International Journal of Advanced Research in Engineering and Applied Sciences

ISSN: 2278-6252
Impact Factor: 5.795

AN APPROACH OF EXPERIMENTAL STUDY ON HCCI ENGINE

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Abstract: *Spark ignition engine (S.I) and compression ignition engine (CI) development is reached to peak stage from the last decades even it may have the substantial advantages in efficiency and exhaust emissions still it may need to go for further advancement by research activities for the day to day changes for the future requirements . The CI engine has a fuel efficiency advantage over the SI engine due to higher thermodynamic efficiency and lower pumping losses. In regard to the exhaust emissions the SI engine holds an advantage over the CI engine. From researches the new combustion concept is the homogenous charge compression ignition (HCCI), is a promising technology that combines elements of the diesel and gasoline engine. Engine operations in HCCI mode for the advanced reciprocating internal combustion engine allows for improvement of thermal efficiency and substantial reduction NOx emission. The attractive properties are increased fuel efficiency due to reduced throttling losses, increased expansion ratio and higher thermodynamic efficiency. The most production feasible solution for gasoline HCCI engine is application of exhaust gas recirculation. This technique increases thermal energy of a mixture, thus allowing for autoignation at moderate compression ratios. However, high exhaust gas recirculation rate decreases be applied in order to improve volumetric efficiency and extend high load limit. However increase the amount of intake air can lead to reduction of start of compression temperature via decreases of residuals in a mixture .in order to achieve HCCI mode of combustion, temperature of start of compression must be kept within narrow limits. HCCI is a way to increase the efficiency of the gasoline engine. With the advantages there are some mechanical limitations to the operation of the HCCI engine. The implementation of homogenous charge compression ignition (HCCI) to gasoline engines is constrained by many factors. The main drawback of HCCI is the absence of direct combustion timing control. Therefore all the right conditions for auto ignition have to be set before combustion starts*

In this experimental study investigations and modeling are studied. Experiments were carried out using four stroke single cylinder and six cylinder research engines. The single cylinder engine was equipped with fully variable valve train and direct gasoline injection. Application of mechanical boosting allowed for widening achievable load range in HCCI mode of operation. Numerical calculations allowed for determination of admissible valve train setting and intake pressure, which guarantee proper temperature of start of compression.

Keywords: *HCCI, diesel engine, combustion, CFD CI, SI, NOx, CR*

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1. INTRODUCTION

As we know there are basically two modes different combustions in SI and CI engines. One is petrol and other Diesel fuel consumption modes. The combustion processes of them are very different one is homogeneous and other is heterogeneous. In the Diesel engine the combustion is initiated by auto ignition (spontaneous ignitions) because of high pressure and temperature at the end of compression stroke. However, in the petrol engine the combustion is caused by a spark that ignites a mixture that has been premixed before in the carburetor. Due to these different kinds of combustion, the two engines have different characteristics. The CI has a high efficiency, but it is very contaminating. Contrarily, the SI is not very efficient because of its low compression ratio but it has low emissions However, the IC engine is certainly not the best apparatus in every aspect but it seems to be a good on overall considerations. It is possible to develop further as the IC engine to be the better in some property but this should usually cost in another angle.

Till today internal combustion engines (ICEs) are playing important role in the automobile field because of their simplicity, robustness and high thermal efficiency and easy to use. Homogeneous charge compression ignition engine have been often considered for development substitution to the IC engines as an equivalent alternative engine for transportation and stationary applications in near future. Automobile and engine manufacturers are interested in homogeneous charge compression ignition engine due to their potential for high efficiency and low emissions. Homogeneous charge compression ignition combustion is a thermal auto ignition of a premixed fuel air mixture, with no flame propagation. The combustion temperature is low enough that the engine produces extremely low nitrogen oxide (NOX) emissions (a few parts per million) with no need for after treatment. Also, lean, premixed combustion results in near zero particulate matter emissions finally homogeneous charge compression ignition engines do not require spark plugs or a three way catalyst and are therefore expected to have lower maintenance requirements.

The reason why it’s so well accepted can be explained by its overall appearance regarding properties like performance, economy, durability, controllability but also the lack of other competitive alternatives. Research engine was fuelled with gasoline with the use of direct injection. Analysis of attainable increase of maximum engine load via boost application was performed on the base of measurement data and supported by engines cycle modeling. The main advantage of the homogeneous charge compression ignition (HCCI) combustion systems versus spark ignition and diesel engines is a sustainable reduction of cylinder out NO_x emission. Additionally fast heat release rate allows for an increase of thermal efficiency in comparison to spark ignition engines (5). In order to obtain the auto-ignition temperature it is necessary providing additional energy to the in-cylinder load. This can be achieved in several ways. In early experiments on this combustion system intake air preheating was widely used often combined with elevated compression ratios (3). However this technique is not applicable in production auto-motive engines. The most production viable solution for introducing additional energy into the cylinder is internal exhaust gas re circulation(EGR) utilizing negative valve overlap (NVO) however this technique application is limited to low and medium loads(7). Substantial dilution of the in-cylinder load by re circulated exhaust provides reduction volumetric efficiency, and therefore limits high load boundary in HCCI combustion mode. Moreover, engine operation in HCCI mode at loads above 0.5 MPa of indicated mean effective Pressure (IMEP) is associated with high mechanical and thermal loads of combustion chamber parts (6). Mechanical loads are the result of relatively high pressure rise rate. The thermal loads are increased by higher mean in-cylinder temperatures due to the large amount of re-circulated exhaust. In case of negative valves overlap, in cylinder load is compressed twice during a single engine cycle. Supercharging of the HCCI engine allows for increase of the permissible engine load if limitations come from insufficient amount of the intake air. Increase of intake pressure allows for application of lower EGR rates. However, fast heat release and large amounts of fuel at higher engine loads can result with excessive pressure rate rise. Application of boost and increase of in cylinder charge mass allows substantial reduction of NOX emission and pressure rate rise simultaneously

