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# A Review on Diesel Homogeneous Charge Compression Ignition Engine

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## ABSTRACT

Nowadays the Automotive industries are facing the problem of improving the fuel economy and lower emissions. The homogeneous charge compression ignition (HCCI) is an advanced combustion technology that is cleaner and more proficient than alternate kinds of combustion. This paper presents the experimental results regarding HCCI, engine. HCCI engine provides better fuel conversion efficiency and low NOx emission,but nevertheless it has some fundamental issues, for example, concession combustion phase control, controlled auto-ignition, operating range, preparation of homogeneous charge, cold start and emissions of unburned hydrocarbon (UHC), and carbon monoxide (CO) should be defeated for effective process of HCCI engine. Most of the researcher worked out in preparation of homogeneous fuel-air mixture.The main objective of this paper is to provide review on the HCCI external mixture formation and (Direct Injection) DI-HCCI methods. The various methods of combustion phase control by HCCI combustion are also discussed in this paper.

**Keywords:** *HCCI, stratified charge compression ignition (SCCI), low temperature combustion (LTC), Emissions, Direct Injection.*

## 1. INTRODUCTION

Internal combustion engines are the main sources for automotive industries. Engines create control by expending an enormous measure of fuel by combustion, and emit harmful exhaust emissions, for example, unburned hydrocarbon (UHC), carbon monoxide (CO), carbon dioxide (CO2), oxides of nitrogen (NOx), and soot issue [1].The vehicle populace is extending exponentially because of the quick change in the populace. The emission enactments additionally end up plainly stringent. The primary assignment for the researchers, scientists, specialists and intellect is to get an explanation to decrease the engine out flow, and powerful usage of energy. Later most recent two decades, several vehicular industries bring together numerous present automotive vehicles, for the most part to high fuel economy, minimize the emissions, and to utilize altered alternative fuels. In such way, the investigators and architects gave careful consideration towards the propelled methods of combustion like HCCI, stratified charge compression ignition (SCCI), and low temperature combustion (LTC) as the consequences of predominant fuel change efficiencies and ultra-low emissions of NOx and soot.[2]

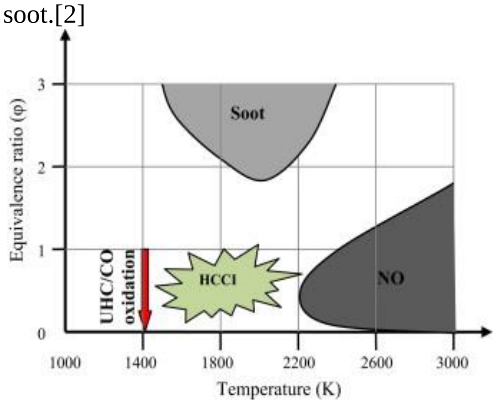


Figure 1.HCCI Combustion instantaneous decrease of $NO_X$ and soot [6]

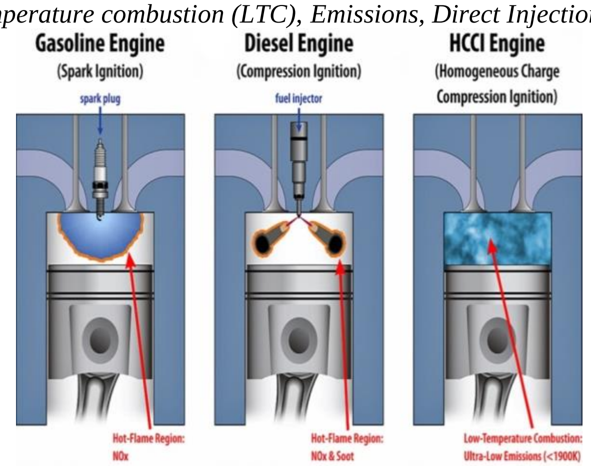


Figure 2. HCCI combustion is a combination of SI and CI combustion methods [6]

