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Effect of Modified Design on Engine Fuel Efficiency

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ABSTRACT
This paper covers key and representative developments in the area of high efficiency and cleans internal combustion engines. The main objective is to highlight recent efforts to improve (IC) engine fuel efficiency and combustion. Rising fuel prices and stringent emission mandates have demanded cleaner combustion and increased fuel efficiency from the IC engine. This need for increased efficiency has placed compression ignition (CI) engines in the forefront compared to spark ignition (SI) engines. However, the relatively high emission of oxides of nitrogen (NOx) and particulate matter (PM) emitted by diesel engines increases their cost and raises environmental barriers that have prevented their widespread use in certain markets. The desire to increase IC engine fuel efficiency while simultaneously meeting emissions mandates has thus motivated considerable research. This paper describes recent progress to improve the fuel efficiency of diesel or CI engines through advanced combustion and fuels research. In particular, a dual fuel engine combustion technology called “reactivity controlled compression ignition” (RCCI), which is a variant of Homogeneous Charge Compression Ignition (HCCI), is highlighted, since it provides more efficient control over the combustion process and has the capability to lower fuel use and pollutant emissions. This paper reviews recent RCCI experiments and computational studies performed on light- and heavy-duty engines, and compares results using conventional and alternative fuels (natural gas, ethanol, and biodiesel) with conventional diesel, advanced diesel and HCCI concepts.

Keywords: Blending; Combustion, Fuel efficiency HCCI, In-cylinder fuel, NO*x*RCCI,

I. INTRODUCTION

Engineers are working to increase the efficiency of internal combustion engines by developing several advanced combustion

modes. One of these modes is called (homogeneous charge compression ignition) HCCI. In the HCCI combustion, a highly homogenized mixture of air, fuel, and A combustion product from the previous cycle is auto-ignited by compression.

"This Combustion mode aims at combining the advantages of modern diesel and gasoline Combustion processes, namely low emissions and high efficiency," states Rizzoni. Another research trend targets ways to recover the energy that is normally dissipated through the coolant and the exhaust gas systems of automotive power trains using innovative waste heat recovery devices. These systems can convert thermal energy into mechanical or electrical energy, thus increasing the overall efficiency of the vehicle. Organic Rankine cycle, thermoelectric systems, turbo compounding, and recuperative thermal management systems all have potential for significantly increase engine efficiencies.

II. GOALS FOR ADVANCED COMBUSTION SYSTEMS

- Improve engine efficiency
- fuel economy and meet CO2 emissions regulations
- Lower engine-out NOx and PM/soot emissions to meet stricter regulations
- Reduce size, costs, and fuel consumption penalties of after treatment systems (especially NOx)
- Operate effectively over wide speed/load range
- In Europe: Options for mitigating diesel/gasoline supply/demand imbalance

A smaller but still significant aspect of fuel-efficiency research is called "intelligent energy management." "This ability to more intelligently control the accessory loads in a vehicle—such as the alternator or power steering, etc.—will also contribute to better gas mileage," says Rizzoni. "With smarter control of these loads and the addition of stop-start technology there can be significant increases in fuel economy, with small or no increase in total vehicle cost."Many researchers have shown that HCCI and premixed charge compression ignition (PCCI) concepts are promising techniques for simultaneous NOx and soot reduction. In addition to significant NOx and soot reductions, premixed LTC operation can provide fuel efficiency advantages due to reduced combustion duration and lower heat transfer (HT) losses. But HCCI and PCCI combustion generally suffer from high levels of carbon monoxide (CO) and unburnt hydrocarbon (UHC) emissions. However, in recent years several researchers have demonstrated that boosted HCCI and PCCI combustion can exhibit nearly 100 per cent combustion efficiency. These improvements came through the use of piston designs featuring

RCCI combustion has been investigated on Heavy-Duty (HD) and Light-Duty (LD) engines at the Engine Research Center (ERC) of UW-Madison and at the Oak Ridge National Laboratory (ORNL). The heavy-duty engine is a 2.44 L Caterpillar 3401 single cylinder oil test engine (SCOTE) and the light-duty engines include single cylinder and four-cylinder General Motors (GM) 1.9-L common rail diesel engines. The HD engine EGR system comprises an electrically driven supercharger and a diesel particulate filter (DPF), to prevent fouling of the EGR cooler and supercharger. The EGR supercharger was implemented as a pump to maintain constant EGR levels with constant surge tank pressures as the DPF fills. Conversely, the use of the supercharger in this manner allows experimentation with more than practical turbocharger efficiency levels, especially if the pressure difference between the intake and exhaust surge tanks is small. However, effort was made to avoid such conditions. The multi-cylinder LD engine is also equipped with a variable geometry turbocharger (VGT), and an electronic EGR valve with a high pressure loop EGR cooling system. The HD and LD engine geometries are shown in the Table 1 and Table 2 and the experimental set ups are shown in Fig. 1 and Fig. 2.minimum crevice volumes, as well as use of high intake pressures

