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Performance and emission characteristics of HCCI engine fueled with Natural Gas: A Technical Review

Prof. Vivek G. Trivedi[1] and Nejal N. Patel[2]

[1]Assistant Professor, Mechanical Engineering Department, L.D. College of Engineering
[2]PG scholar, Mechanical Engineering, L.D. College of Engineering

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ABSTRACT

Alternate fuels have been used to fulfill the demand of fuel for engines used at various fields and also due to the decreasin g petroleum fuel resources. Moreover the very low emissions norms have led to the experimentation, analysis and optimization of operating parameters of the engines run with these alternate fuels. Optimization of operating parameters to suit these alternate fuels have led to various new combustion techniques and one of these is HCCI. HCCI technique is a promising combustion mode with high efficiency and low emissions of NOx and PM. This experiment's objective is to analyses the working of a single cylinder diesel engine under HCCI combustion mode using CNG, renewable fuel widely available from the agricultural wastes. The engine is run at its conventional mode and at HCCI mode with both Diesel HCCI and also CNG HCCI.

HCCI - Homogeneous Charge Compression Ignition

Homogeneous charge compression ignition (HCCI) is an innovative technology. In the HCCI engine, ultra -lean air-fuel mixture is highly compressed by the piston and ignited at the self-ignition temperature. Then, combustion occurs in the entire combustion chamber, and the combustion rate is very high, combustion is initiated by spontaneous auto -ignition of multiple sites under high temperature and high pressure conditions. As a result of ultra-lean combustion under a high compression ratio, high thermal efficiency and extremely low NOx emission are achieved. HCCI engines combine characteristics of both spark-ignited engines and compressed ignited engines. Similar to spark ignited engines, HCCI uses a pre-mixed fuel-in-air charge, and similar to compressed ignited engines, the mixture is compression ignited. The diluted premixed charge facilitates a relatively uniform auto-ignition event rather than a non-premixed flame found in diesel engines, and thus HCCI engines can achieve fewer emissions of particulate matter. Homogeneous charge compression ignition, when applied to a gasoline engine, offers the potential for a noticeable improvement in fuel economy and dramatic red uctions in NOx emissions as compared to the spark ignition operation. Ultra low NOx levels and near zero soot emissions while maintaining high thermal efficiency, makes Homogenous Charge Compression Ignition (HCCI) combustion one of the most promising inte rnal combustion engine strategies for the future. The advantages of HCCI combustion is due to its nature of very lean and premixed rapid combustion with high heat release rate and no flame front. HCCI combustion has high thermal efficiency because of ability to run with high compression ratios, no throttle loss, lean and almost constant volume combustion.

HCCI has the following advantages,

- High efficiency
- Low NOx
- Low particulate matter (smoke)
- Ability to operate on a variety of fuels
- Low exhaust temperature

While the potential benefits of HCCI combustion are great, there are many difficulties need to be prevailed over. Producing high levels of CO and HC emissions, problems in cold start and reduced normal operating range of HCCI engines are some of these difficulties. One of the most important technical challenges is to control the start of combustion (SOC) across the speed and load range of engine.

