Lecture-17

Prepared under
QIP-CD Cell Project

Internal Combustion Engines

Combustions in SI Engines

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Combustion in SI Engine

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

- **Abnormal Combustion:** When the combustion gets deviated from the normal behavior resulting in loss of performance or damage to the engine.

- 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.

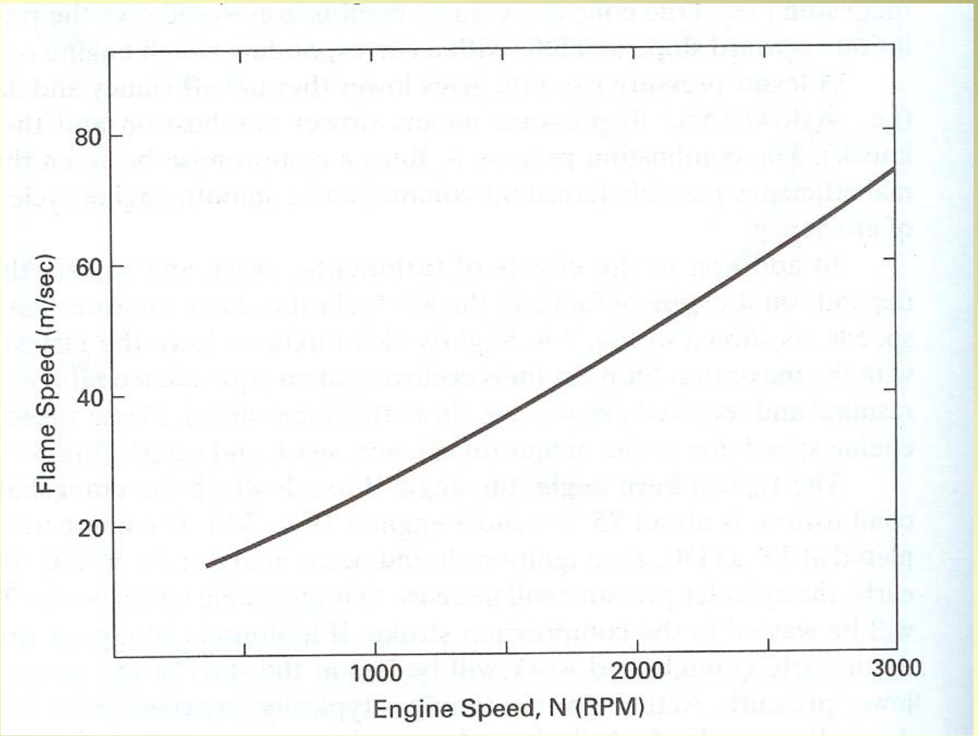
Flame speed affects the combustion phenomena, pressure developed and power produced.

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. A lean mixture can be burnt without difficulty.

2. Engine Speed: When engine speed increases, flame speed increases due to turbulence, swirl squish, and tumble.



Factors Affecting Flame Speed (FS)

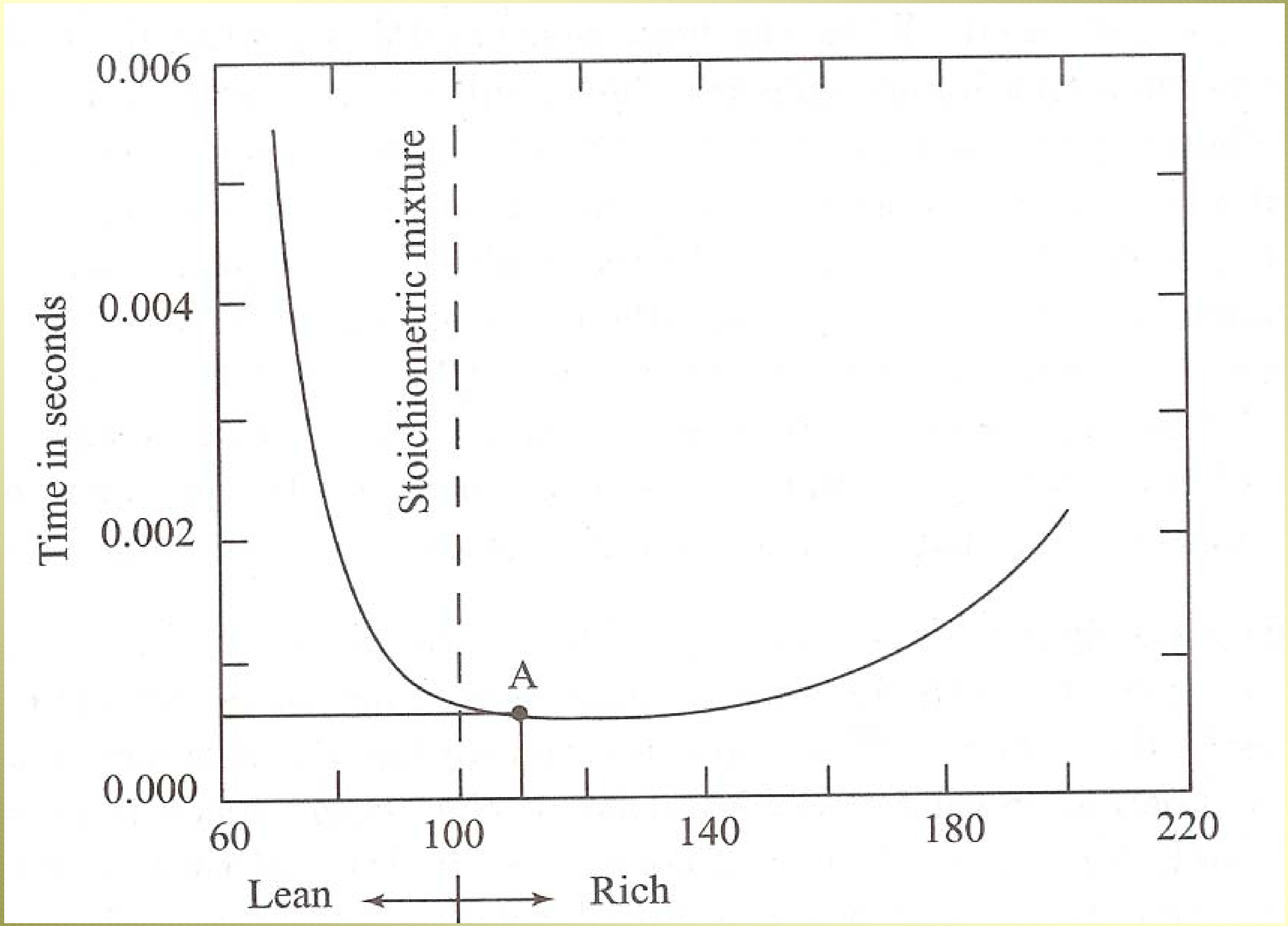
3. **Compression Ratio (CR):** A higher CR increases the pressure and temperature of mixture. This reduces the initial phase of combustion, and hence less ignition advance is needed. High p and T of the compressed mixture speed up the 2nd phase of combustion. Increased CR reduces the clearance volume, and hence the density of charge. This further increases the peak pressure and temperature, reducing the total combustion duration. Thus, an engine with higher CR have higher flame speeds.

