AN ANALYSIS OF OPTIMUM WORKING CONDITIONS OF HCCI ENGINES

S. Chakradhar Goud *

Dr. Maheshwar **

Dr. B. Anjaneya Prasad ***

ABSTRACT

The time when fuel cells are ready for significant use seems to be far off. Therefore it is necessary to find alternative fuels to be used in the standard internal combustion engine to bridge this gap. Simultaneously it is necessary to improve the combustion engine in terms of fuel efficiency and emissions. The necessity to further improve the conventional internal combustion engine is the main challenge scientists and engineers now face. The homogenous charge compression ignition (HCCI) is a promising new engine technology that combines elements of the diesel and gasoline engine operating cycles. As a way to increase the efficiency of the gasoline engine, the attractive properties are increased fuel efficiency due to reduced throttling losses, increased expansion ratio and higher thermodynamic efficiency. 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. This paper investigates the past and current research done and considerable success in doing detailed modeling of HCCI combustion. This paper aims at studying the fundamentals of HCCI combustion, the strategy to control the limitation of HCCI engine and finding optimum operating conditions for HCCI engine operation, work on the combustion timing and the engine operating zone for HCCI engines. Four main areas of timing control were identified in an investigation of the available literature: thermal control through exhaust gas recirculation (EGR), variable compression ratio (VCR), variable valve timing (VVT), fuel injection systems and fuel mixtures or additives. To investigate HCCI Combustion Process a detail CFD (Computational Fluid Dynamics) approach will be used to limit the drawback of HCCI Engine.

Keywords: *HCCI, Diesel Engine, Combustion, VVT, Fuel Injection, CFD.*

* JJT Universtiy, Rajasthan.

** Professor & Principal, Hi-Tech College of Engineering, Hyderabad.

*** Professor, JNTUH, Hyderabad.

INTRODUCTION

The concept of the internal combustion engine is quite old and the main principles have not changed since the times of Rudolf Diesel. Yet there is still room for an improvement. The approaches to reduce the emission, technology changes, such as engine modifications, exhaust gas recirculation, and catalytic after treatment, take longer to fully implement, due to slow fleet turnover. However, they eventually result in significant emission reductions and will be continued through worldwide.. 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. The approach to alternative combustion processes studies the formation of NOx and soot in the conventional direct injection diesel engine is due to the heterogeneous not premixed combustion characterized by high local temperatures and a local lack of oxygen. With alternative combustion methods, suitable combustion control is applied to avoid the conditions where particulates or NOx are formed.

One alternative for improving engine efficiency and reducing engine emissions is to change the combustion process so as to improve the engine performance. The combustion of a homogeneous air/fuel mixture in the cylinder of a diesel engine is very efficient way to do this. In a sense, the **H**omogeneous **C**harge **C**ompress **I**gnition (HCCI) combustion system merges the advantages of SI engine combustion using a homogeneous mixture and that of a diesel engine with also alternative fuels. The fuel efficiency from the CI engine and the emission levels from the SI engine, and this can be reached with Homogeneous Charge Compression Ignition (HCCI).In the last few years, several studies have shown that the formation of the individual pollutants can be avoided by a far-reaching charge homogenization before combustion and by considerably reducing the combustion gas temperature. One of the method is **Homogenous Charge Compressed Ignition (HCCI).**

HCCI combustion was first applied to two-stroke engines [1], [2] with improvement in fuel efficiency and combustion stability. When HCCI as applied to the four-stroke engine, the fuel efficiency could be improved up to 50 % compared to the SI engine [3].

By analyzing the Internal Combustion engine, transforms the energy obtained in a chemical reaction into mechanical energy. The reaction takes place when a fuel reacts with air, following this equation

$$CH_x + a \cdot (O_2 + 3.77 * N_2) \rightarrow CO_2 + b \cdot H_2O + c \cdot O_2 + d \cdot N_2$$

where CH_x denotes hydrocarbures present in the combustible, O_2 and N_2 are the oxygen and nitrogen present in the air, CO_2, H_2O, O_2 and N_2 are the exhaust gas. This reaction is exothermic, so we can obtain energy. The reaction takes place inside a cylinder. This cylinder contains a piston connected to a mechanism of a crank and a crankshaft.