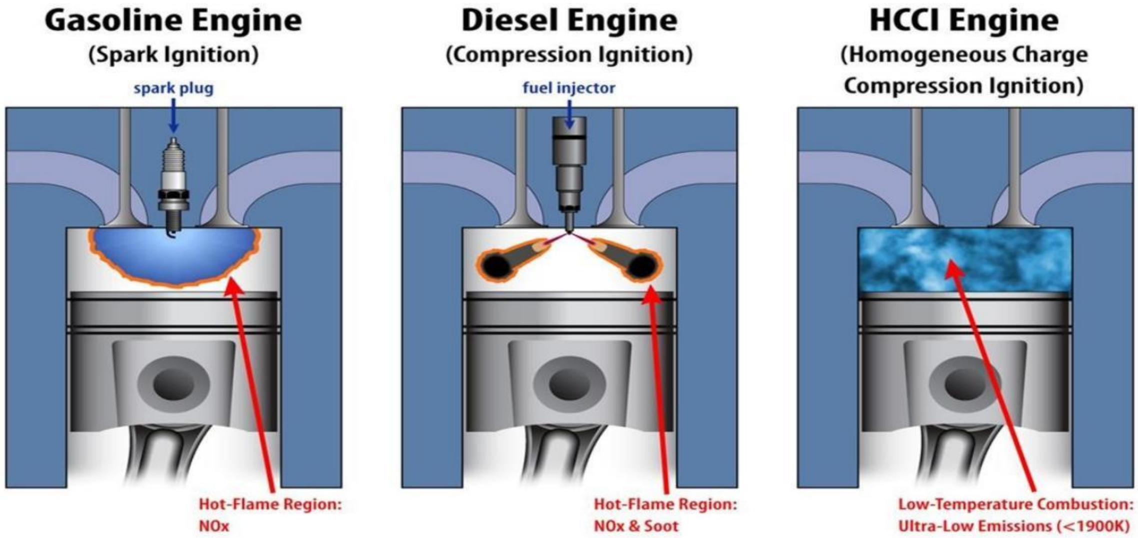

Fig. 1.1: Comparison of SI, CI and HCCI

Literature Survey of HCCI Engine

Kathi Epping, Salvador Aceves, Richard Bechtold, John Dec, This paper describes the current state of HCCI technique listing the various barriers that are to be overcome before its implementation for commercial use. HCCI engines work on the principle of combustion of dilute premixed charge. The charge burns volumetrically throughout the cylinder volume. In HCCI, the higher efficiencies are attained along with low emissions of PM (particulate matter) and NOx. There is no flame front propagation taking place and combustion is almos t simultaneous throughout the chamber but the temperature attained is lower than that needed for NOx formation. HCCI engines are not suitable for Idle and heavy load conditions. Hence a dual mode engine is usually used where the engine runs as conventional SI or CI engine under idle and Heavy load conditions and switched to HCCI mode for low to mid load conditions.

HCCI is feasible only with the use of electronic control system and also the emissions of CO and HC are higher from an HCCI engine than the conventional engine though NOx and PM being lower in the emission. Lower fuel injection pressure can be used with HCCI. It has little sensitivity to fuel characteristics like lubricity and can be used on any hydrocarbon and alcohol liquid fuel as long as the fuel is vaporized and mixed with air. Dual fuel method in HCCI is proved to maintain a good combustion over a wide range of speed and load.[1]

Miguel Torres Garcia, Francisco Jose Jimenez-Espadafor Aguilar This paper describes the experimental results for the modified diesel engine in HCCI combustion mode fueled with commercial diesel fuel compared to the diesel engine mode. An experimental installation, in conjunction with systematic tests to determine the optimum crank angle of fuel injection has been used to measure the evolution of the cylinder pressure and to get an estimate of the heat release rate from a single -zone numerical model. From these the angle of start of combustion has been obtained. The performances and emissions of HC, CO and the huge reduction of NOx and smoke emissions of the engine are presented. These results have allowed a deeper analysis of the effects of external EGR on the HCCI operation mode, on some engine design parameters and also on NOx emission reduction.

The air–fuel equivalence ratio has a direct effect on HCCI timing, advancing the start of combustion when the air–fuel equivalence ratio diminishes. This has a negative effect on engine power because the pressure increases during compres - sion stroke. Soot emissions are negligible in the HCCI combustion mode, and are independent of the EGR rate. Engines running in the HCCI combustion mode with EGR reach ultra-low NOx emissions. In general the CO and HC are higher in the HCCI combustion mode than in the diesel mode due to early injection and fuel adhering to the cylinder walls[2].

