19AGT Heat Power Engineering
Theory of Combustion

1.1 Combustion in S.I. engines

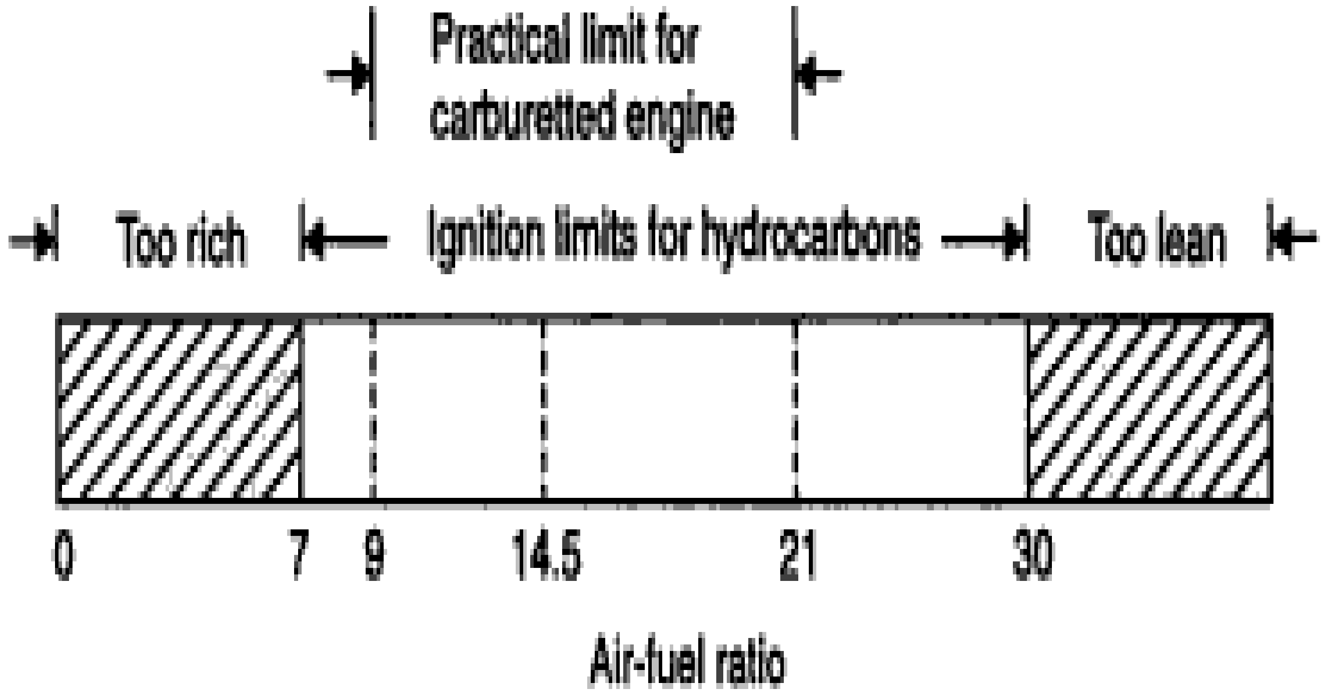
- Ignition Limits

Ignition Limit corresponds approximately to that mixture ratio, at lean & rich ends of the scale, where the heat released by spark is no longer sufficient to initiate combustion in the neighbouring UN burnt mixture. The flame will propagate only if the temperature of the burnt gases exceeds approximately 1250^{o} C in the case of hydrocarbon-air mixture.

The lower & upper ignition limits of the mixture depend upon mixture ratio & flame temperature. The ignition limits are wider at increased temperature because of higher rates of reaction.

