REVIEW ON HCCI ENGINE

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ABSTRACT

Homogeneous Charge Compression Ignition (HCCI) is a new combustion technology that may develop as an alternative to diesel engines with high efficiency and low NOx and particulate matter emissions. HCCI engines can operate on gasoline, diesel fuel and most alternative fuels. The Homogenous Charge Compression Ignition (HCCI) is a promising new engine technology that combines elements of the diesel and gasoline engine operating cycles. Like an SI engine, the charge is well mixed which minimizes particulate emissions, and like a CIDI engine it is compression ignited and has no throttling losses, which leads to high efficiency. However, unlike either of these conventional engines, combustion occurs simultaneously throughout the cylinder volume rather than in a flame front. With the advantages there are some mechanical limitations to the operation of the HCCI engine. The main drawback of HCCI is the absence of direct combustion timing control. This seminar report reviews the technology involved in HCCI engine, and its merits, demerits and applications. The recent developments in HCCI engine are also discussed.

Keywords: Auto- Ignition, Catalyst, Emission, Exhaust Gas Recirculation, Flame Propagation

I. INTRODUCTION

The internal combustion engine is the key to the modern society. Without the transportation performed by the numbers of vehicles on road and at sea we would not have reached the living standard of today. Internal Combustion Engines (ICEs) play a important role in the automobile industry owing to their simplicity, robustness and high thermal efficiency. The Internal Combustion (IC) Engines are perhaps the most widely spread apparatus for transforming liquid and gaseous fuel to useful mechanical work. The reason why it's so well accepted can be explained by its overall appearance regarding properties like fuels economy, durability, controllability but also the lack of other competitive alternatives.[2]

There are two types of internal combustion engines: the Petrol(SI) and the Diesel(CI). The combustion processes of them are very dissimilar. In the CI engine the combustion is initiated because of some special conditions of pressures and temperatures. But, in the SI engine the combustion is caused by a spark that ignites a mixture that has been prepared before. Due to these different types of combustion, the two engines have different characteristics. The CI is highly efficient, but it is very contaminating. Perversely, the SI is not very efficient but it has low emissions.[3]

The observableultimatecombination would be to find an engine category with the high efficiency of the CI engine and the very low emission of the SI engine with Two Way Catalyst. One such type is named

Homogeneous Charge Compression Ignition, HCCI. With the advent of increasingly stringent fuel consumption and emissions standards, engine manufacturers face the challenging task of conveying conventional vehicles that accept by these regulations. HCCI combustion has the potential to be very efficient and to produce low emission. HCCI engine can operate on gasoline, diesel fuel, and mostalternative fuels. Although HCCI has been validated and known for relatively some time, only the recent advent of electronic sensors and controls has made HCCI engines a prospectiveappliedcertainty. HCCI represents the next major step beyond high efficiency CIDI and SIDI engines for use in transportation vehicles. In some regards, HCCI engines integrate the best features of both SI gasoline engines and CIDI engines. Like an SI engine, the charge is well prepared which results in minimum particulate emissions, and like a CI engine it is compression ignited and has no throttling losses, which leads to high efficiency. But, disparate either of these conventional engines, combustion occurs simultaneously throughout the cylinder volume rather than in a flame front. HCCI engines have the potential to be lesser cost than CIDI engines because they would probably uses a lower pressure fuel injection system. The emission controlling systems for HCCI engines have the capability to be less expensive and less dependent on unusualexpensive metals than either SI or CIDI engines. HCCI is an idea whose time has come with nearly all of the parts and pieces of technology and know-how in place to make a real go of it.[1]

II. HOMOGENEOUS CHARGE COMPRESSION IGNITION ENGINE

2.1. HCCI Engine Fundamentals

The HCCI engine is often described as a hybrid between the SI engine and the CI engine. The combination of these two designs offers diesel-like high efficiency without the difficult and costly to deal with NOx and PM emission. In its most basic form, it simply means that fuel is homogeneously blended with air in the combustion chamber very similar to a regular spark ignited gasoline engine, but with a very highproportion of air-fuel i.e. lean mixture. As the engine's piston reaches its highest point (TDC) on the compression stroke, the air-fuel mixture auto-ignites from compression heat, much like a diesel engine. The result is the best of worlds, low fuel usage and low emissions. As in a diesel engine, the fuel is exposed to adequately high temp for auto ignition to occur, but for HCCI a homogeneous fuel-air mixture is used. The homogeneous mixture is prepared in the intake manifold as in a SI engine, using a low pressure injection system. The Homogeneous Charge Compression Ignition (HCCI) engine is a capable option to the current SI engines and CI engines. To limit the rate of combustion, much diluted mixture have to be prepared.[2]