Factors Affecting Flame Speed (FS)

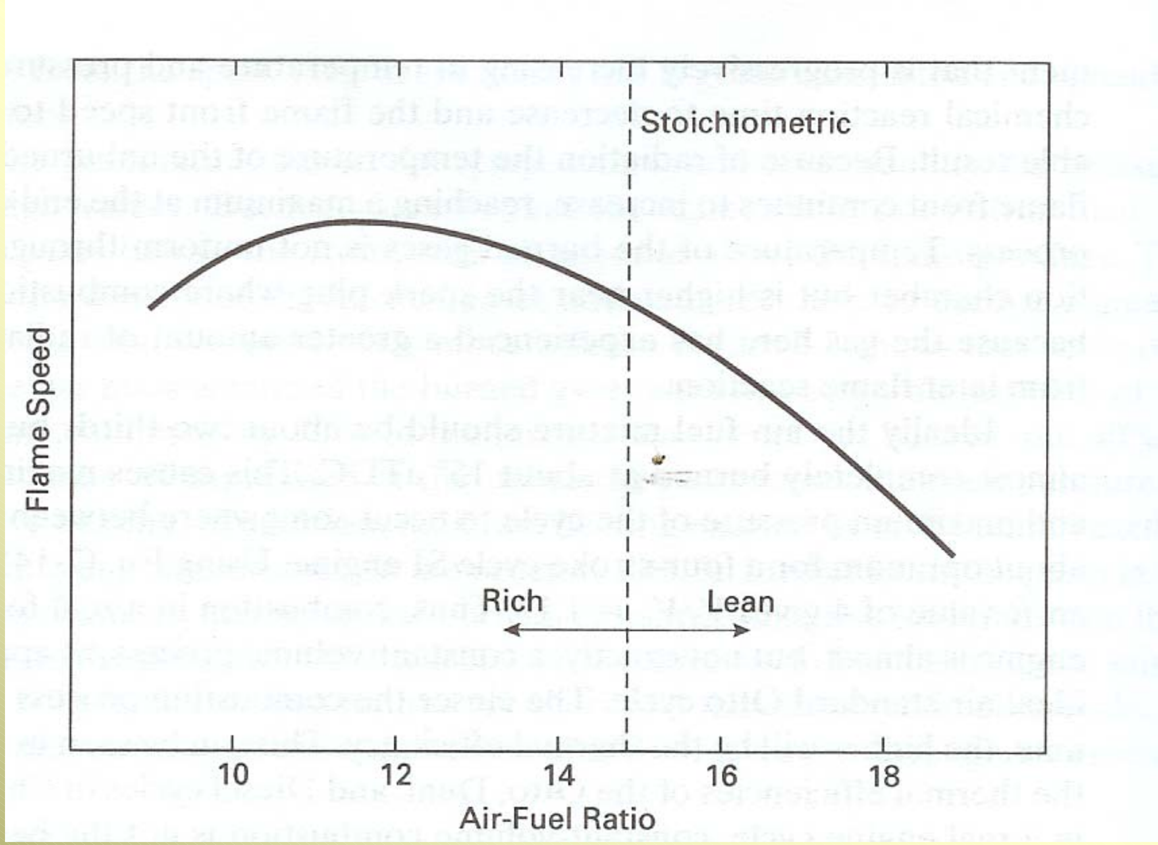
4. Inlet Temp. & Pressure: FS increases with an increase of inlet temperature and pressure. A higher values of these form a better homogeneous mixture, which helps in increasing the FS.

5. Fuel-Air Ratio: The highest flame speeds (*minimum time for complete combustion*) are obtained with slightly rich mixture (point A). When the mixture is leaner or richer, flame speed decreases (*a lean mixture releases less thermal energy, and hence a lower flame temperature; while a rich mixture leads to incomplete combustion, and hence a release of less thermal energy*).

Effect of mixture strength on burning rate

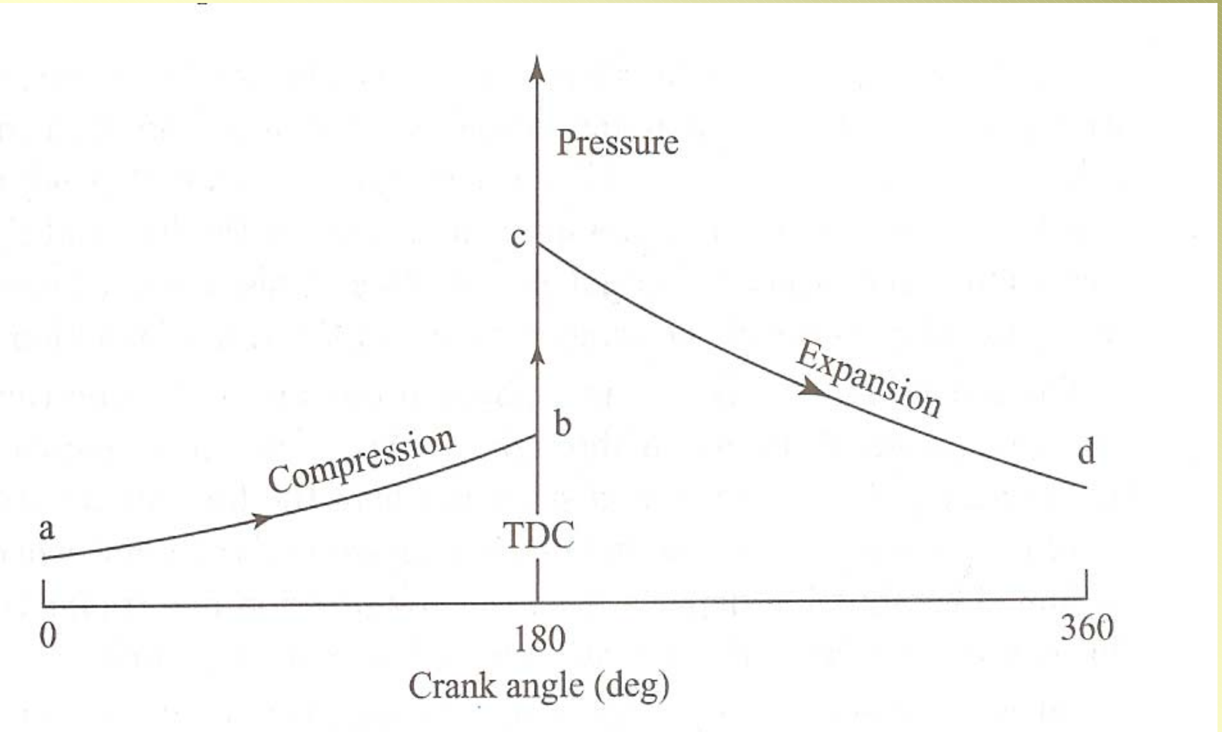


Average flame speed in CC of an SI engine as a function of air-fuel ratio.



