COMBUSTION PROCESS IN CI ENGINES

In SI engine, uniform A: F mixture is supplied, but in CI engine A: F mixture is not homogeneous and fuel remains in liquid particles, therefore quantity of air supplied is 50% to 70% more than stiochiometric mixture.

The combustion in SI engine starts at one point and generated flame at the point of ignition propagates through the mixture for burning of the mixture, where as in CI engine, the combustion takes place at number of points simultaneously and number of flames generated are also many. To burn the liquid fuel is more difficult as it is to be evaporated; it is to be elevated to ignition temperature and then burn.

STAGES OF COMBUSTION IN CI ENGINE (JAN 2007/JULY2006)

The combustion in CI engine is considered to be taking place in four phases:

- Ignition Delay period /Pre-flame combustion
- Uncontrolled combustion
- Controlled combustion
- After burning

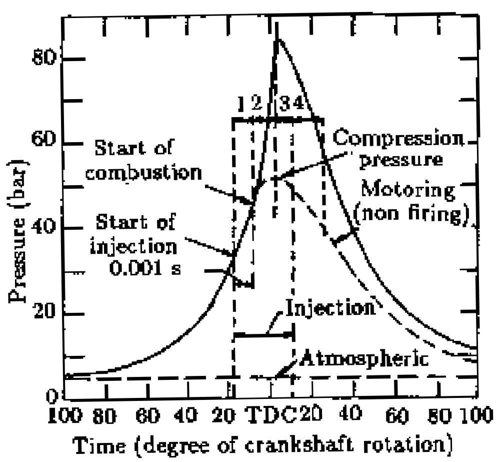


Fig1.Stages of combustion

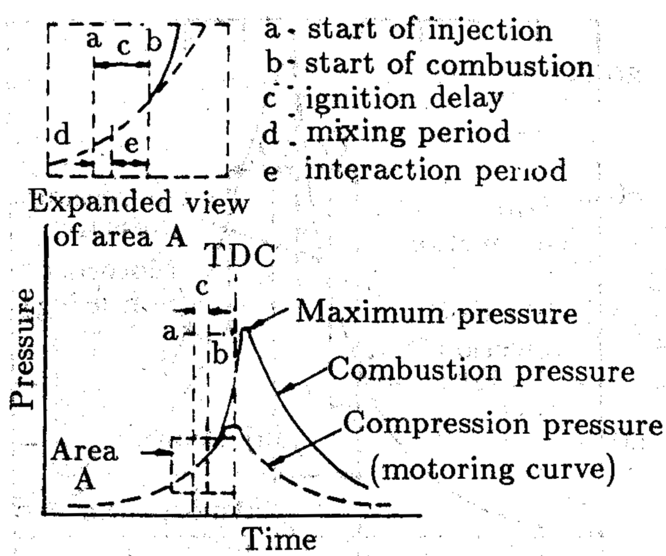


Fig 2. Pressure Time diagram illustrating Ignition delay

Ignition Delay period /Pre-flame combustion

The fuel does not ignite immediately upon injection into the combustion chamber. There is a definite period of inactivity between the time of injection and the actual burning this period is known as the ignition delay period.

In Figure 2. the delay period is shown on pressure crank angle (or time) diagram between points a and b. Point "a" represents the time of injection and point "b" represents the time of combustion. The ignition delay period can be divided into two parts, the physical delay and the chemical delay.

The delay period in the CI engine exerts a very great influence on both engine design and performance. It is of extreme importance because of its effect on both the combustion rate and knocking and also its influence on engine starting ability and the presence of smoke in the exhaust.

2 Period of Rapid Combustion

The period of rapid combustion also called the uncontrolled combustion, is that phase in which the pressure rise is rapid. During the delay period, a considerable amount of fuel is accumulated in combustion chamber, these accumulated fuel droplets burns very rapidly causing a steep rise in pressure. The period of rapid combustion is counted from end of delay period or the beginning of the combustion to the point of maximum pressure on the indicator diagram. The rate of heat-release is maximum during this period. This is also known as uncontrolled combustion phase, because it is difficult to control the amount of burning / injection during the process of burning.

It may be noted that the pressure reached during the period of rapid combustion will depend on the duration of the delay period (the longer the delay the more rapid and higher is the pressure rise since more fuel would have been present in the cylinder before the rate of burning comes under control).