In the SI engine there is a spark discharge close to TDC during the compression stroke. The created flame front expands relatively slowly inside the cylinder until all ignitable mixture is consumed during relatively long burn duration. The fuel has to withstand the increased temperature during the compression stroke and combustion without any self-ignition before the flame front reaches the fuel element. This means that auto ignition resistant gasoline qualities are the primary fuel type for the SI engine. Since the ordinary air-fuel mixture needs to be near stoichiometric for complete flame propagation [4], this usually leads to decreased engine efficiency when the load has to be reduced.

In CI engines, The fuel is injected at high pressure, and air is entrained into the fuel jet. This creates a fuel-rich premixed reaction zone in the central region where soot formation and particulate growth takes place. In the periphery at the turbulent diffusion flame the soot oxidation and NOx formation occurs [5]. The injected fuel amount controls the load, and therefore the CI engine can be operated without a throttle, yielding a further advantage compared to the SI engine. The NOx and soot emissions can be reduced with oxidizing catalysts, NOx traps, Selective Catalytic Reduction (SCR) catalysts and particulate traps. The emission reduction equipment and the high pressure fuel injection system leads to a higher manufacturing cost for the CI engine compared to the SI engine. To overcome these limitations of SI engine and CI engine a blend of twos was developed long ago i.e. Homogeneous charge compression Ignition (HCCI)

HOMOGENEOUS CHARGE COMPRESSION IGNITION (HCCI)

The Homogeneous Charge Compression Ignition (HCCI) engine is often described as a hybrid between the spark ignition engine and the diesel engine. The blending of these two designs offers diesel-like high efficiency without the difficult--and expensive--to deal with NOx and particulate matter emissions. In its most basic form, it simply means that fuel is homogeneously (thoroughly and completely) mixed with air in the combustion chamber very similar to a regular spark ignited gasoline engine, but with a very high proportion of air to fuel i.e. lean mixture. As the engine's piston reaches its highest point (top dead center) on the compression stroke, the air/fuel mixture auto-ignites from compression heat, much like a diesel engine. The result is the best of both worlds: low fuel usage and low emissions.

Despite advantages, HCCI engines produce high HC and CO emissions as the ignition timing and combustion duration is difficult to control. Therefore, the HCCI operating zone is limited between misfire and knocking. Lack of direct control over ignition initiation is one of the obstacles that need to be addressed. The auto-ignition timing relies on indirect ways such as the air-fuel charge, octane number, temperature, and pressure [6].

Homogeneous charge compression ignition (HCCI) uses a lean premixed air-fuel mixture that is compressed with a high compression ratio. During the end of the compression stroke, ignition occurs through self-ignition in the whole combustion chamber at once. Since the mixture is lean, the maximum temperature, both locally and overall, becomes low compared to other engines, which effectively reduces NOx formation. However, at richer mixtures the combustion becomes too fast and knocking, or ringing, occurs. Therefore, if a higher load is desired, supercharging, or turbo charging is necessary. The load limit (without supercharging) is said to be either the engine structure capabilities (knocking limit) or NOx emissions. The problem with the HCCI engines is related to the lean mixtures, the fast combustion, and the high compression ratio (high engine efficiency) that causes the exhaust temperature to become quite low. This can make it difficult to get both turbo charging and oxidizing catalysts to work. The commercialization of the HCCI engine would require overcoming certain challenges. 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 CO2 [7] 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.

HCCI operate well at medium loads but at higher loads combustion becomes intense and rapid [8]. Hence, they operate with lower Indicated Mean Effective Pressure (IMEP) because at higher loads they experience knock. Researchers have proposed to utilize conventional SI operation at high loads and use HCCI for low loads [9]. On the other hand, at very low loads a lean mixture provides inadequate energy and the engine misfires. These two concerns lead to a very constricted operating zone for HCCI.

HCCI combustion is achieved by controlling the temperature, pressure and composition of the air/fuel mixture so that it auto ignites near top dead center (TDC) as it is compressed by the piston. This mode of ignition is fundamentally more challenging than using a direct control mechanism such as a spark plug or fuel injector to dictate ignition timing as in SI and CI engines, respectively. While HCCI has been known for some twenty years, it is only with the recent advent of electronic engine controls that HCCI combustion can be considered for application to commercial engines. Even so, several technical barriers must be overcome before HCCI engines will be viable for high-volume production and application to a wide range of vehicles.In HCCI mode, combustion initiation has to be controlled indirectly, via in-cylinder temperature at the start of compression. Four main areas of timing control were studied as thermal control through exhaust gas recirculation (EGR), variable compression ratio (VCR), variable valve timing (VVT), optimizing fuel injection systems and fuel mixtures or additives. The objectives of the study are :