Lean air-fuel mixtures have slower flame speeds with maximum speed occurring when slightly rich at an equivalence ratio near 1.2.

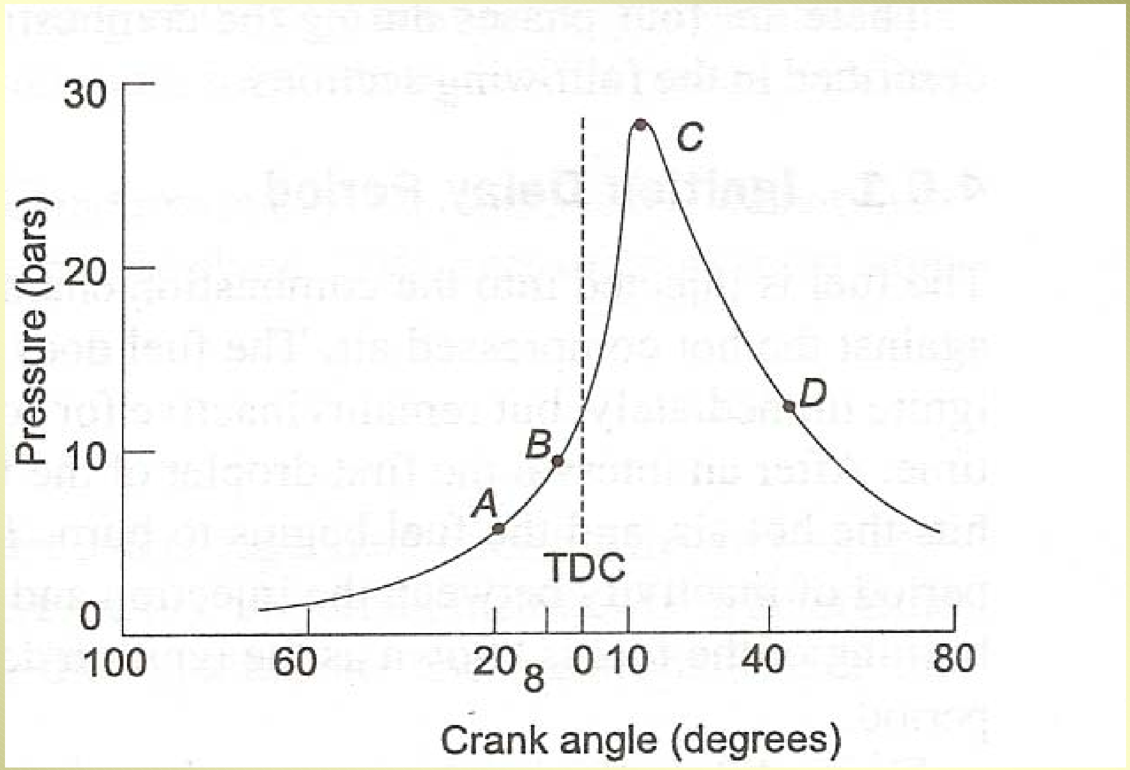
Stages of Combustion



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

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

Actual p-θ diagram



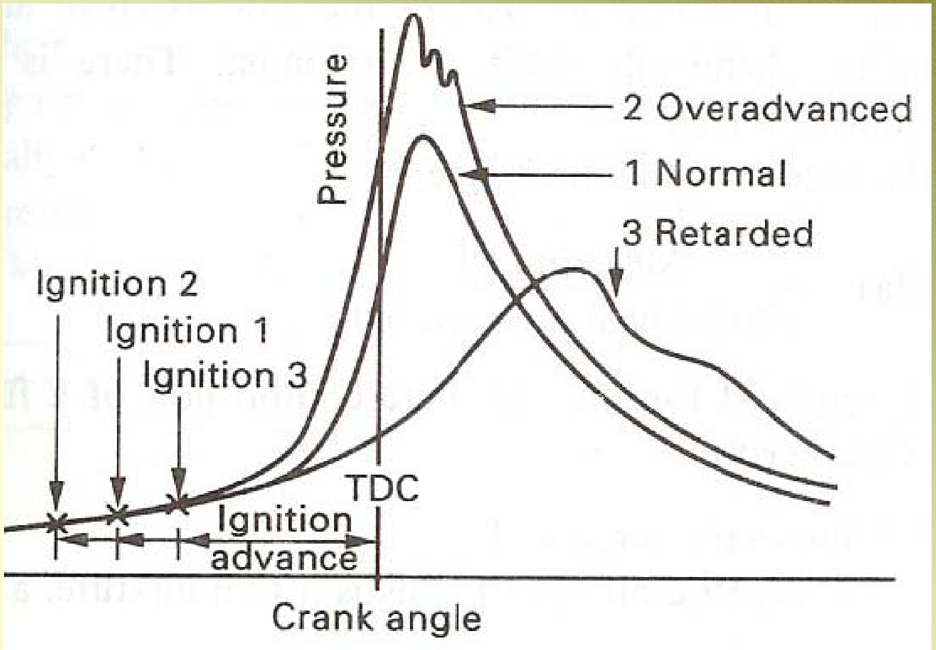
I. **Ignition lag (A→B): Flame front begins to travel.**