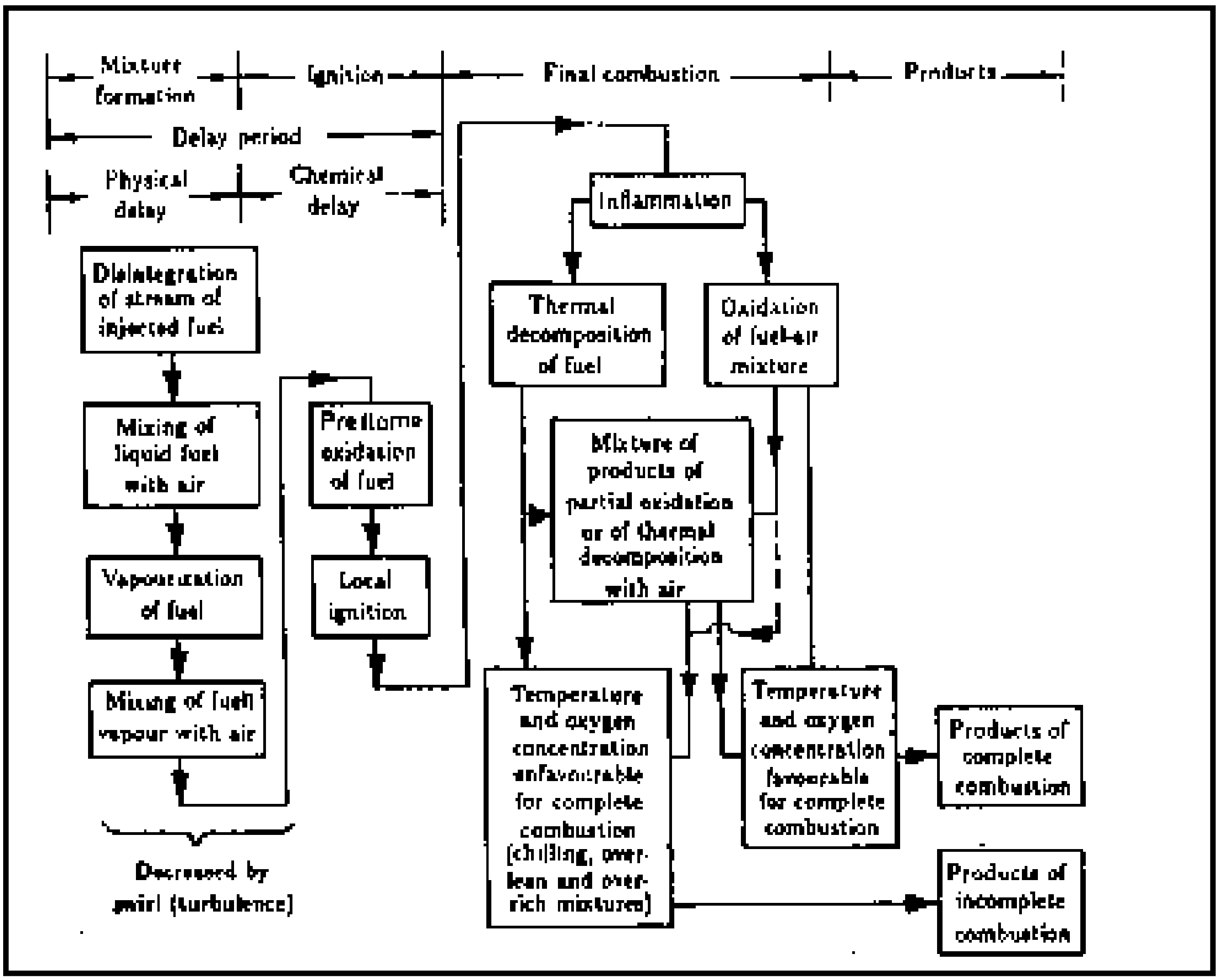
3 Period of Controlled Combustion

The rapid combustion period is followed by the third stage, the controlled combustion. The temperature and pressure in the second stage are so high that fuel droplets injected burn almost as they enter and find the necessary oxygen and any further pressure rise can be controlled by injection rate. The period of controlled combustion is assumed to end at maximum cycle temperature.

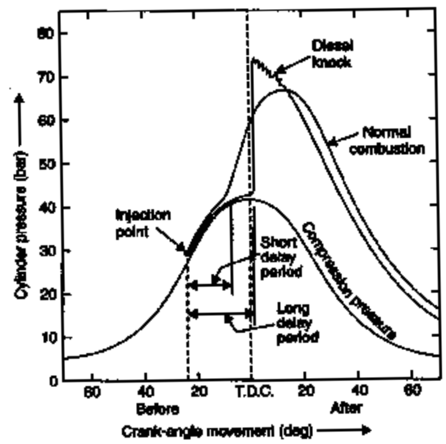
4 Period of After-Burning

Combustion does not stop with the completion of the injection process. The unburnt and partially burnt fuel particles left in the combustion chamber start burning as soon as they come into contact with the oxygen. This process continues for a certain duration called the after-burning period. This burning may continue in expansion stroke up to 70 to 80% of crank travel from TDC.

