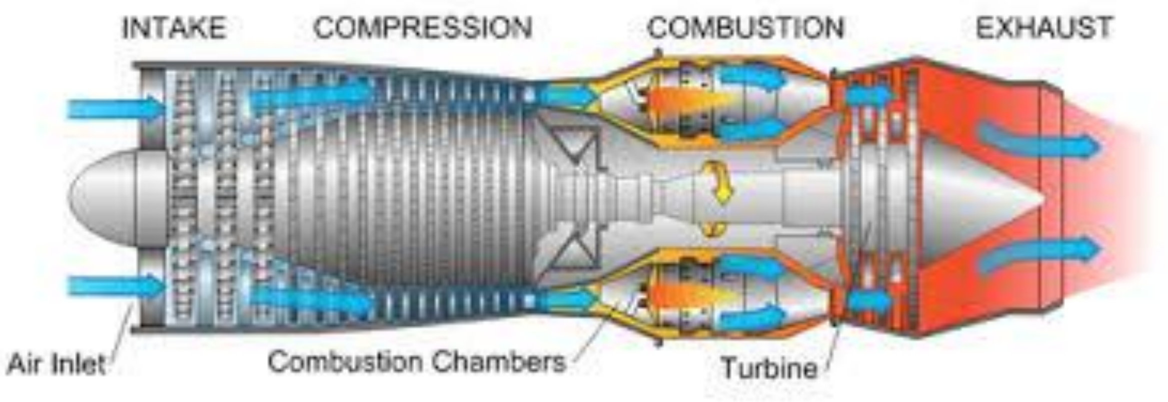
TIKRIT UNIVERSITY

COLLEGE OF ENGINEERING

MECHNICAL DEPARTMENT

INTERNAL COMBUSTION ENGINE



Chapter Seven

Combustion in SI & CI Engines

Course Instructor

Dr. Khalaf I. Hamada

Assistant Professor

Basic characteristics of SI & CI Engines

In Spark Ignition (SI) Engine the combustion takes place by generation of spark using spark plug.

It has low compression ratio (8:1 – 12:1)

The air-fuel ratio remains close to stoichiometric value (~14.5:1) from no load (~20:1) to full load (~10:1).

In Compression Ignition (CI) Engine the combustion of fuel takes place by the heat of the compressed air.

It has high compression ratio (14:1 to 24:1)

The overall air-fuel ratio thus varies from about (~18:1) at full load to about (~80:1) at no load.

Combustion may be defined as a relatively rapid chemical combination of hydrogen and carbon in fuel with oxygen in air resulting in liberation of energy in the form of heat.

Following conditions are necessary for combustion to take place:

- ✓ **The presence of combustible mixture**
- ✓ **Some means to initiate combustion**
- ✓ **Stabilization and propagation of flame in combustion chamber (Flame propagation).**

In SI engines, Combustion either occurs normally - **with ignition from a spark and the flame front propagating steadily throughout the mixture** - or abnormally.

Normal Combustion: **When the flame travels evenly or uniformly across the combustion chamber.**

Combustion **is dependent upon the rate of propagation of flame front (or flame speed).**

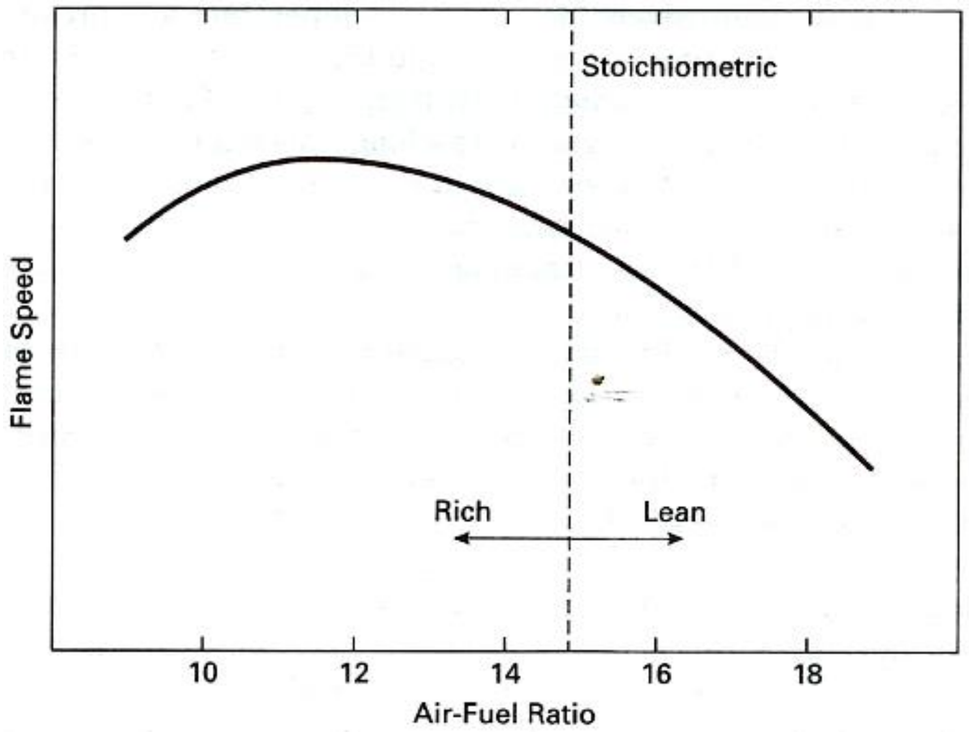
Flame Front: Boundary or front surface of the flame that separates the burnt charges from the unburnt one.