Among these, the HCCI engines can possibly chance the severe emission measures (EURO VI) and CO2 emission criteria [4,5]. Fig. 1 shows the district of HCCI combustion great over the unburned hydrocarbon/carbon monoxide oxidation breaking point and rescues the betterment of both NOx and PM. The HCCI combustion is thought to be a standout amongst other combustion innovations to be received more extensive in the demand not so distant future, as it offers a broad selection of fuel versatility [11] with higher fuel conversion efficiency, and low emissions. Fuel flexibility is more over made reference to as a potential favourable position. The arranging of lean homogeneous mixture and low temperature combustion (LTC) are received in HCCI innovation to smother the NOx and PM emissions from the engine. Fig. 2 shows the similarity of SI, CI and HCCI performances. In HCCI engines, a lean homogeneous combustible mixture (fuel–air equivalence ratio $\Phi<1$) is arranged, before the beginning of ignition and auto ignited as an importance of temperature increase in the compression stroke. [3]

The HCCI working is indistinguishable to spark ignition engine which utilizes the homogeneous charge for burning and in the same way to compression ignition engine that takes the auto ignition of the blend. Subsequently, HCCI is the combination of SI and CI combustion processes. In SI engines, three areas of combustion, specifically the burnt area unburned area and a thin flame reaction area amidst for turbulent flame spread over the cylinder. In CI engines, fuel is dispersed inside the cylinder and a particular dissemination flame goes within the cylinder [7]. In HCCI engine combustion self-started ignition of the whole cylinder charge happens without any dissemination flame or flame front spread. The contrast of various parameters affecting the combustion methods in SI, CI, and HCCI are known in Table 1&2. [2]

Table 1. Difference between traditional SI Engine and HCCI Engine.

| **Basic of comparison** | | **SI Engine** | | **HCCI Engine** |
|---|---|---|---|---|
| Ignition method | | Spark ignition | | Auto ignition |
| Ignition point | | Single | | Multi points |
| Fuel economy | | Good | | Best |
| Injection type | | Port injection | | Both port and direct injection |
| Max efficiency | | 30% | | More than 40% |
| Throttle loss | | More | | No |
| Equivalence ratio | | 1 | | Less than 1 |
| Compression ratio | | Low | | High |
| Combustion duration | | More | | Less |
| Major emissions | HC,CO | And NOx | | HC and CO |

Table 2: Comparison between Diesel Engine and HCCI Engine

| **Basic of comparison** | **Diesel Engine** | **HCCI Engine** |
|---|---|---|
| Ignition Type | Direct injection | Both port and direct injection |
| Max efficiency | 40% | More than 40% |
| Fuel economy | Better | Best |
| Combustion temperatures | 1900-2100K | 800-1100K |
| Combustion duration | More | Less |
| Major emissions | NOx, PM and HC | HC and CO |

Engines are worked in the district of lower equivalence ratios to enhance efficiency and decrease emissions. Because of huge rise in the vehicle populace, the advanced combustion technology is utilized principally in IC engines. The NOx discharge can be entire just by lessening the flame temperature of combustion. Lean burns engines form brings down temperatures, which is the main influence to decrease the creation of NOx. The excess air utilized in lean burning outcomes in a more total ignition of the fuel, which decreases both the UHC and CO emissions. The HCCI engines are worked in auto-ignite off the fuel by the compression as the piston proceeds to the top dead center. The engine must be worked on a variable compression ratio (VCR) to change the auto-ignition of the cylinder charge close to the TDC. An extensive change of fuels can be burnt effectively by implementing the VCR system. A part of alternate strategies for fuel adaptability for the given engine are charge heating [16], boost pressure, exhaust gas re-use variable valve actuation (VVA) etc. [2]

**HCCI**

The mixture planning in HCCI engines is a critical parameter and it can be accomplished by utilizing either port fuel injection or port fuel injection with diesel vaporizer that prompts a homogeneous charge mixture.Common rail Direct injection (CRDI) is another technique embraced, where fuel can be injected very early in the compressor stroke or at a later stage under high pressure to accomplish a homogeneous mixture. The most widely recognized techniques embraced to encourage auto-ignition of the blend should be possible by expanding the compression ratio, heating the charge, exhaust gas recirculation and utilizing blends of mixes.