The sequence of the events in the entire combustion process in a CI engine including the delay period is shown in Figure 3 by means of a block diagram.



Ignition Delay or Ignition Lag (VTU Feb 2006)



The delay period is the time between the start of injection and start of combustion. The delay period extends for about 13 deg movement of crank. This delay time decreases with increase in speed. If there is no delay, the fuel would burn at injector and there would be oxygen deficiency around the injector, which results in incomplete combustion. If the delay period is too long, amount of fuel availability for simultaneous explosion , is too great , which results in rapid pressure rise. The delay period should be as short as possible since long delay period gives more rapid rise in pressure and thus causes knocking.

Component of Ignition Delay or Ignition Lag (VTU Feb 2006)

Ignition delay can be divided into two parts:

Physical Delay: The physical delay is the time between the beginning of injection and the attainment of chemical reaction conditions. During this period, the fuel is atomized, vaporized, mixed with air and raised to its self-ignition temperature. This physical delay depends on the type of fuel, i.e., for light fuel the physical delay is small while for heavy viscous fuels the physical delay is high. The physical delay is greatly reduced by using high injection pressures and high turbulence to facilitate breakup of the jet and improving evaporation.

Chemical Delay: During the chemical delay reactions start slowly and then accelerate until inflammation or ignition takes place. Generally, the chemical delay is larger than the physical delay. However, it depends on the temperature of the surroundings and at high temperatures, the chemical reactions are faster and the physical delay

Total delay period = Physical delay + Chemical delay

$$t_t = t_p + t_c \, ,$$

In CI engine $t_p >> t_c$,

In SI engine $t_p \approx 0$

Combustion phenomenon in CI engine V/s combustion in SI engine. (VTU July 2006)

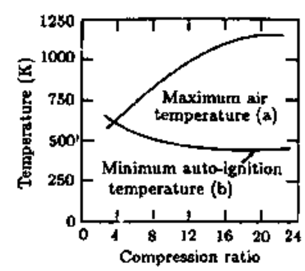
SL NO	COMUSTION IN SI ENGINE	COMBUSTION IN CI ENGINE
1	Homogeneous mixture of petrol vapour and air is compressed (CR 6:1 to 11:1) at the end of compression stroke and is ignited at one place by spark plug.	Air alone is compressed through large Compression ratio (12:1 to 22:1)and fuel is injected at high pressure of 110 to 200 bar using fuel injector pump.
2	Single definite flame front progresses through air fuel mixture and entire mixture will be in combustible range	Fuel is not injected at once, but spread over a period of time. Initial droplets meet air whose temperature is above self ignition temperature and ignite after ignition delay.
3	For effective combustion, turbulence is required. Turbulence which is required in SI engine implies disordered air motion with no general direction of flow to break up the surface of flame front and to distribute the shreds of flame thought-out in externally prepared homogeneous combustible mixture.	For effective combustion, swirl is required. Swirl which is required in CI engine implies an orderly movement of whole body of air with a particular direction of flow, to bring a continuous supply of fresh air to each burning droplets and sweep away the products of combustion which otherwise suffocate it.
4	In SI Engine ignition occurs at one point with a slow rise in pressure	In the CI engine, the ignition occurs at many points simultaneously with consequent rapid rise in pressure. There is no definite flame front.
5	In SI engine physical delay is almost zero and chemical delay controls combustion	In CI engine physical delay controls combustion.
6	In SI engine , A/F ratio remains close to stoichiometric value from no load to full load	In CI engine , irrespective of load, at any speed, an approximately constant supply of air enters the cylinder. With change in load, quantity of fuel is changed to vary A/F ratio. The overall A/F can Range from 18:1 to 80:1.
5	Delay period must be as long as possible. High octane fuel(low cetane) is required.	Delay period must be as short as possible. High cetane (low octane) fuel is required

Home work : Good SI engine fuel is bad CI engine fuel – Justify this statement

EFFECT OF VARIOUS FACTORS ON DELAY PERIOD IN CI ENGINE (VTU July 06/July07)

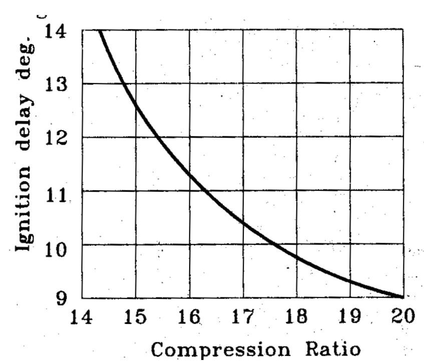
Many design and operating factors affect the delay period. The important ones are:

