The Lecture Contains:

HCCI DIESEL ENGINES

The objective of application of HCCI concept to the diesel engines is control of NO_x and particulates simultaneously which otherwise is difficult to achieve in the conventional CI engines. For HCCI combustion the efforts are directed mainly towards:

- Creation of premixed, lean homogeneous mixture, and
- Compression ignition and control of rate of combustion to obtain low emissions and optimum engine performance.

The basic objective is to increase the formation of premixed charge prior to ignition so that a large fraction of the fuel per cycle burns as premixed. Subsequent to ignition the rate of combustion is to be controlled to keep it within acceptable limits. The different methods which may be adopted to achieve the above two objectives are:

Premixed Charge Formation:

- Fuel introduction in Intake manifold or port
- Early (much before the conventional injection timing) and multiple direct fuel injection in the cylinder
- Late direct fuel injection (at TDC or later) in the cylinder

The different fuel injection timings that may be adopted in a diesel engine to obtain a long ignition delay and consequently a high fraction of premixed charge before start of combustion are shown schematically in Fig 7.10. For HCCI mode of operation a high fraction of premixed charge is essentially required before start of compression ignition .

Ignition and Combustion Control:

- Multiple/split injection
- High amount of EGR
- Reduction in compression ratio

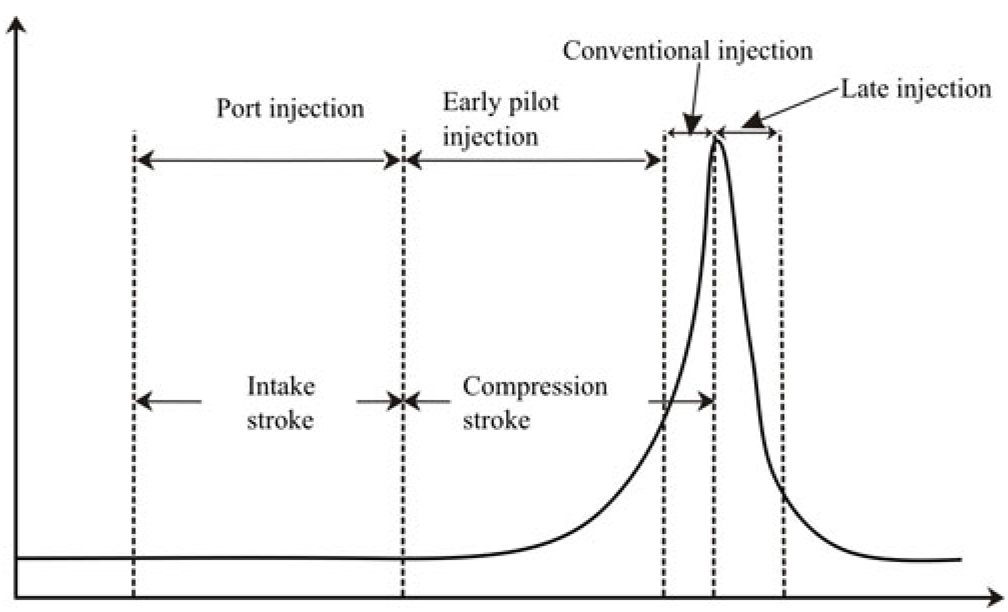

Figure 7.10	Formation of lean premixed charge in HCCI engine concepts based on fuel injection timing.

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Intake Manifold or Port Injection:

With fuel injection in the intake manifold or at the port sufficient time is available for the fuel to vaporize and mix with air and high degree of mixture homogeneity is achieved. As the boiling point of diesel fuel is high the fuel vaporization may be enhanced by heating of intake manifold. Autoignition occurs due to compression. In this approach, very low NO_x down up to 1/100th of the conventional diesel operation are possible. Smoke is very low, but higher HC and CO emissions are obtained as considerable fraction of lean homogeneous mixture may not burn or burns only partially.
Intake charge heating although, improves fuel evaporation and charge homogenization, but results in early ignition causing high rate of pressure rise and noisy combustion. If no intake heating is used, some fuel may remain in liquid state until late in the compression stroke causing locally over rich mixtures resulting in formation of soot. EGR has been employed along with intake mixture heating to retard autoignition and control rate of combustion. Use of very lean mixtures also results in retard of ignition but it limits imep to very low values that can be obtained without knocking combustion. Use of a lower engine compression ratio to retard ignition results in loss of engine efficiency. Thus, intake manifold fuel injection is not considered a practical approach for HCCI operation due to its negative effects on fuel efficiency and hydrocarbon emissions and low knock limited value of imep

Early In-Cylinder Injection:

This approach has two advantages:

(i) Higher temperatures and density compared to intake air are available. Hence, External heating of air is not necessary and,

(ii) One injection system can be used for early injection for HCCI operation and also for the conventional diesel combustion operation at higher loads.

