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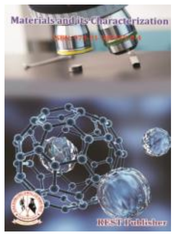

The Combustion Control in Homogeneous Charge Compression Ignition Engines

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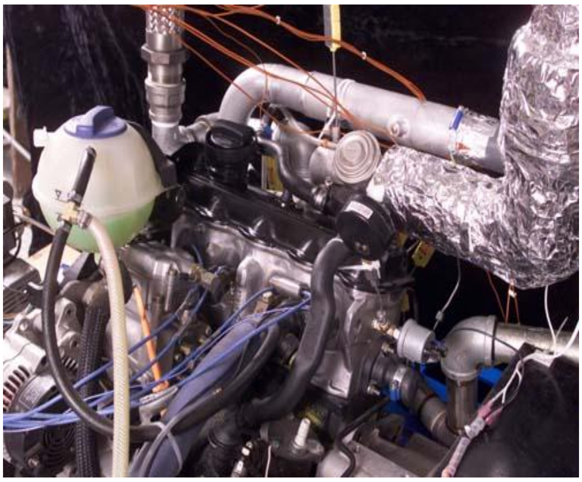
Abstract: *The Homogeneous charge compression ignition engine is renowned because of its high efficiency and ultra low emission. The combustion occurring in an HCCI engine is fundamentally different from the combustion in a SI Engine or in a CI Engine. In HCCI Engines the heat release occurs as a global auto ignition process, which differs from the turbulent flame propagation or mixing controlled combustion used in current engines. The advantage of this global auto ignition is that the temperatures within the cylinder are uniformly low, yielding very low emissions of Nox. The inherent features of HCCI combustion allows for design of engines with efficiency comparable to or potentially higher than diesel engines. While HCCI engines have great potential, several technical barriers exist which currently prevent widespread commercialization of this technology. The most significant challenge is that the combustion timing cannot be controlled by typical in-cylinder means. This paper focuses on understanding basic characteristics of controlling and operating HCCI engines.*

1. INTRODUCTION

HCCI Engine is a form of Internal Combustion Engine in which fuel is homogenously premixed with air at the inlet as in a spark-ignited engine. When the piston reaches its TDC, this lean fuel-air mixture auto ignites as in a diesel engine. A feature of the HCCI engine is that it burns cooler than spark-ignited and diesel engines. Low temperature combustion considerably reduces the emissions of nitrogen oxides. In addition premixed combustion in HCCI engines reduces particulate matter emissions to very low levels. An HCCI engine can operate using any fuel, so long as the fuel can be vaporized and mixed with air before ignition. TheHCCI ncept has the potential to meet the need for a high efficiency and low emissions engine. While the HCCI concept has great promise, there are still many technical barriers that currently prevent practical implementation. This paper provides information about those barriers. Combustion control is the biggest challenge to HCCI engines becoming a commercial success. For this reason, several methods have been proposed for achieving combustion control in HCCI engine over the wide range of operating conditions required for typical transportation engine applications. HCCI ignition occurs at many points simultaneously, with no requirement for flame propagation. Combustion was described as very smooth, with very low cyclic variations. The port injection method of introducing the mixture into the cylinder during the intake stroke is the simplest way to form a homogenous in-cylinder fuel/air mixture. This method ensures effective premixing, because sufficient time for evaporation of premixed fuel is allowed. To reduce simultaneously the formation of Nox and soot in combustion process, sufficient mixing time is required before the start of combustion, which allows learn low temperature combustion. In a general way, exhaust gas recirculation (EGR) has been regarded as the simplest and most effective method for reducing Nox emissions for every kind of internal combustion engine. Controlling the operation of an HCCI engine over a wide range of speeds and loads is probably the most difficult hurdle facing HCCI engines.

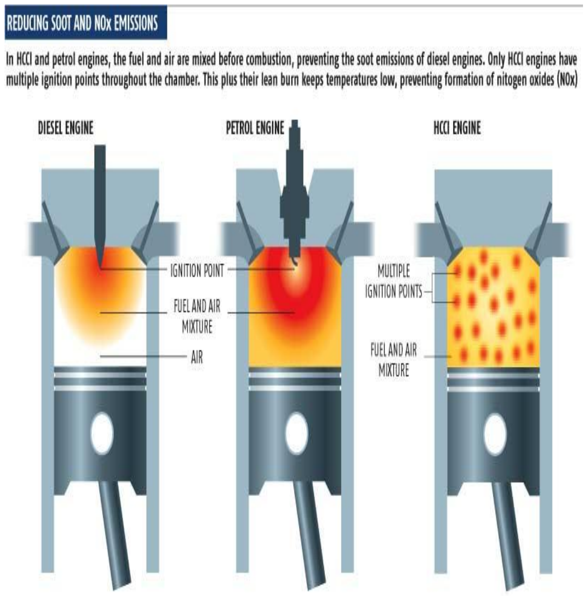
2.BASICS OF HCCI ENGINE

In HCCI the fuel is homogenously premixed with air as in a spark-ignited engine and when the piston reaches its TDC; this lean fuel-air mixture auto ignites as in a diesel engine. An HCCI engine can operate using any fuel, so long as the fuel can be vaporized and mixed with air before ignition. In HCCI Engines the heat release occurs as a global auto ignition process. It burns cooler than spark-ignited and diesel engines. The combustion cycle in HCCI is essentially an Otto combustion cycle. HCCI technology could be scaled to virtually every size and class of transportation engines, From small motorcycles to large ships. Stationary HCCI engines could replace the spark-ignited and diesel engines currently used.