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

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

Effect of Ignition: Constant Volume Cycle

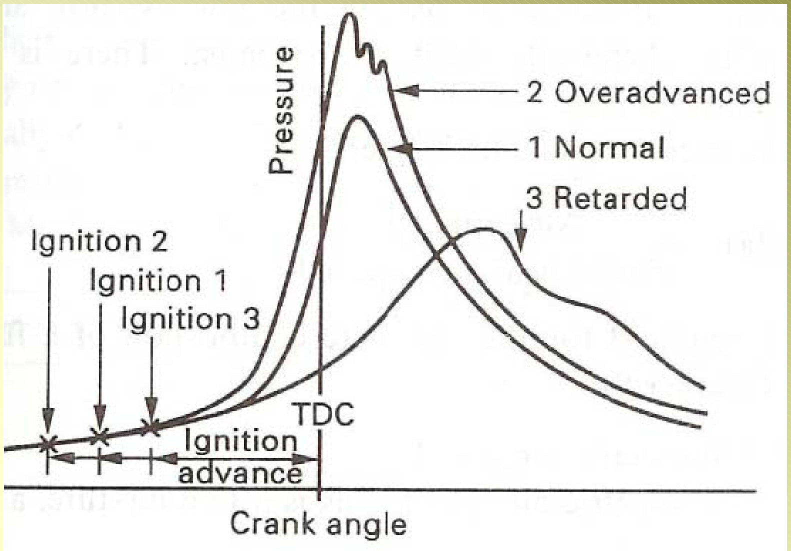
❖ Because of ignition lag, it is necessary to ignite the charge in the cylinder some degrees before the crankshaft reaches TDC. The number of degrees before TDC at which ignition occurs is called **Ignition Advance.**



❖ 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.

Effect of Over-advanced ignition

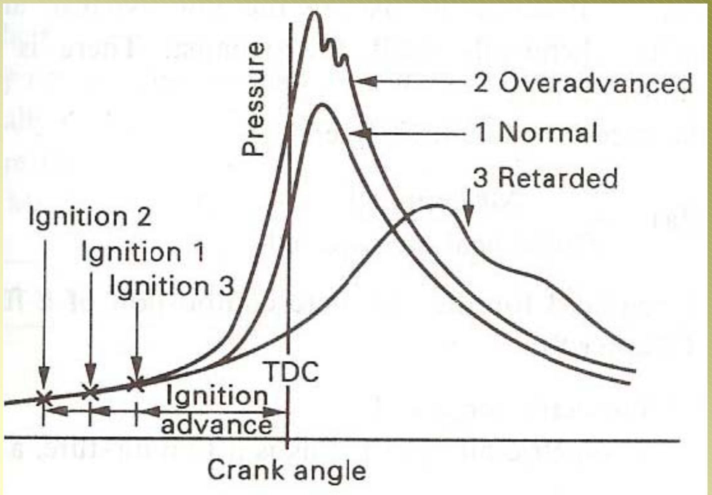
- **When the engine ignition is over-advanced, combustion is initiated too early and the cylinder pressure begins to rise rapidly while the piston is still trying to complete its compression stroke.**



- **This creates excessive cylinder pressures and may even produce shock waves in the cylinder as illustrated by the ragged top on curve 2. An over-advanced engine will run rough, it will tend to overheat resulting in loss of power.**

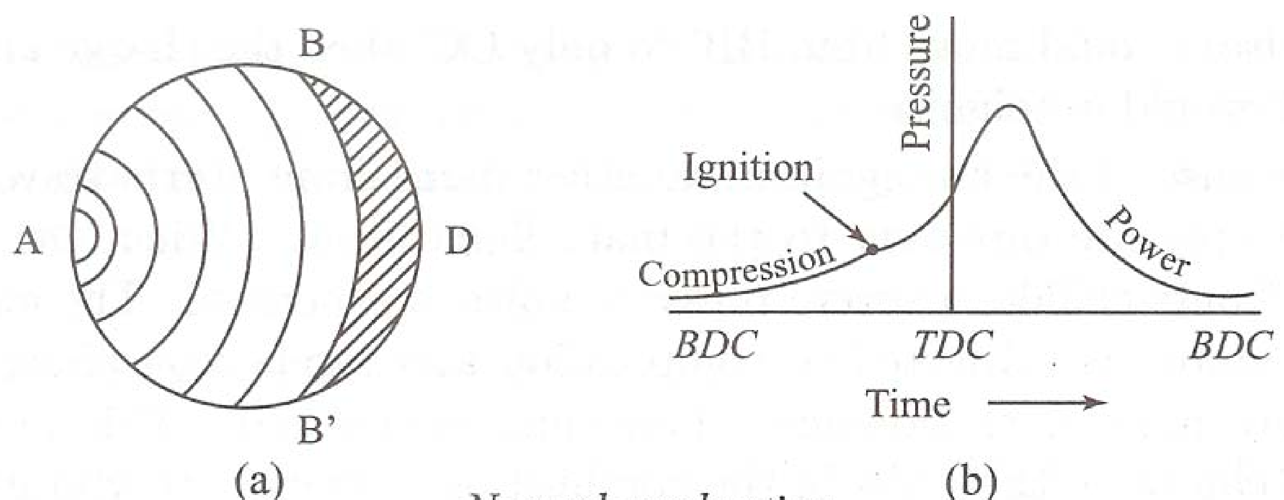
Effect of Retarded Ignition

❖ 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 stroke.



❖ 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.