1. With CFD code / simulation program, to evaluate different operation conditions for controlling the combustion timing of HCCI engine by building a detailed model.
2. To evaluate the VCR and VVT timing results for optimizing valve systems.
3. To evaluate fuel mixture and additive for combustion process
4. To analyze the fuel injection systems for HCCI.
5. To obtain combustion stability and analyzing turbulence fluctuations at different parameters , I.e. loads , speeds
6. To estimate soot limit according to latest Euro norms 5 , analyzing NOx emission levels , co, HC at stoichiometric conditions by applying boost pressure / EGR.

ANALYSIS OF OPTIMUM WORKING CONDITIONS FOR HCCI

HCCI research has continued over the past 20 years. HCCI combustion was first discovered as an alternative combustion mode for two-stroke IC engines by Onishi et al. [1979]. They successfully utilized a perceived drawback of “run-on” combustion with high level of residuals and high initial temperature at light load condition to achieve a stable lean combustion with lower exhaust emissions, specifically UHC, and fuel consumption. This new combustion mythology was named “Active Thermo-Atmosphere Combustion” (ATAC). By observing the combustion process in an optical engine they found that during this combustion mode there was no discernable flame propagating through the chamber, indicating combustion occurred as a multi-center auto ignition process. Onishi et al. identified that the critical parameter to obtain ATAC was the initial temperature of the well-mixed charge consisting of fuel, air and residuals.

In the same year Noguchi et al. [1979] conducted a spectroscopic analysis on HCCI combustion in an opposed piston, two-stroke engine. They measured high levels of CHO•, HO2•, and O• radicals within the cylinder prior to auto ignition, which demonstrated that pre-ignition chemical reactions had occurred and these reactions contributed to the auto ignition. After auto ignition took place, H•, CH•, and OH• radicals were detected, which were indicative of high-temperature chemical reactions. In a traditional SI engine, these radical species are only associated with end-gas auto ignition, namely knock, which confirmed the similarities between the reactions of HCCI and knock in an SI engine.

To investigate the fuel suitability and broaden the stable operation range for HCCI in two-stroke engines, Lida [1994, 1997] and Kojima and Norimasa [2004] performed a series of experiments using fuels such as methanol, di-methyl ether, ethanol, propane and n-butane to investigate fuel adaptation and the composition and the exhaust mechanism of the exhaust gas. In addition, Honda demonstrated the reliability of HCCI engines in a pre-production two-stroke motorcycle engine [Yamaguchi, 1997]. Based on previous HCCI works in two-stroke engines, Najt and Foster [1983] successfully conducted HCCI experiments in a four-stroke engine with blends of paraffinic and aromatic fuels over a range of engine speeds and dilution levels. The intake air had to be heated to a high level to achieve HCCI operation due to the low level of internal residuals inherent in four-stroke engines.

From simplified chemical kinetically controlled modeling and heat release analysis, they concluded that HCCI combustion is a chemical kinetic combustion process, in which HCCI auto ignition is controlled by the same low temperature (below 1000 K) chemistry as that occurring during SI engine knock and in which most of the energy release is controlled by the high temperature (above 1000 K) chemistry. They realized that HCCI suffers from uncontrolled ignition timing and limited operating range. Thring [1989] extended the work in a four-stroke engine using fully-blended gasoline and mapped the operating regime as a function of equivalence ratio and External EGR rate. The load range limitations of HCCI were noted and an engine operating strategy was put forward, suggesting use of HCCI mode at part load and transitioning into SI flame mode at high load condition.

Experiments have been conducted in four-stroke engines operating on fuels as diverse as gasoline, diesel, methanol, ethanol, LPG, natural gas, etc. with and without fuel additives, such as isopropyl nitrate, di-methyl ether (DME), di-tertiary butyl peroxide (DTBT) etc.. A variety of physical control methods (e.g., EGR) have been examined in an effort to obtain wider stable operation [Odaka et al., 1999; Ryan and Callahan, 1996; Christensen et al., 1997, 1998, 2000; Aceves et al., 1999; Allen and Law, 2002; Nordgren et al., 2004; Caton et al., 2005]. From these investigations and many others in the past five years it appears that the key to implementing HCCI is to control the charge auto ignition behavior which is driven by the combustion chemistry.

