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Low Temperature Combustion: A Review

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ABSTRACT

At present achieving fuel economy and reducing emissions are the two main targets set by the automotive industries. The homogeneous charge compression ignition (HCCI) is an advanced combustion technology that is cleaner and more proficient than alternate kinds of combustion. Regardless of the way that the fuel conversion efficiency and NO$x$emission of HCCI engine are more prominent in examination with conventional engines, HCCI combustion has a few fundamental issues, for example, concession combustion phase control, controlled auto-ignition, operating range, preparation of homogeneous charge, cold start and emissions of unburned hydro carbon (UHC), and carbon monoxide (CO) should be defeat for effective process of HCCI engine. Most of the researcher worked out on preparation of homogeneous fuel-air mixture. In this paper, review to give an overview on earlier work did on the external mixture formation methods and which are implemented and offered in the present years. The various methods of combustion phase control by HCCI combustion are also discussed and various Numerical investigations methods on HCCI engine are also presented.

Keywords: *Bio Fuels, HCCI, stratified charge compression ignition (SCCI), low temperature combustion (LTC), Emissions, Simulation*

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 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]

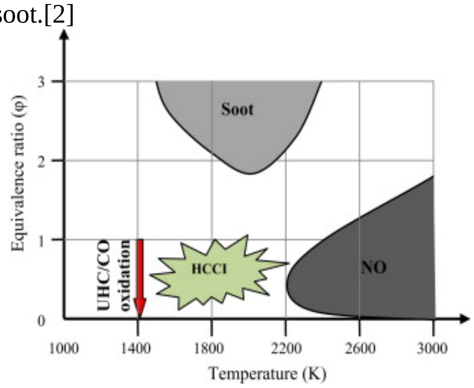


Figure 1.HCCI Combustion instantaneous decrease of NO_X and soot

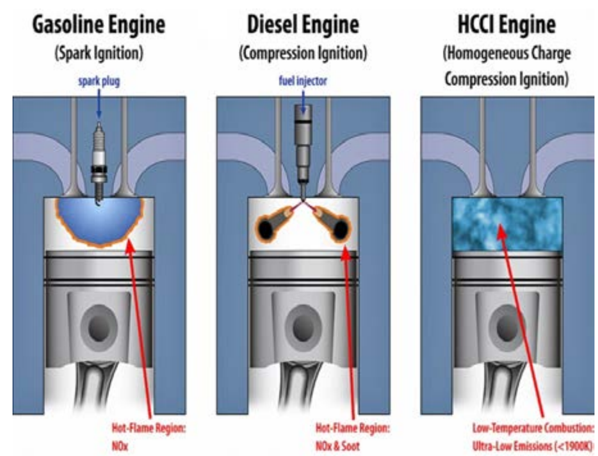


Figure 2. HCCI combustion is a combination of SI and CI combustion methods [6]

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 broad selection of fuel versatility [11] with higher fuel conversion efficiency, and low emissions. Fuel flexibility is more over make reference to as a potential favorable 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 begin 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 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 with in the cylinder [7]. In HCCI engine combustion self-started ignition of whole cylinder charge happens without any dissemination flame or flame front spread. The comparison 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]

Challenges of HCCI combustion

Considering the pioneering exploration of HCCI combustion, hurdles that must be stunned before the prospective benefits of HCCI combustion can be completely acknowledged underway applications turned out to be clear with an ever growing number of studies. This segment depicts the primary challenges with this combustion mode.

Combustion phase control

The fundamental test of the HCCI engine is to control ignition timing, which impacts the power and the traditional engine ensure a prompt part to control the start of ignition. Not at all like, spark timing in spark ignition engines and fuel injection timing in compression ignition engines, the HCCI engine needs begin of combustion controlled by auto-ignition. The fuel– air mixture is premixed homogeneously, in advance the start of ignition started by the auto-ignition of time– temperature history. This marvel of auto-ignition prompts the principle combustion control which is influenced by the some elements fuel auto-ignition science and thermodynamic properties, combustion period, wall temperatures, centralization of responding sorts, residual rate, level of mixture homogeneity, intake temperature, compression ratio, measure of exhaust gas re-use, engine speed, engine temperature, convective heat transfer to the engine, and other engine parameters. Henceforth, the HCCI combustion control closed a broad assortment of speed sand loads is the most troublesome consignment. Adjusting combustion is the best vital parameter, since it influences the power output and the engine efficiency. On the off chance that combustion happens too early, power drop as far as efficiency and genuine harm to the engine happens, and if combustion happens too late the chance of misfire rises. Most of the investigators acknowledge in transit that HCCI combustion is regulated by chemical kinetics [37].