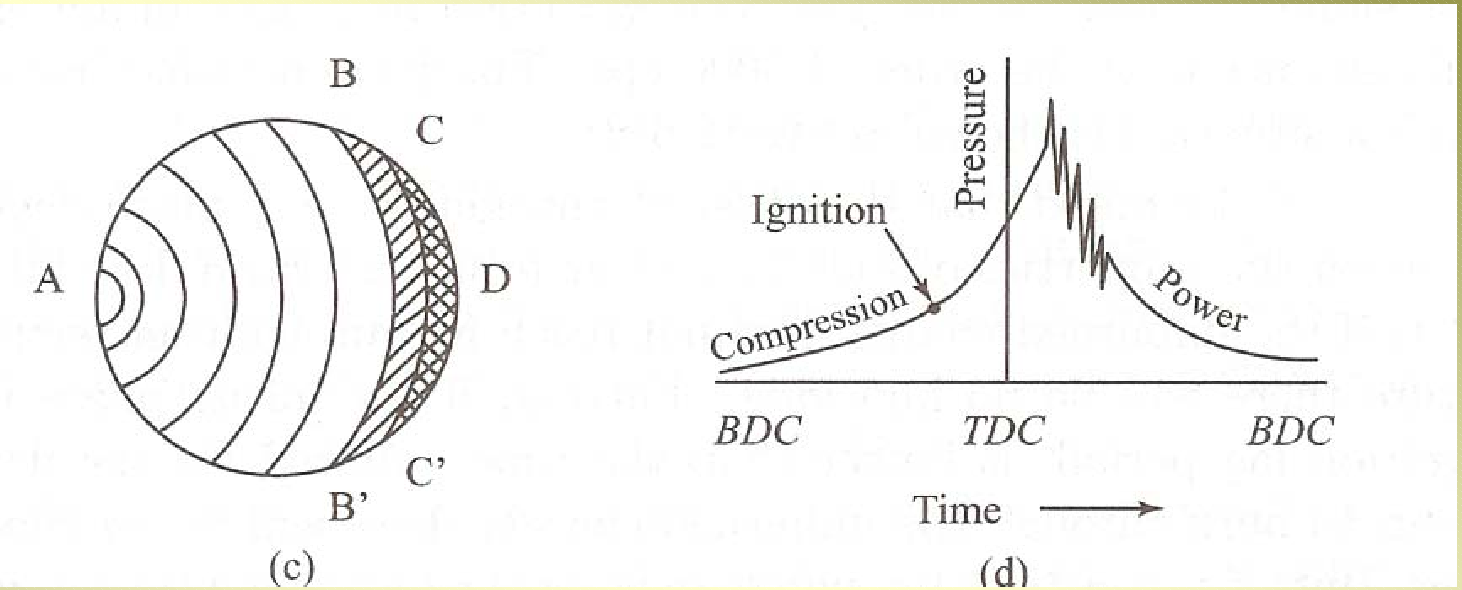
Knocking



Normal combustion

Flame travels from A→D and compresses the end charge BB´D and raises its temperature. Temperature also increases due to heat transfer from the flame front. Now, if the final temperature is less than the auto-ignition temperature, Normal Combustion occurs and charge BB´D is consumed by the flame itself.

Knocking

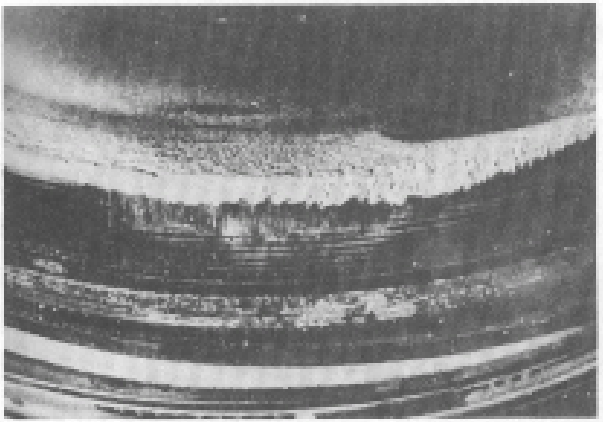


Now, if the final temperature is greater than and equal to the auto-ignition temperature, the charge **BB´D** auto-ignites (**knocking**). A second flame front develops and moves in opposite direction, where the collision occurs between the flames. This causes severe pressure pulsation, and leads to engine damage/failure.

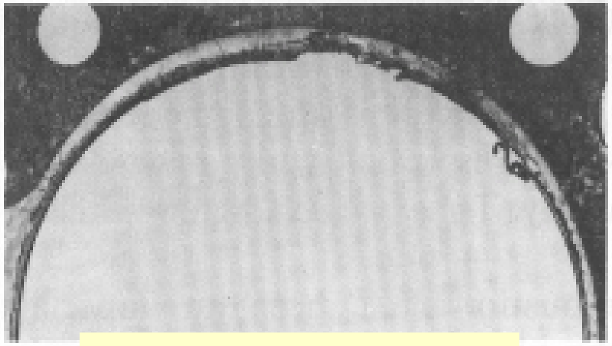
Engine Damage From Severe Knock

Damage to the engine is caused by a combination of high temperature and high pressure.

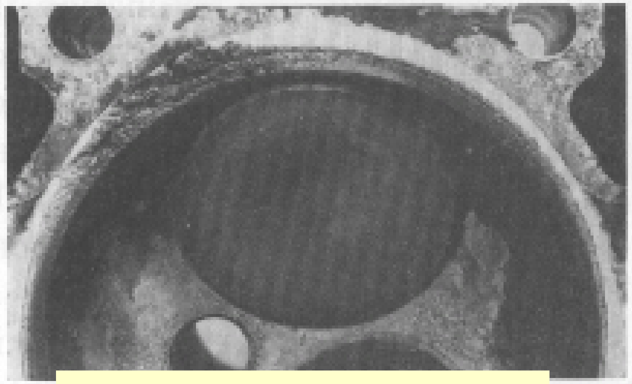
Piston



Piston crown



Cylinder head gasket



Aluminum cylinder head

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): When CR ratio increases, p and T increase 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 temperature and density at the time of ignition. This decreases the knocking tendency.**

Effect of Variables on Knock – Density Factors

3. Inlet temperature of mixture: An increase in the inlet temperature of mixture makes the compression temperature higher. This increases the knocking tendency. Further, volumetric efficiency is lowered. Hence, a lower inlet temperature 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 the 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.

Effect of Variables on Knock – Time Factors

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

- **Composition Factors:** These includes ratio of air-fuel mixture, and the properties of fuel employed in the engine.

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.