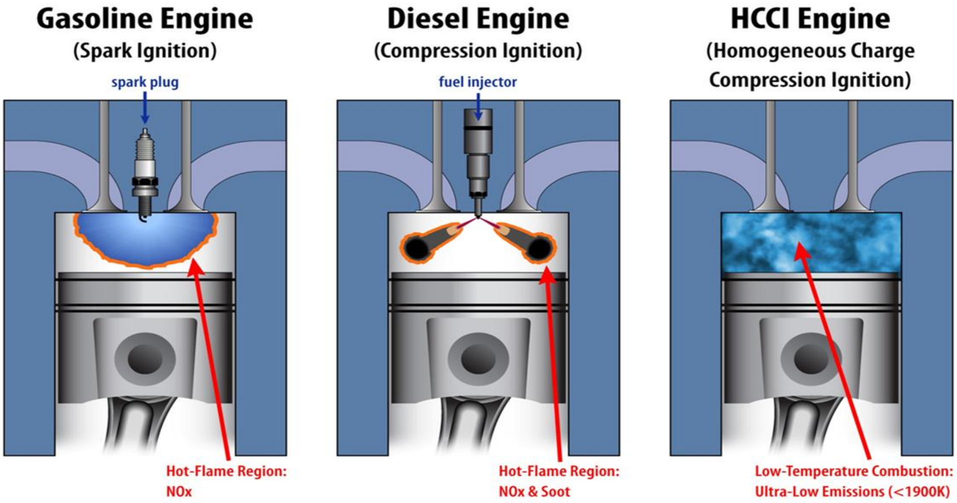

Fig.1 Homogeneous Charge Compression Ignition (HCCI) engine

Compared to the CI engines the HCCI has a nearly homogeneous charge and virtually no problems with soot, PM and NO_X formation. Also HC and CO levels are higher than in conventional SI engines. Generally, the HCCI engine shows high efficiency and lesser emissions than conventional internal combustion engines.HCCI uses a lean prepared air fuel mixture which is compressed with a high compression ratio. During the end of the compression stroke, ignition occurs through self-ignition in the whole combustion chamber at once. Engine efficiency rises with increases in the leanness of the premixed gas, in the combustion rate and in the compression ratio. In the HCCI engine, ultra-lean premixed gas is compressed and ignited at the self-ignition temperature. Then, combustion occurs in the whole combustion chamber, and the combustion rates are very high. As a result of ultra-lean combustion with a high compression ratio, high thermal efficiency and very low NOx emissions are achieved as compared to the conventional spark ignition engines.[2]

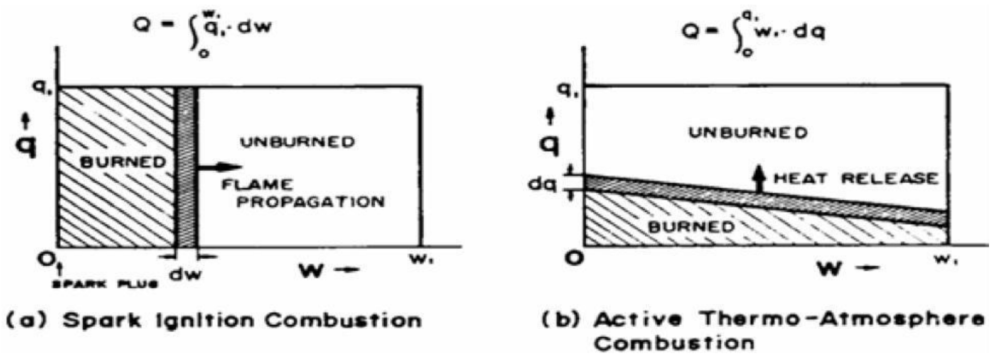

Fig.2 The Difference between SI and HCCI Combustion Process

Fig.2 shows the difference between SI combustion and HCCI. In the SI engine we have three zones, a burnt region, and an unburned zone and between them a thin reaction zone where the chemistry takes place. This reaction zone propagates through the combustion chamber and therefore we have flame propagation. Even though the reactions are fast in the reaction region, the combustion process will take some time as the regionmust propagate from spark plug to the far liner wall. With the HCCI process the whole mass in the cylinder will react at once. The right part of Figure 2 shows HCCI, or Active Thermo Atmosphere Combustion