Abnormal pressure increase with noise

The quick release of heat, which is affected by auto-ignition of the entire, homogeneous charge in the meantime amid compression stroke. The immediate heat release brings about unexpected ascent in temperature took after by sudden pressure increase, and then increase stages of noise. Predominant this quick heat release is critical, in light of the statement that it is the primary cause of pressure rise, which may make a severe damage to the engine. The adequate pressure rise constrain is 8 bar/CA on behalf of noise [3].

High intensities of unburned hydrocarbon and carbon monoxide emissions

In a convection engine the HC and CO emissions are a direct result of burning of whichever rich or exceptionally lean stoichiometric blends. The lean mixture of the temperature cutoff points of combustibility, despite the fact the rich mixture experiences absence of oxidant in the combustion chamber. The combustion of the efficiency is enhanced just, on the off chance that the exhaust holds small levels of unburned hydrocarbon emissions. The lean process of the HCCI combustion creates a lot of UHC and CO emissions. The UHC emission in HCCI engines is by and large caused by the in entire oxidation of fuel through an overabundance oxidizer, which is open for ignition. Some extraordinary causes of UHC are crevice volumes appear in the combustion chamber, valve over lapping, wall deposit retention and so on. The outflow gas temperature is too poor to oxidize UHC and CO to CO2 and H2O totally, notwithstanding amid exhaust stroke. Because of advanced combustion procedure, catalytic convertors are also wasteful to oxidize these ingredients. The combustion of efficiency in HCCI is extraordinarily enhanced by the entire oxidation of the fuel ultimately by work stroke [36].

Prolonging the operative range to high load

This can be done by Dual Mode Operation: Extending the Functional reaches to High Loads even though HCCI engine has been shown to work well at low-to-medium loads, troubles have been experienced at high-loads. Combustion can chance on show to be extremely fast and exceptional, causing inadmissible noise, potential engine harm, and in the long run unsatisfactory levels of NOx emissions. Combustion can turn out to be extremely fast and extraordinary, causing inadmissible noise, potential engine harm, and in the long run unsuitable intensities of NOx emissions. Preliminary investigation indicates the working reach can be expanded essentially by in part stratifying the charge at high loads to extend the release of heat occasion. A few potential components exist for accomplishing incomplete charge stratification, incorporating fluctuating in-cylinder fuel infusion, infusing water, differing the intake and in-cylinder mixing procedures to get non-uniform fuel/air/residual mixtures, and changing cylinder streams to shift heat transfer. The extent to which these methods can expand the working assortment is at present obscure and R&D will be required. Due to the trouble of high-load operation, most beginning ideas include changing to old-style combustion for working situation where HCCI operation is further troublesome. This double mode operation gives the benefits of HCCI over critical segment of the driving cycle yet adds to the multifaceted nature by exchanging the engine among working modes [37].

Cold start

Subsequently temperatures are low at cool begin forms and the loss of heat from the compressed charge to the cold ignition chamber walls is so high, the HCCI engine will encounter a vital trouble in firing amid cold begin operation. To tire out these troubles, the engine may must be begun in a traditional mode and after that changed to the HCCI mode after a short warm-up period. In this way, keeping up a genuine homogeneous burning after cold begin will likewise be a genuine test. HCCI operation for cold start is a zone where substantially more developmental struggle is required. Clearly, accomplishing a robust HCCI combustion at light load with full HCCI advantage in fuel efficiency and emissions is as vital as stretching out the HCCI operation to better loads.

Preparation of Homogeneous mixture

This is especially critical for poor volatility diesel-fueled HCCI combustion. The principle objectives here were to stay away from wall impact to advance fuel vaporization and air mixing to confine PM and HC emissions and to prevent oil dilution [3].

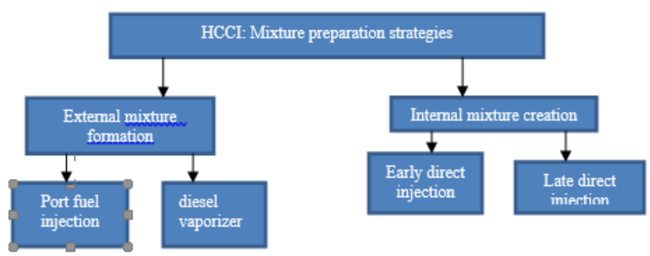


Figure 3.Strategies for mixture preparation.[3]

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 outside mixture (8, 9, 10).