Even more than in IC engines, compression ratio is a critical parameter for HCCI engines. Using high octane fuels, the higher the compression ratio the better in order to ignite the mixture at idle or near-idle conditions. However, compression ratios beyond 12 are likely to produce severe knock problems for the richer mixtures used at high load conditions. It seems that the best compromise is to select the highest possible CR to obtain satisfactory full load performance from SI fuels [Najt and Foster, 1983]. The choice of optimum compression ratio is not clear; and it may have to be tailored to the fuel and other techniques used for HCCI control. For early direct-injection diesel-fueled HCCI engines compression ratios must also be limited to mitigate the problem of over advanced auto ignition resulting from pre-ignition chemical reactions [Gray and Ryan, 1997; Ryan et al., 2004; Helmantel et al., 2005]. For these applications other measures should be explored for control of HCCI operation at idle or near idle conditions.Another critical factor to obtain appropriate combustion phasing in HCCI is EGR [Cairns and Blaxill, 2005]. At lower load conditions for HCCI, especially, using high octane number fuels, the effect of internal EGR is to provide sufficient thermal energy to trigger auto ignition of the mixture late in the compression stroke. At higher load conditions for HCCI, especially, using high cetane number fuels cold external EGR is required to retard over-advanced combustion phasing. Effects of external EGR on auto ignition of the mixture are different from that of internal EGR even when both the EGR mixtures are at the same temperature [Law et al., 2002].

In four-stroke engines with flexible valve actuation, there are several strategies for internal EGR. One is the re breathing strategy of Law et al., [2001] where the exhaust valve remains open throughout the intake stroke; another is the exhaust recompression strategy [Zhao et al., 2002]. Milovanovic et al. [2004] demonstrated that the variable valve timing strategy has a strong influence on the gas exchange process, which in turn influences the engine parameters and the cylinder charge properties, hence the control of the HCCI process. The EVC timing has the strongest effect followed by the IVO timing, while the EVO and IVC timing have the minor effects. Caton [2005] showed that the best combination of load range, efficiency, and emissions may be achieved using a re induction strategy with variable intake lift instead of variable valve timing. However, no strategy is able to obtain satisfactory HCCI combustion at near-idle loads. Also, under high levels of internal EGR the emissions are re-ingested in the engine and have an extra chance to be burned in the next cycle.

Intake air temperature can be used to modify HCCI combustion phasing, but the controllable range has severe limits. Outside this range the engine volumetric and thermal efficiency are largely reduced due to too advanced auto ignition timing. Also variation of intake temperature is generally a slow process, so this method is not really practical, especially under a transient condition [Sjöberg et. al. 2005]. Increasing cylinder pressure through supercharging or turbo charging is an effective means to increase the engine's IMEP and extend the operational range of equivalence ratio for a HCCI combustion mode. Unfortunately, the higher cylinder pressures make auto ignition control at high loads even more critical, which limits its potential application. Christensen et al. [1998] achieved high loads up to 14 – 15 bar and ultra low NOx emissions; and by preheating the intake air CO emission was negligible. However, the typical low exhaust temperatures of HCCI require special care in turbocharger design in order to achieve high load/high efficiency operation. Hyvönen et al. [2003] investigated that the HCCI operation ranges with both mechanical supercharging and simulated turbo charging and compared with a natural aspirated SI with gasoline as fuel. The operating range can be more than doubled with supercharging and higher brake efficiency than with a natural aspirated SI is achieved at the same loads.

An alternative solution to extending operating the range is to operate the engine in a 'hybrid mode', where the engine operates in HCCI mode at low, medium and cruising loads and switches to spark ignition (SI) mode (or diesel mode-CI) at cold start, idle and higher loads [Milovanovic et al., 2005].Urushihara et al. [2005] used SI in a stratified charge to initiate autoignition in the main homogeneous lean mixture eliminating the need to raise the temperature of the entire charge. A higher maximum IMEP was achieved with SI-CI combustion than with conventional HCCI combustion. However, nitrogen oxide (NOx) emissions increased due to the SI portion of the combustion process.

