ISSN 2229-5518

# HOMOGENEOUS CHARGE COMPRESSION ENGINE

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## Abstract:

The Homogeneous Charge Compression Ignition Engine, HCCI, has the potential to combine the best of the Spark. Ignition and Compression Ignition Engines. With high octane number fuel the engine operates with high compression ratio and lean mixtures giving CI engine equivalent fuel consumption or better. Due to premixed charge without rich or stoichiometric zones, the production of soot and NOx can be avoided. This paper presents some results from advanced laser diagnostics showing the fundamental behaviour of the process from a close to homogeneous combustion onset towards a very stratified process at around 20-50% heat released. The need for active combustion control is shown and possible means of control are discussed.

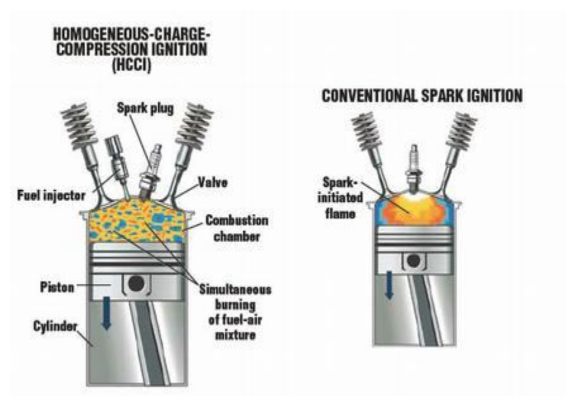
## INTRODUCTION:

The internal combustion engine is the key to the modern society. The problem with the SI engine is the poor part load efficiency due to large losses during gas exchange and low combustion and thermo dynamical efficiency. The problem with the CI engine is the emissions of nitrogen oxides, NOx, and particulates.. The obvious ideal combination would be to find an engine type with the high efficiency of the CI engine and the very low emissions of the SI engine with TWC. One such candidate is named Homogeneous Charge Compression Ignition, HCCI. The major benefit of HCCI compared to CI is the low emissions of NOx and PM.

## FUELS FOR HCCI COMBUSTION:

### Gasoline:

Gasoline has multiple advantages as an HCCI fuel. Gasoline also has a high octane number (87 to 92 in the U.S. and up to 98 in Europe), which allows the use of reasonably high compression ratios in HCCI engines. Actual compression ratios for gasoline-fueled HCCI engine data vary from 12:1 to 21:1 depending on the fuel octane number, intake air temperature, and the specific engine used (which may affect the amount of hot residual naturally retained). This compression-ratio range allows gasoline-fueled HCCI engines to achieve relatively high thermal efficiencies (in the range of diesel-fueled CIDI engine efficiencies). A drawback to higher compression ratios is that the engine design must accommodate the relatively high cylinder pressures that can result, particularly at high engine loads (see discussion in Section V B). Additional advantages of gasoline include easy evaporation, simple mixture preparation, and a well developed refueling infrastructure.




### Diesel Fuel:

Diesel fuel auto ignites rapidly at relatively low temperatures but is difficult to evaporate. To obtain diesel-fuel HCCI combustion, the air-fuel mixture must be heated considerably to evaporate the fuel. The compression ratio of the engine must be very low

(8:1 or lower) to obtain satisfactory combustion, which results in a low engine efficiency. Alternatively, the fuel can be injected in-cylinder, but without air preheating, temperatures are not sufficiently high for diesel-fuel vaporization until well up the compression stroke. This strategy often results in incomplete fuel vaporization and poor mixture preparation, which can lead to particulate matter and NOx emissions. However, one concept for direct injection of diesel fuel, involving late injection (after TDC) with high swirl, has been successful at thoroughly vaporizing and mixing the fuel before ignition at light loads.

**Propane:**

Propane is an excellent fuel for HCCI. High efficiencies can be achieved with propane-fueled HCCI engines because propane has a high octane number (105). Because propane is a gaseous fuel, it can be easily mixed with air. Some infrastructure also exists for propane. Because it can be maintained as a liquid at moderate pressures, the amount of fuel that can be stored onboard a vehicle is comparable to what can be stored for typical liquid fuels.

**Natural Gas:**

Because natural gas has an extremely high octane rating (about 110), natural gas HCCI engines can be operated at very high compression ratios (15:1 to 21:1), resulting in high efficiency. However, similar to gasoline or propane, the engine design must accommodate the relatively high cylinder pressures that can result.