Sufficient time is available when the fuel is injected early in the compression stroke to fully vaporize and form homogeneous mixture with air at the time of ignition.
One of the problems faced in practice is that the fuel is injected early during compression when the density of air is low. It results in long length of spray penetration and the liquid fuel may impinge on the combustion chamber and cylinder walls. To prevent fuel impingement redesigning of the injection system may be necessary. Some of the approaches used are:

- Injector in the centre of the cylinder with more number (numbering up to 30) of smaller holes
- Use of two side injectors opposite to each other so that spray travel distance is larger compared to the central injector.
- Multiple injection events with small quantities in each injection. A multiple injection strategy using common rail injection system is shown in Fig 7.11. The first injection is made around 90º btdc followed by equally spaced several injection pulses. It allows each fuel pulse to mix well with air. The main injection is made at tdc.

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The engine compression ratio is reduced to13.5 - 14:1 so that ignition delay is long to allow formation of a homogeneous mixture. In split/multiple injection approach, the first injection is made at least 50 to 60 º btdc. Cooled EGR is used to retard start of combustion of the premixed charge so that a higher engine power is obtained before knock combustion results. The low temperature autoignition is obtained near tdc just prior to main injection. The main fuel injection is made slightly after tdc. This strategy shows improved combustion efficiency without excessive CO and HC emissions.

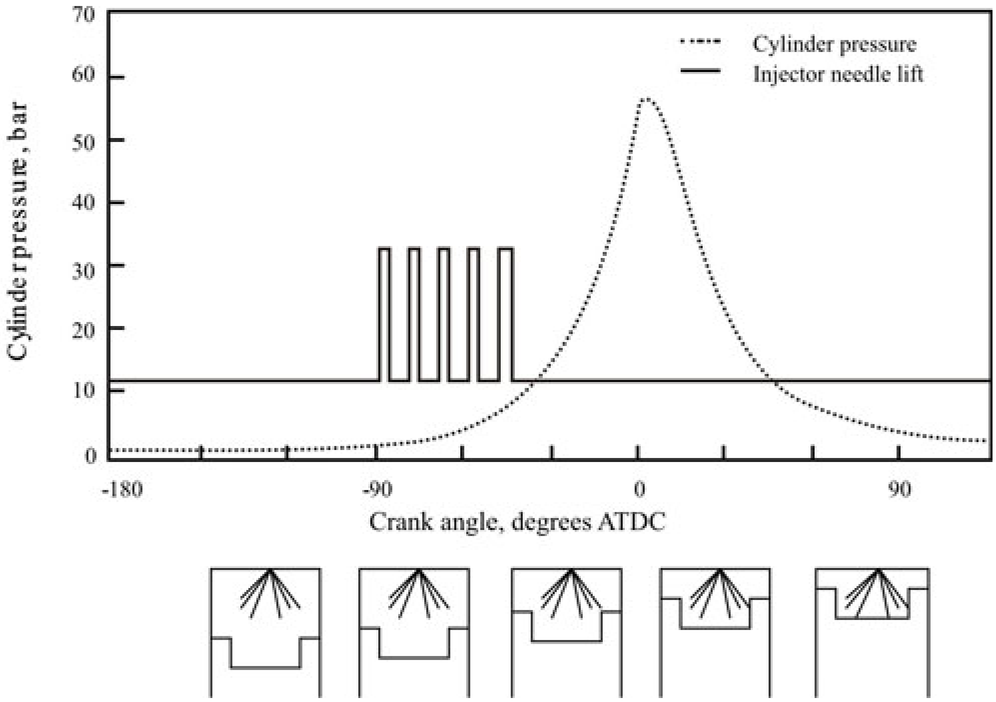

Figure 7.11	Schematic of multiple injection strategy for HCCI operation of a diesel engine

Late In-Cylinder Injection:

If the injection is made very close to or after tdc the fuel encounters a gradual decrease in gas temperature and pressure. It results in a long ignition delay and allows more time for mixture formation and favourable conditions for HCCI combustion are obtained. As most of the fuel now burns as premixed, a drastic reduction in soot formation is observed and high rates of EGR can be used to obtain very low NO_X.