Flame Speed: The speed at which the flame front travels. It affects the combustion phenomena, pressure developed and power produced.

Burning rate of mixture depends on the flame speed and shape/contour of combustion chamber.

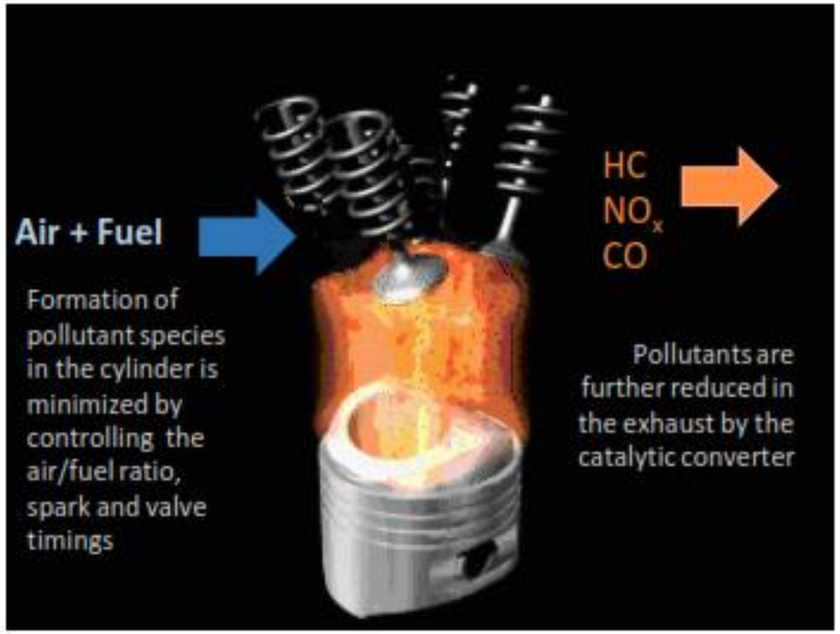
Factors Affecting Flame Speed (FS)

1. Turbulence: Helps in mixing and accelerates chemical reaction.
2. Engine Speed: When engine speed increases, flame speed increases due to turbulence
3. Compression Ratio: an engine with higher CR have higher flame speeds
4. Inlet Temp. & Pressure: FS increases with an increase of inlet temperature and pressure.
5. Fuel-Air Ratio: The highest flame speeds (minimum time for complete combustion) are obtained with lightly rich mixture. When the mixture is leaner or richer, flame speed decreases

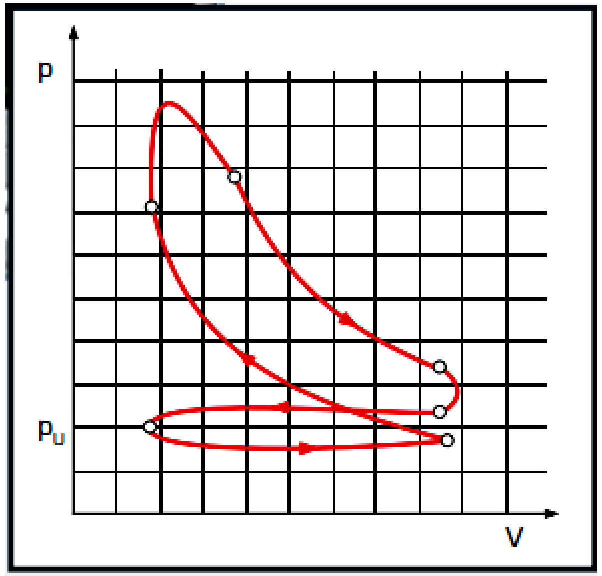


❑How the combustion process characterized in IC Engines?

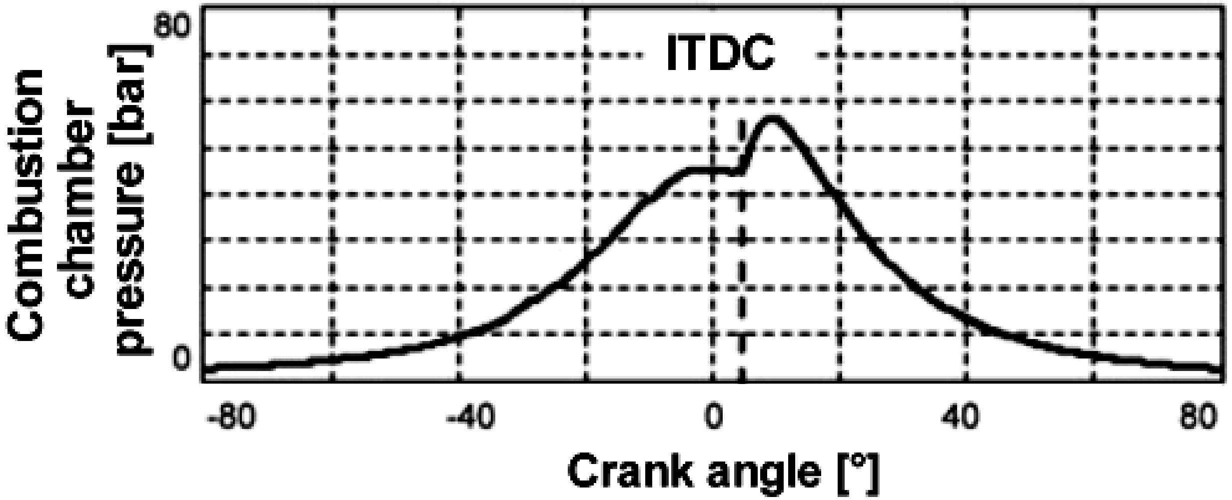
✓ There are four diagrams can be considered to characterized the combustion process characterized in IC Engines.