2. RESEARCH ASPECTS

With improvement in fuel efficiency and combustion stability, Combustion of HCCI was first applied to two-stroke engines [1], [2]. On four-stroke engine, when HCCI combustion is applied seems the fuel efficiency could be improved up to 50 % compared to the SI engine [3].Applying the technical knowledge of HCCI for the development of homogeneous charge compression ignition engine that meets the advanced reciprocating internal combustion engine program targets. Many tasks were involved in the development of the homogeneous charge compression ignition engine for the advanced reciprocating internal combustion engine. Four main timing control areas were identified by the available literature investigations: thermal control through variable compression ratio (VCR), variable valve timing (VVT), exhaust gas recirculation (EGR), and fuel mixtures or additives. CFD (Computational Fluid Dynamics) approach will be used to investigate HCCI Combustion Process and to know the detail of its combustion limits and its drawbacks of HCCI Engine combustion. As estimation of influence of boost pressure on HCCI engine working process. In order achieve auto-ignition in cylinder temperature was elevated with the use of internal EGR obtained via the NVO technique.

The research aspects for the study considered as

- Ignition Timing Control
- Engine Cold-Start
- Release rate
- Multi-Cylinder Engine Effects
- Fuel System
- Control Strategies and Systems
- Transient Operation

The progress towards development of practical homogeneous charge compression ignition engine system for stationary power generation was made in this experimental study as under

- Importance
- Working principle
- Starting of HCCI engines
- Control methods of HCCI
- Dual mode transitions
- Characteristics
- Recent developments
- Conclusion

3. IMPORTANCE OF RESEARCH

As compared with Carnot cycle Otto cycle (SI) engine and diesel cycle (CI) engines are less efficient and developed equivalent efficiencies as Carnot efficiency by intensive researches from Stirling cycle and Ericsson cycle does not find practical applications due to their practical operational difficulties. So SI and CI engines are in use form last decades. Spark Ignition (SI) and the Compression Ignition (CI) engine reached almost saturated in the in the development in last decades. Due to various limitations of most developed and widely used petrol and diesel engines, Researchers are continued in different direction for further development to overcome the present problems ; SI engines have very high NOx and PM emissions and CI engines have high efficiency because of it difficulties in the long run the homogenous charge compression ignition (HCCI) is a promising new engine technology that combines elements of both the diesel and gasoline engine operating cycles with alternative combustion technology and also with high efficiency and lower NOx and particulate matter emissions. Hence HCCI concept given importance for further study to overcome the problems with both SI and CI engines and also it has the following overcomes on comparison

- High efficiency, no knock limit on compression ratio.
- Low NOx and no NOx after treatment systems required.
- Low PM emissions, no need for PM filter.
- HCCI provides up to a 15-percent fuel savings, while meeting current emissions standards.
- HCCI engines can operate on gasoline, diesel fuel, and most alternative fuels.
- In regards to CI engines, the omission of throttle losses improves HCCI efficiency.

4. CONCEPT OF HCCI AND ITS WORKING

HCCI is characterized by the fact that the fuel and air are mixed before combustion starts and the mixture auto-ignites as a result of the temperature increase in the compression stroke. It is neither SI engine combustion nor CI engine combustion but it is new combustion technique between SI and CI combustion. HCCI is a relatively new combustion technology. It is a hybrid of the traditional spark ignition (SI) and the compression ignition process (such as a Diesel engine). Optical diagnostics research shows that HCCI Combustion initiates simultaneously at multiple sites within the combustion chamber and that there is no discernable flame propagation show in figure 1 below.

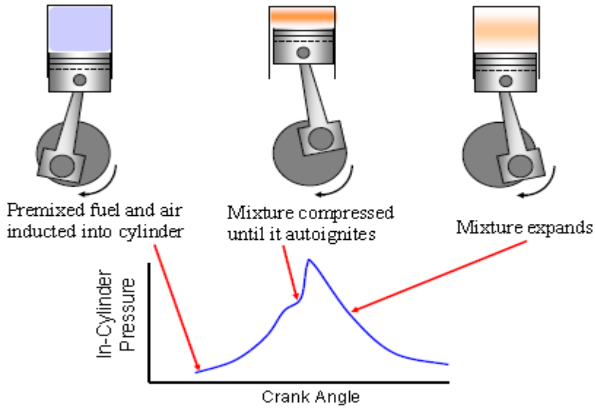

Figure: 1 cylinder pressure versus crank angle

Homogeneous Charge Compression-Ignition engines have the potential to provide dramatic increases in fuel efficiency over standard stoichiometric SI engines, while dramatically reducing NOx emissions