## HOW HCCI IMPROVES FUEL ECONOMY

In a "homogeneous charge compression ignition" (HCCI) engine, fuel and air are mixed together and injected into the cylinder. The piston compresses the mixture until spontaneous combustion occurs. The engine thus combines fuel-and-air premixing (as in an SI engine) with spontaneous ignition (as in a diesel engine). The result is the HCCI's distinctive feature: combustion occurs simultaneously at many locations throughout the combustion chamber.

In a gasoline spark-ignition engine (left), combustion begins when a mixture of fuel and air is ignited by the spark plug. In a diesel engine (center), combustion begins when fuel is injected into hot, highly compressed air. In a homogeneous charge compression ignition engine (right), well-mixed fuel and air are compressed until combustion occurs at multiple points throughout the combustion chamber

That behavior has advantages. In both SI and diesel engines, the fuel must burn hot to ensure that the flame spreads rapidly through the combustion chamber before a new "charge" enters. In an HCCI engine, there is no need for a quickly spreading flame because combustion occurs throughout the combustion chamber Ignition timing in an HCCI engine depends on two factors: the temperature of the mixture and the detailed chemistry of the fuel. Both are hard to predict and control. So while the HCCI engine performs well under controlled conditions in the laboratory, it is difficult to predict at this time what will happen in the real world.

Using the results of their engine tests as a guide, the researchers developed an inexpensive technique that should enable a single engine to run in SI mode but switch to HCCI mode whenever possible. A simple temperature sensor determines whether the upcoming cycle should be in SI or HCCI mode (assuming a constant fuel). The mode-switching capability could appear in production models within a few years, improving fuel economy by several miles per gallon in millions of new cars each year. Over time, that change could cut oil demand in the United States alone by a million barrels a day.

Homogenous-charge compression ignition technology (HCCI) in the quest for more fuel-efficient internal combustion engines. HCCI engines inject a premixed charge of fuel and air into the cylinder. But combustion is not set off by a spark plug. Instead, the mixture is compressed until it auto ignites, much like in a diesel at a much lower temperature. This virtually eliminates NOx emissions and lowers throttling losses, which could lead to a 30% boost in fuel economy. HCCI engines would also use a higher ratio of air to fuel, high compression ratios (on the order of 12:1), and burn a variety of fuels, including methane.

The trick, according to scientists, is to ensure the air/fuel mixture ignites exactly when the piston reaches its zenith. But HCCI engines inherently lack traditional methods of timing ignition. In diesels, for example, ignition starts when fuel is injected into the hot, compressed air.

And in standard engines, sparking the plug initiates ignition. HCCI engines also lack the means to control the heat-release rate. In diesels, this takes place by adjusting the rate and duration of fuel injection, while in standard engines, engineers manage it via control of spark plug intensity and spark duration.

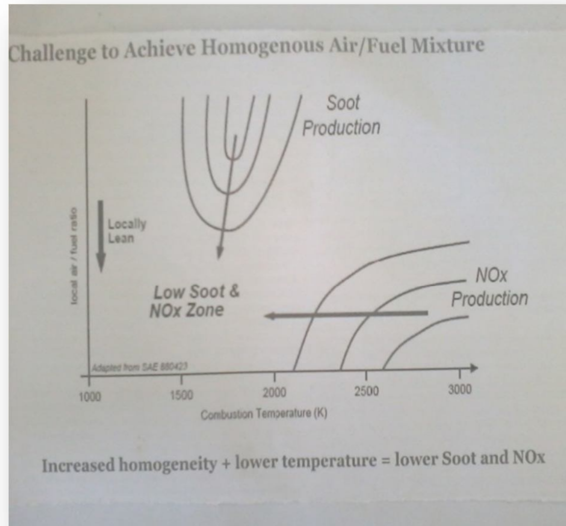
Overall, the challenge is to establish closed-loop control of the fuel and air systems to keep combustion optimized despite changes in speeds and loads. If the control is off, for example, and the there is a misfire, the gas mixture injected in to the cylinder for the next cycle-could be too cold for auto ignition and the engine could stop.

HCCI engine will generate less horsepower than a traditional internal combustion engine with the same displacement. This means friction losses in HCCI engines are a larger fraction of total power output than in traditional car engines. One is to recirculate exhaust gases into the fuel/air mix to quickly raise its temperature. The other is to add dimethyl ether to the fuel/air mixture to improve combustion.