- compression ratio
- engine speed
- output
- injection timing
- quality of the fuel
- intake temperature
- intake pressure



Effect of Compression Ratio on Maximum Air Temperature and Minimum Autoignition Temperature

1.Compression Ratio. The increase in the compression temperature of the air with increase in compression ratio evaluated at the end of the compression stroke is shown in Fig. It is also seen from the same figure that the minimum auto ignition temperature of a fuel decreases due to increased density of the compressed air. This results in a closer contact between the molecules of fuel and oxygen reducing the time of reaction. The increase in the compression temperature as well as the decrease in the minimum auto ignition temperature decrease the delay period. The maximum peak pressure during the combustion process is only marginally affected by the compression ratio (because delay period is shorter with higher compression ratio and hence the pressure rise is lower).



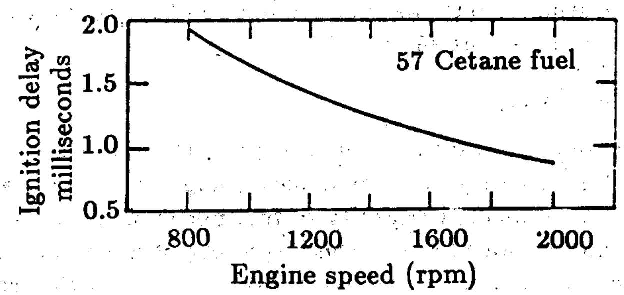
Then why we do not use very high compression ratio in CI?

One of the practical disadvantages of using a very high compression ratio is that the mechanical efficiency tends to decrease due to increase in weight of the reciprocating parts. Therefore, engine designers always try to use a lower compression ratio which helps in easy cold starting and light load running at high speeds.

2.Engine Speed:

The delay period could be given either in terms of absolute time (in milliseconds) or in terms of crank angle degrees

With increase in engine speed, the loss of heat during compression decreases, resulting in the rise of both the temperature and pressure of the compressed air thus reducing the delay period in milliseconds. However, in degrees of crank travel the delay period increases as the engine operates at a higher rpm. The fuel pump is geared to the engine, and hence the amount of fuel injected during the delay period depends on crank degrees and not on absolute time. Hence, at high speeds, there will be more fuel present in the cylinder to take part in the second stage of uncontrolled combustion resulting in high rate of pressure rise.

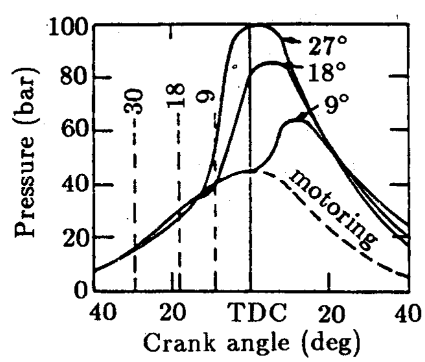


3 Outputs

With an increase in engine output the air-fuel ratio decreases, operating temperatures increase and hence delay period decreases. The rate of pressure rise is unaffected but the peak pressure reached may be high.

4. Injection timing:

The effect of injection advance on the pressure variation is shown in Fig. for three injection advance timings of 90°, 18°, and 27° before TDC. The injected quantity of fuel per cycle is constant. As the pressure and temperature at the beginning of injection are lower for higher ignition advance, the delay period increases with increase in injection advance. The optimum angle of injection advance depends on many factors but generally it is about 20°bTDC.



Effect of Injection Timing on Indicator Diagram

5. Quality of Fuel used:

The physical and chemical properties of fuel play very important role in delay period. The most important property of fuel which is responsible for chemical delay is its self-ignition temperature. Lower the self-ignition temperature, lower the delay period.

The cetane number (CN) of the fuel is another important parameter which is responsible for the delay period. A fuel of higher cetane number gives lower delay period and provides smoother engine operation.

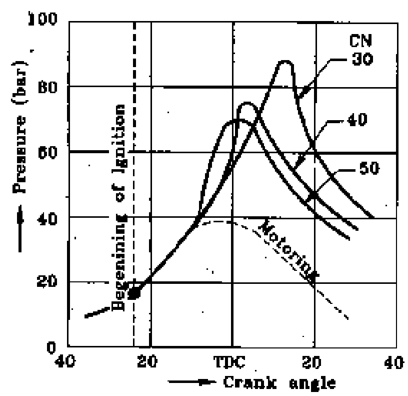


Fig. 18.2. Effect of CN on indicator diagram.