✓ P-v diagram.



✓ P-θ diagram.

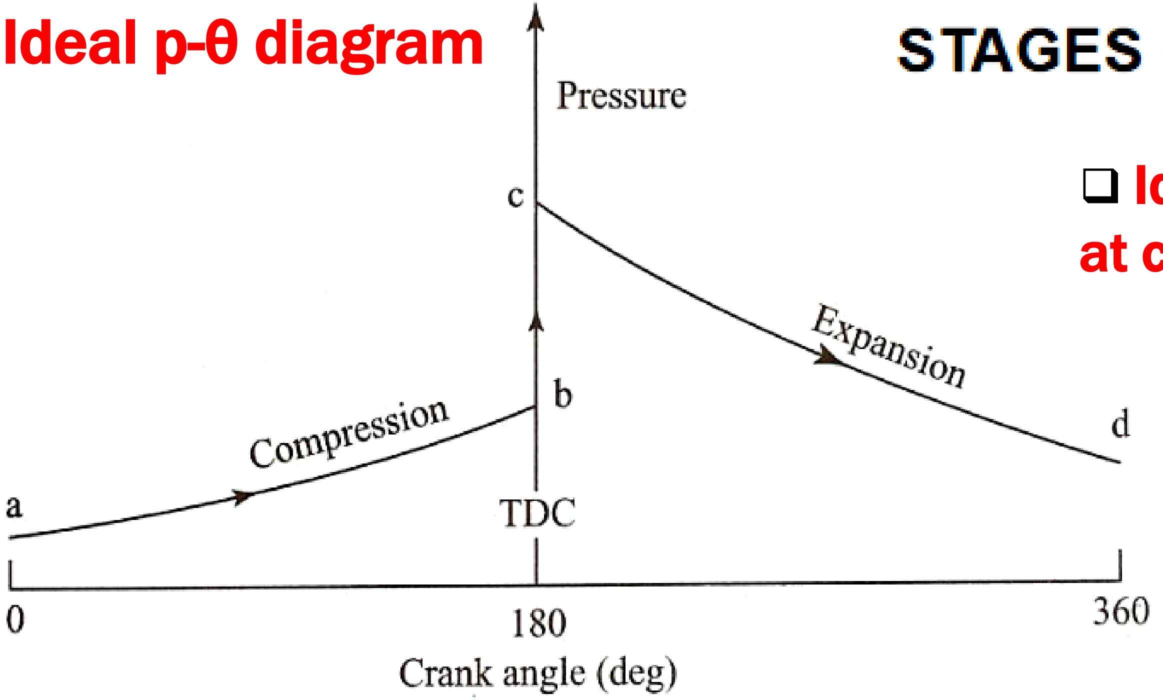


✓ MFB diagram.

✓ HRR diagram.

STAGES OF COMBUSTION IN SI ENGINE

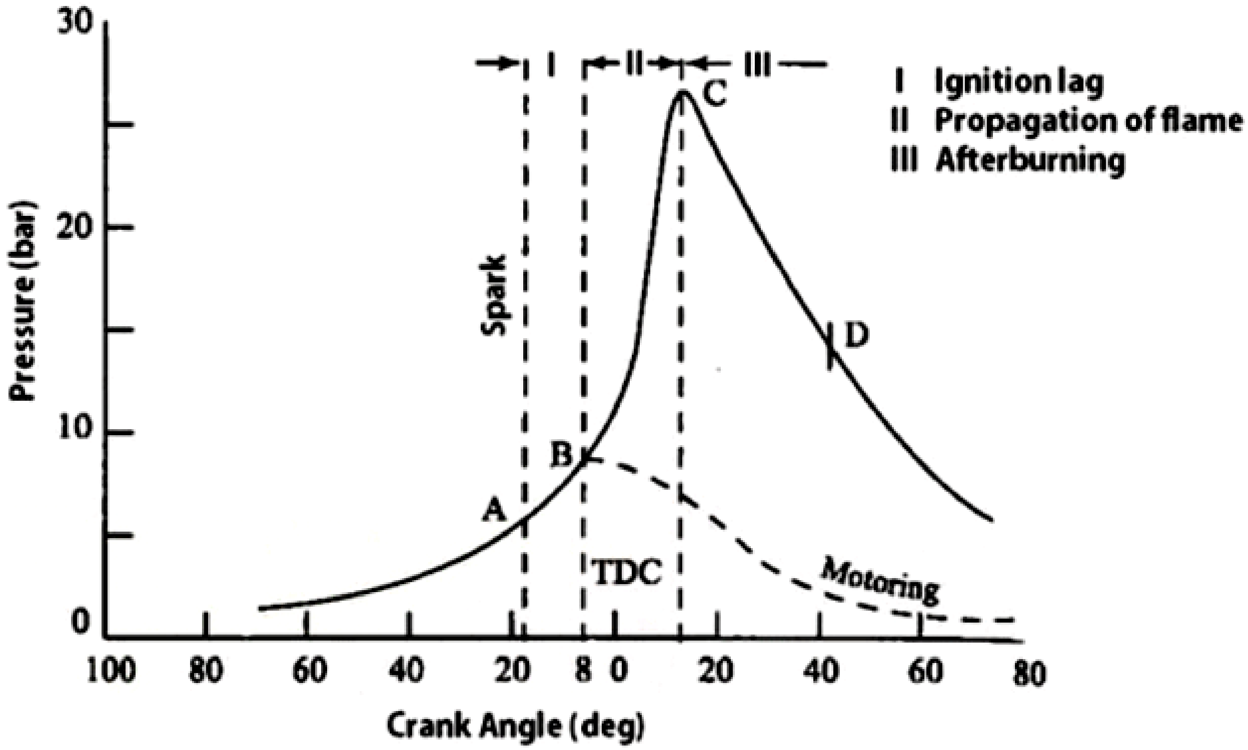
Ideal p-θ diagram



- Ideally, entire pressure rise during combustion occurs at constant volume, i.e., when the piston is at TDC.

