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# HCCI Engine fueled with biodiesel: A Comprehensive Review

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***Abstract: The Homogeneous charge compression ignition (HCCI) combustion is an alternative to current engine combustion systems and research in HCCI is being carried out to use it as a method to reduce emissions. HCCI has the potential nearly to eliminate engine-out NOx emissions while producing efficiencies as in diesel engine, when a pre mixture of gas-phase fuel and air is burned spontaneously and entirely by an auto ignition process. Homogeneous Charge Compression Ignition (HCCI) engines promise high thermal efficiency combined with low levels of nitric oxide and particulate matter emissions. The purpose of this study is to summarise the alternative fuel effect for the HCCI engine combustion process.***

***Key Words: Homogeneous Charge Compression Ignition (HCCI), Diesel, Diesel Engine, Performance and Exhaust Emission***

## INTRODUCTION

Demand for petroleum products is increasing day-by-day however the resources are fairly limited. Beside this, there are grave concerns over environmental pollution specially pollution from the automotive/engine exhaust. Therefore it is necessary to develop a technology, which could overcome both issues. HCCI is a technology, which is highly efficient as well as less polluting. HCCI is a hybrid of both spark ignition (SI) and compression ignition (CI) combustion concepts [1].

Reducing exhaust emissions and increasing the fuel economy of internal combustion engines are of global importance. To meet the demand of economy, energy conservation, less environmental harmful exhaust emissions, especially carcinogenic $NO_x$ and responsibility for a greenhouse effect $CO_2$ and higher thermal efficiency present generation engines must be characterized by: low fuel consumption; high efficiency; reliability; low price and low cost of usage. Although there is a lack of direct ignition control, the HCCI combustion concept is an effective way to meet these requirements. This new concept of engine that achieves higher efficiency at lower fuel consumption and generates less $NO_x$ emissions has recently been proposed. This developed as alternative for diesel engine with high efficiency, low NOX and emission.

Engines are operated in the region of lower equivalence ratios to improve efficiency and reduce emissions. Due to enormous increase in the vehicle population, the lean combustion technology is employed mainly in IC engines. The $NO_x$ emission can be reduced only by reducing the flame temperature of combustion. Lean burn engines produce lower temperatures, which is the key factor to reduce the formation of thermal oxides of nitrogen. The excess air employed in lean burning results in a more complete combustion of the fuel which reduces both the hydrocarbon and carbon monoxide emissions. Moreover, the heat transfer losses in the IC engine can be decreased only minimizing the combustion temperature. The HCCI combustion is one in which the low temperature combustion (LTC) is used to reduce the heat transfer losses, and the heat of fuel is completely released in a few crank angles near top dead centre (TDC).One major advantage of the HCCI concept is that the lean and premixed combustion reduces the formation of harmful pollutants, mainly particulate matter and nitric oxides [4].

## HCCI IN DIESEL ENGINE

As known, some of the very early 2-stroke and 4- stroke diesel engines had been operated with compression ignition of premixed air and fuel mixtures through early injection onto the hot surface of a heated chamber. However, the best, but little known, example of HCCI diesel engines ever developed is the 2-stroke diesel model airplane engine developed since the 1940s by a small British company called Progress Aero Works (PAW). The fuel is a special blend of kerosene, oil, ether, and an ignition improver. The fuel is fed into the engine's intake through a carburettor so that a premixed air/fuel mixture is formed in the cylinder. Here, to get the engine firing, it is necessary to screw in the compression screw on the top of the engine so as to set the engine to a higher compression ratio. After the engine has started, it is needed to unscrew the compression to achieve maximum power output. These little PAW engines produce power from 0.06 bhp to 1.2 bhp at speeds from 10,000 rpm to over 20,000 rpm and are readily available from the manufacturers.

Due to the need for substantial reductions in both NOx and PM emissions, systematic investigation had begun of the potential for diesel fuelled HCCI engines for automotive applications in the mid-1990s. The research and development of HCCI diesel engines had been pursued along three main technical routes, depending on the mixture preparation process involved. The first approach involves injecting the fuel into the intake air, upstream of the intake valve, similar to a conventional port-fuel injection (PFI) SI engine. This method has been used in the past for diesel fumigation wherein diesel or often other more volatile fuels are injected in the manifold together with direct injection of diesel into the cylinder. Most recently, research on this premixed HCCI diesel combustion has been mostly performed to demonstrate the strong potential of HCCI to substantially reduce NOx and smoke emissions as well as to understand the fundamental characteristics of HCCI diesel combustion [11]. However, this approach is unlikely to be developed into a practical solution due to poor vaporization of the diesel fuel, high fuel consumption, and high uHCs. With the advent of fully flexible high-pressure electronic fuel injection systems, in particular the common rail (CR) fuel injection system, direct fuel injection into the cylinder well before TDC has been the most popular approach to achieve HCCI combustion in diesel engines [12–14].

By injecting all or part of the fuel early in the compression stroke, the higher cylinder temperature and densities can facilitate the fuel vaporization and promote its subsequent mixing with air. In addition, the flexibility of fuel injection timing and multiple injections can be employed to control and optimize the combustion phasing. However, the most successful HCCI diesel system in production to date is achieved through the employment of the late injection after TDC developed by the Nissan Motor Company [15]. Known as MK (Modulated Kinetics), this combustion process has been used at part load and low to medium speeds in their production diesel engines since 1998. Further enlargement of HCCI combustion operation was achieved in their second-generation system in 2001 to include the entire range of the Japanese 10–15 mode test.