The late injection strategy has the advantage in that the start of combustion is better related to the injection timing and hence the combustion process can be controlled by injection timing. Also, very little changes are necessary in the injection equipment.

Nissan Motor Corporation developed an HCCI diesel engine using late injection strategy with low compression ratio. They called it MK (modulated Kinetics) combustion system. Late fuel injection and low compression ratio were combined with 30 – 45 % EGR to prolong ignition delay beyond end of injection. Injection timing was around 3-6 degrees btdc. Injection duration was reduced by use of high injection pressures and larger nozzle orifices such that the injection duration was 4-10º CA shorter than the delay period. The fraction of fuel that burns premixed increases substantially giving very low soot formation. Use of EGR and low compression ratio gave low NO_x emissions. NO_x obtained were less than 1/10 th and PM emissions less than half at 6 bar bmep and 2000 rpm compared to conventional diesel engine.

Emissions with HCCI Operation

Emission potential of HCCI operation relative to conventional diesel engines is illustrated in Fig 7.12. The HCCI engine employed multiple early injection strategy with compression ratio equal to 13.4:1 and high rates of EGR. The NO_X emissions were just 0.074 times (7.4%) and soot emissions were only 5.5% of the conventional CI engine operation. NO_X emissions with HCCI operation ranged from 0.01 to 0.06 g/kWh and the soot emissions were below 0.02 g/kWh. Nearly 95% reduction in soot and NO_X emissions are obtained compared to the conventional diesel operation. However, due to quenching of combustion in excessively lean mixture HC increased to 348%. CO increased to 487% of the conventional CI engine. As the mixture is not entirely homogeneous and some over rich zones exist more CO is produced. Although excess air is present in burnt gases but the combustion temperatures are low to promote oxidation reactions of HC and CO in the post combustion gases.