1.1 Combustion in S.I. engines

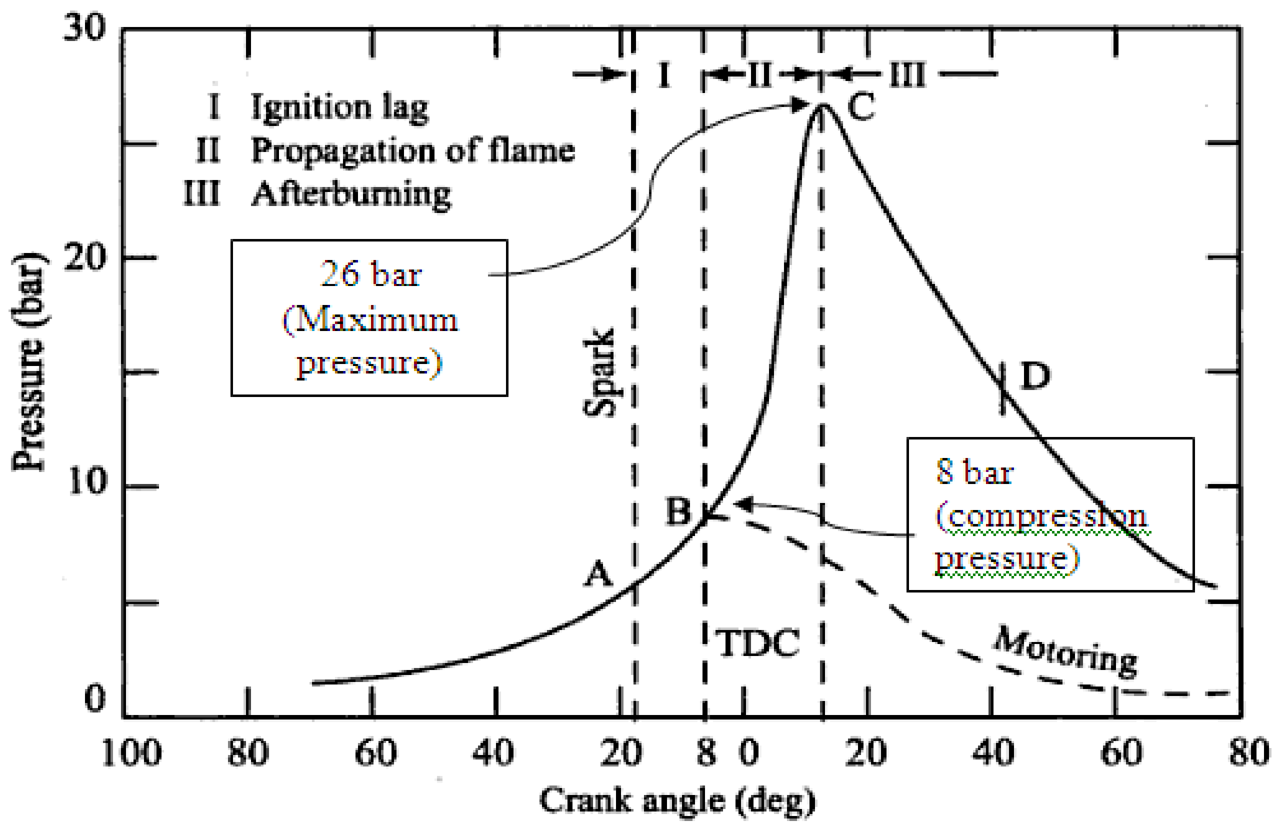
- Ignition Limits



Ignition limits for hydrocarbons.

1.1 Combustion in S.I. engines

- Stages of combustion in S.I. Engine



Stages of Combustion in an SI Engine

1.1 Combustion in S.I. engines

- Stages of combustion in S.I. Engine

Stage I:-Ignition Lag or Preparation Phase.

- It is a chemical process which depends on-nature of fuel, temperature & pressure, proportion of exhaust gas, rate of burning and temperature .It is the growth and development of a semi propagating nucleus of flame.(At the moment of spark discharge, the temperature exceeds $10{,}000^{o}$ c)
- At the end of this stage, the first rise of pressure (on indicator diagram) can be detected. It is the point where the line of combustion departs from the compression line.

1.1 Combustion in S.I. engines

- Stages of combustion in S.I. Engine

Stage II: - Propagation of flame

- -It is a simple, pure and mechanical process. The starting point of the second stage is where first measurable rise of pressure can be seen on the indicator diagram. i.e. the point where the line of the combustion departs from the compression line. During second stage, the flame spreads throughout the combustion chamber. The second stage ends as maximum pressure (on indicator diagram) is reached.