Xingcai Lu, Yong Qian, Zheng Yang, Dong Han This study is dedicated to the fundamental research of the combustion and emissions characteristics of compound HCCI combustion fueled with gasoline and diesel blended fuel. Moreover, this study attempts to investigate the potential of compound HCCI combustion to achieve clean combustion at full load ranges with the application of the intake air boost.

With an increase in the premixed ratio The CO, HC and soot emissions increase at first and then decrease whiles the NOx emissions decrease monotonically. With an increase in the total fuel consumption per cycle the CO emissions increase at first and then decrease; and the HC emissions decrease monotonically while the NOx and soot emissions increase gradually. The intake air boost has great potential to simultaneously reduce the NOx and soot emissions of compound HCCI combustion while maintaining the original CO and HC emission levels. Ultra-low NOx and smoke emissions are obtained of diesel-line compound HCCI combustion using intake charge boost.[3]

Augusto F. Pacheco, Mario E.S. Martins, Hua Zhao, “A drive cycle comparison of a passenger car running with and without the HCCI technology is performed, showing the potential changes and the possibility to comply with new and tighter emissions standards. Commercial simulation software was employed for the vehicle simulation whereas engine data was experimentally obtained and included in the model to evaluate the changes on emissions and fuel consumption of a passenger car running the New European Driving Cycle (NEDC) when using the HCCI engine configuration.

There is main conclusion, in comparison to the original SI engine, 53% reduction in NOx emissions was achieved. Th e Euro 6 standard cap for NOx emissions is 60 mg/km for PI engines and 80 mg/km for CI ones; the HCCI/SI engine NOx emissions were kept at 37.3 mg/km, which ensures its potential for achieving future emission legislation. HC emissions were 5% higher on HCCI, but they were still lower than both PI and CI Euro 6 standard limits. CO emissions were more than 30% lower with the HCCI/SI switching engine. In comparison to the SI combustion engine, the fuel consumption was reduced by 21% as a result of the higher efficiency of the HCCI/SI engine. Likewise, due to the reduced fuel consumption, CO_2 emissions were reduced on more than 21% when using HCCI.[4]

Literature Survey of Natural Gas (CNG) in HCCI Engine

Chedthawut Poompipatpong, Kraipat Cheenkachorn, A diesel engine was modified for natural gas operation to optimize performance using gaseous fuel. A variation of combustion ratios (CR) including 9.0:1, 9.5:1, 10.0:1 and 10.5:1 was utilized to evaluate engine performance and emissions from the same engine over th e engine speeds between 1000 and 4000 rpm. Tested engine performance parameters include brake torque, brake power, specific fuel consumption (SFC) and brake thermal efficiency. Emissions tests recorded total hydrocarbon (THC), nitrogen oxides (NOx) and carbon monoxide (CO).

Using the same engine, natural gas showed improved performance over the diesel engine, approximately 5.67%e13.07%. For CRs ranging from 9:1 to 10.5:1, a CR of 9.5:1 had the highest thermal efficiency at speeds between 1500 and 2500 rpm. THC emissions were directly proportional to CR. NOx emissions increased with an increase in CR and then fell off after CR of 10:1 . The highest average concentration of CO was observed at a CR of 9:1. CO emissions then dropped to the lowest concentration at a CR of 9.5:1 before steadily increasing with compression ratio.[5]

Giuseppe Genchia, Emiliano Pipitonea, This paper regards an experimental study on a particular internal combustion engine process which combines Double Fuel combustion with Homogeneous Ch arge Compression Ignition (HCCI) using mixtures of natural gas (NG) and gasoline. The tests performed on a CFR (co-operative fuel research) engine demonstrate that HCCI combustion can be achieved using NG-gasoline mixtures without knocking occurrence for low to medium engine load varying the proportion between the two fuels.