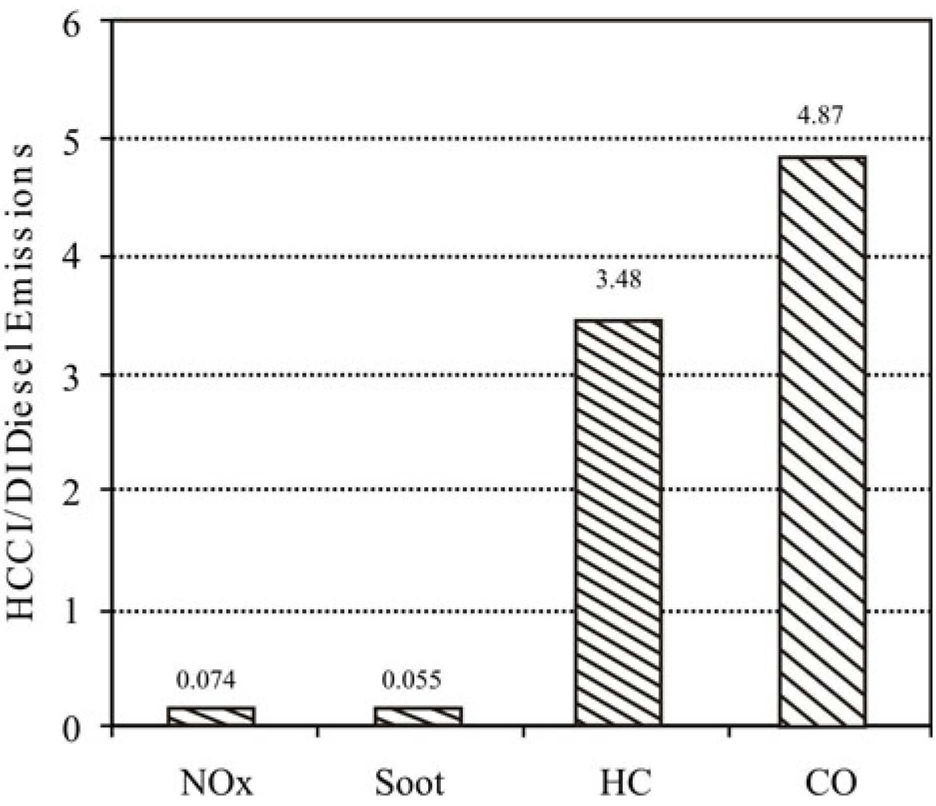

Fig 7.12	Comparative emissions with HCCI and conventional CI engine operation; multiple early injection strategy of HCCI operation.

Regimes of HCCI and Conventional CI Engine Operation

Developments in application of HCCI combustion to conventional diesel engines may be summarized as below:

- Most of the strategies for HCCI operation essentially attempt to increase the fraction of fuel burned as premixed charge.
- The premixed charge obtained with early and more so with late in-cylinder injection actually may not

be fully homogeneous.

- The attempt is to keep local fuel-air ratio lean to reduce soot formation.
- Most of the highly premixed charge undergoes precombustion reactions and burns simultaneously such that no flame front is present and low temperatures are maintained.
- The production diesel engines are unable to operate on homogeneous charge through out the entire operational range. HCCI mode of operation is feasible only at part loads. At high loads, conventional diesel combustion is to be employed.

Combustion concepts likely to be employed in the different speed-load operation regimes of a future diesel engine are shown on Fig 7.13. As the HCCI operation in the entire range of engine loads and speeds is not possible , it is envisaged that the future low emission engines would operate in combination of HCCI operation at low BMEP and the conventional compression ignition mode in the high BMEP region . The technologies already developed for control of emission in the conventional CI mode such as EGR , turbocharging , high pressure injection would be employed during high engine power operation.

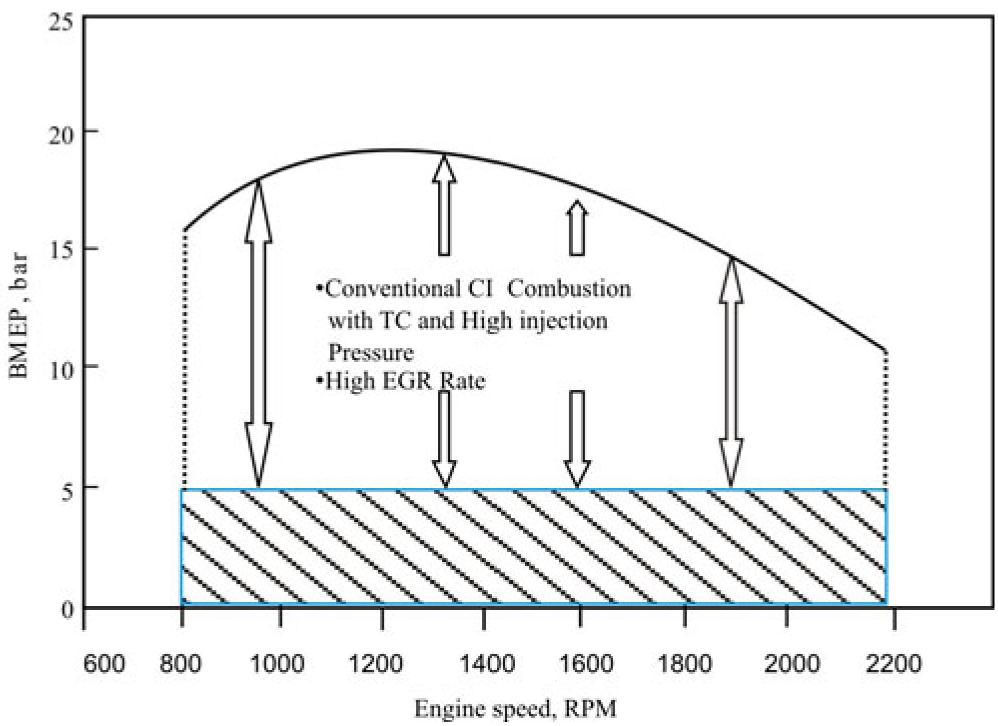

Figure 7.13	Combustion concepts and operation map for a future clean diesel engine

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