# A Review on Homogenous Charge Compression Ignition Engine

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***Abstract*: Homogeneous charge compression ignition (HCCI) engine uses a relatively new mode of combustion technology. In principle, there is no spark plug or injector to assist the combustion process, and the combustion starts at multiple spots once the mixture has reached its auto ignition temperature. The challenges over the operation of HCCI mode engines are the difficulties of controlling the auto-ignition of the mixture, operating range, homogeneous charge preparation, cold start, controlling knock and emissions of unburned hydro carbon (UHC) and carbon monoxide (CO), need to be overcome these difficulties for achieve successful operation of HCCI mode engine. This paper reviews the working principle of HCCI mode engine and analyse the knocking in the HCCI combustion. And also review the impact of Homogeneous charge on HCCI combustion parameters such as Heat release rate and maximum pressure. However, reviews the performance and emission characteristics of HCCI engine. For each of these parameters, the theories are discussed about successful operation of HCCI engine with comparative evaluation of performance and emission are reported in the specialized literature.**

***Keywords*: Homogeneous charge compression ignition engine, knocking, performance, Combustion and exhaust emission.**

## I-INTRODUCTION

Internal combustion (IC) engines are widely used in numerous applications throughout the world. A new mode of combustion is being sought in order to reduce the emissions levels from these engines: homogeneous charge compression ignition (HCCI) engine technology is a potential candidate. The HCCI technique is the process by which a homogeneous mixture of air and fuel is compressed until auto-ignition occurs near the end of the compression stroke, followed by a combustion process that is significantly faster than either Compression Ignition (CI) or Spark Ignition (SI) combustion. The major disadvantage of SI engines is its low efficiency at partial loads. The compression ratio in SI engines is limited by knock and can normally be limited in the range from 8 to 12 contributing to the low efficiency. Conventional diesel combustion, as a typical representation of CI combustion, operates at higher compression ratios than SI engines. In this type of engine, the air–fuel mixture auto-ignites as a consequence of piston compression instead of ignition by a spark plug. The processes which occur between the two moments when the liquid fuel leaves the injector nozzles and when the fuel starts to burn are complex and include droplet formation, collisions, breakup, evaporation and vapour diffusion. The rate of combustion is effectively limited by these processes. A part of the air and fuel will be premixed and burn fast, but for the larger fraction of the fuel, the time scale of evaporation, diffusion, etc. is larger than the chemical time scale. Therefore, the mixture can be divided into high fuel concentration regions and high temperature flame regions. In the high fuel concentration regions, a large amount of soot is formed because of the absence of $O_2$. Some soot can be oxidized with the increase of in-cylinder temperature. The in-cylinder temperature in a conventional diesel engine is about 2700 K, which leads to a great deal of NOx emissions. HCCI technology claimed to improve the engine thermal efficiency while maintaining low emissions and can be implemented by modifying either SI or CI engines using any fuel or combination of fuels. The air/fuel mixture quality in HCCI engines is normally lean, it auto ignites in multiple locations and is then burned volumetrically without discernible flame propagation. Combustion takes place when the homogeneous fuel mixture has reached the chemical activation energy and fully controlled by chemical kinetics rather than spark or injection timing. Since the mixture is lean and it is fully controlled by chemical kinetics, there are new challenges in developing HCCI engines as it is difficult to control the auto-ignition of the mixture and the heat release rate at high load operation, achieve cold start, meet emission standards and controls knock. The advantages of using HCCI technology in IC engines are: (1) high efficiency relative to SI engines approaching the efficiency of CI engines due to the ability of these engines to high compression ratio (CR) and fast combustion; (2) The ability to operate on a wide range of fuels and (3) The ability to be used in any engine configuration: automobile engines, stationary engines, heavy duty engines or small sized engines. On the other hand, HCCI engines have some disadvantages such as high level so un burned hydrocarbons (UHC) and carbon monoxide (CO) as well as knocking under certain operating conditions. Emissions regulations are becoming more stringent and NOx and soot emissions levels in HCCI engines have been greatly reduced without sacrificing efficiency, which is close to that of CI engines. However, knocking is still the major issue because of its sudden onset. Knocking is due to premature combustion where the ignition takes place before the piston reaches top dead Centre (TDC) and it reduces engines reliability due to high vibration effects. The performance of an HCCI engine is strongly dependent on the fuel type and this affects the emissions levels as well. Since the emissions levels become one of the factors driving engine technology today, HCCI development has moved to a next level. Due to the importance of HCCI technology, which potentially can replace the conventional SI and CI engines, there is a need to report the recent development of HCCI engines. This paper reviews the working principle of HCCI engine and discussed the combustion parameters as heat release rate and maximum pressure in combustion process. However analyse the knocking in HCCI combustion and discussed the controlling parameter of knocking. The performance and emission characteristics of HCCI engine is also briefly discussed in this paper.