a → b : Compression
b → c : Combustion
c → d : Expansion

Actual p-θ diagram



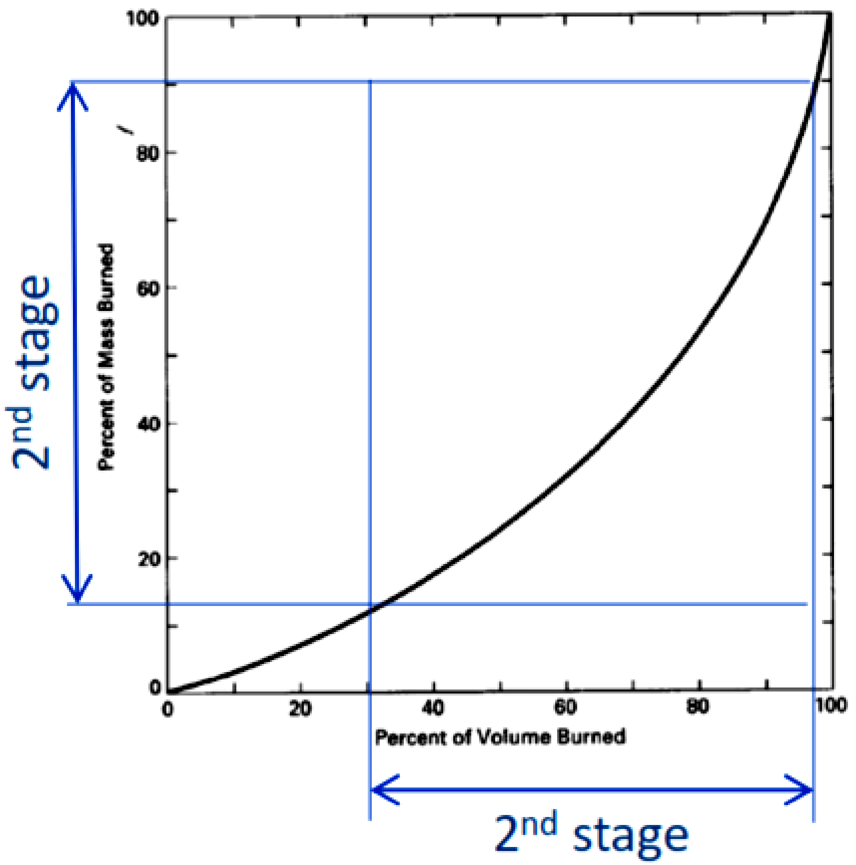
I. Ignition lag (A→B): Flame front begins to travel.

II. Spreading of Flame (B→C): Flame spreads throughout the Combustion Chamber (Flame propagation).

III. Afterburning (C→D): C is the point of max. pressure, a few degrees after TDC. Power stroke begins.

2nd stage: flame propagation

- Most of the fuel-air mixture is burned in this stage
- Most of the useful work is produced in this stage



There are several factors which affect the 2nd (flame speed) :

1- Fuel - air ratio: Flame speed is reduced both for lean and as well as for very rich mixture, and as a results increase the 2nd stage period.

2-Intake P &T: Increase in intake pressure and temperature increases the flame speed, and as a results decrease the 2nd stage period.

3- Compression Ratio: The higher CR reduces the ignition lag and help to decrease the 2nd stage period.

4-Engine load: With increase in engine load the cycle pressure increases hence the flame speed increase, and as a results decrease the 2nd stage period.

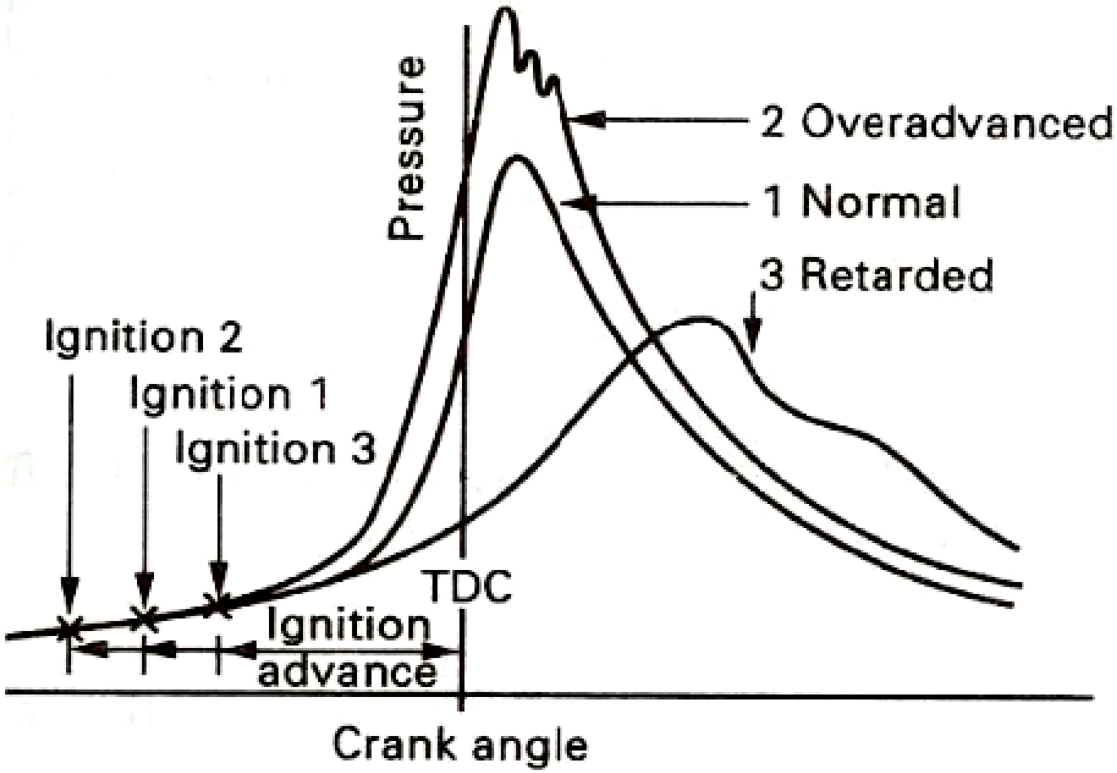
5-Turbulence: Turbulence plays a very vital role in combustion phenomenon through intensifies the process of heat transfer and mixing and as a results decrease the 2nd stage period.