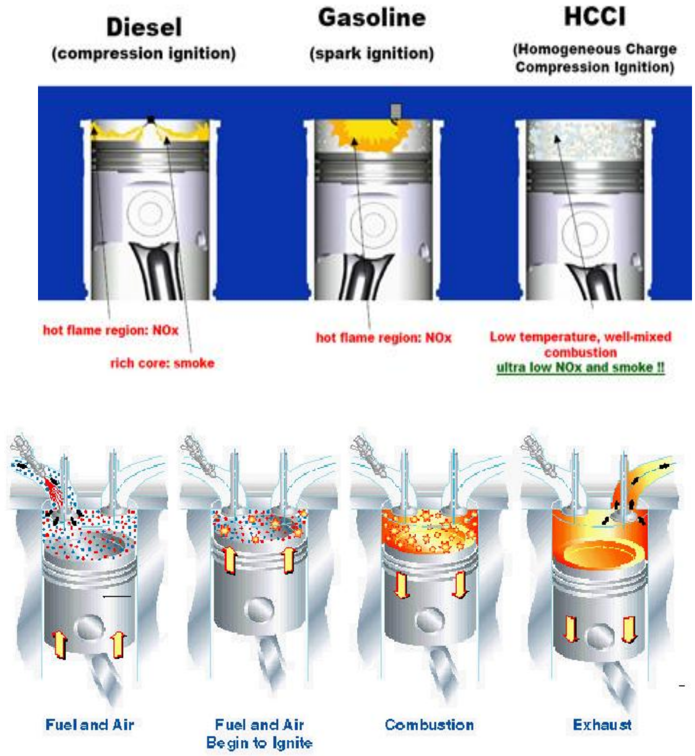

Figure: 2 compression HCCI ignition with SI and CI

4.1 Starting HCCI engines

HCCI engines are often difficult to start, at cold start charge does not readily auto ignite , the compressed gas temperature in an HCCI engine is reduced because the charge receives no preheating from the intake manifold and the compressed charge is rapidly cooled by heat transfer the cold combustion chamber walls. Without some compensating mechanism, the low compressed charge temperatures could prevent and HCCI engine form firing. So early proposal was to start in SI mode or CI mode and then run in HCCI mode. A common approach has been to start. The engine ignition mode or diesel mode and transition to HCCI mode after warm up. It involves at high compression ratios the risk of knocking and cylinder failure. Ian auxiliary injector was installed in the cylinder head in addition to the original injector to achieve engine cold-start and warm-up and used to inject the pilot diesel fuel before the Top dead centre of compression stroke. The pilot fuel was used to ignite the premixed fuel injected by the original injector near the TC of intake stroke. When the engine warmed up, the engine was changed to HCCI mode, which used only one pulse fuel injection by the main injector before the TC of exhaust stroke. However, successful transition typically, requires advanced engines equipped with variable compression ratio (VCR) or variable valve timing (VVT), which may be expensive or difficult to implement for heavy duty engines. In practice operation in SI mode requires equivalence ratio of 0.6-0.65 or greater (Flynn et al. 200), which is high enough to damage the engine if thermal auto ignition or knock occurs during the transition. Instead of attempting to start the engine in SI mode and transition to HCCI mode, a brand new approach is used: start the engine directly in HCCI mode by preheating the intake with a gas fired burner. This was easy to implement by adding a burner to the pre-heater. The burner is run for a period of time (30 minutes) until the pre-heater reaches a high temperature (300^{o}C). At this condition, running the intake charge through the pre-heater while simultaneously spinning the engine with an air starter is enough to achieve HCCI ignition. Thus the engine is started in homogeneous charge compression ignition mode by running a natural gas fueled combustor that heats the preheated. The intake gases are then circulated through the hot pre heater reaching a high enough temperature for homogeneous charge compression ignition to occur. Once combustion starts itself sustaining and therefore the burner can be turned off quickly after ignition. Now in take air preheating with hot exhaust (HE) and burner system allows startup in HCCI mode with conventional starter .figure 3 shows the curve of starting mode in HCCI .the burner is a source of emission and a consumer of fuel and as such in practical development of an HCCI engine for stationary power generation. This would have to be

ISSN: 2278-6252
Impact Factor: 5.795

considered as a contributor to the overall system emission and fuel consumption. Starting in HCCI mode instead of (late fire) SI to HCCI transition avoid potential risk of knock damage that could occur with SI operation at high CR near Stoichiometric ratio.

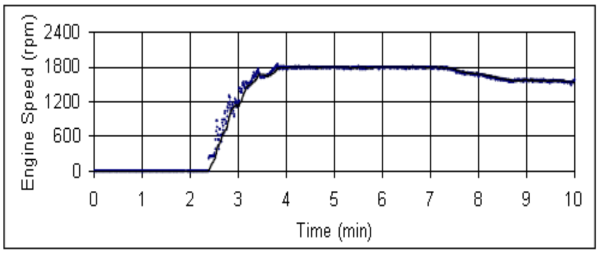

Figure:3 Engine speed versus time for HCCI mode startup

4.2 fueling system

The fueling system presents several changes because HCCI combustion is extremely sensitive to equivalence ratio. Just a few cycles of HCCI combustion at high equivalence ratio (ϕ>0.5) are enough to cause physical damage to the engine .therefore the fuelling system has to guarantee that no equivalence ratio excursions will occur "safe equivalence ratio (ϕ ▯0.45)under any circumstances. It may also be desirable to run at low equivalence ration for low load operation. these difficulty requirement where met with a novel solution: the stock carburetor tuned for natural gas was replaced with a carburetor tuned for liquid petroleum gas (LPG) .considering that average composition of natural gas is approximately C1.2H3.5 and average composition of LPG is C3.5H8.5 a carburetor tuned for operating at equivalence ratio 0.9 on LPG will run at ϕ ▯0.3 -0.5 when fueled with natural gas . This is ideal for HCCI as the carburetor is quite efficient at maintaining the equivalence ratio. The equivalence ratio is reduced below 0.4 with an electronic control valve that reduces pressure in natural gas line.

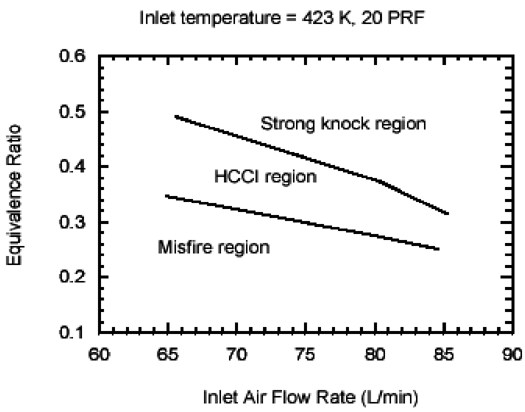

Figure 3.1 inlet air flow rate versus equivalence ratio.