Ganesh et al. [8] The research studied the performance and emissions behavior of HCCI engine fuelled by diesel fuel with external mixture formation (diesel fuel vaporizer). In this regards, to control the early ignition of diesel vapour –air mixture cooled 30^0c EGR method was implemented. The results given that at 30% EGR rate given low NOx and smoke emissions and also observed the fuel consumption increased.

Singh et al.[9] was developed of methodology for prepared external mixing device diesel vaporizer. They explored the combustion characteristics at three dissimilar relative air–fuel ratios (λ = 4.95, 3.70 and 2.56) while altering EGR percentage. As stated that at λ>3.70 with noiseless and smooth engine process. During their research concentrated on the Start of combustion, EGR state (0, 10%, 20%), an efficient HCCI condition, two phases of heat release.

G.Nagarajan et al.[10] has been conducted experimentally to investigate HCCI mode and DI diesel and DI biodiesel mode of operation (DI @ 23⁰ advanced TDC and 200 bar nozzle initial pressure).The results given that the decreased in preparation phase due to better mixture preparation. Also, huge decreased in NOx and smoke emissions stated without and with 10% exhaust gas re-use.

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

Researcher	Used fuel	Preparation of homogeneous charge technique	advantages	Disadvantages
D.Ganesh et al[8]	Diesel	Fuel vaporizer with Port fuel injection	Reduced 90-98%NOx emissions and good fuel efficiency	Control of combustion problematic and UHC and CO are increased
Singh et al [9]	Diesel	Diesel fuel vaporizer	Reduced NO_x and smoke emissions and lower maximum cylinder pressure	Higher UHC and CO emissions was reported
G.Nagarajan et al[10]	Diesel	Diesel fuel vaporizer	ReducedNO_x55%and 80% and 20% and 30% reduction in smoke emissions are reported.	Higher UHC 0.565g/kwh and 0.676g/kwh (in diesel engine 0.262 g/kwh) and CO 0.22 and 0.13 g/kwh was noticed

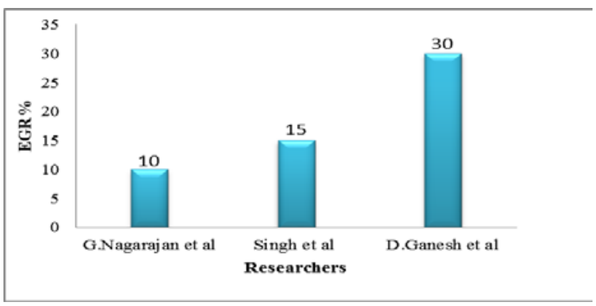


Figure.4Maximum EGR usage in single cylinder engine for HCCI

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 amid 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 vaporization the fuel in the intake manifold.

Maurya et al.[11]Has been conducted experiments and investigated using 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 little NOx emissions.

Agarwal et al.[12] Has been conducted experimentally to investigate of ethanol and methanol in the HCCI engine by changing the intake air temperatures. The results given that the methanol and ethanol are the best substitutes for the petroleum fuels.

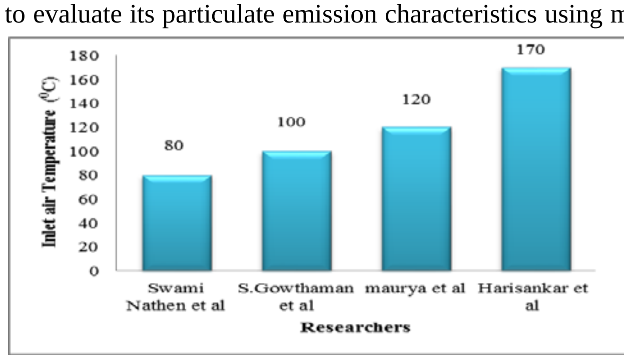
HarisankarBendu et al.[13]Did Experiments conduct the HCCI mode with a Port fuel injection of ethanol. It was found at 170°C, the maximum value of combustion efficiency and brake thermal efficiency of ethanol are observed. Also reported that, the NO emission was below 11 ppm despite the fact that the smoke emission is negligible.