(ATAC). We get that the entire mass is active but the reaction rate is less. This means the combustion will take some time even if all the charge is active. The total amount of heat released, will be the same for both the processes. It could be seen that the combustion process can have the same duration even though HCCI normally has a faster burn rate.[1]

Since the mixture is lean, the max temp, both locally and overall, becomes low compared to other engines, which efficiently reduces NOx formation. However, at rich mixtures the combustion becomes too fast and knocking, or ringing, occur. Thus, if a high load is required, supercharging, or turbo charging is essential. The load limit without supercharging is said to be either the engine structures capabilities or NOx emission. The difficulty with the HCCI engine is correlated to the lean mixture, the fast combustion, and the high compression ratiothat origins the exhaust temperature to develop quite low. This can make it difficult to get both turbocharging and oxidizing catalyst to do work.[2]

Despite advantages, HCCI engines produce high HC and CO emissions as the ignition timing and combustion duration is difficult to control. Therefore, the HCCI operating zone is limited between misfire and knock. Absence of direct control over ignition instigation is one of the obstacles that need to be addressed. In self-ignition combustion, the ignition times varies with the temperature of the intake air, coolant, and lubricating oil. Because the efficiency varies along with this variation, the ignition timing must be precisely controlled. Studies on HCCI engines have exposed that the load range over which HCCI engine can operate is limited by the risk of misfiring, combustion instability, and engine knock. Furthermore, the higher pressure of gas within cylinderbecause of the higher compression ratio and more rapid combustion makes a need for engine with a higher withstand pressure.

2.2. HCCI Working Process in Detail

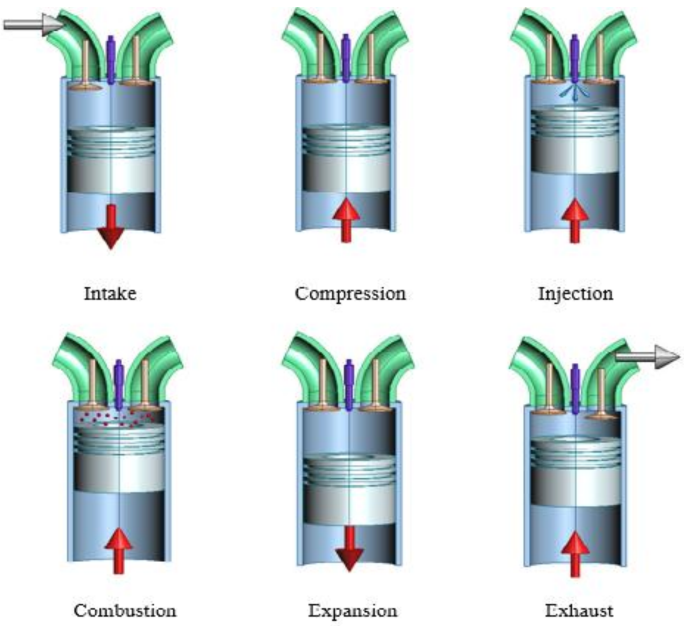

Fig.3 HCCI working process

Intake: At first the charge (fuel and air mixture) is sent through the intake manifold. The fuel simply injects into the cylinder since there is vacuum inside the cylinder. The pressure in the cylinder is same as that of the pressure associated with the charge.

Compression: The charge is compressed by the piston until the pressure and temperature reaches to the highest value. The charge is divided into well-defined flecks which are distributed throughout the volume of the combustion chamber. Then the charge will attains its auto-ignition points.

Combustion: When the charge attains its auto ignition temperature the whole mass in the cylinder will burn at once. Hence it avoids burn duration and flame propagation. But in SI engine there will not be stages of combustion.

Expansion: When the charge burns the heat energy released will be converted into work energy and pushes the piston downwards from Top Dead Centre to Bottom Dead Centre.