6. Engine Speed: The turbulence of the mixture increases with an increase in engine speed.

Effect of Ignition Timing (Spark Timing): Because of ignition lag, it is necessary to ignite the charge in the cylinder some degrees before the crankshaft reaches TDC. The number of degrees before TDC at which ignition occurs is called Ignition Advance.

Effect of Over-advanced ignition: When the engine ignition is over-advanced (curve 2), combustion is initiated too early and the cylinder pressure begins to rise rapidly while the piston is still trying to complete its compression stroke.

This creates excessive cylinder pressures and may even produce shock waves in the cylinder. An overadvanced engine will run rough, it will tend to overheat resulting in loss of power.



Effect of Retarded Ignition: When the engine ignition is retarded (curve 3), combustion is initiated late. In fact, combustion will continue while the piston is sweeping out its power.

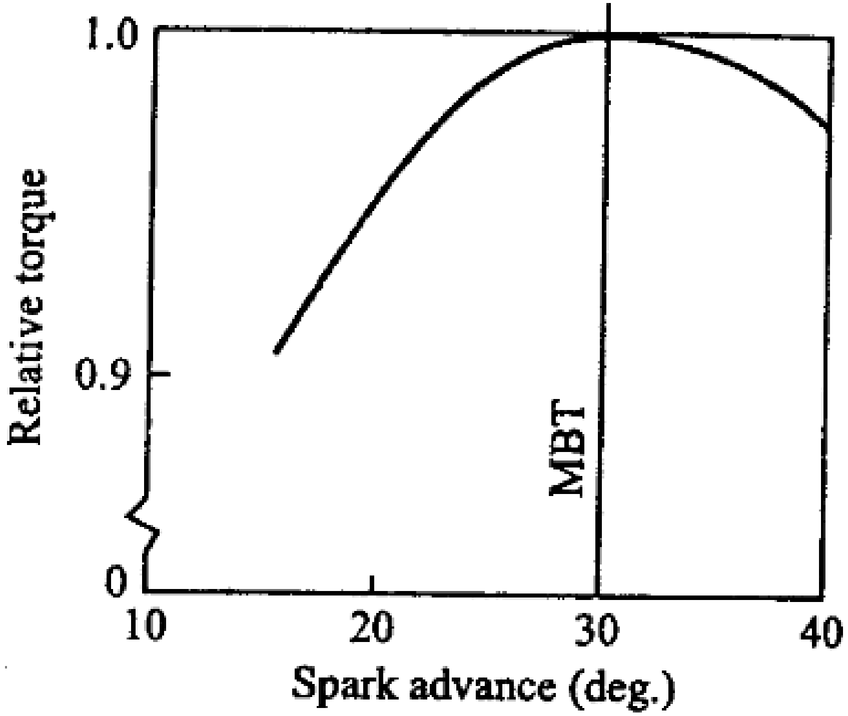
Maximum pressure will occur late, and will not as high as that of the normal case.