1.1 Combustion in S.I. engines

- Stages of combustion in S.I. Engine

Stage III →after burning

- End of second stage means completion of flame travel. But it does not result in complete heat release (burning of fuel).
- Even after the passage of flame, some chemical adjustments continue throughout the expansion stroke- near the walls and behind the turbulent flame front. The rate of combustion reduces due to surface of the flame front becoming smaller and reduction in turbulence.

Effect of engine variables on Ignition Lag

Ignition lag is a chemical process. The ignition lag in term of crank angle is 10° to 20°& in terms of second, 0.0015 second. The duration of ignition lag depend on

- Fuel- it is depend on chemical nature of fuel. The higher, the self ignition temp of fuel, the longer, the ignition lag
- Mixture Ratio-The ignition lag is smallest for the mixture ratio which gives the maximum temperature this mixture ratio is some what richer than the stoichiometric ratio.
- Initial pressure and temperature –increasing the intake temp, pressure, compression ratio and retarding spark, all reduce the ignition lag.

Effect of engine variables on Ignition Lag

- <u>Electrode gap-</u> It affects establishment of the nucleus of flame. If the gap is too small, quenching of the flame nucleus may occur & rang of fuel –air ratio for the development of a flame nucleus is reduced.
- <u>Turbulence-</u> measured in degree of crank-rotation the ignition lag increases almost linearly with engine speed. For this reason. It becomes necessary to advance the spark timing at higher speed.

Excessive turbulence of the mixture in the area of the spark plug is harmful, since it increases the heat transfer from the combustion zone & leads to unstable development of the nucleus of flame. That is way the spark plug is usually arranged in a small recess in the wall of the combustion chamber.

Effect of engine variables on Flame Propagation

- Fuel –Air ratio:- With hydrocarbon fuels the maximum flame velocities occur when mixture strength is 110% of stoichiometric . Lean mixtures release less thermal energy resulting in lower flame temperature & flame speed. Very rich mixtures have incomplete combustion (Some carbon only burns to CO & not to CO_2), which results in production of less thermal energy & hence flame speed is again low.
- Compression ratio-A higher compression ratio increases the pressure & temperature of the working mixture & decrease the concentration of residual gases. High pressures & temperature of the compressed mixture also speed up the second phase of combustion. Total ignition angle is reduced. Maximum pressure are increased
- Intake temp & pressure-increase in the intake temp & pr. Increase the flame speed.

Effect of engine variables on Flame Propagation

- Engine load:-With increases in the engine load the cycle pressures increase. Hence the flame speed increases.
- Turbulence:-The flame speed is very low in non-turbulent mixtures. A turbulent motion of the mixture intensifies the processes of heat transfer & mixing of the burned & unburned portions in the flame front (diffusion). These two factors cause the velocity of turbulent flame to increase practically in proportion to the turbulence velocity. However, excessive turbulence is also undesirable.

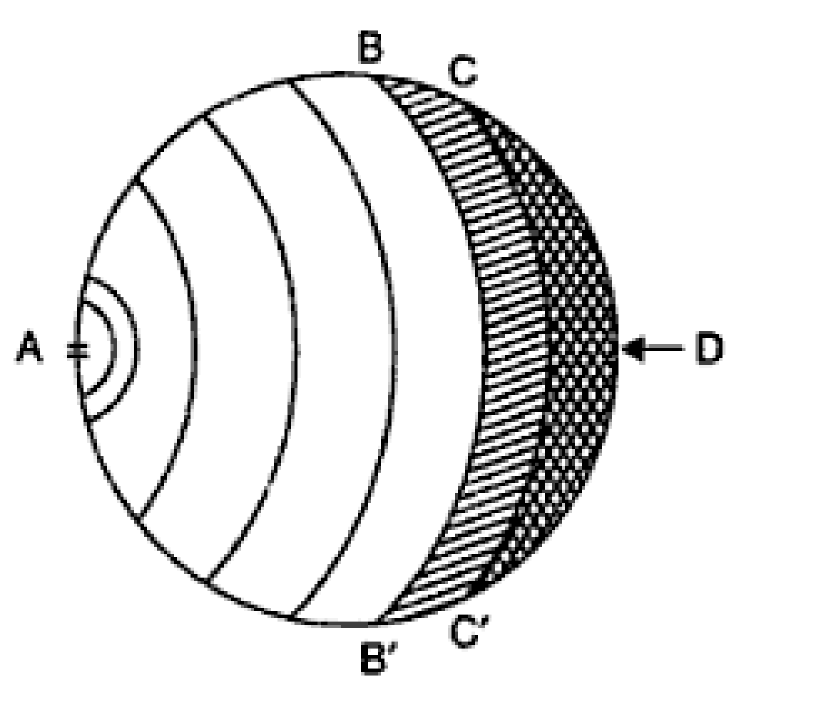
Effect of engine variables on Flame Propagation