Spark ignition has also been used for affecting the HCCI combustion initiation. For the same combustion phasing, compression ratio and inlet air temperature can be decreased with spark assistance. The effect from spark assistance decreases with decreasing equivalence ratio (φ) and can be used low to about $\varphi = 0.333$ [Kontarakis et al., 2000; Hyvönen et al., 2005]. Recent advances in extending the operational range have utilized stratification at all three parameters: fuel, temperature and EGR. Fuel injection system determines mixing effect of fuel, air and EGR. For gasoline a conventional PFI injection system can form a good homogeneous mixture [Kontarakis et al., 2000]. Fuel stratification can extend the HCCI low and high load limit. Additionally, by a direct injection accompanied with exhaust recompression strategy [Willand et al. 1998], the fuel injected into exhaust prior to the intake process will undergo pre-ignition reactions and thus promote whole chemical reaction system. As a consequence, the operational range can be extended toward low load conditions. However, the stratified mixture resulting from late injection leads to more NOx and even PM formation. Stratification of fuel is absolutely necessary for HCCI using diesel type fuels, at high load conditions. Although the HCCI combustion of diesel type fuels can be more easily achieved than with gasoline type fuels because of the diesel fuels' lower auto ignition temperature, overly advanced combustion timing can cause low thermal efficiency and serious knock at high load conditions. In addition, mixture preparation is a critical issue. There is a problem getting diesel fuel to vaporize and premix with the air due to the low volatility of the diesel fuel [Christensen et al., 1999; Peng et al., 2003]. Many of investigators [Ryan and Callahan,1996; Christensen et al., 1999; Helmantel and Denbratt, 2004; Ra and Reitz, 2005] have indicated the potential for HCCI to reduce NOx and PM emissions. However, premixed HCCI is not likely to be developed into a practical technique for production diesel engines due to fuel delivery and mixing problems.

This has led to the consideration of alternative diesel-like fuel delivery and mixing techniques, such as early direct-injection HCCI and late direct-injection HCCI, which produce a stratification of equivalence ratio. Early direct-injection has been perhaps the most commonly investigated approach to diesel-fueled HCCI. By appropriate configuration of the cylinder, fuel mixing with air and EGR can be promoted. However, the injector must be carefully designed to avoid fuel wall wetting, which can result in increased UHC emissions and reduced thermal efficiency [Akagawa et al., 1999]. If mixing is not achieved, NOx and PM formation will be enhanced. Combustion phasing remains a critical issue in this kind of HCCI. The UNIBUS (UNIform BUIky combustion System) using early direct-injection, which was introduced into production in 2000 on selected vehicles for the Japanese market, chose a dual injection strategy [Yanagihara, 2001]. Su et al. [2005] used multi-injection modes. The injection rate pattern, the mass ratios between pulses and the pulse number have been proved to be very important parameters in achieving acceptable results.

One of the most successful systems to date for achieving diesel-fueled HCCI is late-injection DI-HCCI technique known as MK (modulated kinetics) incorporated into their products of the Nissan Motor Company. In the MK system, fuel was injected into the cylinder at about 3 CAD ATDC under the condition of a high swirl in the special combustion chamber. The ignition delay is extended by using high levels of EGR [Mase et al. 1998; Kimura et al., 2001].

The effectiveness of combustion retardation to reduce pressure-rise rates increases rapidly with increasing temperature stratification. With appropriate stratification, even a local stoichiometric charge can be combusted with low pressure-rise rates. Sjöberg et al. [2005] suggested that a combination of enhanced temperature stratification and moderate combustion retardation can allow higher loads to be reached, while maintaining a robust combustion system. The effect of EGR stratification also takes a role in enhancing stability through fuel and temperature stratifications. Controlling the coolant temperature also extends the operational range for a HCCI combustion mode [Milovanovic et al., 2005]. Additionally, Since MTBE and ethanol have low cetane numbers, two additives mixing in diesel fuel could delay overly advanced combustion phasing [Akagawa et al., 1999]. Moreover, water injection also improved combustion phasing and increased the duration of the HCCI, which can be used to extend the high load limit [Nishijima et al., 2002]. However, UHC and CO emissions increased for all of the cases with water injection, over a broad range of water loading and injection.A multi-pulse injection strategy for premixed charge compression ignition (PCCI) combustion was investigated in a four-valve, direct-injection diesel engine by a computational fluid dynamics (CFD) simulation using KIVA-3V code coupled with detailed chemistry[14]. The effects of fuel splitting proportion, injection timing, spray angles, and injection velocity were examined. The mixing process and formation of soot and nitrogen oxide (NOx) emissions were investigated as the focus of the research. The results showed that the fuel splitting proportion and the injection timing impacted the combustion and emissions significantly due to the considerable changes of the mixing process and fuel distribution in the cylinder. While the spray, inclusion angle and injection velocity at the injector exit, can be adjusted to improve mixing, combustion and emissions, appropriate injection timing and fuel splitting proportion must be jointly considered for optimum combustion performance.