**Methods of preparation of external mixture**

A few researchers presented an electronically precise fuel vaporizer used on behalf of low volatility and high boiling point fuel certain a diesel. The diesel vaporizer designed a precise aspect and dispersed aerosol using a quick evaporation because of a better surface to volume ratio. The smoke emissions were expressed to be insignificant and the exhaust gas re-use was used for ignition control and the NOx outflows. The process temperature of vaporizer is over the boiling point of fuel for effective preparation of an outside mixture (8,9,10).

Ganesh et al. [8] studied the performance and emission characteristics of the HCCI with port fuel injection method aided by fuel vaporizer on a single cylinder, air cooled DI diesel engine. Cooled EGR (30℃) in 10, 20 and 30% amount was applied to control the early ignition. The results concluded that at

30% EGR rate given low NOx, smoke emissions and poor fuel economy.

Singh et al. [9] focused on the relative air–fuel ratios and EGR rates. Results given that, at λ>3.70 with noiseless and smooth engine process.

G.Nagarajan et al. [10] had conducted experiments to investigate HCCI mode and DI diesel and DI biodiesel mode of operation. The results given that, ignition delay reduced due to better mixture preparation. Also, huge decrease in NOx and smoke emissions with 10% exhaust gas recirculation. The experimental conditions of authors [8-10] is presented in Table 3 and Figure 3.

Table.3 Overview of Approaches of Outside mixture preparation after literature

| Researcher | Used as fuel | Preparation of homogeneous charge technique | Advantages | Disadvantages |
|---|---|---|---|---|
| D. Ganesh et al [8] | Diesel | Fuel vaporizer with Port fuel injection | 90-98% of NOx emissions were decreased and gives good fuel efficiency | The UHC emission was more due to poor combustion efficiency. |
| Singh et al [9] | Diesel | Diesel fuel vaporizer | Air–fuel ratios (λ = 4.95, 3.70 and 2.56) At λ>3.70 Reduced $NO_x$ and smoke emissions and lower maximum cylinder pressure | The UHC and CO emissions were more |
| G.Nagarajan et al[10] | Diesel | Diesel fuel vaporizer | $NO_x$ and smoke emissions were reduced | - |

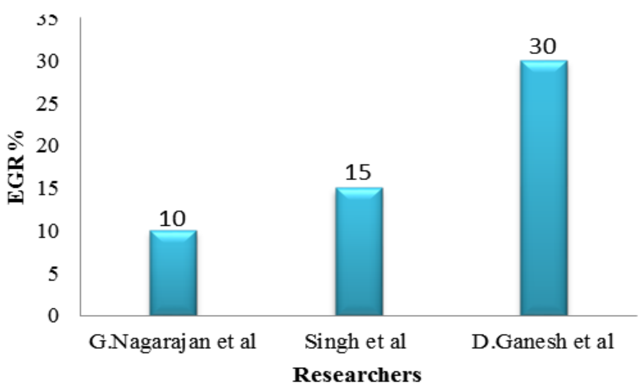


Figure.3. Maximum EGR usage in single cylinder engine for HCCI

**Port fuel injection**

The port fuel injection is the easiest technique of preparation of outside mixture, in which injector is mounted in the intake manifold, near the intake valve. This method progresses the fuel distribution and volumetric efficiency through carburetion. The mixture goes into the cylinder a mid-engine suction and the turbulence made by intake flow enhances assist homogenization. Already stated strategy for blend arrangement has been expressed to be effective with petrol and alcoholic fuel. The primary impediment of this system is injection timing can't impact the beginning of ignition. Additionally, heavy fuels with lower volatility of PFI outcomes in poor vaporization in increased wall impact.

A few researchers utilized a more intake air temperature to vaporize the fuel in the intake manifold.

Maurya et al. [11] conducted experiments with port fuel injection method for preparing homogeneous mixture. Experiments were performed by altering the intake charge temperature (120-150$^0$c) and equivalence ratio (2.0-5.0) at constant speed 1500 rpm with a specific end goal to accomplish the stable HCCI ignition. As reported that at 120$^0$c, λ =2.5 given better combustion characteristics, combustion efficiency and less NOx emissions.