4.3 control methods of HCCI combustion

To commercialize of the HCCI engine it has to overcome certain challenges which are existing at present. Low combustion temperatures, though conducive for low NOx emissions, lead to high HC and CO emissions. This is because of incomplete conversion of fuel to CO_2 [7] in complete combustion causes CO emissions, and also it is difficult to control ignition timing and the rate of combustion for a required speed and power range [8]. The control over ignition timing is achieved by a spark plug or fuel spray in gasoline engines and diesel engines, respectively. Absence of such mechanisms makes it difficult to directly control ignition in HCCI and therefore, indirect methods are adopted. The auto-ignition events in HCCI is difficult to control, unlike the ignition even in spark-ignition (SI) and diesel engines which are controlled by spark plugs and in cylinder fuel; injectors, respectively but in HCCI engine auto-ignition challenges are controlling ignition timing over a range of speeds and loads, extending the operating range to high loads, achieving cold start capability and reducing hydrocarbon and carbon monoxide emissions at low loads. HCCI engines have a small power range, constrained at low loads by lean flammability limits and high loads by in-cylinder pressure restrictions so it requires the spontaneous and simultaneous combustion of fuel-air mixture need to be controlled and no direct control methods possible as in SI or CI engines. As stated above there are four main key areas were identified for timing control from the available literature: like thermal control through exhaust gas recirculation (EGR), variable compression ratio (VCR), variable valve timing (VVT), and fuel mixtures or additives. In HCCI mode, combustion initiation has to be controlled indirectly, via in-cylinder temperature at the start of compression. Some of the controlling parameters are

- Variable compression ratio(VCR)
- Variable induction temperature
- Variable valve actuation(VVA)
- Variable valve timing(VVT)
- Exhaust gas recirculation(EGR)

4.3.1 Variable compression ratio method (VCR)

The geometric compression ratio can be changed with a movable plunger at the top of the cylinder head. This concept used in “diesel” model aircraft engine. This could be achieved through a couple of different methods. One method would be to place a plunger within the cylinder head that could vary the compression ratio. Another option would be to have an opposed-piston design which would include variable phase shifting between the two crankshafts. Other possibilities exist as well but the key is to develop these in order to have excellent response time to handle transient situations. In order to study the VCR (Variable Compression Ratio) effect on the engine performance we could change the amount of compression for each cylinder and can study the effect. This could change the engine characteristics. By incorporating a device that could change cylinder volume rapidly, individual control of each cylinder could be conceivably achieved

4.3.2 Variable induction temperature

Pre-heating of intake air, intercooler by-pass, etc.are the Intake air thermal management- The simplest method uses a resistance heater to vary inlet temperature but this method is slow. Now FTM (Fast Thermal Management) is used. It is accomplished by rapidly varying the cycle to cycle intake charge temperature by rapid mixing as shown in figure-4

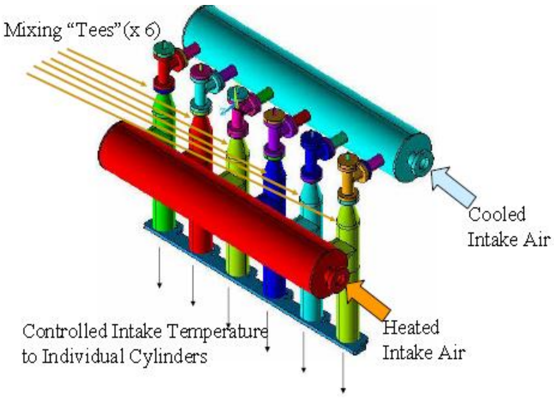

Figure: 4 fast thermal management

Rapid mixing of cool and hot intake air takes place by FTM system and can achieve optimal temperature as demanded and hence better control is possible. In FTM Control method Combustion timing can be controlled by adjusting balance of hot and cold flow

4.3.3. Variable valve actuation (VVA)

Early exhaust valve closure –internal exhaust gas recirculation. High positive valve overlap, Late intake valve opening, Variable Valve Actuation (VVA) system, VVA, irreversible expansion on intake valve are various controlling methods.

Within combustion chamber VVA method gives finer control and it involves controlling the effective pressure ratio. It controls the point at which the intake valve closes. If it closes after the BDC, the compression ratio and the effective volume will changes. Negative valve overlap combined with fuel injection heat supply during gas exchange phase.

4.3.4 Variable Valve Timing (VVT)

VVT allows variation of the compression ratio not through geometric means but through timing of the opening and closing of the intake and exhaust valves. In addition, this system can act as a more direct method of EGR by controlling the amount of trapped residual gases thus allowing temperature and mixture control. As VVT allow the variation of compression ration not through geometric means but through timing of valve opening hence by changing the timing of the intake/exhaust valve changes the amount of combustible air in the cylinder thus controlling combustion strength and timing. This could be used to change the cylinder performances individually if a good control method is found. It should be noted that typical VVT schemes run cylinders with set timing, whereas these could need flexibility not only in timing but per cylinder.

4.3.5 Exhaust gas recirculation (EGR)

It is the process of recycling exhaust gases and adding them to the intake air. With EGR it is possible to control temperature, mixture, pressure, and composition. In comparison to the other control methods EGR is relatively simple, and has a great benefit. EGR can produce more power in an engine because more fuel could be pumped into the cylinder without spontaneous ignition due to the relative inertness of the emissions gas compared to air. It also could be used to control individual cylinder performance.