**Table – 1 Properties of Diesel [5].**

| **Property name** | **Diesel Property** |
|---|---|
| Density kg/m$^3$ (at 15°C) | 830 |
| kinematic Viscosity at 40°C (m$^2$/s) | 1.3 |
| Flash point (Temp in °C) | 55 |
| cetane number | 51 |
| Molecular weight | 200 |
| Specific gravity (kg/m$^3$) | 0.85 |
| Auto- ignition temperature(°C) | 263 |

## HCCI ENGINE EMISSIONS

Dae [9] studied the improved emission characteristics of an HCCI engine with various premixed fuels. Partial HCCI combustion was used as a control mechanism. The premixed fuel is supplied via a port fuel injection system located in the intake port of a DI diesel engine. The results show that with diesel premixed fuel, a simultaneous decrease of NOx and soot can be obtained by increasing the premixed ratio. However, when the inlet charge is heated for the improved vaporization of diesel fuel, the higher inlet temperature limits the operational range of HCCI combustion due to severe knocking and high NOx emission at high premixed ratios. Gasoline premixing shows the most significant effects in the reductions of NOx and soot emissions, compared to other kinds of premixed fuels.

Dae [7] studied the combustion and emission characteristics of a partial HCCI engine with a two stage injection system. The effect of the premixed ratio and timings of the first and main injection on the combustion characteristics and exhaust emissions in a DI diesel engine were discussed. The results showed that two-stage injection was very effective in reducing NOx emissions from a DI diesel engine. Additionally, at optimized injection timing, the ignition of the premixed fuel can be controlled by the main injection without premature auto ignition.

The effect of narrow fuel spray angle injection and dual injection strategy on the exhaust emissions of a common rail diesel engine was investigated by Myung [6]. The investigation showed that a dual injection strategy consisting of an early timing for the first injection for HCCI combustion and a late timing for the second injection was effective to reduce the NOx emissions while it suppresses the deterioration of the combustion efficiency caused by the HCCI combustion.

E. Mancaruso et al [2], studied the effect of both the new homogeneous charge compression ignition (HCCI) combustion process and the use of bio-fuel, optical measurements were carried out into a transparent CR diesel engine. OH and HCO radical were detected and their evolutions were analyzed during the whole combustion. Moreover, soot concentration was measured by means the two colour pyrometry method. The reduction of particulate emission with biodiesel as compared to the diesel fuel was noted.

Miguel [10] experimentally studied the performance of a modified diesel engine operating in the HCCI combustion mode versus the original diesel combustion mode. The experimental results for the modified diesel engine in the HCCI combustion mode fueled with commercial diesel fuel were compared to those of 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 the combustion has been obtained. The performance 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.

Homogeneous charge compression ignition (HCCI) combustion of diesel fuel with external mixture formation was studied by Ganesh [8]. A fuel vapouriser was used to achieve excellent HCCI combustion in a single cylinder air-cooled direct injection diesel engine. No modifications were made to the combustion system. In this study, a vaporized diesel fuel was mixed with air to form a homogeneous mixture and inducted into the cylinder during the intake stroke. To control the early ignition of the diesel vapour–air mixture, the cooled (30°C) EGR technique was adopted. Experiments were conducted with diesel vapour induction without EGR and diesel vapour induction with 10%, 20% and 30% EGR, and the results are compared with those of conventional diesel fuel operation (DI at 23° BTDC and 200 bar injection pressure).

Francisco J. et al [3] studied low temperature combustion mode with diesel and biodiesel. This paper shows a methodology for HCCI combustion mode of biodiesel mixtures based on a high swirl ratio and EGR rate combined with late injection where HRR, $NO_x$, CO, HC and soot emissions have been analyzed. This strategy has reduced fuel wall impingement encountered when early injection is used. $NO_x$ emissions reduce as EGR increases, as with conventional diesel combustion. A small increase in $NO_x$ emissions is observed when the Biodiesel percentage increases, although this is probably related to ignition timing.

Gajendra singh et al [1] studied combustion, performance and emission characterization of biodiesel fueled HCCI engine using external mixture formation technique. Effect of EGR was investigated and it was found to be a very effective tool to control HCCI combustion. This study concludes that reduction in power output and an increase in ISFC were observed upon increasing the biodiesel content in the test fuel. A small increase in CO, HC and smoke emissions was observed with increasing biodiesel content due to slower evaporation rate of biodiesel. A significant reduction in $NO_x$ emissions was also observed with for biodiesel blends.

## CONCLUSION

The literature review shows that the HCCI mode operation in IC engines reduces the emissions, which is the most important criterion for the current environmental norms, and also, the study found that the HCCI mode also decreases the overall fuel consumption. There is a limited number of research works available related to the usage of bio-fuels in HCCI mode. In this regard this research work aims to study the emissions, efficiency and fuel consumption in the HCCI mode with conventional diesel and bio diesel.

1) The IMEP increases with the increase of premixed ratio at low to medium loads.
2) The emissions of NOx and smoke are low in all advanced combustion modes in comparison with conventional diesel engine.
3) The lower soot generation for biodiesel is hypothesized due to a lower soot formation rate and a higher soot oxidation rate.
4) The HCCI combustion engines have the potential to improve the thermal efficiency, while reducing the trade-off emissions in conventional diesel engines.

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