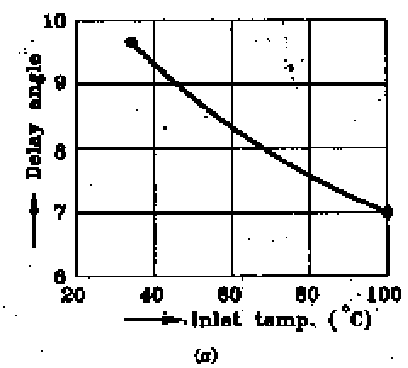
The effect of cetane number on the indicator diagram when injection timing is same is shown in adjacent figure.

The delay period for a fuel having CN = 50 is lowest and pressure rise is also smooth and maximum pressure rise is least as most of the fuel burns during controlled combustion.

The other properties of fuel which affects the physical delay period are volatility, latent heat, viscosity and surface tension. The viscosity and surface tension are responsible for the better atomization whereas latent heat and viscosity are responsible for the rapid evaporation of fuel.

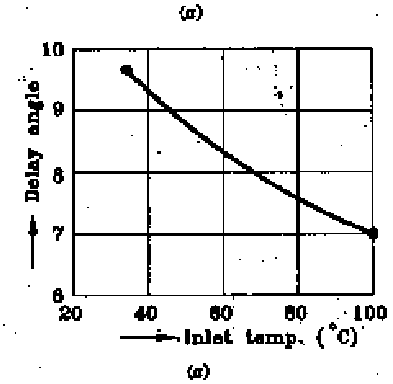
6. Intake Temperature

The delay period is reduced either with increased temperature. However, preheating of charge for this purpose is not desirable because it reduces the density of charge and volumetric efficiency and power output.



7. Intake pressure

Increase in intake pressure or supercharging reduces the auto ignition temperature and hence reduces the delay period. The peak pressure will be higher since the compression pressure will increase with intake pressure.



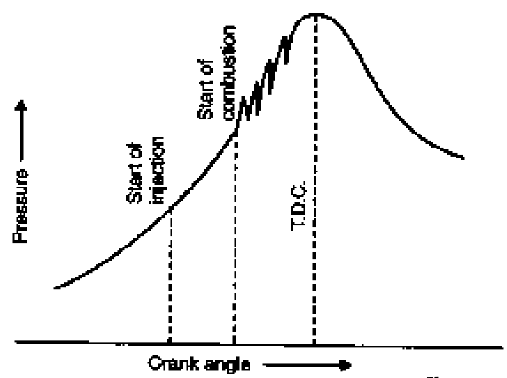
The following table gives the summary of the factors which influence the delay period in CI engine.

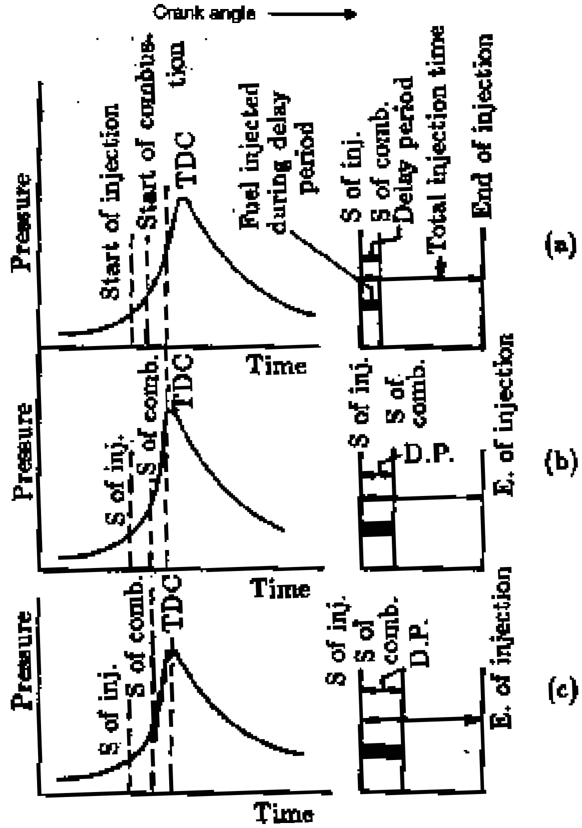
EFFECT OF VARIABLE ON DELAY PERIOD – SUMMARY

SL No	Increase in variables	Effect on Delay period	Reason
1	Cetane Number of fuel	Reduce	Reduces the self ignition temperature
2	Injection pressure	Reduce	Reduces the physical delay due to greater surface to volume ratio
3	Injection timing advance	Increase	Reduces the pressure and temperature when the injection begins
4	Compression ratio	Reduce	Increases air temperature and pressure and reduces auto ignition temperature
5	Intake temperature	Reduce	Increase air temperature
6	Jacket water temperature	Reduce	Increase wall and hence air temperature
7	Fuel temperature	Reduce	Increases chemical reaction due to better vaporization
8	Intake pressure	Reduce	Increases the density and also reduces the auto ignition temperature
9	Speed	Increase in terms of crank angle but reduces in terms of milliseconds.	Reduce loss of heat
10	Load (Fuel/air ratio)	Decrease	Increase the operating temperature
11	Engine size	Increase in terms of crank angle but little effect in terms of milliseconds.	Larger engines operate at normally slow speeds.
12	Type of combustion chamber	Lower for engines with pre-combustion chamber	Due to compactness of the chamber.