Exhaust: The exhaust gases released will be exhausted through the exhaust manifold due to the pressure difference between the exhaust gases and the atmospheric air.[4]

III. REQUIREMENTS FOR HCCI

The HCCI combustion process puts two major requirements on the conditions in the cylinder:-

• The temperature after compression stroke must equal the auto-ignition temperature of the fuel/air mixture.

• The mixture should be diluted enough to give considerable burn rate.[2]

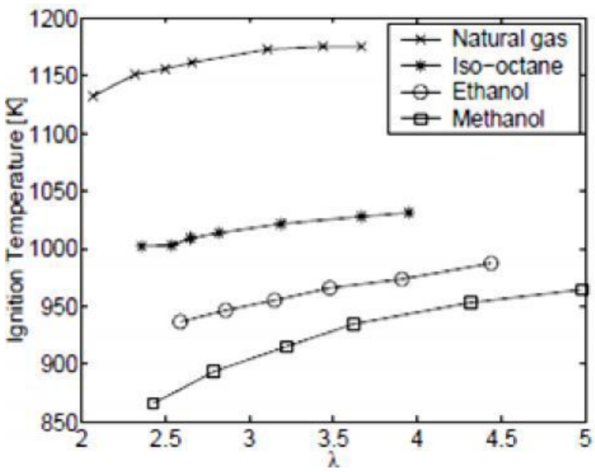

Fig.4 Ignition Temperature for a Few Fuels as a Function of Dilution

Fig.4 shows the auto-ignition temperature for a few fuels as a function of λ. The auto-ignition temperature has some correlation with the fuels resistance of knock in SI engines and thus the octane number. For iso-octane, the auto-ignition temperature is approximately 1000 K. This means that the temperature in the cylinder should be 1000 K at the end of the compression stroke where the reaction could start. This temperature can be reached in two ways, either the temperature inside the cylinder at the beginning of compression is controlled or the increase in temperature due to compression. It could be remarkable to note that the auto-ignition temperature is a very weak role of air-fuel ratio. The change in auto ignition temperature for iso-octane is only 50 K with factor 2 changes in λ. Fig.4 also shows the normal rich and lean limits found with HCCI. With a excessively rich mixture the reactivity of the charge is excessively high. This means that the burn rate become extremely high with richer mixtures. If an HCCI engine is run excessively rich the whole charge can be expended within a fraction of a crank angle. This gives rise to extreme pressure rise rates and hence mechanical stress and noise. With a high auto-ignition temperature like that of natural gas, it is also probable that generation of NOx can be the load limiting factor.[1]

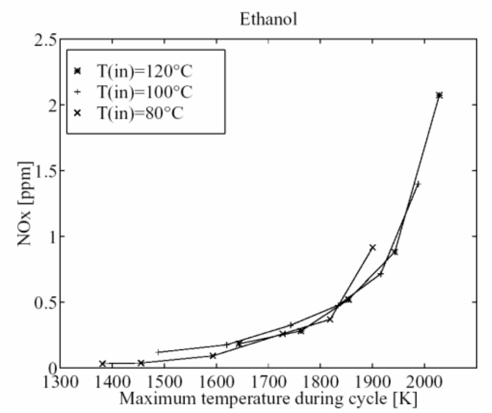

Fig.5 NOx as a Function of Max Temperature Evaluated from the Pressure-Trace

Fig.5 shows the NOx formation as a function of maximum temperature. Very low emissions are measured with the help of ethanol. If the combustion begins at a higher temperature like with natural gas, the temperature after combustion will also be greater for a specified amount of heat released. On the lean side, the temperature increase from the combustion is very low to have complete combustion of charge. Partial oxidation of fuel to CO can occur at extremely lean mixtures; λ above 14 has been tested. However, the oxidation of CO to CO2 requires a temperature of 1400-1500 K. HCCI is directed by three different temperatures. We want to reach the auto-ignition temperature to get things started; the combustion could be then increase the temperature to atleast 1400 K to have good combustion efficiency but it should not beincreased to more than 1800 K to prevent NOx formation.[1]

IV. ADVANTAGES OF HCCI ENGINE

4.1. Extremely low NOX emissions

Perhaps the single largest attraction of HCCI combustion is that it can reduce NOx emissions by 90 to 98% as compared to conventional Diesel combustion. The underlying mechanism responsible for this reduction in NOx emissions is the absence of high temperature region inside the combustion chamber. HCCI combustions occur at the global air-fuel ratio, which is usually lean, and at a temperature considerably below those encountered within the reaction zone in Diesel or Spark-ignition engines.[1]