S. Gowthaman et al.[14] demonstrated that by utilizing with various inlet charge temperatures such as (80- 120°C).It was found at 100°C, reduced of smoke emission, CO and HC and also the results given that the specific fuel consumptions were higher with expanding charge temperature.

Nagarajanet al.[15]Has been conducted experimental to investigated jatropha methyl ester is used a fuel for HCCI operation. They adopted EGR technique cooled 30^{0}c to control the early ignition of JME vapor-air mixture. They reported that 81% decreased in NOx and 72% decreased in smoke emission.

Ramesh et al. [16] carried out experiments to study acetylene as a single fuel in HCCI engines. The result given that the high fuel conversion efficiencies and extensive range of BMEPs. And also reported that the optimized EGR and control the inlet charge temperature to increase in brake thermal efficiencies were attained and to avoid knock, external charge heating.

AkhilendraPratap Singh et al.[17] have worked experimentally using Dissimilar test fuels like diesolin, diesohol, and diesosene to evaluate its particulate emission characteristics using modified



fuels in HCCI mode. Also the investigating showed that, engine performance at different loads.

Figure.5Maximum usage inlet air temperature for HCCI

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

Researcher	**Used 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	HC decreased and CO emissions increased with increase in air-fuel ratio were reported.
Nagarajan et al [15]	jatropha methyl ester	Port fuel injection	At EGR 30^0c cooled given 81% NOx decreased and 72% decreased in smoke emission. And also reduced HC and CO.	-
Ramesh et al [16]	Acetylene	Manifold	Reduced $NO_x$and smoke emissions was noticed	Higher Un burned hydrocarbon 2000ppm (in diesel 300ppm)emissions were noticed and high BMEP hot EGR gives to knock also reported.
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 170^0c gives better combustion efficiency=98.2% and fuel conversion efficiency=43%, Reduced NO_x emission below 11ppm and smoke emission is negligible.	Increased UHC and CO emissions was reported

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 control the auto ignition temperature of blend, confine the rate of heat release at high load operation, and exhaust emissions control and decreasing the knocking. The HCCI combustion can be 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.

Maurya et al.[18]Has been conducted experimentally and studies of HCCI combustion of ethanol at intake air temperature and at various air-fuel ratios. During their experiment scrutinized and discussed on combustion parameters in the combustion chamber. As observed that the controlled combustion parameters, it gives with better efficiency and low emission.

Agarwal et al.[19] Has been conducted experimentally with various intake air temperatures ranging from 1200C to 1600C 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 combustion timing and hence the success of the HCCI combustion process.

Swaminathan et al [20] the researcher 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. [21] have 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. As observed that as the fuel air mixture becomes richer, then the ignition timing is increased.

Rakesh Kumar Maurya et al.[22] focused on three operating parameters and conducted experiments in different air–fuel ratio/engine speed/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 are also analyzed and their results are compared. As stated that effect of signal processing methods on combustion parameters at different engine operating conditions.

Pranab Das et al.[23] concentrated on combustion control approach for HCCI– DI combustion using a dual injection method. The results given that the reduction of NOx and smoke emissions. Further researcher focused [24] on using two injection strategy with blends of n-heptane and isooctane as fuel. It was found that the most critical finding is that a two phase's heat release pattern is seeing for 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. The results given that the cetane number shows a main role in combustion phasing controlling and emission behavior of the HCCI-DI combustion engine.

Subbarao et al.[25] studied on variation of premixed ratio from 0%to 80%. The main injection timing was retarded to 200BTDC from the baseline value of 260BTDC. At 80% premixed ratio 15% and 30% EGR were introduced. As reported that premixed ratio at 80% with 30% exhaust gas re-use gives lower NOX emissions, and also identified as the premixed ratio was increased, there was an enhancement in IMEP, ISFC and smoke opacity with penalties in HC and CO emissions.

Gajendra Singh et al.[26]Explored biodiesel fuelled HCCI combustion using port fuel injector fused with fuel vaporizer. As reported that the EGR was used for controlling the HCCI combustion. And also found Combustion parameter by reason of lower rate of heat release for biodiesel, a small increase in CO, HC and smoke emissions observed with increasing biodiesel fraction because of slower rate of evaporation used for biodiesel. A significant decrease in NOx emission stated for biodiesel blend.

Maurya et al [27] investigated the varieties in cycle-to-cycle process HCCI mode engine. They have reported that the 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.

