Combustion in SI engines

Conditions necessary for combustion are:

- Presence of combustible mixture
- Some means of initiation combustion
- Stabilization and propagation of flame in the combustion chamber

SI engine combustible mixture supplied by carburettor and combustion initiated by an electric spark

\[ C_8H_{18} + 12.5 O_2 = 8CO_2 + 9 H_2O \]
Ignition Limit:

Flame will propagate if temperature of burnt gases exceeds approx. 1500 K
Relative fuel-air ratio lie between 0.5 and 2.1
Stoichiometric mixture is 1:15
Fuel-air must be between 1:30 and 1:7

Upper and lower limit depend upon mixture ratio and temperature.
Ignition limits are wider at increased temperatures because of higher rates of reaction and higher thermal diffusivity coefficients of mixture.
Stages of combustion in SI engine:

- homogeneous mixtures of vapourised fuel, air and residual gases
- electrodes temp. exceeds 10,000°C
- manner of a soap bubble
- flame front travel dependent primarily on the degree of turbulence

Theoretical p-θ diagram
1) Ignition lag or preparation phase (AB):
-growth and development of a semi propagating nucleus of flame
-chemical process depending upon the nature of the fuel, upon both temperature and pressure, the proportion of the exhaust gas, and also upon the temperature coefficient of the fuel, that is, the relationship of oxidation or burning
-point A shows the passage of spark and point B is the first rise of pressure
-ignition lag is generally expressed in terms of crank angle
-Ignition lag is very small and lies between 0.00015 to 0.0002 seconds
-ignition lag of 0.002 seconds corresponds to 35 deg crank rotation when the engine is running at 3000 RPM
-Angle of advance increase with the speed
Stages of combustion in SI engine
2) propagation of flame (BC):
   - Period from the point B where the line of combustion departs from the compression line to point C, the maximum rise of pressure in P-θ diagram
   - Flame propagates at the constant velocity
   - Heat transfer to the cylinder wall is low
   - Rate of heat release depends upon the turbulence intensity and reaction rate

3) After burning (CD):
   - After point C, the heat release is due to the fuel injection in reduced flame front after the start of expansion stroke
   - No pressure rise during this period
EFFECT OF ENGINE VARIABLES ON IGNITION LAG

Ignition lag in terms of crank angle is $10^\circ$ to $20^\circ$ and in terms of seconds, 0.0015 second or so. Duration depends on the following factors:

**Fuel:** Chemical nature of fuel
High self-ignition temperature of fuel longer the ignition lag.

Petrol-247$^\circ$C-280$^\circ$C
Diesel or Jet A-1- 210$^\circ$C
Diethyl ether- 160$^\circ$C
Ethanol-365$^\circ$C
Hydrogen-536$^\circ$C
Phosphorous (white)-34$^\circ$C
Mixture ratio: mixture richer than the stoichiometric ratio provide shorter ignition lag

Initial temperature and pressure: rate of reaction depends on increasing the intake temperature and pressure, increasing the compression ratio, chemical reaction rate and retarding the spark all reduce the ignition lag
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**Electrode gap:** lower the compression ratio and higher the electrode gap is desirable -voltage required at the spark plug electrode to produce spark is found to increase with decrease in fuel-air ratio and with increase in compression ratio and engine load.
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**Turbulence:** directly proportional to engine speed
- engine speed does not affect much ignition lag measured in milliseconds
- but ignition lag increases linearly with engine speed when measured in degree crank angle
- spark advance is desirable in higher engine speed
- Excessive turbulence of the mixture in the area of spark plug is harmful
Rate of flame propagation affects the combustion process in SI engines. Higher combustion efficiency and fuel economy can be achieved by higher flame propagation velocities. Unfortunately flame velocities for most of fuel range between 10 to 30 m/second.

The factors which affect the flame propagations are
- Fuel-ratio
- Compression ratio
- Intake temp. and press.
- Load on engine
- Turbulence and engine speed
- Engine Size
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**F:A ratio:** The mixture strength influences the rate of combustion and amount of heat generated. The maximum flame speed for all hydrocarbon fuels occurs at nearly 10% rich mixture. Flame speed is reduced both for lean and as well as for very rich mixture. Lean mixture releases less heat resulting lower flame temperature and lower flame speed. Very rich mixture results incomplete combustion and also results in production of less heat and flame speed remains low.
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**Compression ratio:** The higher compression ratio increases the pressure and temperature of the mixture and also decreases the concentration of residual gases. All these factors reduce the ignition lag and help to speed up the second phase of combustion.

- The maximum pressure of the cycle as well as mean effective pressure of the cycle with increase in compression ratio.
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**Load on Engine:** With increase in load, the cycle pressures increase and the flame speed also increases.

-In S.I. engine, the power developed by an engine is controlled by throttling. At lower load and higher throttle, the initial and final pressure of the mixture after compression decrease and mixture is also diluted by the more residual gases. This reduces the flame propagation and prolongs the ignition lag. This is the reason, the advance mechanism is also provided with change in load on the engine.

-This difficulty can be partly overcome by providing rich mixture at part loads but this definitely increases the chances of afterburning. The after burning is prolonged with richer mixture. In fact, poor combustion at part loads and necessity of providing richer mixture are the main disadvantages of SI engines which causes wastage of fuel and discharge of large amount of CO with exhaust gases.
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**Turbulence:** Turbulence plays very important role in combustion of fuel as the flame speed is directly proportional to the turbulence of the mixture.
- suitable design of the combustion chamber (geometry of cylinder head and piston crown).
- Insufficient turbulence provides low flame velocity and incomplete combustion and reduces the power output. But excessive turbulence is also not desirable as it increases the combustion rapidly and leads to detonation.
**Engine Speed**

The turbulence of the mixture increases with an increase in engine speed. For this reason the flame speed almost increases linearly with engine speed. *If the engine speed is doubled, flame to traverse the combustion chamber is halved (in milliseconds). Double the original speed and half the original time give the same number of crank degrees for flame propagation.*

-The crank angle required for the flame propagation, which is main phase of combustion will remain almost constant at all speeds. This is an important characteristic of all petrol engines.

