbine connected to the engine exhaust.

Most often, when supercharging alone is said, this refers to a mechanically driven roots blower. When a turbocharger is cited, this refers to supercharging by a centrifugal compressor driven by a centrifugal turbine in the exhaust gases.

Note that a roots blower is used for mechanical drive since it is more appropriate for the low speed operation. A turbine on the exhaust gases produces very high rotational speeds and therefore it cannot be made to power a slow speed roots blower but a high speed centrifugal compressor.

A turbocharged system is better because it does not decrease the higher grade energy i.e. the mechanical power. Also, since 60% and over of the cylinder charge is suddenly expanded to exhaust, the turbocharger actually utilises this energy which would have otherwise been lost.

Supercharging is very important in two stroke engines as these require some means or other of supercharging due to their very nature of operation.

Note that in S.I. engine at part throttle, supercharging is not actually required as air is already being limited by the partial closing of the throttle.