Table.5 Overview on Approaches of combustion control after literature

Researcher	Utilized fuel	Technique of combustion control	Range	Advantages	Disadvantages
Maurya et al[18]	Ethanol	Intake air heating	90-120^{0}c	Given that fuel conversion efficiency and low NO_x and smoke emissions	-
Agarwal et al[19]	Ethanol and methanol	Intake air heating	120-160^{0}c	Reduced $NO_x$and smoke emissions	
Ramesh et al[16]	Acetylene	EGR/intake air heating	40-110^{0}c	low NO_x and smoke emissions	Increased uhc and co
Gajendra Singh et al[26]	Biodiesel	EGR	0-30%	Lower heat rate released	Slightly increased unburned hydrocarbon and CO emissions
Singh et al.[9]	Diesel	Varying air/fuel ratio and EGR	λ ranging 2.56-4.95 and 0-20%	λ>3.70 with quiet and smooth engine operation	High UHC and CO emissions
Pranab Das et al[23]	Diesel	Premixed ratio/EGR	10-80%/ EGR 0-30%	At 80% premixed ratio and EGR at 30% gives low NO_x and smoke emissions	-
Ganesh et al [8]	Diesel	Cooled EGR	10-30%	low NO_x and smoke emissions	-

Table.6 Chemical kinetic mechanism obtainable for altered fuels

Fuel	main components	year	simulation model	Number of species/ Number of reactions	Temperature range(k)	pressure range (bar)	Equivalence ratio range
Bio fuels	ethanol	2017 (28)	stochastic reactor Model(SRM)	57/383	1400-1700k	-	2-6
	ethanol	2017(29)	SRM	47/272	365-465k	-	2-8
	ethanol	2013(30)	COMSOL software	57/383	400- 550k	1-1.5	0.5

Several researchers focused on mathematical model have been developed to help know, correlate, and examine the process of the engine cycles. These consist of combustion models, models of physical properties and models of flow into through and out of the cylinders

Rakesh Kumar Maurya et al.[28] Completed experimental and simulation studies on HCCI engine byutilizing stochastic reactor model (SRM). They have compared the estimate of HCCI combustion parameters with Lu'sskeletal ethanol oxidation mechanism. The results reported that the maximum cylinder pressure reduced mechanisms for predicting combustion parameters. Further[29] simulation studied the HCCI operating range of ethanol at changed compression ratios by changing inlet air temperature and engine speed using stochastic reactor model. They have reported that the higher engine loads and decreased engine speeds it given maximum operating range and higher fuel conversion efficiency and also reported that the emission characteristics of the species.

Sharma et al.[30]has been adopted for Variable volume Batch Type Reactor that is fully automated using detailed chemical mechanisms and capable of modeling unsteady operation. By using COMSOL software package to analyze the chemical reactions and species formation during combustion under various input parameters. The researcher reported that the increased inlet temperature to impact on the decreased preparation phase. Also reported that the increasing the inlet temperatures create to ensure negative impact on volumetric efficiency decreases.

STAR-CD is a famous marketable CFD platform and is all around validated. The validation of the platform among experimental outcomes have completed by researcher like sharma et al.[31]contrast of CI engine in HCCI and traditional modes are completed in their study in view of the extended coherent flame combustion three regions, contrast model on behalf of combustion analysis. The results reported that the decrease in in-cylinder pressures and NO_x emissions with increase in EGR concentration. And also stated that the Uniform is mixing of fuel-air, turbulent kinetic energy and velocity curves are initiate in HCCI mode. And also the focused to study the influence of swirl motion of intake charge on performance and emissions of the engine.[32]

HarisankarBendu et al.[33] studied GRNN based prediction tool was developed to measure the HCCI engine performance and emission parameters. The researcher used, ethanol was injected by PFI during suction stroke, and the intake air temperature varied from 130 to 170^{0}C in steps of 10^{0}C, and also evaluated the performance and emissions parameters. During the process of the GRNN training, the percentage change of error for the training, validation and test data sets were considered. Further [34] research investigated on developed hybrid GRNN_PSO model to optimize the ethanol-fuelled HCCI engine based on the output performance and emission parameters.

Rakesh Kumar Maurya,et al.[35]experimental and simulation were performed using PDF based stochastic reactor model for hydrogen HCCI combustion. The simulation results given at compression ratio 18 the maximum combustion efficiency (98%) and fuel conversion efficiency (46%), NOx emissions significantly decrease with increase λ in hydrogen HCCI combustion.