PHENOMENON OF DIESEL KNOCK (VTU Feb 2006)

Knocking is violet gas vibration and audible sound produced by extreme pressure differentials leading to the very rapid rise during the early part of uncontrolled second phase of combustion.





In C.I. engines the injection process takes place over a definite interval of time. Consequently, as the first few droplets injected are passing through the ignition lag period, additional droplets are being injected into the chamber. If the ignition delay is longer, the actual burning of the first few droplets is delayed and a greater quantity of fuel droplets gets accumulated in the chamber. When the actual burning commences, the additional fuel can cause too rapid a rate of pressure rise, as shown on pressure crank angle diagram above, resulting in Jamming of forces against the piston (as if struck by a hammer) and rough engine operation. If the ignition delay is quite long, so much fuel can accumulate that the rate of pressure rise is almost instantaneous. Such, a situation produces extreme pressure differentials and violent gas vibration known as knocking (diesel knock), and is evidenced by audible knock. The phenomenon is similar to that in the SI engine. However, in SI Engine knocking occurs near the end of combustion whereas in CI engine, knocking the occurs near the beginning of combustion.

Delay period is directly related to Knocking in CI engine. An extensive delay period can be due to following factors:

- ❖ A low compression ratio permitting only a marginal self ignition temperature to be reached.
- ❖ A low combustion pressure due to worn out piston, rings and bad valves
- ❖ Low cetane number of fuel
- ❖ Poorly atomized fuel spray preventing early combustion
- ❖ Coarse droplet formation due to malfunctioning of injector parts like spring
- ❖ Low intake temperature and pressure of air

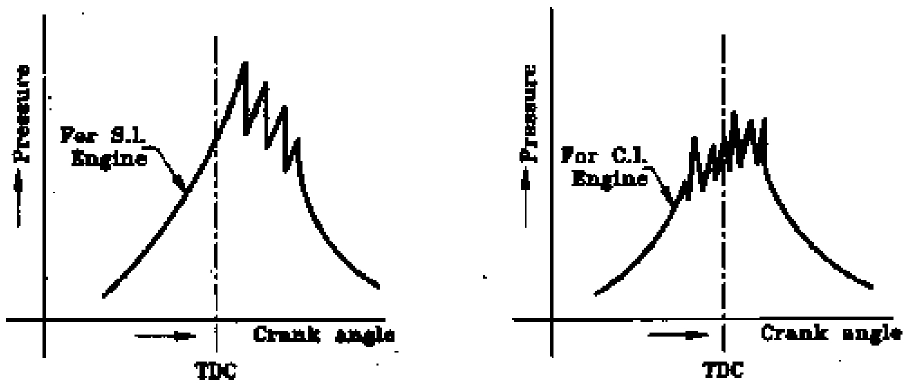
METHODS OF CONTROLING DIESEL KNOCK (VTU Feb 2006)

We have discussed the factors which are responsible for the detonation in the previous sections. If these factors are controlled, then the detonation can be avoided.

- ❖ Using a better fuel. Higher CN fuel has lower delay period and reduces knocking tendency.
- ❖ Controlling the Rate of Fuel Supply. By injecting less fuel in the beginning and then more fuel amount in the combustion chamber detonation can be controlled to a certain extent. Cam shape of suitable profile can be designed for this purpose.
- ❖ Knock reducing fuel injector : This type of injector avoid the sudden increase in pressure inside the combustion chamber because of accumulated fuel. This can be done by arranging the injector so that only small amount of fuel is injected first. This can be achieved by using two or more injectors arranging in out of phase.
- ❖ By using Ignition accelerators : C N number can be increased by adding chemical called dopes. The two chemical dopes are used are ethyl-nitrate and amyle –nitrate in concentration of 8.8 gm/Litre and 7.7 gm/Litre. But these two increase the NO_x emissions
- ❖ Increasing Swirl : Knocking can be greatly reduced by increasing swirl (or reducing turbulence). Swirl helps in knock free combustion.

COMPARISON OF KNOCK IN SI AND C ENGINES

It may be interesting to note that knocking in spark-ignition engines and compression-ignition engines is fundamentally due to the auto ignition of the fuel-air mixture. In both the cases, the knocking depends on the auto ignition lag of the fuel-air mixture. But careful examination of knocking phenomenon in SI and CI engines reveals the following differences:



(a) S.I. engine (b) C.I. engine

1.In spark ignition engines, auto ignition of end gas away from the spark plug, most likely near the end of combustion causes knocking. But in compression engines the auto ignition of charge causing knocking is at the start of combustion.