Double Fuel HCCI combustion can be achieved with natural gas -gasoline mixtures, reaching significantly increments in indicated efficiency (up to +24%) with respect to conventional spark ignition mode, in a load range between 20% and 55% of the maximum SI engine load. The greatest advantage of the Double Fuel HCCI combustion however resulted to be in the pollutant emissions, which, with the only exception of HC, revealed a strong reductio n. In particular, in HCCI mode, lower NO emissions of two order of magnitude have been measured respect to SI mode, with a mean value of only 20 ppm. In light of the constricting environment saving rules and increasing cost of fuels, the negligible NO emis sions, as well as the high indicated engine efficiency, represent the main and most interesting results obtained in this preliminary experimental study.[6]

Ali Yousefzadi Nobakht, R. Khoshbakhi Saray, Arash Rahimi, In this work, a parametric study on natural gas HCCI combustion is conducted in order to identify the effect of inlet temperature and pressure, compression ratio, equivalence ratio and engine speed on combustion and engine performance parameters. In this paper, two kinds of parameters will be discussed. First, in-cylinder pressure diagrams and variation of start of combustion which are combustion parameters will be presented and then the second category, indicated mean effective pressure and thermal efficiency which are performance parameters will be studied.

Results of the work can be summarized as follows:

- Increasing Tivc advances the combustion but decreases the engine efficiency and IMEP
- IMEP and thermal efficiency are increased by inlet pressure increment. Also, combustion takes place earlie r when the Pivc is increased.
- Combustion is advanced with increasing compression ratio, but it has negative effect on engine performance and it decreases IMEP and thermal efficiency.
- Increasing U advances combustion because of higher fuel availability in the combustion chamber. It also improves IMEP and thermal efficiency.
- In higher RPMs, the combustion is retarded and

IMEP and thermal efficiency are increased because the combustion takes place in the expansion stroke to produce more expansion work.

- Among the considered parameters, the equivalence ratio and inlet pressure are the most valuable parameters which can improve the combustion and performance characteristics of the HCCI engine. [7]

Junnian Zheng, Jerald A. Caton is presenting A single zone thermodynamic model with detailed chemical kinetics was used
to determine the effect of operating parameters on nitrogen oxides emissions. The simulation was conducted for a modified single cylinder engine, which possessed a compression ratio of 21.5:1, and had a bore and stroke of 86 and 75 mm, respectively. Several sets of parametric studies were completed to investigate the effect of engine load (imep = 200 –600 kPa), speed (600–3000 RPM), equivalence ratio (0.3–1.0), EGR level (0–40%), temperature at IVC (390–460 K), and fuel compositions (0–10% C2H6) on nitrogen oxides emissions.

Results of this work can be summarized as follows:

- The nitrogen oxides emissions were reduced with decreasing engine load, temperature at IVC, and mole fraction of C2H6. The reduction in the nitrogen oxides emissions mainly resulted from the shortened length of the high temperature period (over 1300 K) associated with the variations of these parameters.
- The nitrogen oxides emissions were reduced with increasing EGR level. The reduction was attributed to the reduction in the combustion temperature due to the increasing amount of EGR.
- The nitrogen oxides emissions were reduced with increasing engine speed. As engine speed was increased, the residence time was shorter for nitrogen oxides to be produced and therefore the nitrogen oxides emissions were lowered.
- The nitrogen oxides emissions first increased and then decreased with increasing equivalence ratio, and the peak NOx appears when the equivalence ratio was around 0.7. For equivalence ratios less than 0.7, the temperature effect dominated the NOx formation. For equivalence ratios higher than 0.7, the higher NOx destruction rate and longer NOx destruction period mitigated the nitrogen oxides emissions production.[8]

Summary of literature survey

- HCCI provides better fuel efficiency and it is most needed in this scenario of emerging technologies.
- HCCI has intrinsic fuel flexibility.
- As seen from above literature survey, use of natural gas as fuel in engine gives best performance and lower emission. So it is economical and environment friendly, that is the reason of selecting natural gas as a fuel.
- The emissions of NOX and smoke are low in all advanced combustion modes in comparison with conventional dieselengine.
- The HCCI combustion engines have the potential to improve the thermal efficiency.

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