5. HCCI COMBUSTION EXPERIMENTS WORKS

Researchers at the Lund institute in Sweden have done a great deal of experimental work on 4-stroke single cylinder HCCI combustion [6-7-29-35] both naturally aspirated and supercharged operation have been studied using natural gas, isooctane and ethanol [35].moderate to high loads were achieved in this study: 14 bar IMEP for natural gas, 12 bar IMEP for ethnol and 10 bar IMEP for Isooctane. NOx was very low over the entire operating range,but HC and CO emissions high. Another study looked at the same fuels in naturally aspirated mode but with variable EGR [34].this work showed that increasing EGR for each of these fuels could further reduced NOx,HC and CO emissions.

Recently the Lund group has operated a six cylinder engine (in this case 1.95L/cylinder) in HCCi mode31. The combustion process was adjusted using variable intake temperature and a dual fuel configuration that allowed for variation of the fuel blends auto ignition characteristics (eg octane number) engine speed also varied. Brake mean effective pressure (BMEP) between 1.5 and 6 bar was achieved and brake thermal efficiency ranged between 26 and 43% nox emissions of under 20 mg/kWh were achieved up to 5 bar BMEP, but rose rapidly at higher load (up to 250-450 mg/kW-h)

5.1 Current-HCCI developed work Engine (Experimental Engine setup)

A cooperative Fuels Research (CRF) single cylinder engine and a single cylinder Ricardo Mark III engine with a Rover K7 head are used to carry out HCCI experiments. The experimental data for the HCCI experiments done in this study and the experimental data for the CFR engine and geometrical specifications of both the CFR and Ricardo engines shown in table-1

Parameters	CFR engine	Ricardo engine
Bore x stroke (mm)	83	80
Stroke(mm)	114	88.9
Compression Ratio	12	10
Displacement [L]	0.622	0.447
Number of valves	2	4
IVO,IVC[aBDC]	-170^0, 34^0	-175^0, 55^0
EVO, EVC [aBDC]	-40^0, 165^0	-70^0, -175^0

The operating parameters of the single cylinder CRF engines is shown in the following table-2

Parameter	CFR engine
Engine speed [rpm]	700
Manifold temp[^{0}C]	88
EGR (%)	1-31
Equivalence Ratio	0.45 – 1.1
Manifold pressure [kpa]	89-92
Fuel[prf]	20,40,60
Oil Temp[^{0}C]	70

PRF number is defined as the volume percentage of iso-Octane in the fuel mixture of n-Heptane (PRF0) iso –Octane (PRF100)

Experiments have been performed on a single cylinder cooperative fuels research (CRF) engine modified for HCCI operation. The engine is naturally aspirated and an intake manifold heater has been installed to allow for preheating the intake air. The engine characteristics and operating parameters used in these experiments are listed in table

The CFR engine has been fitted with an optrand Auto PSI-S(200 bar full scale range)combustion pressure sensor. The signal is acquired with a National Instruments PCI-6110E data acquisition (four input channels with a 5 mega-sample per second per channel maximum acquisition rate) board in Windows NT computes system. The pressure is acquired at every 0.1 crank angle degrees (CAD) using a 3600 /rev crankshaft encoder. Significant noise was present in the pressure data, despite extensive efforts to suppress it. An eighth-order Butterworth digital low pass filter has been used to filter the raw pressure data in post processing. The raw pressure signals are filtered forward and backward to eliminate any phase shift. The pressure data is filtered and then averaged. The rate of heat release was calculated from the average pressure trace using the method describes in the Heywood text.

- Variable compression Waukesha CFR engine
- 20HP general electric Dc motor Dynamometer
- Cooling system
- Air intake System
- Exhaust System
- Data Acquisition
- Gas Analysis/Sampling

Figure: 5 Research engine with variable valve actuation system

Pure propane and a blend of 15% by volume dimethyl- ether (DME) in methane were the fuels tested. These tests have been designed to characterize the operating parameters that influence HCCI engine emissions and performance. The fuel, intake air temperature, and equivalence ratio were varied in this experiment.

Testing was also conducted with pure methane fuel, but stable HCCI operation was only achieved for one operating point at the upper limit of preheating capacity and compression ratio. Operation in HCCI mode with pure methane was achieved initially using blend of methane and DME. The flow rate of each fuel was independently controlled and once stable operation was achieved, the DME flow rate was gradually reduced to zero

Propane and the DME in methane blend have similar reaction characteristics in an HCCI engine cycle, exhibiting cool flame heat release [41-40] the low temperature reaction increases charge temperature (and generate a radical pool initiating further chemical reactions) as the charge is compressed. Pure methane has very little cool flame chemistry causing the greater difficulty achieving conditions for auto ignition in an engine cycle relative to the other fuels [63]Simulations have been performed to look at the effect of several different control parameters on HCCI combustion

By a computational fluid dynamics (CFD) simulation using KIVA-3V code coupled with detailed chemistry[14] was found a multi pulse injection strategy for premixed charge compression ignition(PCCI)combustion fuel splitting proportion, injection timing, spray angles, and injection velocity effects are were examined. As the focus of the research the mixing process and formation of soot and nitrogen oxide (NOx) emissions were investigated. Due to the considerable changes of the mixing process and fuel distribution in the cylinder the result showed that the fuel splitting proportion and the injection timing impacted significantly on the combustion and emissions. Appropriate injection timing and fuel splitting proportion must be jointly considered for optimum combustion performance and the spray, inclusion angle and injection velocity at the injector exit can be adjusted to improve mixing, combustion and to minimize emissions.

On different fuels many experimental investigations were conducted with regard to homogeneous- charge compression- ignition. Dual fuel is the one of the approach, in dual fuel approach N-heptane and n-butane was considered for covering an appropriate range of ignition behavior typical for higher hydrocarbons [15]. For both fuels starting from detailed chemical mechanisms, reaction path analysis was used to derive reduced mechanisms, which were validated in homogeneous reactors and showed a good agreement with the detailed mechanism. Through the Conditional Moment Closure (CMC) approach the reduced chemistry was coupled with multi zone models (reactors network) and 3D-CFD.