-If speed is doubled, first stage will be doubled in terms of crank angle but constant in terms of milliseconds

**Q:** Petrol engine is running at 1500 rpm, ignition lag-8° CA and propagation of flame-12°, if ignition speed is doubled calculate the total ignition period.
Engine Size

Engines of similar design generally run at the same piston speed. This is achieved by using small engines having larger RPM and larger engines having smaller RPM. Due to same piston speed, the inlet velocity, degree of turbulence and flame speed are nearly same in similar engines regardless of the size. However, in small engines the flame travel is small and in large engines large.

Therefore, *if the engine size is doubled the time required for propagation of flame through combustion space is also doubled*. But with lower RPM of large engines the time for flame propagation in terms of crank would be nearly same as in small engines. In other words, the number of crank degrees required for flame travel will be about the same irrespective of engine size provided the engines are similar.
ABNORMAL COMBUSTION

- Occurs due to engine operating conditions
- Variety of ways in which abnormal combustion can occur such as “detonation or knock”, “preignition”, “run-on” etc.

**Detonation or knocking**
- Normal flame front travels at 15 to 30 m/s speed
- Temperature increases due to flame front advance, radiation and reactions of unburnt mixture
- During abnormal combustion end charge auto-ignites before the flame front reaches
- Velocities reached during detonation are 300 to 1000 m/s
- Press rise almost 3 to 4 times i.e. 50 bar to 150-200 bar
- This pressure frequency or vibration frequency in SI engine can be up to 5000 Cycles per second. Denotation is undesirable as it affects the engine performance and life, as it abruptly increases sudden large amount of heat energy. It also put a limit on compression ratio at which engine can be operated which directly affects the engine efficiency and output.
(a) Normal combustion
(b) Detonation or knock
**Auto ignition**

A mixture of fuel and air can react spontaneously and produce heat by chemical reaction in the absence of flame to initiate the combustion or self-ignition. This type of self-ignition in the absence of flame is known as Auto-Ignition. The temperature at which the self-ignition takes place is known as self-igniting temperature. The pressure and temperature abruptly increase due to auto-ignition because of sudden release of chemical energy. This auto-ignition leads to abnormal combustion known as detonation which is undesirable because its bad effect on the engine performance and life as it abruptly increases sudden large amount of heat energy. In addition to this knocking puts a limit on the compression ratio at which an engine can be operated which directly affects the engine efficiency and output.
**Pre-ignition**

Pre-ignition is the ignition of the homogeneous mixture of charge as it comes in contact with hot surfaces, in the absence of spark. Auto ignition may overheat the spark plug and exhaust valve and it remains so hot that its temperature is sufficient to ignite the charge in next cycle during the compression stroke before spark occurs and this causes the pre-ignition of the charge. *Pre-ignition is initiated by some overheated projecting part such as the sparking plug electrodes, exhaust valve head, metal corners in the combustion chamber, carbon deposits or protruding cylinder head gasket rim etc.* Pre-ignition is also caused by persistent detonating pressure shockwaves scoring away the stagnant gases which normally protect the combustion chamber walls. The resulting increased heat flow through the walls, raises the surface temperature of any protruding poorly cooled part of the chamber, and this therefore provides a focal point for pre-ignition.
*Effect of detonation*

The harmful effects of detonation are as follows:

*Noise and roughness*: knocking produces a loud pulsating noise and pressure waves. These waves vibrate back and forth across the cylinder. The presence of vibratory motion causes crankshaft vibrations and the engine runs rough.

*Mechanical damage:*

(a) High pressure waves generated during knocking can increase rate of wear of parts of combustion chamber. Sever erosion of piston crown (in a manner similar to that of marine propeller blades by cavitation), cylinder head and pitting of inlet and outlet valves may result in complete wreckage of the engine.

(b) Detonation is very dangerous in engines having high noise level. In small engines the knocking noise is easily detected and the corrective measures can be taken but in aero- engines it is difficult to detect knocking noise and hence corrective measures cannot be taken. Hence severe detonation may persist for a long time which may ultimately result in complete wreckage of the piston.

*Carbon deposits*: Detonation results in increased carbon deposits.
**Increase in heat transfer:** Knocking is accompanied by an increase in the rate of heat transfer to the combustion chamber walls.

The increase in heat transfer is due to two reasons.

- The minor reason is that the maximum temperature in a detonating engine is about 150°C higher than in a non-detonating engine, due to rapid completion of combustion.
- The major reason for increased heat transfer is the scouring away of protective layer of inactive stagnant gas on the cylinder walls due to pressure waves. The inactive layer of gas normally reduces the heat transfer by protecting the combustion and piston crown from direct contact with flame.

**Decrease in power output and efficiency:** Due to increase in the rate of heat transfer the power output as well as efficiency of a detonating engine decreases.

**Pre-ignition:** increase in the rate of heat transfer to the walls has yet another effect. It may cause local overheating, especially of the sparking plug, which may reach a temperature high enough to ignite the charge before the passage of spark, thus causing pre-ignition. An engine detonating for a long period would most probably lead to pre-ignition and this is the real danger of detonation.