## II-LITERATURE REVIEW

Considerable amount of research work has been done on HCCI engine. Some of them are presented below.

Rakesh Kr Maurya et al. [1] used port fuel injection technique for preparing homogeneous mixture. Twin cylinder engine was converted into HCCI mode in which one cylinder worked on homogeneous charge compression ignition and the left as conventional compression ignition diesel engine. Experiments were performed by altering the intake charge temperature and equivalence ratio at constant speed 1500 rpm in order to achieve the stable HCCI combustion. It was found that stable homogeneous charge combustion was
achieved within the range of air-fuel ratio (2.0-5.0). For ethanol, the highest indicated thermal efficiency was found to be 44.78 % and maximum IMEP obtained was 4.3 bar at 2.5 air fuel ratio and 120 ºC intake air temperature. The combustion characteristics, combustion efficiency and emissions were also discussed.

Haoyue Zhu et al. [2] conducted an experimental study to the blending of ethanol in biodiesel. Addition of ethanol reduced viscosity, surface tension, whereas enhances interaction and wave growth at liquid gas interface. Ethanol and improved spray atomization in order to obtain more homogenous mixture. Engine tests were performed on a one cylinder, based on multi CIDI engine with some modification. They worked for reduction of soot and NOx for diesel, biodiesel, and biodiesel–ethanol. In a moderate exhaust gas recirculation (EGR), premixed low temperature combustion (LTC) mode was investigated. The research
focused on blended ethanol, enhance fuel and air mixing rate, prolongs ignition delay, increased fuel oxygen from 10.2% to 15.1% as a result of reduction in soot.

Vittorio Manente et al. [3] conducted an experimental study to perform a sweep, in the start of injection of the pilot and pilot-main interaction ratio at high load. A start of injection SOI sweep was carried out in order to understand the most convenient stratification level that maximized the efficiency and minimized the emissions. The experiment was based on a single cylinder DI engine with modification, engine boosted by using compressed air on external airline. Fuel was injected by using Bosch injection system. The fuel used was ethanol (99.5% by volume, heating value 29 MJ/kg). They perform low load analysis and high load analysis at different operating parameter. Results showed that low NOx, soot, CO and HC can be achieved when EGR rate varied between 40-47% and air fuel ratio between 1.15 and 1.25. Pilot injections were placed at -60o TDC while pilot main ratio was found to be 50-50. The use of some oxygenate were able to reduce soot production.

J. Hunter Mack et al. [4] investigated the effect of water fraction in ethanol on the HCCI engine operating limits, intake temperature, heat release rate and exhaust emissions. The experiments were conducted on Volkswagen 1.9 L 4 cylinder engine. The liquid fuels were port injected by MSD injector and controlled by MSD software. In all the experiments ethanol fuel flow rates were held constant with varying fraction 100%, 90%, 80%, 60%, and 40% of ethanol in water mixtures, and it was concluded that stable HCCI operation was obtained for fuels containing up to 40% water. Results indicated that by increasing intake heating value, HCCI engine can be operated with high fraction of water in ethanol.

Samveg Saxenaet al. [5] focused on the use of wet ethanol, as a fuel for homogeneous charge compression ignition engines. By using exhaust heat recovery to increase the temperature and provide the high input energy required for igniting wet ethanol. As the main cost of ethanol extraction is distillation cost, which increased more for extraction of low amount of water present in fuel. The experiments were conducted on 4 cylinder 1.9L Volkswagen TDI engine at 1800 rpm. In this experimental engine, some modification was
done in piston for reducing heat loss. An external High Pressure compressor, with 6m3 surge tank was provided intake air with precise pressure regulation. Results indicated that the most excellent circumstances for using wet ethanol in an HCCI engine with exhaust heat recovery were with high intake pressure and high equivalence ratio. The utilization of 20% water in fuel is possible, by using exhaust heat recovery while intake pressure at 1.4-2 bar and fuel air ratio 0.25 to 0.55. Hotter intake temperature will caused earlier combustion timing, causing exhaust temperature reduction, which decreased intake temperature, leading to later combustion timing, causing hotter exhaust temperature that further advanced the combustion timing.