## EMISSION CONTROL BY HCCI:

Extensive experimental research shows that the engine exhaust emissions and fuel efficiency of modern diesel engines indicate several unfavorable conditions for biodiesel fuels when the engines are operated in conventional high temperature combustion cycles. The homogeneous charge compression ignition (HCCI) is an alternative combustion concept for internal combustion engines. The HCCI combustion engine offers significant benefits in terms of high thermal efficiency and ultra low emissions ($NO_x$ and PM). Provides an innovative way for the diesel engine industry to meet tougher, new emissions standards for soot and nitrogen oxides

## COMPARISON OF $NO_x$ EMISSIONS :



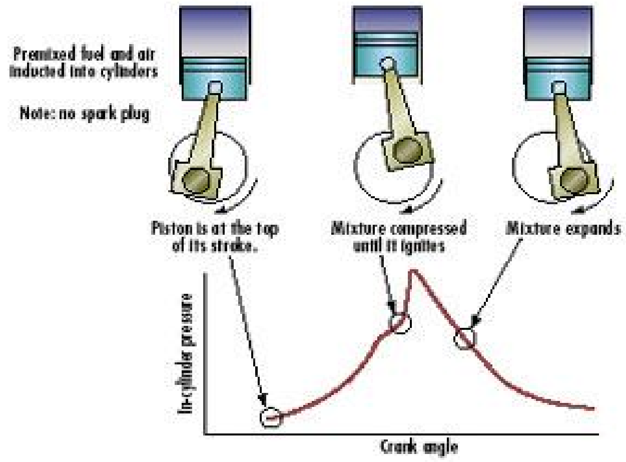

- Offers a means to control emission levels as well as combustion phasing and engine efficiency in HCCI engines
- Results in engine efficiency comparable to that of diesel engines
- Suitable for two-stroke, four-stroke and rotary HCCI engines, as well as hybrid HCCI/spark-ignited engines
- Researchers have demonstrated effective HCCI phasing control over a wide range of engine speeds and loads
- Produces particulate emission levels similar to those obtained with spark-ignited engines
- Achieves particulate control without the need for expensive and complex particulate traps
- Reduces nitrogen oxides in lean-burn engines without the need for nitrogen oxide catalysts

## CHALLENGES FOR HCCI:

In traditional spark engines, combustion timing is easily adjusted by the engine management control module changing the spark event and perhaps fuel delivery. It's not nearly so easy with HCCI's flameless combustion. Combustion chamber temperature and mixture composition must be tightly controlled within quickly changing and very narrow thresholds that include parameters such as cylinder pressure, engine load and RPMs and throttle position, ambient air temperature extremes and atmospheric pressure changes. Most of these conditions are compensated for with sensors and automatic adjustments to otherwise normally fixed actions. Included are: individual cylinder pressure sensors, variable hydraulic valve lift and electromechanical phasers for camshaft timing. Perhaps just as challenging though will be the problem of keeping these advanced control systems affordable.

## ADVANTAGES OF HCCI:

- Lean combustion returns 15 percent increase in fuel efficiency over a conventional spark ignition engine.
- Cleaner combustion and lower emissions (especially NOx) than a conventional spark ignition engine.
- Compatible with gasoline as well as E85 (ethanol) fuel.
- Fuel is burned quicker and at lower temperatures, reducing heat energy loss compared to a conventional spark engine.
- Throttle less induction system eliminates frictional pumping losses incurred in traditional (throttle body) spark engines.




## DISADVANTAGES OF HCCI:

- High cylinder pressures require stronger (and more expensive) engine construction.
- More limited power range than a conventional spark engine.
- The many phases of combustion characteristics are difficult (and more expensive) to control.
- It is clear that HCCI technology offers superior fuel efficiency and emissions control compared to the conventional tried-and-true spark ignition gasoline engine but refinements have to be done to implement at present.

## CONCLUSION:

HCCI engines have the potential to match or exceed the efficiency of diesel-fueled CIDI engines without the major challenge of NOx and PM emission control or a major impact on fuel-refining capability. Also, HCCI engines would probably cost less than CIDI engines because HCCI engines would likely use lower-pressure fuel-injection equipment, and the combustion characteristics of HCCI would potentially enable the use of emission control devices that depend less on scarce and expensive precious metals. In addition, for heavy-duty vehicles, successful development of the diesel-fueled HCCI engine is an important alternative strategy in the event that CIDI engines cannot achieve future NOx and PM emissions standards. R&D will accelerate the introduction of HCCI engines and realization of their potential to reduce petroleum use in the transportation sector.