Combustion Chamber - Definition

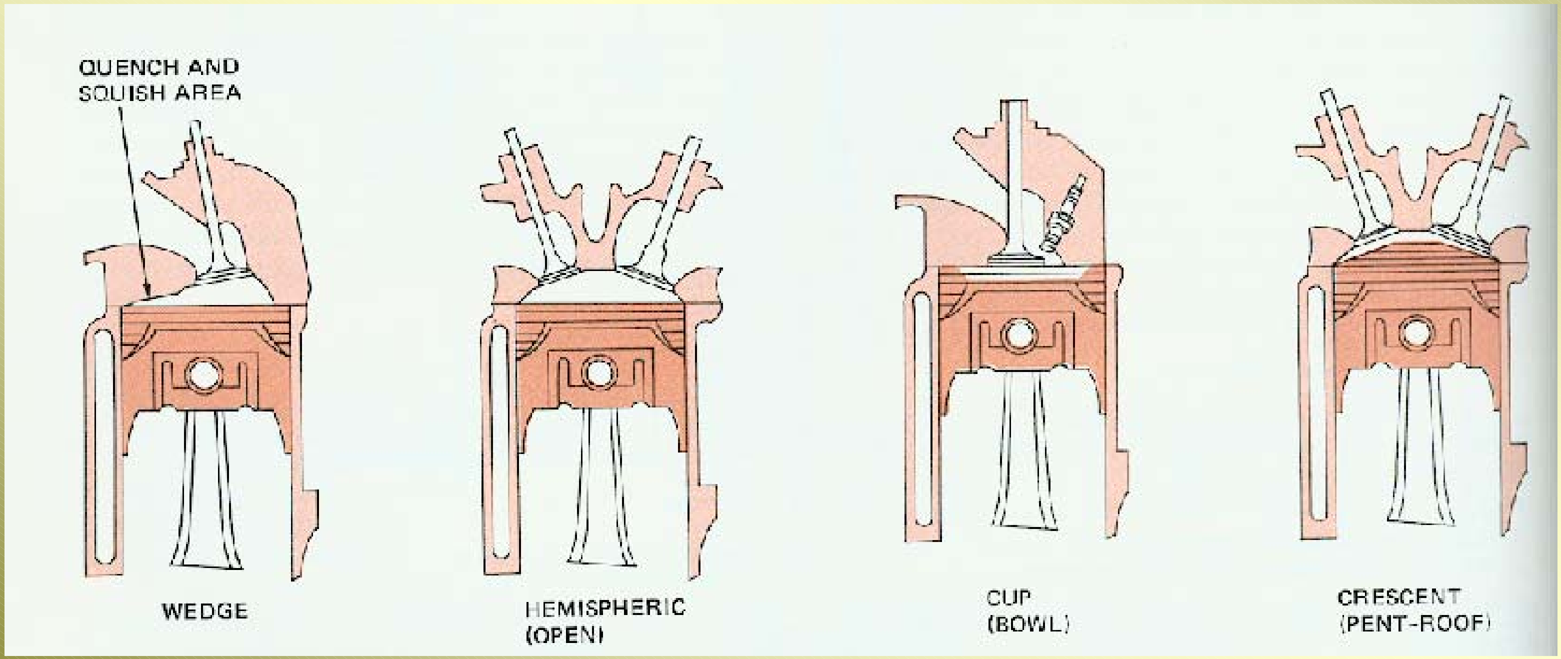
- The combustion chamber consists of an upper and lower half.
  - Upper half- Made up of cylinder head and cylinder wall.
  - Lower half- Made up of piston head (Crown) and piston rings.

Design Considerations

- Minimal flame travel
- The exhaust valve and spark plug should be close together
- Sufficient turbulence
- A fast combustion, low variability
- High volumetric efficiency at WOT
- Minimum heat loss to combustion walls
- Low fuel octane requirement

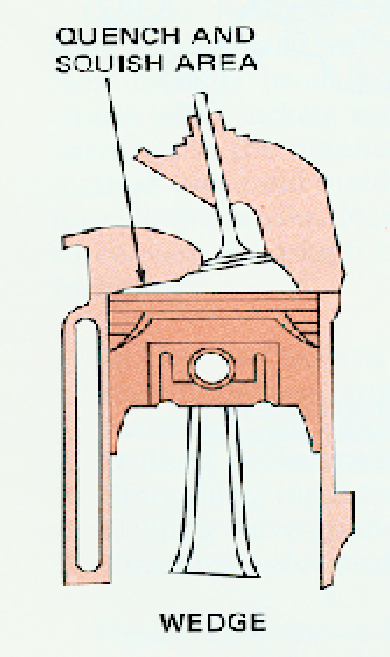
Chamber Shapes

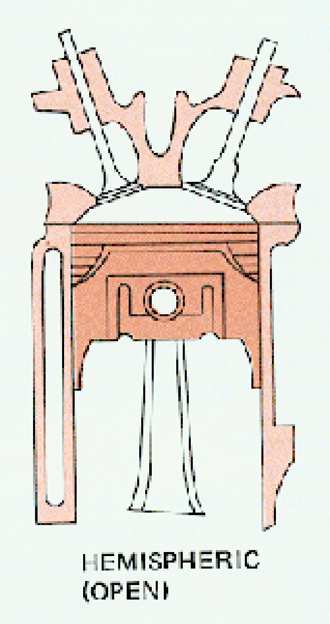
- A basic shapes
  - Wedge
  - Crescent
  - Hemispherical
  - Bowl in Piston



Chamber Shapes

- **Wedge**
  - **Asymmetric design**
  - **Valves at an angle and off center**

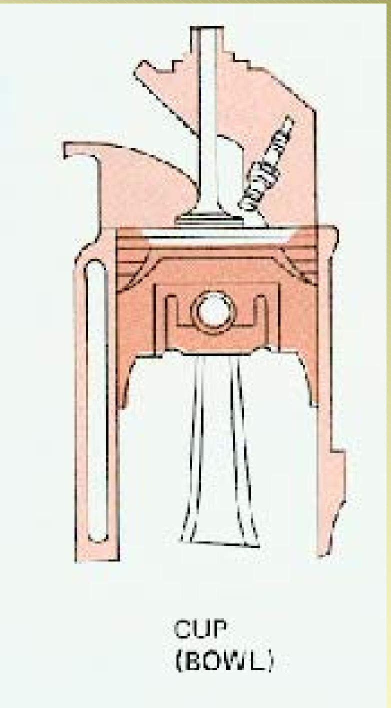


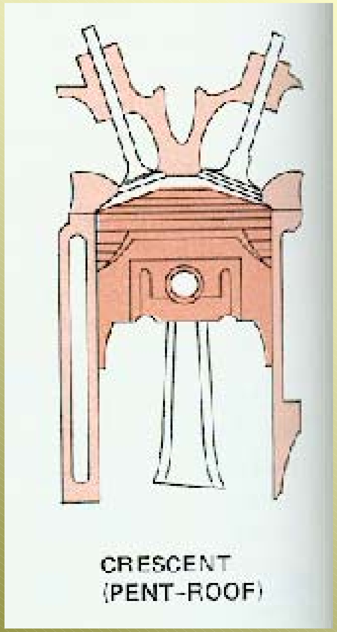


- **Hemispherical (Hemi)**
  - **Symmetric design**
  - **Valves placed on a arc shaped head**

Chamber Shapes

- **Bowl-in-Piston**
  - **Symmetric design**
  - **Valves are placed perpendicular to head**





- **Crescent (Pent-Roof)**
  - **The valves are placed at an angle on flat surfaces of the head**