In a model based control strategy, in 2002 a study introduces a modeling approach for investigating the effects of valve events to adapt the injection settings according to the air path dynamics on a Diesel HCCI engine; based on a Knock Integral Model and intake manifold conditions the start of injection is adjusted. Researcher complements existing air path and fuel path controllers, and aims at accurately controlling the start of combustion [16].Experimental results were presented, which stress the relevance of the approach.

Modeling approach study was introduced in 2002 for investigating the effects of valve events HCCI engine simulation and gas exchange processes in the framework of a full-cycle HCCI engine simulation [17]. KIVA-3V is a multi-dimensional fluid mechanics code, which was used to simulate exhaust, intake and compression up to a transition point, before which chemical reactions become important. To compute the combustion events and the part of expansion the results are then used to initialize the zones of a multi-zone, thermo-kinetic code, the application of the method was illustrated in the context of variable valve actuation after the description and the validation of the model against experimental data,. It has concluded that early exhaust valve closing, accompanied by late intake valve opening, has the potential to provide effective control of HCCI combustion. With appropriate extensions, that modeling approach can account for mixture in homogeneities in both temperature and composition, resulting from gas exchange, heat transfer and insufficient mixing.

A multi-dimensional CFD code, KIVA-ERC-Chemkin that is coupled with Engine Research Center (ERC)-developed sub-models and the Chemkin library, was employed. Simulations of combustion of direct injection gasoline sprays in a conventional diesel engine were presented and emissions of gasoline fueled engine operation were compared with those of diesel fuel [18]. Using a reduced mechanism for primary reference fuel the oxidation chemistry of the fuels was calculated, which was developed at the ERC. With available experimental measurements for a range of operating conditions, the results show that the combustion behavior of DI gasoline sprays and their emission characteristics are successfully predicted and are in good sense. It seems that gasoline has much longer ignition delay than diesel for the same combustion phasing, thus NOx and particulate emissions are significantly reduced compared to the corresponding diesel cases. The results of parametric study indicate that expansion of the operating conditions of DI compression ignition combustion is possible. Further investigation of gasoline application to compression ignition engines is recommended.

For an idealized engine configuration under HCCI-like operating conditions [19] Three-dimensional time-dependent CFD simulations of auto ignition and emissions were reported. The main focus is on NOx emissions and detailed NOx chemistry as an auto ignation mechanism of n-heptane and iso–octane. To accelerate the computation of chemical source terms a storage/retrieval scheme is used, and turbulence/chemistry interactions were treated using a transported probability density function (PDF) method. Simulations that include the direct in-cylinder fuel injection, and feature direct coupling between the stochastic Lagrangian fuel-spray model and the gas-phase stochastic Lagrangian PDF model. For the conditions simulated, consideration of turbulence/chemistry interactions is essential. Simulations that ignore these interactions fail to capture global heat release and ignition timing, in addition to emissions. For these lean, low-temperature operating conditions, engine-out NOx levels are low and NOx pathways other than thermal NO are dominant. In some cases Engine-out NO_2 levels exceed engine-out NO levels. For accurate emission predictions, In-cylinder in homogeneity and unmixedness must be considered. These findings are consistent in recently reported literature of HCCI engine with results.

With CHEMKIN-PRO's HCCI Combustion Model the effect of EGR on HCCI engine operation application of many automotives can be modeled. Always user needs more accurate emission results that can be by the multi zone model. It allows specifying non-uniform initial conditions and heat transfer for regions within the cylinder [20].

Motion planning in the control of the coupled air path dynamics of turbocharged Diesel engines using Exhaust Gas Recirculation was demonstrated in the research [21] of 2007. Very large rates of burned gas need to be considered for HCCI combustion mode and proven on realistic test-bench cases that the proposed approach can handle such situations. The air path dynamics has a strong coupling; nice properties that make it easy to steer through control strategy. Over a wide range of set points it triangular form yields exponential convergence. To satisfy operational constraints it can also shown through simple analysis, provided transient are chosen sufficiently smooth.

For a Stochastic Reactor Model (SRM) for HCCI engines was suggested [22] a storage/retrieval technique. This technique enables fast evaluation in transient multi-cycle simulations. The Stochastic Reactor Model uses chemical kinetics, accounts for turbulent mixing and convective heat transfer in detailed, and predicts ignition timing, cumulative heat release, maximum pressure rise rates, and emissions of CO, CO2, unburnt hydrocarbons, and NOx. When coupled to a commercial one as an example of research, dimensional CFD engine modeling package, the scheme enables convenient simulation of transient control, using a simple table on a two-dimensional parameter space spanned by equivalence ratio and octane number. Developed computational tool was believed that it will be useful in identifying parameters for achieving stable operation and control of HCCI engines over a wide range of conditions. Furthermore, a tabulation tool enables multi-cycle and multi-cylinder simulations, and thereby allows studying conveniently phenomena like cycle-to-cycle and cylinder-to-cylinder variations. Optimization of engine operating parameters becomes feasible in particular, simulations of transient operation and control, design of experiments.

5. 2 Dual mode transitions

When auto-ignition occurs too early or with too much chemical energy, combustion is too fast and high in-cylinder pressure can destroy the engine. For this reason, HCCI is typically operated at lean overall fuel mixtures so this restricts engine operation at high loads practical HCCI engine will need to switch to a conventional SI or diesel mode at very low and high load conditions due to dilution limits there are two modes: one is HCCI-SI dual mode and other is HCCI-DI dual mode. SI mode transitions equips VVA and spark ignition system and Operates in HCCI mode at low to medium loads and switches into SI mode at higher loads this transition is not very stable and smooth . DI-HCCI mode has long ignition delay and rapid mixing is required to achieve diluted homogeneous mixture. Combustion noise and NOx emissions were reduced substantially without an increase in PM and combustion facing is controlled by injection timing. Thus DI-HCCI proves to be promising alternative for conventional HCCI with good range of operation.