CONCLUSION

The conclusion of the review on the arrangement of homogeneous mixture and combustion phase controlling are the main aims of investigator 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 a great amount of air fuel mixture related to other injection approaches, except the absences start of combustion control.
- The emissions of the NOx and soot are decrease in all unconventional combustion modes in contrast 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 rate of heat release is possible.
- The variable compression ratio is utilized to change the auto-ignition for adaptable fuels which can change by fuel mixing or additive also.

REFERENCES

1. Horng-Wen Wu, Ren-Hung Wang, Dung-Je Ou, Ying-Chuan Chen, Teng-yu Chen. Reduction of smoke and nitrogen oxides of a partial HCCI engine using premixed gasoline and ethanol with air. Appl Energy; 88:3882–90 (2011).
2. H. Zhao. Homogeneous Charge Compression Ignition (HCCI) and Controlled Auto Ignition (CAI) Engines for the Automotive Industry. Wood head Publishing Ltd., Brunel University UK.(2007).
3. Bendu H, MuruganS. Homogeneous charge compression ignition (HCCI) combustion: Mixture preparation and control strategies in diesel engines. Renewable and Sustainable Energy Reviews, vol.38, pages:732–746.(2014).
4. Diesel Net. Emission standards. ⟨http://www.dieselnet.com/standards/⟩[accessed 15.08.13].
5. EPA ⟨http://epa.gov/carbonpollutionstandard/⟩[accessed 15.08.13].
6. Clean combustion research centre⟨http://ccrc.kaust.edu.sa/Pages/HCCI.aspx⟩.
7. Heywood JB. internal combustion engine fundamentals. United States of America: McGraw-Hill (1988).
8. Ganesh D, Nagarajan G Homogeneous charge compression ignition (HCCI) combustion of diesel fuel with external mixture formation. Energy;35:148–57 (2010).
9. Singh AP, Agarwal AK. Combustion characteristics of diesel HCCI engine: an experimental investigation using external mixture formation technique. Appl Energy;99:116–25 (2012).
10. Ganesh D, Nagarajan G, Ibrahim MM. Study of performance, combustion and emission characteristics of diesel homogeneous charge compression ignition (HCCI) combustion with external mixture formation. Fuel; 87:3497–503(2008).
11. Maurya RK, Agarwal AK. Experimental study of combustion and emission characteristics of ethanol fuelled port injected homogeneous charge compression ignition (HCCI) combustion engine. Appl Energy; 88:1169–80 (2011).