Agarwal et al. [12] have worked on HCCI engine fulled with ethanol and methanol by changing the intake air temperatures. The results stated that, methanol and ethanol are the best substitutes for the petroleum fuels.

HarisankarBendu et al. [13] did Experiments on HCCI mode with Port fuel injection of ethanol. From the investigation, it was reported that, at 170°C, the maximum value of combustion efficiency and brake thermal efficiency of ethanol was observed. Also reported that, the NOx and smoke emissions were reduced.

S. Gowthaman et al. [14] conducted experiments with various inlet charge temperatures such as (80- 120°C). From the investigation, it was found that smoke, CO and HC emissions were reduced but higher the specific fuel consumptions with expanding charge temperature about 100°C.

Nagarajanet al. [15] have done experiments on HCCI engine with jatropha methyl ester fuel. Cooled EGR technique was adopted to control the early ignition of JME vapor-air mixture. From the investigation, it was observed that, 81% of NOx and 72% of smoke emissions were reduced.

Ramesh et al. [16] carried out experiments to study the performance characteristics of acetylene fuel in HCCI engine. The result given that, the high fuel conversion efficiencies and extensive range of BMEPs. And also reported that, optimized EGR and control the inlet charge temperatures increase in brake thermal efficiency and knock, external charge heating were avoided.

AkhilendraPratap Singh et al. [17] worked on three dissimilar fuels like diesolin, diesohol, and diesosene to evaluate its particulate emission characteristics using modified fuels in HCCI mode, engine performance at different loads were discussed.

The experimental conditions of authors [11-17] is presented in Table 4 and Figure 4.

The difficulties involved in the external mixture formation such as Port fuel injection and Fuel vaporizer with Port fuel injection methods for fuel control during engine transients,combustion phase control and extended the operating load. So that another methodology common rail direct injection is to give better improvement compare to others methodology.

Table.4 Overview of Approaches of Outside mixture preparation after literature

| **Researcher** | **Used as fuel** | **Preparation of homogeneous charge technique** | **Advantages** | **Disadvantages** |
|---|---|---|---|---|
| Maurya et al [11] | Ethanol | Port fuel injection | At $120^0$, $\lambda = 2.5$ gives better combustion efficiency=97.47% and fuel conversion efficiency=44.78%, and $NO_x$ emissions are lower than 10ppm was noticed | The CO emission was more due to higher air-fuel ratio. |
| Nagarajan et al [15] | jatropha methyl ester | Port fuel injection | At EGR $30^0$c cooled given 81% NOx decreased and 72% decreased in smoke emission. And also reduced HC and CO. | - |
| Ramesh et al [16] | Acetylene | Manifold | $NO_x$ and smoke emissions were reduced. | Limited to part load operation. |
| Akhilendrapratpsingh et al[17] | Diesoline ,Diesohol ,Diesosene | Port fuel injection | It observed that Gasoline, alcohols and kerosene given better combustion, performance and reduced NOx emissions. | - |
| Harisankar et al [13] | Ethanol | Port fuel injection | At $170^0$c gives better combustion efficiency=98.2% and fuel conversion efficiency=43%, $NO_x$ and smoke emissions were reduced. | The UHC and CO emissions were more. |

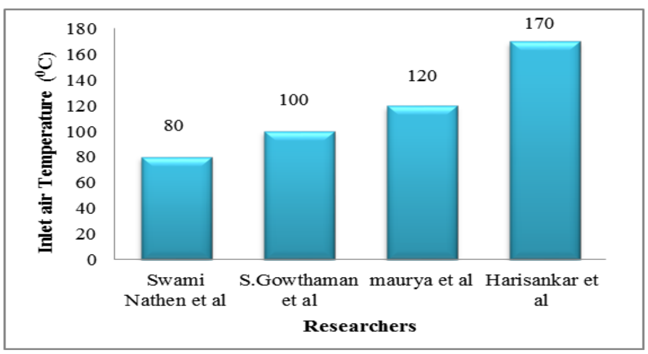


Figure.4. Maximum usage inlet air temperature for HCCI

The difficulties involved in the external mixture formation such as Port fuel injection and Fuel vaporizer with Port fuel injection methods for fuel control during engine transients,combustion phase control and extended the operating load. So that another methodology common rail direct injection is to give better improvement compare to others methodology.