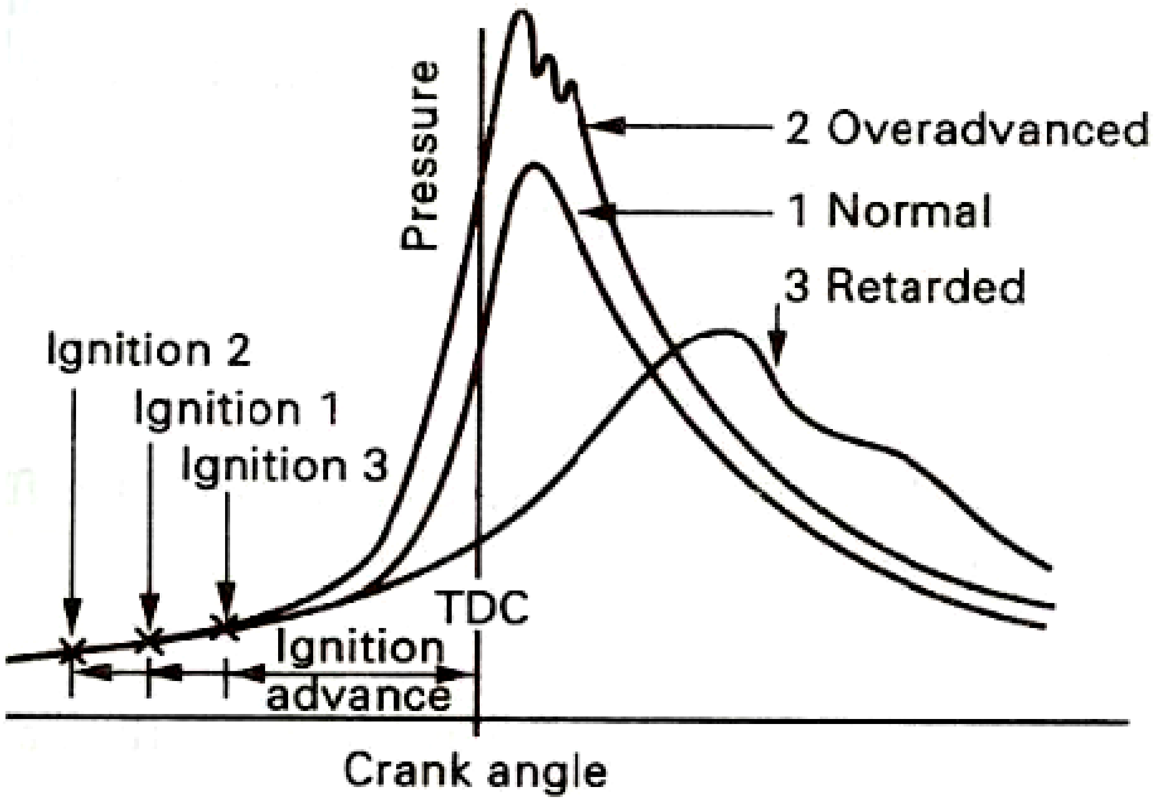
A retarded engine will produce less power output, and due to the late burning the engine will run hot, and may cause damage to the exhaust valves and ports.

The **optimum angle** of advance allows combustion to cease just after TDC, so that maximum possible pressure is built at a point just at the beginning of expansion stroke. This is shown as the **normal curve**, indicating smooth engine running.

Optimum Spark Time Setting

The optimum timing which gives the maximum brake torque called ***maximum brake torque***, or MBT, timing

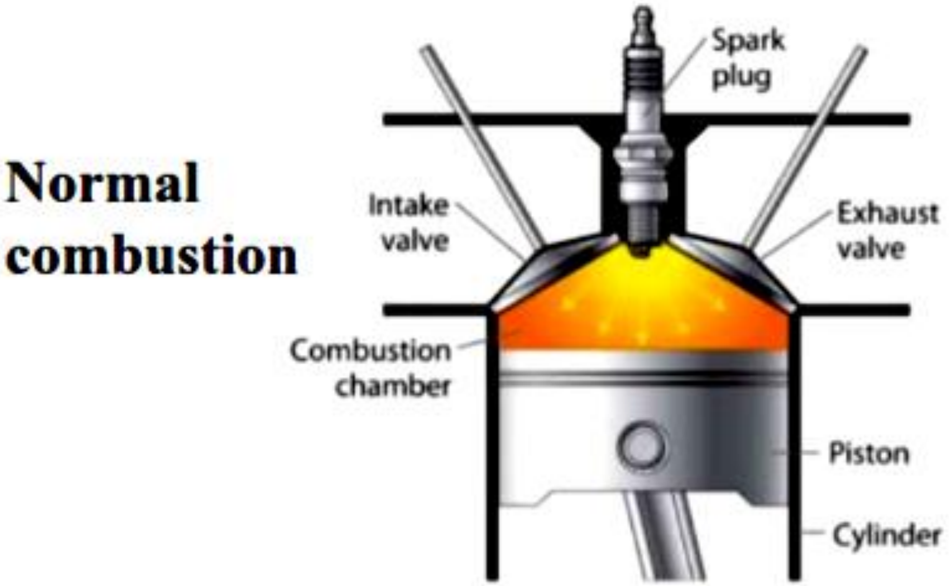




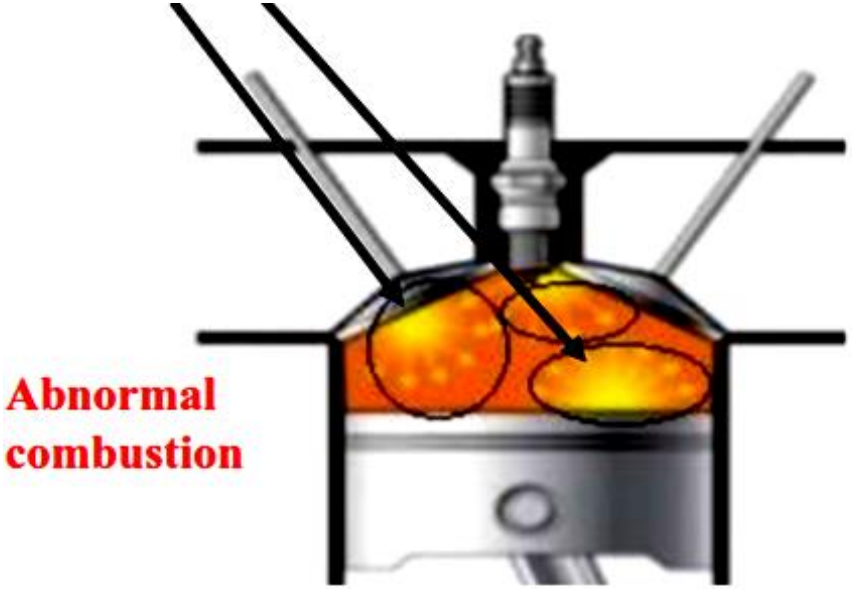
This is explain why engine torque (at given engine speed and intake manifold conditions) varies as spark timing is varied relative to TC.