4.2. Low PM emissions

HCCI combustion has also been reported to produce low levels of smoke and PM emissions. The mechanisms for these smoke reductions are not as well documented but it is thought that the absence of diffusion-limited combustion and localized fuel-rich regions discourages the formation of soot. One exception to this can occur when poor mixture preparation leads to liquid fuel deposition on the combustion chamber and localized fuel rich regions of combustion.[1]

4.3. High fuel efficiency & High part load efficiency

The fuel efficiency will increase from 15 to 30 %, because the entire mass of the charge will be distributed homogeneously throughout the volume of the chamber so the whole mass will be burned at a time and the unburned fuel is nearly zero percent. HCCI combustion is generally characterized by high heat-release rates, which can approximate the ideal Otto cycle when properly phased in relation to the engine cycle. The distributed low-temperature reactions and non-luminous combustion result in reduced heat rejection to the engine. Hence HCCI combustion is, in itself, conducive to high thermodynamic cycle efficiencies. HCCI fuel efficiencyas compare to those of conventional Diesel combustion at part load.[2]

4.4. Possibility of knocking is avoided

In SI engine there will be auto ignition and spark ignition from each side and leads to detonation. But here unlike that there will be homogeneous combustion.

4.5. No problems of flame propagation and burn duration

Numerous ignition points throughout the mixture ensure very rapid combustion and Very lean mixtures (low equivalence ratios (f ~ 0.3)) can be used.[3]

4.6. Fuel flexibility

It can use gasoline, diesel as well as alternatives fuels like ethanol, methanol, natural gas etc.

V. DISADVANTAGES OF HCCI ENGINE

5.1. Controlling Ignition Timing over a Range of Speeds and Loads

Expanding the controlled operation of an HCCI engine over a wide-rangingspeeds and loads is probably the most difficult hurdle facing HCCI engines. Unlike in spark-ignition or conventional diesel engines, a direct method to control the start of combustion is not existing. HCCI ignition is determined by the charge mixture composition and its temperature history. Changing the power output of an HCCI engine requires a change in the fuelling rate and, hence, the charge mixture. Accordingly, the temperature history must be adjusted to maintain proper combustion timing. Also, change in the engine speed changes the amount of time for the auto ignition chemistry to occur relative to the piston motion. Again, the temperature history of the mixture must be adjusted to compensate. These control issues become predominantly challenging during rapid transients.[1]

5.2. Smaller Power Output

A current drawback of HCCI combustion is that it is presently limited in power output. Although HCCI engines have been demonstrated to operates well at low to medium loads, problems have been encountered at high loads. Combustion can become very rapid and extreme which causesundesirable noise, engine damage, and eventually unacceptable levels of NOx emissions. Fuels with inherently lower heat release rates like methane, can be combusted at lower A/F ratios and achieve higher specific engine outputs.[2]

Given this apparent limitation in A/F ratio for HCCI combustion, power increases can be obtained by augmenting the air flow through the engine. Supercharging has been proven to be effective in this respect, and it also has a beneficial influence on reducing the heat release rate. Increasing the engine speed may also be an effective method of increasing HCCI power output.[1]

Another approach to overcome the limitations in power output has been to pursue the development of "dual-mode" engines that employ HCCI combustion at low loads and Diesel combustion or spark-ignition at high loads.

5.3. Cold-Start Capability

At cold-start, the compressed gas temperature in HCCI engine will get reduced because of the charge receives no preheat from the intake manifold and the compressed charge is rapidly cooled by heat transfered to the cold combustion chamber walls. Without some compensating mechanism, the low compressed-charge temperature could prevent an HCCI engine from firing. Different mechanisms for cold-starting in HCCI mode have been proposed, such as using a fuel additive, and increasing the compression ratio using Variable Compression Ratio or Variable Valve Timing.[1]

Perhaps the most practical approach would be to start the engine in spark-ignition mode and transition to HCCI mode after warm-up. For engines equipped with Variable Valve Timing, it may be possible to make this warm up period as short as a few fired cycles, since high levels of hot residual gases could be retained from previous spark-ignited cycles to initiate HCCI combustion. Even though solutions appear possible, proper R&D will be essential to advance these concepts and prepare them production engines.[1]