D.Ganesh et al. [6] prepared to the mixture outside the combustion chamber. Vaporized diesel fuel was homogeneously mixed with air and introduced into the combustion chamber during intake stroke. They conducted experiments on single cylinder diesel engine with a modification to achieve HCCI mode adding with vaporizer, ECU to control port fuel injection system, exhaust gas recirculation and DAS, fuel metering system and crank angle encoder. First they started engine with conventional mode and the injected fuel externally, such that mechanical governor cuts-off the supply of diesel. In order to control ignition they conducted experiment with diesel vapour induction without EGR and by 10%, 20%, 30%, EGR. Results showed the importance of EGR role in controlling combustion phase. EGR was used to decrease the cylinder temperature and pressure, that's why combustion phasing is very sensitive for exhaust gas recirculation. EGR plays important role to combustion control and the rate of pressure rise in the combustion chamber. Brake thermal efficiency was decreased with the increase in EGR% reported. The HCCI reduced 90-98% NOX but the HC and CO emission was usually around 30% more in comparison to the conventional diesel engine.

Akhilendra Pratap Singh et al. [7] reported that, homogeneous mixing of charges is the very difficult part in diesel fueled HCCI combustion because less volatility of diesel. Therefore they used a device called 'diesel vaporizer' to prepare the homogenous fuel–air mixture. The vaporizer was nothing but a chamber made by copper wounded externally by a band heater that was controlled by

PID temperature controller. Experiments were performed at three different relative air–fuel ratios (k = 4.95, 3.70 and 2.56) while changing EGR percentage. For experiment they used a constant speed, 2-cylinder 4-stroke DI diesel engine. Only one cylinder was modified into HCCI combustion mode, while the other in conventional mode. They discussed the Start of combustion, EGR condition (0, 10%, 20%), efficient HCCI condition, two stage of heat release.

Bahram Bahri et al. [8] focused on the affects of misfire in the exhaust emissions, IMEP, trace heat release and combustion phasing matrix. The useful characteristics for misfire detection in the ethanol fueled homogeneous charge compression ignition engine were discussed. They used ANN model to sense misfire. Experimentally prove capability of model with 100 % accuracy. They have also conducted experiment on a single cylinder 4- stroke, CIDI engine modified into HCCI mode. To facilitate homogeneous charges in cylinder a fuel premixing system, air pre heater (3 KW heater) was placed into intake manifold. The ignition timing, misfire and misfire generation, and burn duration were determined. According to them a cycle was measured a partial misfire when its HRR was decreased by 10% or more and for misfire cycle it was found to be less than 50%. In this work they reported 3-type of misfire, first was fuel unavailability, second was lean air fuel mixture and third was the insufficient temperature. As per the results, ethanol HCCI was responsive to the equivalence ratio, dissimilarity of homogeneous charge combustion matrix. The maximum HRR was found well related to misfire, IMEP. Cyclic SOC, CASO, CAMHRR are not effective parameter for misfire detection in HCCI.

Suyin Gan et al. [9] reviewed the functioning of HCCI combustion in CIDI engines, using different types of injection variation with time and crank angle. For example, early injection, multiple injections and late injection strategies, physical variation like injector characteristics, geometry of piston and cylinder, compression ratio, swirl ratio. They reported that homogeneity of charge was the key feature of HCCI and discussed effect of design and operating parameter intake air temperature, EGR on HCCI diesel emission specially NOx and soot on combustion.

L. Starcket al. [10] investigated the quality of fuel for better HCCI performance. Define the HCCI index and fuel matrix. These indexes were based on comparison of tested fuel by reference fuel, here EN590 (cetane no. 51.5) was used as reference fuel. The results indicated that a low cetane number and high volatility fuel with suitable chemical composition would be improve the operational limit of HCCI by greater than 30% without any reduction in the performance under conventional diesel combustion mode. According to them, the most excellent fuel for HCCI performances are reactive compounds and having low cetane no.