**Common rail Direct injection method**

Numerous researchers have shown comprehensive experimentally on the common rail DI-HCCI to extend the operating load and the combustion phase controlled and also additional reduces the soot and NOx emission to nearly zero level with a little lower brake fuel conversion efficiency.

Pranab Das et al. [18] concentrated on combustion control approach for DI-HCCI combustion using a dual injection method. The results revealed that, NOx and smoke emissions were reduced and extended experiment [19] by using two injection strategies with blends of n-heptane and isooctane fuel. It was found that the most critical output is that a two phase's heat release pattern is observed in high cetane fuel. And also stated that the quantity of isooctane is increased, low temperature heat release part reduces and peak heat release rate, peak pressure rise rate and SOC moves away from the TDC due to longer preparation phase. And also concluded that, cetane number shows a main role in combustion phasing controlling and emission behaviour of the DI-HCCI combustion engine.Can cinar et al. [20] studied the impacts of utilization of DEE on the combustion and outflow emissions in a DI-HCCI engine. The results shown that single phase ignition observed by adding of premixed DEE fuel, and also found that the reduced NOx and soot emissions.Qiang fang et al. [21] investigated the effects of EGR and pilot injection amount on engine performance and emission. The results reported that, increase the pilot injection amount and low range of EGR rates decreases NOx and soot emissions.Junjun Ma et al. [22] focused on the possessions of premixed ratio and DI timing. The results revealed that the increasing the premixed ratios and effective enhanced the brake, fuel conversion efficiency at low to medium load and NOx emissions were decreased.Wang et al. [23] explored the impacts of dimethyl ether (DME) blended with diesel on the combustion and outflow emissions in a DI-HCCI engine. The results given that, better performance with DME blended fuelled engine and observed that, NOx and soot emissions were controlled the common rail system with two or more injection methods.Zaidi et al. [24] a diesel engine was modified to operate as an electronically controlled DI-HCCI engine. The results given that, the fuel consumption decreased by 20-30% and also reduced NOx emissions. Lee et al. [25] studied the single-pilot injection and double pilot injection methods with extensive injection timing, variety different injection amount ratios and several dwell times. The results revealed that the single- pilot injection is the best method to reduce the NOx and smoke emissions compare to other.

**Techniques of HCCI Combustion control**

The combustion control of the HCCI mode engine is one of the testing factors in HCCI advancement. These difficulties ought to be annihilated for the effective process of HCCI engine. The real difficulties are controlling the auto ignition temperature of the blend, confine the rate of heat release at high load operation, and exhaust emissions control and decreasing the knocking. The HCCI combustion can be more precise by preheat the inlet air, pressurized inlet air, variable compression ratio, variation of valve timing, boost injection pressure, changing equivalence ratio, utilizing ignition improver or fuel additives and exhaust gas recirculation.