5.4. High HC and CO emissions

HCCI engines have inherently low emission of NOx and PM, but relatively high emissions of hydrocarbon (HC) and carbon monoxide (CO). Some potential exists to diminish these emissions at low load by using direct in cylinder fuel injection to achieve suitable partial-charge stratification. Though, in most of the cases, controlling HC and CO emissions from HCCI engines will require exhaust emission control devices. Catalysts technology for HC and CO removal is well known and has been standard equipment on automobiles for several years. Though, the cooler exhaust temperature of HCCI engines may increase catalyst light-off time and decrease meaneffectiveness. As a result, achieving future emission standards for HC and CO will likely require further development of oxidation catalysts for low-temperature exhaust streams. However, HC and CO emission control devices are simple and less dependent on scarce, costly precious metals than are NOx and PM emission control devices. So, simultaneous chemical oxidation of HC and CO in an HCCI engine is much simple thansimultaneous chemical reduction of NOx and oxidation of PM (in a CIDI engine).[1]

VI. APPLICATIONS

HCCI engine has wide range of applications in different field of engineering which are as follow:-

- Hydrogen IC Electric Generator

- Automobiles
- Heavy duty vehicles
- Marine engines
- Applications requiring faster rpm like turbochargers, compressors[4]

VII. RECENT DEVELOPMENTS IN HCCI ENGINE

7.1. Ongoing research

Recent developments in the HCCI technology have given very positive results to overcome the limitations of this technology. The technology has huge scope of use and it is used in a wide range of industries, which makes it a promising technology for the coming generations. Automobile giants like GM, Ford and Cummins have been exploring the possibilities in the HCCI technology for more than 15 years. General Motors has started educational programs in various Universities to promote the research work in this technology. HCCI has also enabled engineers to experiment with different blends of fuel mixture so that performance and efficiency of HCCI engines can be tested with different mixtures of non-conventional fuels. As the demand of conventional fuels is increasing, scope of research and experimentation in HCCI technology will increase only with time.[1]

7.2. Prototypes

In May 2008, General Motors had given Auto Express access to a Vauxhall-Insignia prototype fitted with a 2.2-litre HCCI engine, which will be offered along with their EcoFLEX range of small capacity, turbocharged petrol and diesel engines when the car goes into production. Official numbers are not yet available, but fuel economy is expected to be in the zone of 43mpg with CO_2 emission of about 150 grams per kilometer, improving on the 37mpg and 180g/km produced by the current 2.2-litre petrol engine. The new engine operates in HCCI mode at low speeds or when cruising, switching to conventional spark-ignition when the throttle is opened. General Motors has demonstrated Opel Vectra and Saturn Aura with modified HCCI engines.[1]

Mercedes Benz has developed a prototype HCCI engine called Dies Otto, with controlled auto ignition. It was displayed in its F700 concept car at the 2007 Frankfurt Auto Show.[4]

Volkswagen is developing two types of engine for HCCI operation, called Combined Combustion System or CCS, is based on the VW Group 2.0 litre diesel engine but uses homogenous inlet charge rather than traditional diesel injection. It requires the use of synthetic fuel to achieve maximum benefit. And the second is called Gasoline Compression Ignition or GCI; it uses HCCI when cruising and SI when accelerating. Both engines have been demonstrated in Touran prototypes, and the company supposes them to be prepared for production in about 2015.[4]

VIII. CONCLUSION

The HCCI, combustion process is an interesting option to the conventional SI and CI processes. A high-efficiency, gasoline-fueled HCCI engine represents a major step beyond SIDI engines for light-duty vehicles. HCCI engines have the potential to match or exceed the efficiency of diesel engines without the major challenge of NOx and PM emission control or a major impact on fuel-refining ability. Also, HCCI engines would perhaps less costly than CIDI engines because HCCI engines would expected use low- pressure fuel injection equipment and the combustion characteristics of HCCI would potentially allow the use of emission control device that independent of scarce and expensive precious metals. In addition, for heavy duty vehicles, effective development of the diesel fueled HCCI engine is an important alternative strategy in the event that CIDI engines cannot achieve future pollution standards. HCCI engines are a promising technology that can help decrease some of our energy issues in the near years.

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