- Engine speed – the higher the engine speed the greater the turbulence inside the cylinder. For this reason the flame speed increases almost linearly with engine speed. The crank angle required for the flame propagation, which is the main phase of combustion, will remain almost constant at all speed.
- Engine size- engine of similar design generally run at the same piston speed. This is achieved by smaller engine having larger RPM & larger engines having smaller RPM. Due to the same piston speed. The inlet velocity, the degree of turbulence & the flame speed are nearly same in similar engines regardless of the size.

    i.e. the number of crank degrees required for flame travel will be about the same irrespective of engine size, provided the engine are similar.

1.2 Abnormal Combustion

- **Detonation type of abnormal combustion.**



A= Source of ignition causing hollow nucleus to be formed and flame front to propagate further.
BB' Type equation here. = intermediate position of the flame front
CC' = intermediate position of flame front
CC'D = unburnt end charge reaching critical temperature
In abnormal combustion, the end charge auto-ignites before the flame front reaches it.

1.2 Abnormal Combustion

- **Detonation type of abnormal combustion**.
- Figure shows combustion with detonation. The flame front has reached BB' and the unburnt charge BB'D has reached the critical conditions for auto-ignition. In this case there is a possibility of detonation. If the flame front can proceed from BB' to D and consume the unburnt charge in a normal manner, prior to completion of the Ignition delay period, there will be no detonation.
- If, however, the flame front is able to proceed only as far as, say CC', during the ignition delay period, then the remaining portion of the unburnt charge CC'D will auto-ignite and cause extreme pressure fluctuations from about 50 bar to 150-200 bar.

Effects of detonation

- **Noise and vibration**: the presence of vibratory motion causes crankshaft vibrations and the engine runs rough.
- **Mechanical damage**: the cylinder head and valves may be pitted, increased rate of wear may occur.
- **Carbon Deposits**: detonation results in increased carbon deposits.
- **Increase in heat transfer**: occurs due to scouring away of protective layer of inactive stagnant gas on the cylinder walls due to pressure waves.
- **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**: The increased rate of heat transfer to walls causes local overheating of spark plug, which ignites charge before the spark, thus causing Pre- ignition.

Control of detonation

Methods of controlling detonation:

By controlling following engine variables, detonation can be controlled.

- Increasing engine rpm.
- Retarding spark timing
- Reducing pressure in inlet manifold by throttling. In supercharged engines reducing supercharging pressures reduces detonation.
- Making the ratio too lean or too rich, preferably latter.
- Water injection.

Control of detonation

By design features, detonation can be reduced.

- Use of low compression ratio.
- Increasing turbulence
- Relocating spark plugs or use of two or more spark plugs.
- Suitable combustion chamber design to reduce flame length and to reduce temperature of end gas.
- It can be eliminated by using High octane fuels, or by adding additives known as dopes to petrol.

What is Ignition delay? How it affects the combustion process in **S.I. Engine**?