2.In order to avoid knocking in SI engine, it is necessary to prevent auto ignition of the end gas to take place at all. In CI engine, the earliest auto –ignition is necessary to avoid knocking

3.The knocking in SI engine takes place in homogeneous mixture, therefore , the rate of pressure rise and maximum pressure is considerably high. In case of CI engine, the mixture is not homogenous and hence the rate of pressure is lower than in SI engine.

4.In CI engine only air is compressed, therefore there is no question of Pre-ignition in CI engines as in SI engines.

5.It is lot more easy to distinguish between knocking and non-knocking condition in SI engines as human ear easily finds the difference. However in CI engines, normal ignition itself is by auto-ignition and rate of pressure rise under the normal conditions is considerably high (10 bar against 2.5 bar for SI engine) and causes high noise. The noise level becomes excessive under detonation condition. Therefore there is no definite distinction between normal and knocking combustion.

6.SI fuels should have long delay period to avoid knocking. CI fuels should have short delay period to avoid knocking.

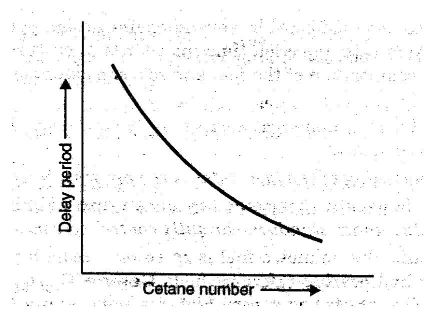
The following table gives a comparative statement of various characteristics that reduce knocking in SI and CI engines

S. No.	*Factors Affecting Knock*	*S.I. Engines*	*C.I. Engines*
1.	Self ignition temperature	High	Low
2.	Delay period of fuel	Long	Short
3.	Compression Ratio	Low	High
4.	Inlet Temperature	Low	High
5.	Inlet Pressure	Low	High
6.	Speed	High	Low
7.	Cylinder Size	Small	Large
8.	Combustion chamber wall Temperature	Low	High

Knock rating of CI fuels (CETANE NUMBER) (VTU July 2007/ Jan 07.)

The cetane number is a numerical measure of the influence the diesel fuel has in determining the ignition delay. Higher the cetane rating of the fuel lesser is the propensity for diesel knock. The cetane number of a diesel fuel is a measure of its ignition quality.

The cetane number of a fuel is the percentage by volume of cetane in a mixture of cetane [$C_{16}H_{34}$] and α-methylnapthalane [$C_{10}H_7$ CH_3] that has same performance in the standard test engine as that of the fuel. Cetane is arbitrarily assigned a number 100 and originally α-methylnapthalane was given a number 0 but now reference fuels is heptamethylnonane (HMN) which is given a value of 15. HMN is used because it is more stable compound and has slightly better ignition quality.

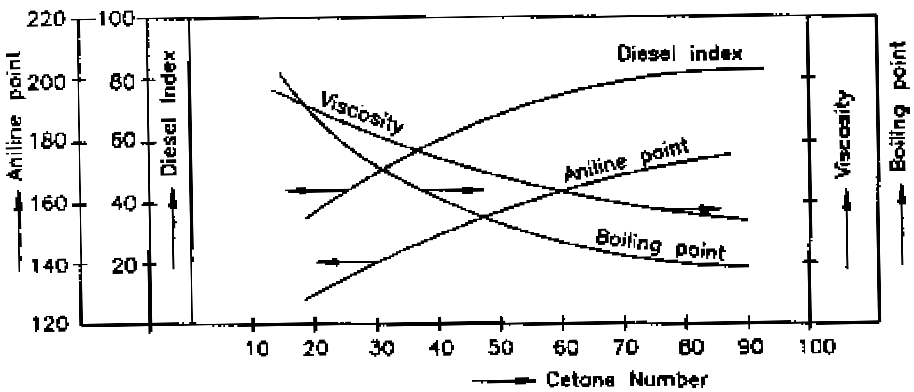


The relation between the cetane number and delay period is shown in adjacent figure

Cetane number 40 means a mixture containing 40 % cetane and 60 % of heptamethylnonane (HMN) by volume which gives same ignition delay as tested fuel. For high sped engine, cetane number of 50 is required, for medium speed engine about 30.