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

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

A study introduced in 2002 which introduced a modeling approach 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]. A multi-dimensional fluid mechanics code, KIVA-3V, was used to simulate exhaust, intake and compression up to a transition point, before which chemical reactions become important. The results are then used to initialize the zones of a multi-zone, thermo-kinetic code, which computes the combustion event and part of the expansion. After the description and the validation of the model against experimental data, the application of the method was illustrated in the context of variable valve actuation. It has been shown 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.

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]. 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. The oxidation chemistry of the fuels was calculated using a reduced mechanism for primary reference fuel, which was developed at the ERC. The results show that the combustion behavior of DI gasoline sprays and their emission characteristics are successfully predicted and are in good agreement with available experimental measurements for a range of operating conditions. It is seen 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.

Three-dimensional time-dependent CFD simulations of auto ignition and emissions were reported for an idealized engine configuration under HCCI-like operating conditions [19]. The emphasis is on NOx emissions. Detailed NOx chemistry is integrated with skeletal auto ignition mechanisms for n-heptane and iso-octane fuels. A storage/retrieval scheme is used to accelerate the computation of chemical source terms, and turbulence/chemistry interactions were treated using a transported probability density function (PDF) method. Simulations include direct in-cylinder fuel injection, and feature direct coupling between the stochastic Lagrangian fuel-spray model and the gas-phase stochastic Lagrangian PDF method. 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. Engine-out NO2 levels exceed engine-out NO levels in some cases. In-cylinder in homogeneity and unmixedness must be considered for accurate emissions predictions. These findings are consistent with results that have been reported recently in the HCCI engine literature.Determining the effects of EGR on HCCI engine operation is just one of many automotive applications that can be modeled with CHEMKIN-PRO's HCCI Combustion Model. For the user needing more accurate emission results, the Multi-zone model allows specifying non-uniform initial conditions and heat transfer for regions within the cylinder[20].

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

A storage/retrieval technique for a Stochastic Reactor Model (SRM) for HCCI engines was suggested [22]. This technique enables fast evaluation in transient multi-cycle simulations. The SRM uses detailed chemical kinetics, accounts for turbulent mixing and convective heat transfer, and predicts ignition timing, cumulative heat release, maximum pressure rise rates, and emissions of CO, CO2, unburnt hydrocarbons, and NOx. As an example, research shown that, when coupled to a commercial 1D CFD engine modeling package, the tabulation scheme enables convenient simulation of transient control, using a simple table on a two-dimensional parameter space spanned by equivalence ratio and octane number. It was believed that the developed computational tool 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. In particular, simulations of transient operation and control, design of experiments, and optimization of engine operating parameters become feasible.

THE SCOPE FOR FURTHER STUDY

The scope further to be concentrate on the various combustion timing issue. In order to investigate the timing control mainly should concentrate on thermal control through exhaust gas recirculation (EGR), variable compression ratio (VCR), variable valve timing (VVT), fuel injection systems and fuel mixtures or additives. Exhaust gas recirculation (EGR) 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, which is 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. To accomplish the set objectives, the plan of study is as follows:

1. Concept Generation:

In concept generation phase should develop as many concepts as possible so that various parameter 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.

2. Concept Selection:

Once brainstorming and concept generation was completed, then to move on to concept of selection to evaluate different designs based on feasibility and expected results.

3. Engineering Design Parameter Analysis:

To determine design parameters of all the necessary components, CFD analysis will be done.

A 3D model will be set up using a CFD package to determine the effect of different techniques applied for improving the combustion of HCCI engine.

CONCLUSIONS AND RECOMMENDATIONS

As number of concepts will be considered in the analysis which could potentially control variations. Hence by evaluating the various results and finding the appropriate conclusion should be conclude the best strategy for combustion process of HCCI engine.