- In abnormal combustion, called detonation, end charge auto-ignites before the flame front reaches it. To auto-ignite, the last unburnt charge must reach above critical temperature and remain at this temperature for certain length of time. This time required in the chemical preparation phase is called "**Ignition Delay**".
- If ignition delay period is longer than the time required for the flame front to burn through the unburnt charge, there will be no detonation in S.I Engine.
- Only when the critical temperature is reached and maintained, and the ignition delay is shorter than the time it takes for the flame front to burn through the unburnt charge, there will be detonation.

The higher compression ratio that can be used in an S.I. engine is limited by the detonation characteristics of the available fuel. Justify this statement.

Ans. In normal combustion, the flame started by spark travels across the combustion chamber. As the flame front advances, it compresses the unburnt charge in last portion of combustion chamber. If this unburnt charge does not reach its critical temperature for auto-ignition, it will not auto-ignite and flame front will move across this unburnt charges in normal manner. In abnormal combustions called *detonation* the end charge auto-ignites before the flame front reaches it. In order to auto-ignite, the last unburnt portion of charge must reach above a certain critical temperature and remain at this temperature for a certain length of time. During this period certain chemical reactions take place which prepare the charge for auto-ignition. The time required in this preparation is called *ignition delay*.

In *order to limit detonation, we should not allow the unburnt charge to reach its critical temperature*. Increase in temperature of mixture reduces delay period of end charges and hence tendency of detonation increases. Increase in temperature is obtained by avoiding detonation, we should limit the compression ratio. Hence there is a critical compression ratio for a fuel for a given engine *setting above which knock occurs*. This *compression ratio is called highest useful compression ratio.*

1.2 Abnormal Combustion

Pre-ignition

- The increase in the rate of heat transfer to the walls may cause local overheating specially of the spark plug, which may reach a temperature high enough to *ignite the charge before the passage of spark. This phenomenon is called Pre-ignition.*
- Pre-ignition may also be caused by *overheated exhaust valves or glowing carbon deposits in the combustion chamber.*

Additional Information

Some part of the cylinder surface may be hot enough (nearly 1100°) to ignite the charge before the spark does so. This is equivalent to advancing the ignition, but since the hot spot surface is larger than the spark, the combustion rate would be faster than that of normal combustion.

Creating very high cylinder pressures and temperatures and thus resulting in excessive negative compression work and increased heat loss to the walls. The overall effect will be the loss in power.

Additional Information

Pre-ignition will also cause higher temperatures and pressures in the end-gas than those caused by normal ignition because of its earlier occurrence on the compression stroke. Thus pre-ignition leads to auto-ignition and hence knock. And auto-ignition encourages *pre-ignition*. *Knock and pre-ignition* are different phenomena. Knock is due to the rapid combustion of the last part of the mixture following the initiation of flame by the spark, whereas pre-ignition is the ignition of the charge by a hot body before the spark occurs.

Additional Information

The result of pre-ignition are to increase the work of the compression stroke, decrease the net work of the cycle, increase the engine pressures, increase the heat loss from the engine and decrease the efficiency. Pre-ignition if not checked gets progressively worse, culminating in severe engine damage.

Pre-ignition can be detected by switching off the ignition when irregular firing might occur for a few strokes before the engine speed drops. The sudden loss of power with no evidence of mechanical malfunctioning may also indicate pre-ignition.

1.2 Abnormal Combustion

Surface ignition

Under certain conditions, air-fuel mixture is ignited by a hot spot in the cylinder.

Initiation of a flame front by a hot surface other than the spark is called *surface ignition*. The hot surface may be the spark plug insulator or electrode, the exhaust valve head, the combustion deposits on the combustion chamber surfaces etc.

Surface ignition occurring before the spark is called ***pre-ignition*** and that occurring after the spark is called ***post-ignition.***

Run-on, run-away, wild ping and rumble are caused by surface ignition which are harmful.

1.3 SI engine combustion chambers

- Basic requirements of a good combustion chamber
- 1. High power output
- 2. High thermal efficiency and low specific fuel consumption
- 3. Smooth engine operation
- 4. Reduced exhaust pollution
- 5. High volumetric efficiency
- 6. Minimum length of flame travel
- 7. Provision of suitable quench region