Combustion in SI engines

Normal combustion is the process where the fuel is burned layer by layer i.e. in a wave form across the combustion chamber by the help of spark only.



Abnormal combustion is the process where the fuel burns not only by spark but also by self ignition process



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. This auto-ignition leads to **abnormal combustion.**

There are two forms of abnormal combustion in SI engines:

1. Knocking (Detonation): is occurred due to auto-ignition of end portion of unburned charge in combustion chamber.

2. Surface Ignition (Pre- ignition or self-ignition): occurs when the fuel mixture in the cylinder burns before the spark-ignition event at the spark plug.

Auto-ignition refers to chemical reaction accelerating to spontaneous ignition of the mixture.

Knock is restricted to the physical manifestation of abnormal oscillations in the cylinder pressure during combustion.

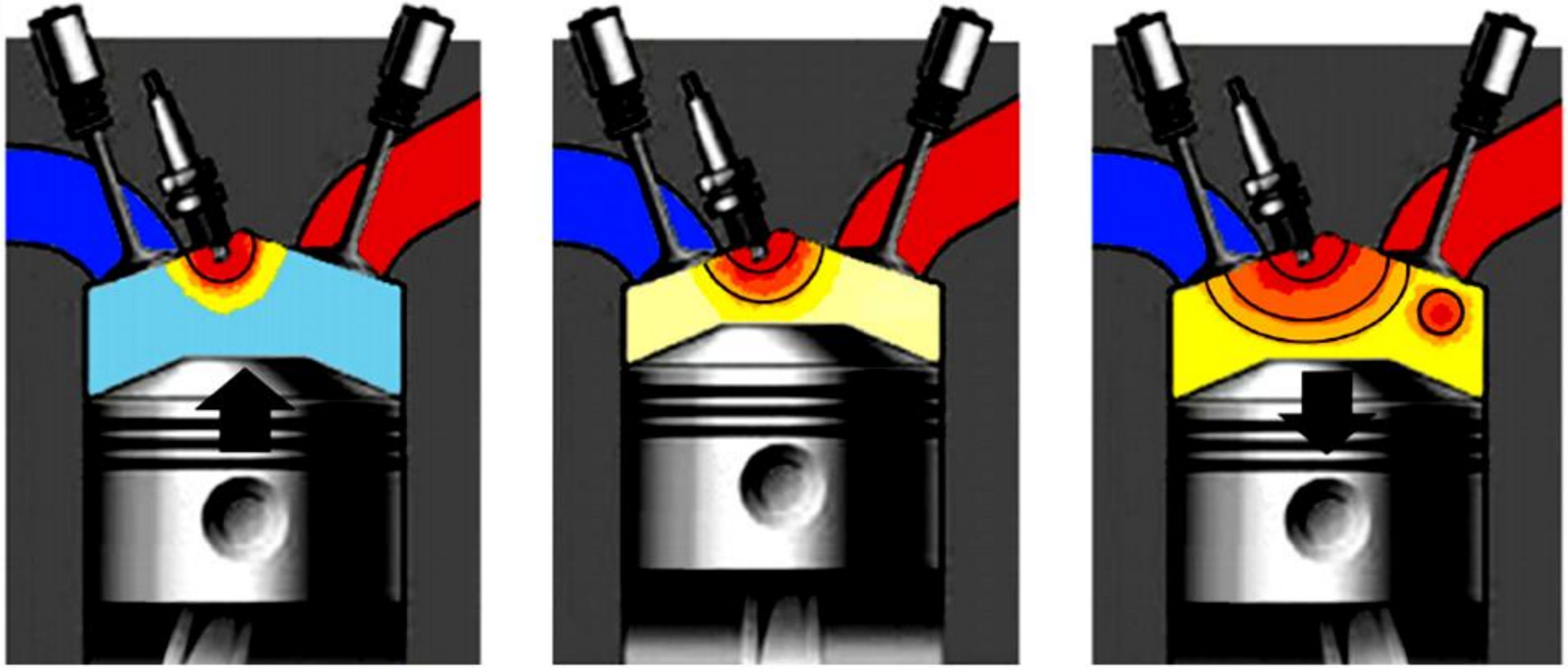
Knock

- **Surface ignition**

– Caused by mixture igniting as a result of contact with a hot surface, such as an exhaust valve