REFERENCES

1. Christensen, M., Johansson, B., Amn´eus, P. Mauss, F., "Supercharged homogeneous charge compression ignition," SAE Paper 980787.
2. Christensen, M., Johansson, B., "Supercharged homogeneous charge compression ignition (HCCI) with exhaust gas recirculation and pilot fuel," SAE Paper 2000-01-1835.
3. Hyv¨onen, J., Haraldsson, G., Johansson, B., "Supercharging HCCI to extend the operating range in a multi-cylinder VCR-HCCI engine," SAE Paper 2003-01-3214 .
4. J. B. Heywood: "Internal Combustion Engine Fundamentals", McGraw-Hill, New York, 1988.
5. J. E. Dec: "A conceptual model of DI diesel combustion based on laser-sheet imaging", SAE Paper 970873,
6. Mingfa Yao and Jung Qin, "Simulating the Homogenous Charge Compression Ignition Process Using a Detailed Kinetic Model for Dimethyl Ether (DME) and Methane Dual Fuel", omogenous Charge Compression Ignition, 2004, Vol –SP1896.
7. Richard R. Steeper and Shane De Zilwa, " Improving the NOx-Co2 Trade-Off of an HCCI Engine Using a Multi-Hole Injector," Homogenous Charge Compression Ignition Engines, vol. Sp-2100, no. 2007, pp. 71.
8. Jincai Zheng, David L. Miller and Nicholas P. Cernansky, "A Global Reaction Model for HCCI Combustion Process", Homogenous Charge Compressed Ignition, 2004, Vol SP-1896, pp.63
9. Magnus Sjoberg and John E. Dec, "Combined Effects of Fuel-type and Engine Speed on Intake Temperature Requirements and Completeness of Bulk-Gas Reactions for HCCI Combustion," Homogenous Charge Compression Ignition Engines, vol. SP-1805, no. 2003,
10. Richard Stone, Introduction to Internal Combustion Engines, 3rd Ed., Warrendale PA USA, SAE International, 1999.

11. Tommy Tzanetakis, “Multi-zone modeling of Primary Reference Fuel HCCI Engine”, Department of Mechanical and Industrial Engineering, University of Toronto.
12. Rowland S. Benson and N. D. Whitehouse, Internal Combustion Engines, Pergamon Press, London, 1979
13. Tommy Tzanetakis, “Knock Limit Prediction via Multi-Zone Modeling of a Primary Reference Fuel HCCI Engine”, Department of Mechanical and Industrial Engineering, University of Toronto.
14. Zhijun Peng , Bin Liu , Weiji Wang and Lipeng Lu “CFD Investigation into Diesel PCCI Combustion with Optimized Fuel Injection”. 18 March 2011.
15. G. Barroso, A. Escher, K. Boulouchos,” Experimental and Numerical Investigations on HCCICombustion”; 2005 SAE_NA section.
16. M. Hillion, J. Chauvin and O. Grondin,N. Petit,” Active Combustion Control of Diesel HCCI Engine: Combustion Timing”.
17. Aristotelis Babajimopoulos, Dennis N. Assanis,Scott B. Fiveland, “An Approach for Modeling the Effects of Gas Exchange Processes on HCCI Combustion and Its Application in Evaluating Variable Valve Timing Control Strategies”.
18. Youngchul Ra, Jeong Eui Yun and Rolf D. Reitz,”Numerical simulation of gasoline-fueled compression ignition combustion with high pressure late direct injection.”
19. P.M. Diaz,Durga Prasad,S.Muthu Raman, “A CFD investigation of emissions formation in HCCI engines,including detailed NOX chemistry”.
20. “Modeling HCCI Engine with Exhaust Gas Recirculation”, Application Note: CHEMKIN-PRO, PRO-APP-Auto-7 (v2.0) August 30, 2010.
21. J. Chauvin, A. Albrecht, G. Corde, N. Petit, “Modeling and control of a diesel HCCI engine”,
22. Ali M. Aldawood, Markus Kraft, Sebastian Mosbach,” Real-time evaluation of a detailed chemistry HCCI engine model using a tabulation technique”, released: 28 June 2007.
23. S. Onishi, S. Hong Jo, K. Shoda, P Do Jo, S Kato: "Active Thermo-Atmosphere Combustion (ATAC) – A New Combustion Process for Internal Combustion Engines", SAE Paper 790501.
24. M. Noguchi, Y. Tanaka, T. Tanaka, Y. Takeuchi: "A study on gasoline engine combustion by observation of intermediate reactive products during combustion", SAE Paper 790840.

25. P. M. Najt, D. E. Foster: "Compression-Ignited Homogeneous Charge Combustion", SAE Paper 830264.
26. L. Cummins: "Internal Fire", dba Carnot Press, USA, 2000.