2. COMBUSTION IN HCCI ENGINES

In a typical gasoline engine, a spark is used to ignite the premixed fuel and air. In diesel engines, combustion begins when the fuel is injected into compressed air. In both cases, the timing of combustion is explicitly controlled. In an HCCI engine however the homogenous mixture of fuel and air is compressed and combustion begins whenever the appropriate conditions are reached. In HCCI Engine there is no well-defined combustion initiator that is to be controlled directly. An engine can be designed so that the ignition conditions occur at a desirable timing. However this would happen only at one operating point. The engine could not change their energy production to meet user demand. To achieve dynamic operation in an HCCI engine, the control system must change the conditions that induce combustion. Thus the engine must control the compression ratio, induced gas temperature, inducted gas pressure, or quality of retained exhaust.

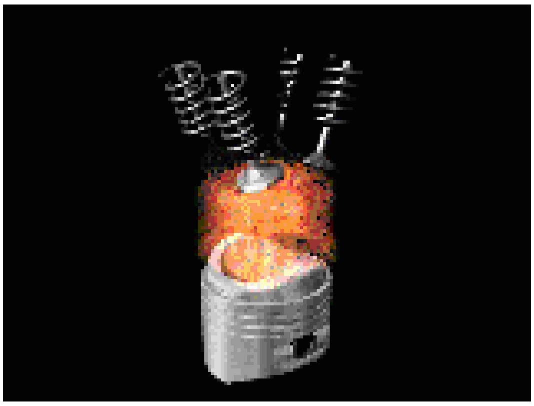


Conventional Diesel engines can be converted to run in the HCCI mode. The intake air should be preheated with an air heater. As of today, various fuels such as propane, butane and methane have been tested on HCCI engine with some positive results. Exhaust gas recirculation was also used to control and improve the performance of this engine; variable valve timing control is being developed on this engine to better control HCCI combustion.

3.COMBUSTION CONTROL IN HCCI ENGINE

Implementation of HCCI combustion requires understanding of the fundamental parameters that affects combustion. HCCI is more difficult to control than other popular modern combustion methods. Homogenous Charge Compression Ignition, or HCCI is a relatively new combustion technology. It is a hybrid of the traditional spark ignition(SI) and the combustion ignition process(such as a Diesel engine). Unlike a traditional S.I. or Diesel engine, HCCI combustion takes place spontaneously and homogenously without flame propagation. This eliminates heterogeneous air/fuel mixture regions. The greatest challenge is controlling the HCCI engines ability to operate under a wide range of speeds and loads. The HCCI engine does not have a combustion trigger such as a spark plug or fuel injector found in conventional engines. Instead, combustion is achieved by controlling the temperature, pressure and composition of the fuel-air mixture so that it spontaneously

ignites at the proper time.



The required control system is fundamentally more challenging than conventional engines because the ignition is sensitive to very small changes in temperature. When a load is suddenly added, as when a vehicle goes from idle to cruising speed, the control system must adjust the temperature, pressure and composition rapidly enough to maintain stable combustion. Several approaches have been suggested for combustion control in HCCI Engine, They are

i. Variable compression ratio control
ii. Variable induction temperature control
iii. Variable valve actuation control
iv. Dimethyl-Ether Additive Control
v. High peak pressures and heat release rates
vi. Inlet heating Control
vii. EGR Control

4.VARIABLE COMPRESSION RATIO CONTROL

There are several methods of modulating both the geometric and effective compression ratio. The geometric compression ratio can be changed with a movable plunger at the top of the cylinder head. The effective compression ratio can be reduced from the geometric ratio by closing the intake valve either very late or very early with some form of variable valve actuation. Both of the approaches mentioned above require large amounts of energy to achieve fast responses and are expensive.

Variable Induction Temperature Control

This technique is also known as fast thermal management. It is accomplished by rabidly varying the cycle to cycle intake charge temperature. It is also expensive to implement and has limited bandwidth associated with actuator energy.

Variable Exhaust Gas Percentage Control

Exhaust gas can be very hot if retained or re inducted from the previous combustion cycle or cool if recalculated through the intake as in conventional EGR systems .The exhaust gas dual effects on HCCI combustion. It dilutes the fresh charge, delaying ignition and reducing the chemical energy and engine work. Hot combustion products conversely will increase the temperature of the gases in the cylinder and advance ignition.