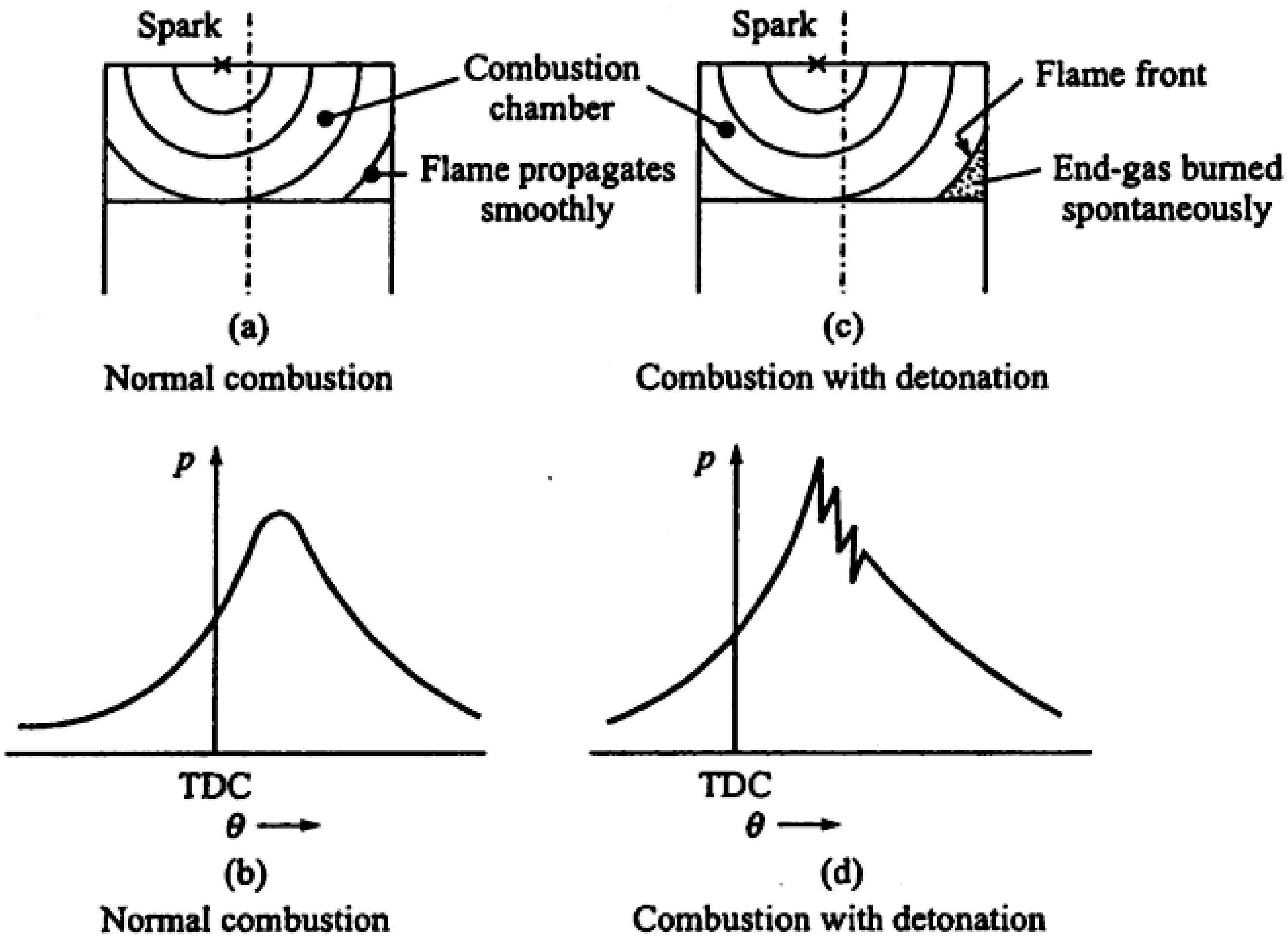
- **Self-Ignition**

– Occurs when temperature and pressure of unburned gas are high enough to cause spontaneous ignition



(a) Ignition by the spark-plug. (b) Flame propagation. (c) Auto-ignition ahead of the flame.

Comparison between normal and abnormal with knocking (or detonation)



(a) Normal combustion

(c) Combustion with detonation

(b) Normal combustion

(d) Combustion with detonation

The harmful effects of detonation (knocking) are as follows:

1. Noise and roughness:

2. Mechanical damage: Knocking can increase rate of wear of parts of combustion chamber.

3. Carbon deposits: Detonation results in increased carbon deposits.

4. Increase in heat transfer: Knocking is increasing the rate of heat transfer to the combustion chamber walls.

5. 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.

Effect of Variables on Knock – Density Factors

Density Factors: Factors that reduce the density of the charge also reduce the knocking tendency by providing lower energy release.

1. Compression ratio (CR): Increasing CR ratio leads to increase *p* and *T* and an overall increase in density of charge raises the knocking tendency.

2. Mass of inducted charge: A reduction in the mass of inducted charge (*by throttling or by reducing the amount of supercharging*) reduces both *T* and ρ at the time of ignition. This decreases the knocking tendency.

3. Inlet T of mixture: An increase in the inlet *T* of mixture makes the compression *T* higher. This increases the knocking tendency. Further, volumetric efficiency is lowered. Hence, a lower inlet *T* is always preferred. However, it should not be too low to cause starting and vaporization problems.

4. Retarding spark timing: Having a spark closer to TDC, peak pressures are reached down on the power stroke, and are of lower magnitudes. This might reduce the knocking tendency, however, it will affect the brake torque and power output.

Effect of Variables on Knock – Time Factors

Time Factors: Increasing the flame speed or the ignition lag will tend to reduce the tendency to knock.

1. Turbulence: Increase of turbulence increases the flame speed and reduces the time available for the end charge to reach auto-ignition condition. This reduces the knocking tendency.
2. Engine size: Flame requires more time to travel in Combustion Chamber of larger engines. Hence, a larger engines will have more tendency to knock.
3. Engine speed: An increase in engine speed increases the turbulence of the mixture considerably resulting in increased flame speed. Hence, knocking tendency reduces at higher engine speeds.
4. Spark plug locations: To minimize the flame travel distance, spark plug is located centrally. For larger engines, two or more spark plugs are located to achieve this.

Effect of Variables on Knock – Composition Factors

1. Fuel-air ratio: The flame speeds are affected by fuel-air ratio. Also, the flame temperature and reaction time are different for different fuel-air ratios.
2. Octane value: In general, paraffin series of hydrocarbon have the maximum and aromatic series the minimum tendency to knock.