Fast Combustion

- Effect of spark plug location

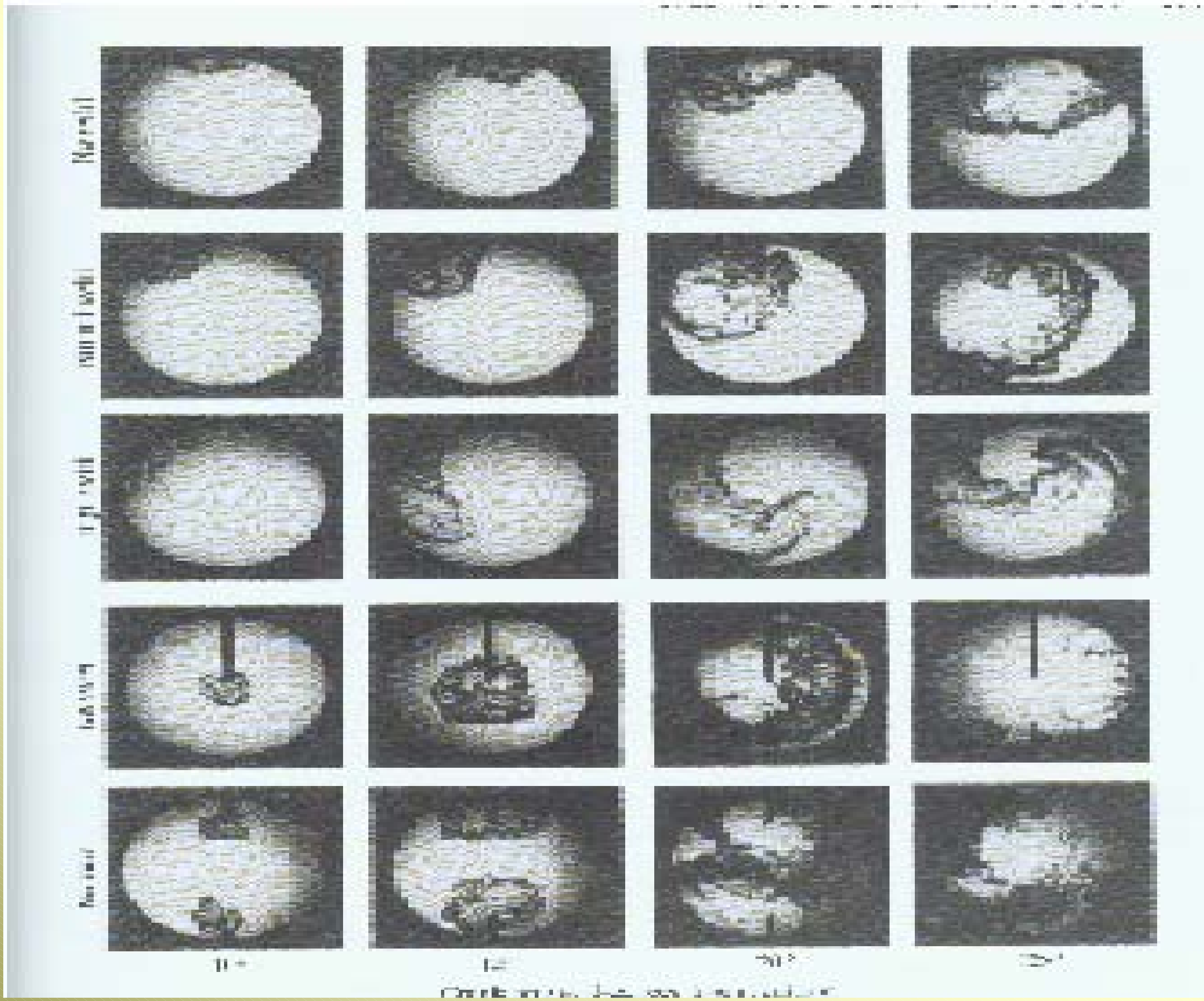
Side plug w/o swirl

Side plug with normal swirl

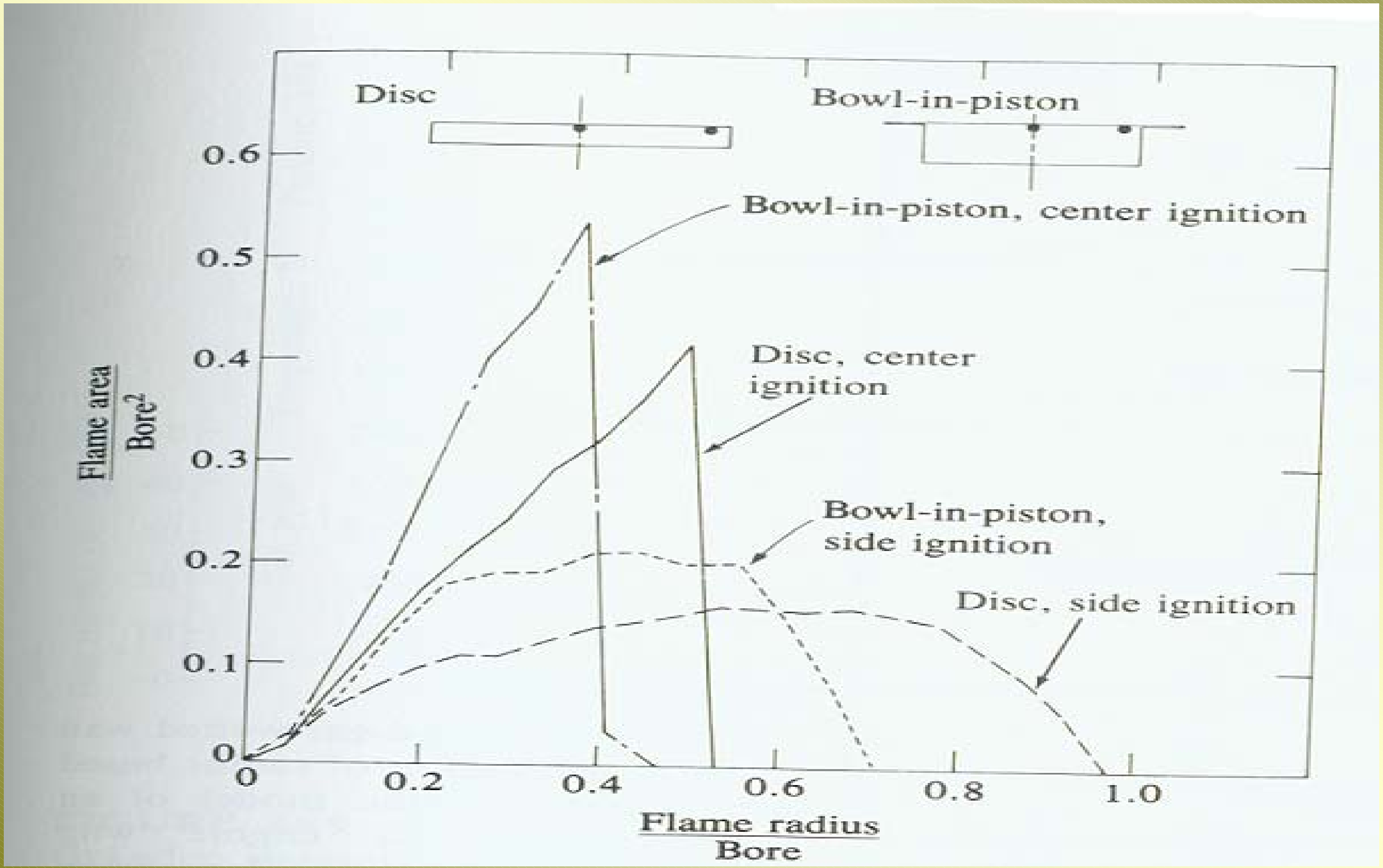
Side plug with high swirl

Central plug w/o swirl

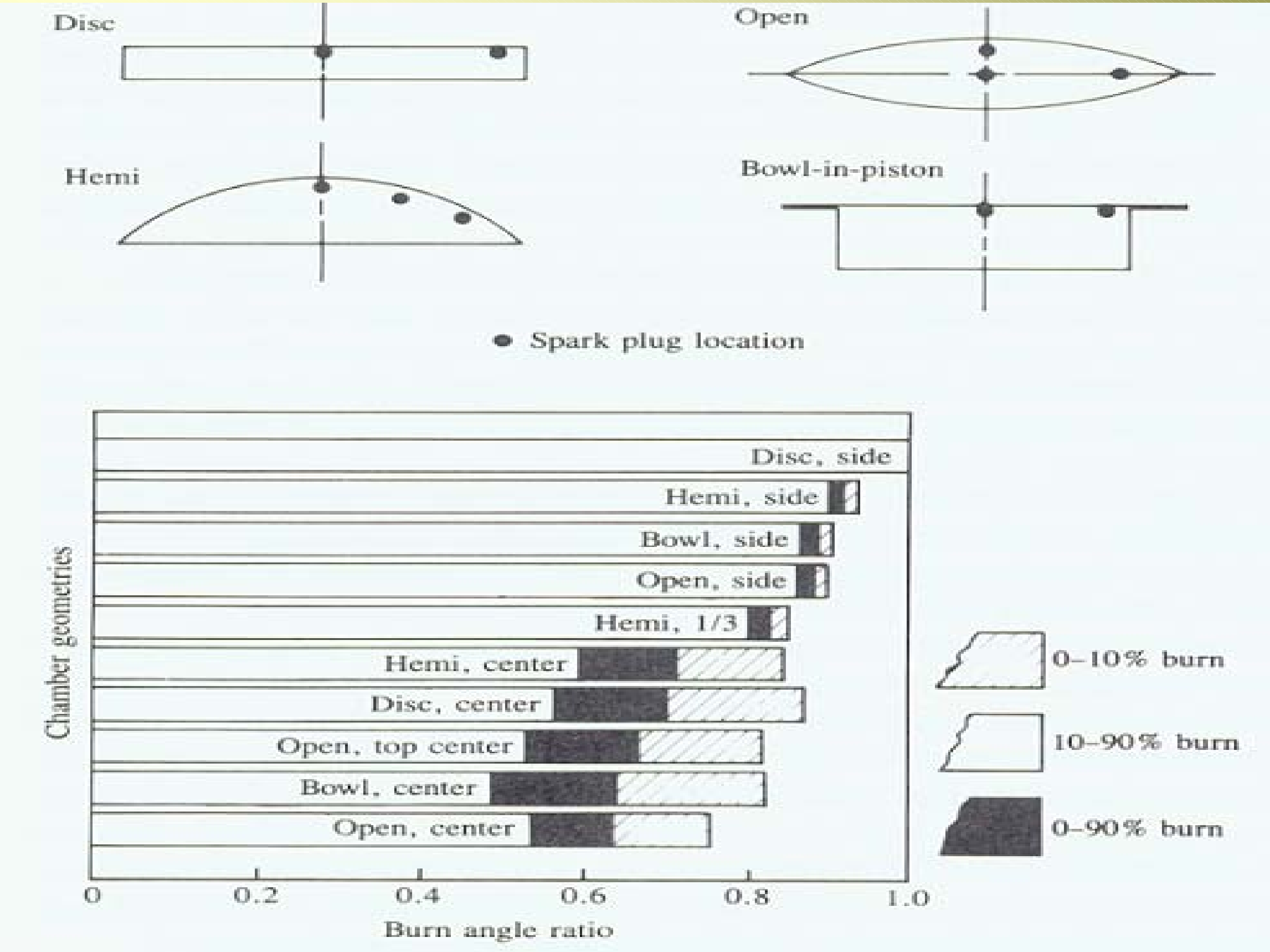
Two plugs w/o swirl



Fast Combustion in Relation to Shape



Comparison of Burn Angles



Heat Transfer

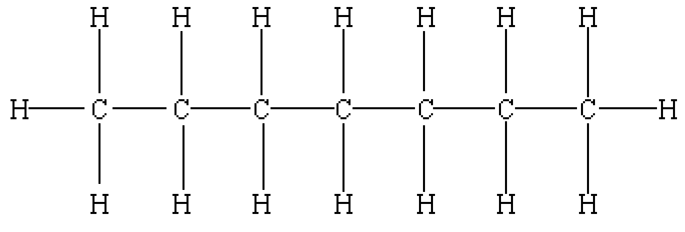
- Want minimum heat transfer to combustion chamber walls
- Open and hemispherical have least heat transfer
- Bowl-in-piston has high heat transfer

Low Octane

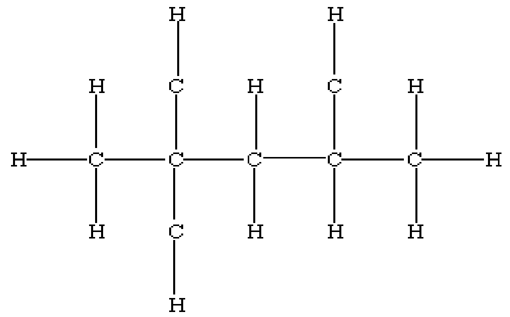
- Octane Requirement related to knock
- Close chambers (bowl-in-piston) have higher knock at high compression ratios than Open chambers (hemispherical and pent-roof)

Octane Rating

- Research Octane Number (RON)
- Motor Octane Number (MON)
- Octane is one factor in the combustion process that another group will speak about
- Straight chain C-H bonds such as heptane have weaker C-H bonds than branched chained C-H bonds in branch chained HC such as iso-octane
- Straight bonds are easier to break



n-Heptane



Iso-Octane

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

Conclusion

- **Optimum chamber**
  - **Central spark plug location**
  - **Minimum heat transfer**
  - **Low octane requirement**
  - **High turbulence**

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Web Resources

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