Variable Valve Actuation Control

Variable valve actuation allows control over the compression ratio and the exhaust gas percentage. However, fully variable valve actuation is complicated and the component is expensive.

High Peak Pressures and Heat release rates

In a typical gasoline or diesel engine, combustion occurs via a flame. Hence at any point in time, only a fraction of the total fuel is burning. This results in low peak pressures and low energy release rates as fuel is burnt over a long period of time. In HCCI, however the entire fuel/air mixture ignites and burns nearly simultaneously resulting in high peak pressures and energy release rates. To withstand the higher pressures, the engine has to be structurally stronger.

Several strategies have been proposed to lower the rate of combustion. Two different blends of fuel can be used. That way, the two fuels will ignite at different points of time resulting in lesser combustion speed. The problem with this idea is the requirement to set up an infrastructure to supply the blended fuel. Dilution for example with exhaust, reduces the pressure and combustion rate at the cost of work production.

Dimethyl-Ether Additive Control

Auto ignition timing may be controllable by blending low cetane number fuel (Natural gas) with high cetane number fuel(DME). Dimethyl ether is an ideal fuel additive for natural gas HCCI because has a small ignition delay and because DME has similar reaction chemistry to methane and DME does not tend to promote soot formation. DME concentration is always adjusted to achieve peak heat release at TDC. Residual gases are not considered in this analysis in order to isolate specific temperature effects. Thus the charge is pure fuel and air and the intake equivalence ratio is equal to the in-cylinder equivalence ratio.

Inlet Heating Control

HCCI control by inlet heating involves adjusting the mixture temperature so that conditions are appropriate for auto ignition of the charge to occur at the desired crank angle, TDC in this case. A heat source such as an electric heater or air-to-air heat exchanger with hot exhaust gases would be required in an operating engine. The mixture at the start of the cycle is fuel and air only with no residual gases considered. The inlet temperature is the temperature specified in the cylinder at beginning of the compression stroke. The 100ppm Nox constraint is reached at equivalence ratios of to for all cases. This Nox limit could probably be extended with some EGR, at the expense of efficiency. Supercharging and increasing the compression ratio decreases the required inlet heating and this appears to also reduce the peak temperature at a fixed equivalence ratio, leading to lower Nox for these cases. With inlet heating auto ignition can be achieved even at very low temperature. Supercharging heats the intake air, so that little additional heating may be required under some supercharged conditions.

5.EGR Control

Blending the intake fuel-air mixture with hot residual gases has several effects. First the residual gases will raise the charge temperature. Second, the specific heat ratio of the mixture will decrease, resulting in lower TDC temperature and pressure, relative to the TDC temperature for a pure fuel/air mixture. In a lean burn engine, the intake fuel/air ratio based on the mixture of fuel and air before addition of residual gases will be different than the in-cylinder fuel-air ratio when residual gas has been blended with the intake charge. EGR is the fraction of residual gas in the cylinder relative to the inducted fresh fuel and air. In an operating engine hot residual gases can be introduced into the cylinder in several ways. For example, an insulated line could be run from the exhaust and blended with the intake air or the engine exhaust valve could be closed early with variable valve timing control. The EGR must be effectively mixed with the incoming charge to prevent the possibility of issues such as increased Nox emissions or cycle-to-cycle variations. The Nox limit governs the operation range.

6.OVERALL DISCUSSION OF CONTROL METHODS

Each of the control methods presented has the potential to control combustion timing in an HCCI engine. Some general observations can be made about how these methods can be applied to HCCI engine control. Supercharging will be required to achieve reasonable power density. Intake air compression, either with a mechanical supercharger or turbocharger will need to be able to accommodate a wide range of boost pressure, possibly up to 2 bar of pressure boost. The mechanical pressure limits of the engine will become a constraint with higher levels of supercharging. The constraint on peak Nox also affects power density. Boosting the intake pressure and increasing the compression ratio decreases the quantity of a particular control variable necessary to achieve TDC combustion, i.e. less DME additive, less inlet heating, or less EGR is required. Higher compression ratio engines appear to be the best choice for an HCCI.

Fuels for HCCI Engines

Fuels and additives might improve HCCI engine performance. Propane, methane, natural gas, ethanol, iso-octane and a variety of additives are used. Fuels with a relatively low octane number such as n-heptane or diesel fuel, require lower intake temperatures and fuels with a high octane number such as methane and natural require higher intake temperatures.

Advantages of HCCI

- Very low Nox because of lean mixture results in very low temperature
- Very low dry particulate emissions because of homogenous lean mixture
- Very high efficiency due to very fast combustion, high compression ratio and low heat transfer.
- Does not requires spark plugs.

7.CONCLUSION

In addition, HCCI is a lean combustion process. These conditions translate to a lower local flame temperature which lower the amount of Nitric Oxide (Nox) produced in the process. Nox is a gas that is believed to be responsible for the creation of Ozone (O3).If the engine combustion may control it will be more efficient than SI and CI engines.

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