ISSN: 2278-6252
Impact Factor: 5.795

6.0 COMBUSTION CHARACTERISTICS

Following figure 6 shows the details of heat release rate versus crank angle.

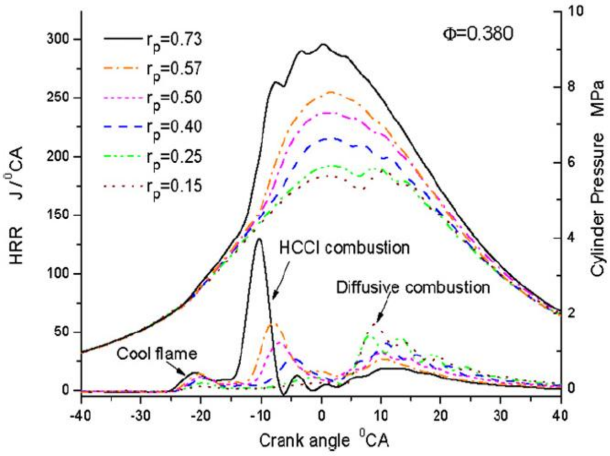

Figure: 6 Heat release rate versus crank angle

7.0 EMISSION CHARACTERISTICS

Emission characteristics curves are drawn for different pressure ratios by taking indicated mean effective pressure (MPa) and NOx emissions in ppm and the details are shown below

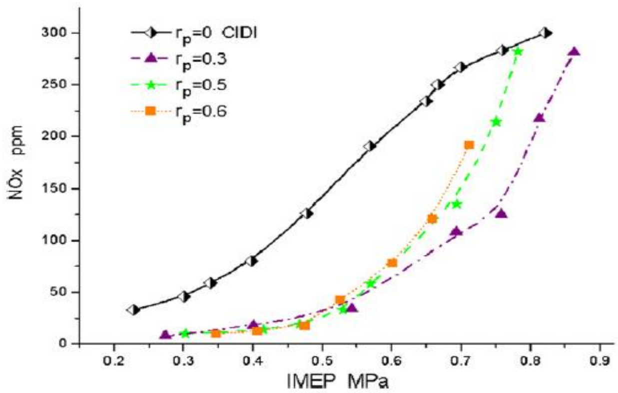

Figure 7 shows NOx emissions in parts per million versus indicated mean effective pressure in mega Pascal

7.1 Approaches to Reduce the Emission

In present days Technology changes to reduce the exhaust emissions by introducing the engine modifications, using exhaust gas recirculation, and catalytic converters after treatment, it takes slow fleet turnover due to fully longer implementation. However, they eventually result in significant emission reductions worldwide and will be continued on an ever-widening basis in the United States. New technologies, like hybrids, solar photo voltaic cells, batteries and fuel cells, show significant promise in reducing emissions from current sources dominated by diesel fuel usage. Some program are underway in California like the turnover of trucks and especially off-road equipment is slow; awareness in the pollution control agencies need to be addressed to the existing emissions with in-use programs, such as exhaust trap retrofits and smoke inspections and pollutions norms. Other steps that can be continued with improved technology for reduction of emissions ,that will allow the use of the diesel engine, with its superior fuel consumption, to continue to benefit of society which will greatly reduces the negative environmental and health impacts to maintain the ecological balance.

The further development of combustion engines continues to be driven by the following legal, social and economic factors: legislation on exhaust gas is becoming more and more restrictive; fuel consumption needs to be reduced in view of global CO_2 emission and the limited fossil resources. In the commercial vehicle segment, the diesel engine has always been prevalent due to its robustness and unequalled efficiency. In the years to come, however, future emission limits will require the simultaneous reduction of nitrogen oxides (NOx) and particulate emissions to extremely low values throughout most of the world.

Emission characteristics of premixed ratio on CO of HCCI-DI

shows the emission characteristics of premixed ratio versus CO% of different equivalence ratios

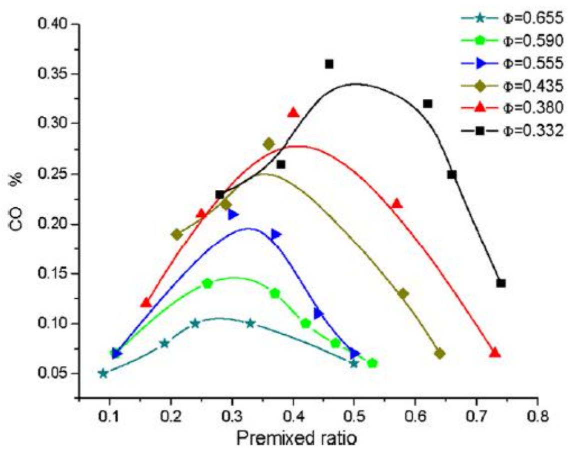

Figure: 8 Effect of premixed ratio on CO emission of HCCI-DI Engine performance

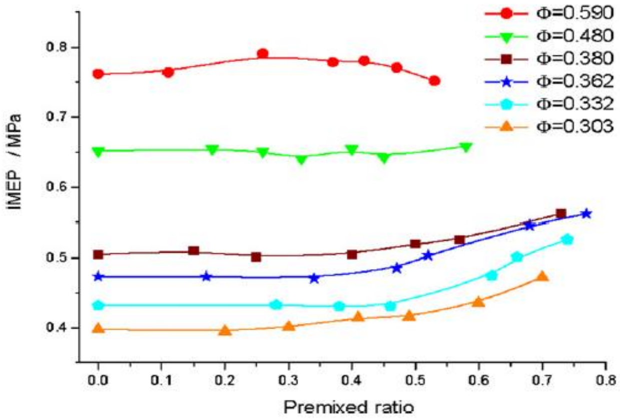

Figure: 9 Effect of premixed ratio on indicated mean effective pressure of HCCI-DI