High octane number implies low cetane number . In other words good CI engine fuel is bad CI engine fuel. An approximate relationship between Cetane (CN) and octane (ON) number is given by $\boxed{CN = 60 - \frac{ON}{2}}$

The following graph shows relationship of other properties of fuel with CN



DIESEL INDEX (DI) (VTU Jan 2007)

Diesel index is a cheap method of predicting ignition quality. This scale is made possible because ignition quality is quite sensitive to hydrocarbons compositions. That is paraffin have high ignition quality and aromatic compounds have low ignition quality. Thus the diesel index gives an indication of ignition quality obtained from certain physical characteristics of fuel as opposed to an actual determination in the test engine. The index is derived from knowledge of aniline point and American petroleum Institute (API) gravity.

$$DI = (\text{Aniline point } °F) \times \frac{\text{API gravity}}{100}$$

Aniline point of fuel is the temperature at which equal parts of fuel and pure aniline dissolve each other. It therefore gives an indication of chemical composition of fuel since the more “parafinnic” the fuel the higher solution temperature. Likewise, a higher API gravity reflects a low specific gravity and indicates a high paraffinic content, which corresponds to a good ignition quality.

Good SI engine fuel is a bad CI engine fuel

To reduce knocking Diesel oil should have low self ignition temperature and short time lag, whereas petrol should have high self ignition temperature and a long ignition lag.

In SI engine knocking occurs near the end of combustion, where as in CI engine this occurs in the beginning of combustion. Because of this dissimilarity in the time of starting of knock in SI and CI engines . The conditions which reduce the knock tendency in SI engine will increase the knocking tendency in CI engine.

Diesel has a high cetane number (40-60) and low octane number(30) and petrol has high Octane number (80-90) ad low cetane number(20).

Figure shows typical indicator diagram of a diesel engine with sharp pressure oscillating during the combustion caused by shock waves when using petrol

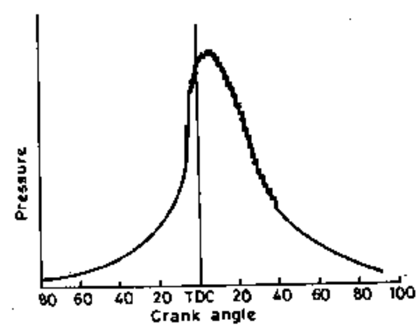
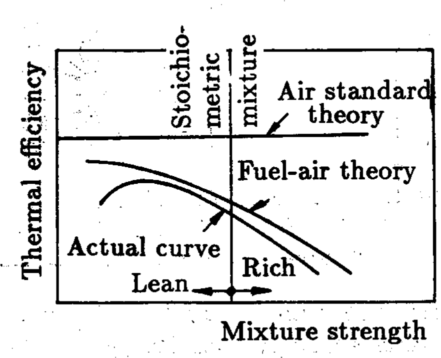


Fig. 6.11. Indicator diagram of diesel engine when using petrol.

Weak mixture gives better efficiency in CI engine- (July 2007)

As the mixture is made lean (less fuel) the temperature rise due to combustion will be lowered as a result of reduced energy input per unit mass of mixture. This will result in lower specific heat. Further, it will lower the losses due to dissociation and variation in specific heat. The efficiency is therefore, higher and, in fact, approaches the air-cycle efficiency as the fuel-air ratio is reduced as shown in adjacent figure.



Thermodynamic analysis of the engine cycles has clearly established that operating an engine with a leaner air-fuel ratio always gives a better thermal efficiency but the mean effective pressure and the power output reduce. Therefore, the engine size becomes bigger for a given output if it is operated near the stoichiometric conditions, the A/F ratio in certain regions within the chamber is likely to be so rich that some of the fuel molecules will not be able to find the necessary oxygen for combustion and thus produce a noticeably black smoke. Hence the CT engine is always designed to operate with an excess air, of 15 to 40% depending upon the application. The power output curve for a typical CI engine operating at constant speed is shown in Fig. given below. The approximate region of A/F ratios in which visible black smoke occurs is indicated by the shaded area.

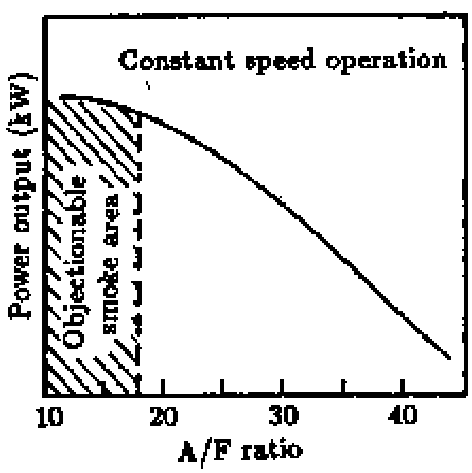


Fig.10.10 Effect of A/F Ratio on Power Output of a CI Engin