Mingfa Yao et al. [11] conducted a study based on fundamental theory of HCCI engine modelling. Five types of numerical simulation models were discussed briefly in order to understand chemical kinetics. HCCI start of combustion and operating range can only controlled by chemical kinetics. They also discussed the challenges of HCCI combustion like operation range, combustion phasing control, cold starting, homogeneous mixture preparation, fuel modification, their effects on chemical kinetics, evaluated control strategies of diesel fuelled HCCI and how they made effect on combustion processes.

Abdul Khaliq et al. [12] in this investigation, they took simple engine used in trucks with some modification. They applied 1st and 2nd law of thermodynamics combined approach for a homogeneous charge compression ignition engine working on ethanol with water fraction. Numerical analysis was performed to examine the effects of turbocharger compressor ratio, ambient temperature, and compressor adiabatic efficiency on first law efficiency, second law efficiency, and energy destruction in each component.

P A Lakshminarayanan et al. [13] the rate of combustion was specifically illustrated with the relation of mixing rate to the turbulent energy produced at the end of the nozzle. It is depends on the injection velocity and by taking into consideration the dissipation of energy in open air and beside the cylinder wall. The complete absence of tuning constants distinguished the model from the other zero-dimensional or pseudo multi-dimensional models.

Onishi S et al. [14] did first time study on HCCI. The experiments were carried out on a 2-stroke gasoline engine. This newly devised combustion system, designated as “Active Thermo-Atmosphere Combustion” (ATAC), it was reported that there is instantaneous combustion different from conventional SI and CI engine combustion processes. He described the regions of formation NOx and soot have been conceptualised in an equivalence ratio temperature map.

Annarita Viggiano et al. [15] proposed multi-dimensional mathematical approach, together with a kinetic reaction mechanism for ethanol oxidation, NOx formation and CO emissions was major issue of his work. This model evaluated turbulent time scale and kinetic timescale by using code and numerical methods. They solved the system of governing equation and optimize result. These pollutants were strictly related to heterogeneity in the cylinder near the surface. This study made understand the feature of HCCI Inhomogeneities in combustion chamber, prediction of ignition delay, thermal chemical properties and their role on performance parameter and emission. They examined emissions, wall heat transfer and temperature in homogeneties.

## III-CONCLUSION

In this review briefly discussed working of homogeneous charge compression ignition engine and combustion characteristics, particularly heat release rate and maximum pressure raise in HCCI combustion. Meanwhile analyse the knocking phenomenon of HCCI combustion and discussed controlling strategies. And also reviews on performance and emissions characteristics of HCCI mode engine and conclude as follows.

Homogeneous charge compression ignition engines have operated with new combustion methods. However HCCI mode engine operates similar to both SI and CI engine, in the sense both SI and HCCI engine operates with premixed charge. And it operates similar to CI engine as ignite the combustion by auto ignition of fuel.

The HCCI engine ignites the combustion process with knocking, knocking occur in conjunction with excessive pressure rise and heat release rate . Although HCCI engine idealised as being uniform auto-ignition event of the entire combustion chamber air fuel mixture at once, in reality ignition occurs sequentially over a shot time at different locations throughout mixture.

From the literature, found that knocking was depending on fuel properties, inlet air temperature, variable compression ratio (VCR) and exhaust gas recirculation (EGR).

The HCCI mode engines have the potential to improve the brake thermal efficiency with consuming less fuel, The HCCI engine operates with lean air- fuel charge for all working conditions.

The HCCI engine has low emissions level of NOx and particulate. However, it has higher level of unburned hydrocarbon and carbon monoxides emissions.

## FUTURE RESEARCH DIRECTION

This review has discussed about fundamental operation of HCCI mode engine and also reviewed combustion, performance and emission characteristics of HCCI engine and compared to conventional engines. From this review technically identified the fundamental phenomenon influencing the HCCI engine operation, such as Homogeneous charge preparation, combustion control. These two issues should be solved for efficient operation of HCCI engine. Even beyond the research is going to review about problem have while preparing the homogeneous charge for HCCI operation and discussed about method of Homogeneous charge preparation. However briefly discussed combustion control technique and it impact on HCCI combustion and emissions in the future research.

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