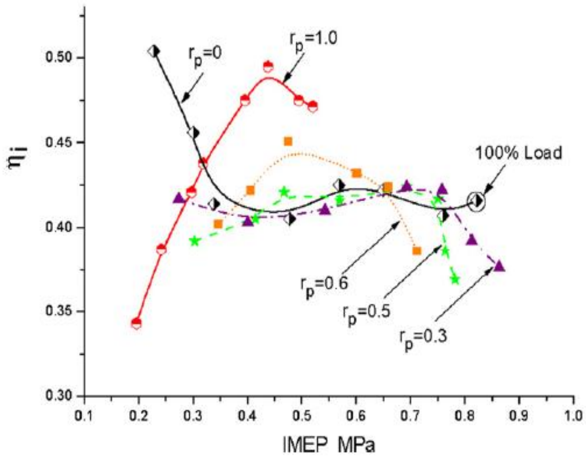

Figure: 10 Comparison of indicated thermal efficiency between HCCI-DI, HCCI and CIDI

7.2 Recent developments in HCCI

Solution for turbo charging includes Use VGT (Variable Geometry Turbine) which allows for a greater range of turbine nozzle area, better chance to achieve high boost. And also Combining turbo charging and super charging may be beneficial.EGR (Exhaust Gas Re-circulation) Can be adopted for higher efficiencies and lower HC and CO emissions. The exhaust has dual effects on HCCI combustion. It dilutes the fresh charge, delaying ignition and reducing the chemical energy and engine work. And also reduce the CO and HC emissions. Many companies recently developed HCCI prototypes .following are the details of some of the companies

a) General Motors has demonstrated Opel Vectra and Saturn Aura with modified HCCI engines.

b) Mercedes-Benz has developed a prototype engine called Dies Otto, with controlled auto ignition. It was displayed in its F-700 concept car and the 2007 Frankfurt Auto show.

c) Volkswagen is developing two types of engine for HCCI operation. The first, called combined combustion system (CCS) is based on VW group 2.0 litre diesel engine but uses homogeneous intake charge rather than traditional diesel injection. It requires the use of synthetic fuel to achieve maximum benefit. The second is called Gasoline Compression Ignition (GCI); It uses HCCI when cruising and spark ignition when accelerating. Both engines have been demonstrated in Touran prototypes, and the company expects them to ve ready for production in about 2015.

d) In May 2008, General Motors gave auto express access to a Vauxhall insignia prototype fitted with a 2.2 litre HCCI engine, which will be offered alongside their eco FLEX range of small capacity, turbocharged petrol and diesel engines when the car goes into production. Official figures are not yet available, but fuel economy is expected to be in the region of 43mpg(Miles per gallon) with carbon dioxide emissions of about 150g/km(grams per kilometer), improving on the 37mpg(Miles per gallon) and 180g/km produced by the current 2.2 litre petrol engine. The new engine operates in HCCI mode at low speeds or when cruising, switching to conventional spark ignition when the throttle is opened

8. CONCLUSIONS

HCCI-DI combustion with *n*-heptane/diesel dual fuel is a 3-stage combustion process consisting of cool flame, HCCI combustion and diffusive combustion. Increase of premixed ratio, shortens the NTC (Negative Temperature Coefficient), increases the peak in-cylinder pressure and temperature and rises the highest heat release rate of HCCI combustion phase. NOx emissions decreases firstly at low premixed ratios and exhibit at eng of increasing high of premixed ratios. Pre-mixed ratios has no significant effect on soot emission and the soot emission could remain at the same level but then have a peak value with a certain higher premixed ratio relating to the equivalence ratio. The change of CO with premixed ratio is mainly depending on whether the premixed equivalence ratio exceeds the critical value. UHC increases almost linearly with the premixed ratio mainly due to incomplete oxidation in the boundary layer and the crevices. The IMEP increases with the increase of premixed ratio at low to medium loads. The indicated thermal efficiency shows deterioration at high load with large premixed ratios. Reduce unwanted emissions Unburned Hydrocarbons (UHC) Carbon Monoxide (CO) Nitrogen Oxides (NOx) Particulates (soot) that come from internal combustion engines (ICE) and increase fuel economy

9. SUMMARY

HCCI engines are a promising technology that can help reduce some of our energy problems in the near term. However, control remains a challenge because HCCI engines do not have a direct means to control the combustion timing. Many concepts to be consider various parameters like, compression ratio, intake/exhaust temperature, intake mass, intake air pressure, composition could be controlled. With the generation of different concept a CFD simulation will be carried out to study the effect of various parameters on engine performance. A few degrees of difference in intake temperature can have significant effects on combustion strength. By varying intake temperatures for individual cylinders, combustion could be controlled, and also based on design of HCCI engine on feasible results. For determine the design parameters at full load / part load conditions CFD package analysis with 3D model could be applied for improving of combustion system. Till today the success of HCCI development is tempered by challenges that must be overcome before it hits the primetime of production. Control of the combustion process over the wide range of operating conditions experienced in everyday driving is the greatest challenge, because unlike a conventional-ignition engine, HCCI's combustion is not controlled by precisely timed spark events. Ensuring auto ignition at extreme temperatures and in the thinner air of high altitudes are the tallest hurdles to overcome.

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