Some Researchers focused on combustion parameters in the combustion chamber and studied combustion and performance characteristics. Maurya et al. [26] did an experimental study on HCCI combustion of ethanol at intake air temperature and at various air-fuel ratios. This experiment focused on combustion parameters and observed that, the controlled combustion parameters, gives better efficiency and low emission. Agarwal et al. [27] showed experiments with various intake air temperatures ranging from $120^0$C to $160^0$C at different air-fuel ratios, for which stable HCCI combustion is achieved. In this regard, the researcher focused on the combustion parameters. As reported, that the inlet air temperature is a very delicate parameter in governing the combustion timing and hence the success of the HCCI combustion process. Swaminathan et al [28] focused on developing a single-hole nozzle with single and multiple injection strategies. The results given that the formation of the cool flame, significant change in HCCI operation. And also reported that there was a change in the brake thermal efficiency and emissions were also under control. Avinash Kumar Agarwal et al. [29] studied and investigated on combustion parameter like ignition timing using a range of experimental data with varying intake air temperature and air-fuel ratio at different engine speeds. From the investigation it was reported that, as the fuel air mixture becomes richer, and then the ignition timing is increased. Rakesh Kumar Maurya et al. [30] focused on three operating parameters and conducted experiments in different air–fuel ratio, engine speed, and load conditions. The researcher developed the cylinder pressure history of 3000 consecutive engine cycles, for investigation purpose with piezoelectric pressure sensor. Different signal smoothening device is also analysed and their results are compared. As stated, that effect of signal processing methods on combustion parameters at different engine operating conditions. Subbarao et al. [31] studied a variety of 0 to 80% premixed ratio. Experiment stated that 80% of premixed ratio with 30% EGR lower the $NO_X$ emissions and also enhancement in IMEP, ISFC and smoke opacity with penalties in HC and CO emissions. Gajendra Singh et al. [32] did experiment on biodiesel fuelled HCCI combustion using port fuel injector fused with fuel vaporizer by EGR technique. By using biodiesel as a fuel, the heat release rate was reduced the combustion chamber and HC, CO and smoke were increased, but NOx was reduced, because of slower, rate of evaporation of fuel. Maurya et al. [33] investigated the varieties in cycle-to-cycle process HCCI mode engine. From the investigation, it was observed that lower intake air temperatures were sufficient to ignite the rich mixtures in HCCI mode of combustion, but higher intake temperatures were desired to ignite the lean mixtures. And also observed that, the knocking tendency was increased with pressure rise at higher temperatures of intake air and rich mixtures. The experimental details of authors [26-32] is presented in Table 5.

Table.5 Overview of Approaches of combustion control after literature

| Researcher | Utilized fuel | Technique of combustion control | Range | Advantages | Disadvantages |
|---|---|---|---|---|---|
| Maurya et al[26] | Ethanol | Intake air heating | 90-$120^0$c | Given that the fuel conversion efficiency and low $NO_x$ and smoke emissions | Limited to part load operation. |
| Agarwal et al[27] | Ethanol and methanol | Intake air heating | 120-$160^0$c | Reduced $NO_x$and smoke emissions | - |
| Singh et al.[29] | Diesel | Varying the air/fuel ratio and EGR | $\lambda$ ranging 2.56-4.95 and 0-20% | $\lambda$>3.70 with quiet and smooth engine operation | The UHC emission was more due to poor combustion efficiency. |
| Subbarao et al[31] | Diesel | Premixed ratio/EGR | 10-80%/ EGR 0-30% | At 80% premixed ratio and EGR at 30% gives low $NO_x$ and smoke emissions | - |
| Gajendra Singh et al[32] | Biodiesel | EGR | 0-30% | Lower heat rate released | Slightly increased unburned hydrocarbon and CO emissions |

**Future Direction of research scope**

- Common rail direct injection HCCI on a diesel engine using with diferent biofuels.
- Modern high-pressure,Multi-pulse diesel fuel injection strategies.

## CONCLUSION

The conclusions of this review is the preparation of homogeneous mixture, and combustion phase controlling are the main objectives of investigators in HCCI combustion to escape of limited fuel-rich regions and soot emissions, promising only by effective preparation of homogeneous mixture despite the fact controlling combustion phase is to attain higher fuel conversion efficiency.

- ❖ The port fuel injection has high amount of air fuel mixture compared to other injection approaches, but the absences start of combustion control.
- ❖ The emissions of the NOx and soot are decreasing in all unconventional combustion modes in comparison with convectional engines; despite the fact unburned hydrocarbon and CO emissions are high in all unconventional combustion engines.
- ❖ The grouping of equivalence ratio and charge temperature resolves the auto-ignition features of the fuel designed for HCCI combustion.
- ❖ EGR can range the auto-ignition; on the other hand combustion control using reducing the heat release rate is possible.
- ❖ The variable compression ratio is utilized to change the auto-ignition for adaptable fuels, which can change by fuel blending or additives also.
- ❖ Dilution of charge prolongs the load range of HCCI engines by delaying the combustion process and it additionally enhances the BTE.
- ❖ Though, taking strict emission norms into concern and continuous enhancement of HCCI engine performance, HCCI idea will turn out to be most appropriate and worthy future innovation of effective combustion.
- ❖ By using Common rail DI-HCCI concept additional reduces the soot and NOx emission to nearly zero level with a little lower brake fuel conversion efficiency.

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