12. Maurya RK, Agarwal AK. Experimental investigations of performance, combustion and emission characteristics of ethanol and methanol fueled HCCI engine. Fuel Process Technology; 126:30–48(2014).
13. Bendu H, MuruganS. Experimental investigation on the effect of charge temperature on ethanol fueled HCCI combustion engine. Journal of Mechanical Science and Technology, Vol. 30(10), pages: 4791-4799, (2016).
14. GowthamanS,Sathiyagnanam AP. Effects of charge temperature and fuel injection pressure on HCCI engine. Alexandria Eng J,; 55:119–25(2016).
15. Ganesh, D., G. Nagarajan, and S. Ganesan. "Experimental Investigation of Homogeneous Charge Compression Ignition Combustion of Biodiesel Fuel with External Mixture Formation in a CI engine." Environmental science & technology 48.5:3039-3046. (2014).
16. Swami Nathan S, Mallikarjuna JM, Ramesh A. Effects of charge temperature and exhaust gas re-circulation on combustion and emission characteristics of an acetylene fuelled HCCI engine. Fuel; 89:515–21. (2010).
17. Singh, AkhilendraPratap, and Avinash Kumar Agarwal. "Diesoline, Diesohol, and Diesosene Fuelled HCCI Engine Development." Journal of Energy Resources Technology 138.5: 052212. (2016).
18. Maurya, Rakesh Kumar, and Avinash Kumar Agarwal. Combustion and emission behavior of ethanol fuelled homogeneous charge compression ignition (HCCI) engine. No. 2008-28-0064. SAE Technical Paper. (2008).
19. Maurya RK, Agarwal AK. Experimental investigation of the effect of the intake air temperature and mixture quality on the combustion of a methanol-and gasoline-fuelled homogeneous charge compression ignition engine. ProcInstMechEng, Part D: J Automobile Engg; 223:1445–58. (2009).
20. Nathan, S. Swami, J. M. Mallikarjuna, and A. Ramesh. An experimental study using single and multiple injection strategies in a diesel fuelled HCCI engine with a common rail system. No. 2009-26-0028. (2009) .
21. Maurya RK, Agarwal AK. Experimental study of combustion and emission characteristics of ethanol fuelled port injected homogeneous charge compression ignition (HCCI) combustion engine. Appl Energy; 88:1169–80. (2011).
22. Maurya, Rakesh Kumar, DevDatt Pal, and Avinash Kumar Agarwal. "Digital signal processing of cylinder pressure data for combustion diagnostics of HCCI engine." Mechanical Systems and Signal Processing 36.1: 95-109. (2013).
23. Das P, Subbarao PMV, Subrahmanyam JP. Study of combustion behavior and combustion stability of HCCI-DI combustion for a wide operating range using a low cost novel experimental technique. SAE technical paper 2014-01-2661; 707. (2014).
24. Das, Pranab, P. M. V. Subbarao, and J. P. Subrahmanyam. Effect of Cetane Number and Fuel Properties on Combustion and Emission Characteristics of an HCCI-DI Combustion Engine Using a Novel Dual Injection Strategy. No. 2015-26-0023. (2015).
25. Das, Pranab, P. M. V. Subbarao, and J. P. Subrahmanyam. "Control of combustion process in an HCCI-DI combustion engine using dual injection strategy with EGR." Fuel 159: 580-589. (2015).
26. Singh G, Singh AP, Agarwal AK. Experimental investigations of combustion, performance and emission characterization of biodiesel fuelled HCCI engine using external mixture formation technique. Sust Energy Technology Assess; 6:116–28. (2014).
27. R.K. Maurya and A. K. Agarwal, “Experimental investigation on the effect of intake air temperature and air-fuel ratio on cycle-to-cycle variations of HCCI combustion and performance parameters,” Applied Energy, vol. 88, no. 4, pp. 1153–1163. (2011).
28. Maurya, Rakesh Kumar, and Nekkanti Akhil. "Numerical investigation of ethanol fuelled HCCI engine using stochastic reactor model. Part 1: Development of a new reduced ethanol oxidation mechanism." Energy Conversion and Management118: 44-54. (2016).
29. Maurya RK, Akhil N. Numerical investigation of Ethanol fuelled HCCI engine using stochastic reactor model. Part 2: parametric study of performance and emissions characteristics using new reduced ethanol oxidation mechanism. Energy Convers Manage; 121:55–70. (2016).
30. Sharma, T. Karthikeya, G. Amba Prasad Rao, and K. Madhumurthy. "Combustion analysis of ethanol in HCCI engine." Trends in Mech. Engg 3.1. (2013).
31. Sharma, T. Karthikeya, G. Amba Prasad Rao, and Madhu Murthy Kotha. "A Computational Study of HCCI Engine with External Mixture Formation Technique." ASME International Mechanical Engineering Congress and Exposition. American Society of Mechanical Engineers. (2014).
32. T. Karthikeya Sharma, G. Amba Prasad Rao, K. MadhuMurthy, Effect of swirl on performance and emissions of CI engine in HCCI mode.Journal of the Brazilian Society of Mechanical Sciences and Engineering, (2014).
33. Bendu H, Deepak BBVL, Murugan S. Application of GRNN for the prediction of performance and exhaust emissions in HCCI engine using ethanol. Energy Convers Manage;122:165–73. (2016).
34. Bendu H, Deepak BBVL, MuruganS. Multi-objective optimization of ethanol fuelled HCCI engine performance using hybrid GRNN–PSO. Applied Energy, vol. 187, pages 601–611. (2017).
35. Rakesh Kumar Maurya. Development of a new reduced hydrogen combustion mechanism with NOx and parametric study of hydrogen HCCI combustion using stochastic reactor model. Energy Conversion and Management, vol. 132,pages-65–81. (2017).
36. Gowthaman, S., and A. P. Sathiyagnanam. "A Review on Methods of Homogeneous Charge Preparation for HCCI Mode Engine." International Journal of Mechanical Engineering and Robotics Research 4.2: 138. (2015).
37. IzadiNajafabadi, Mohammad, and Nuraini Abdul Aziz. "Homogeneous charge compression ignition combustion: challenges and proposed solutions." Journal of combustion. (2013).

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