Table-I HD Engine Geometry

Base engine type	Caterpillar SCOTE
Bore × stroke	13.72 × 16.51 cm
Connecting rod length	26.16 cm
Squish height	0.157 cm
Piston pin offset	None
Displacement	2.44 L
Geometric comp. ratio	16.1:1
Swirl ratio	0.7
Bowl type	Open crater
Number of valves	4
IVO	−335° aTDC
IVC	−85 and −143° aTDC
EVO	130° aTDC
EVC	−355° aTDC

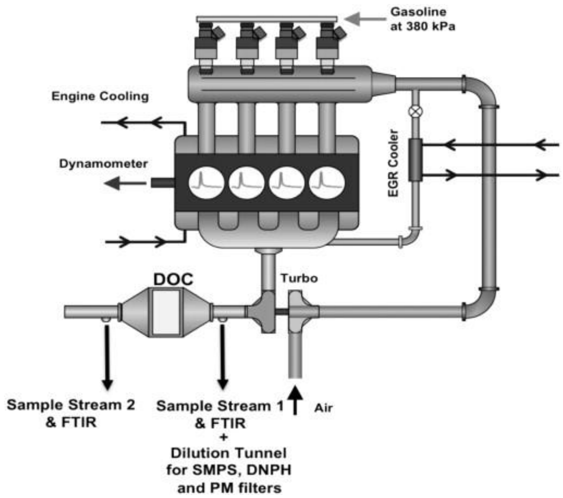

Fig.1 HD Engine set up

Table-II LD Engine Geometry

Engine type	GM DI diesel engine
No. of cylinders	4
Displacement	1.9 L
Boe × Stroke	82 × 90.4 mm
Compression ratio	17.5
No. of Valves/Cyl.	4
Injection system	Common rail
Injector location	Centrally mounted
Rated power	110 kW @ 4000 rpm
Rated torque	315 Nm @ 2000 rpm
IVO	361° aTDC
IVC	588° aTDC
EVO	112° aTDC
EVC	356° aTDC

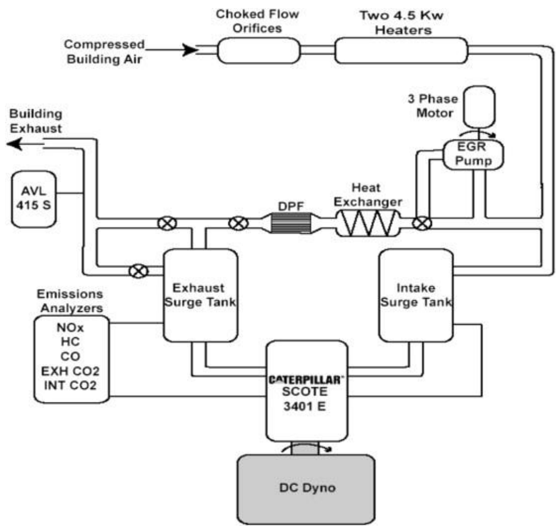

Fig.2 Multi cylinder LD engine set up

RCCI Combustion Strategy Challenges

Despite its promising notion to achieve near-zero NOx and soot emissions while accomplishing peak-indicted thermal efficiencies as high as 53%, the RCCI combustion faces several challenges in its operation as listed below:

- Limited operating range: as compared to the CDC counterpart, the RCCI engine faces constraints on its operating range both at high and low loads. At high loads, its operation is constrained by high levels of PPRR and combustion noise. At low load operating region, RCCI combustion loses its merits over its CDC counter-part, as CDC is capable of achieving similar efficiencies and NOx emission while RCCI suffers from higher UHC and CO emissions. In order to overcome these challenges, mode switching in operation of the RCCI engine has been proposed. Optimal mode-switching operation requires modeling of the dynamics of the operation of the engine which can be utilized in model-based control strategies. • Combustion phasing control: Combustion phasing has significant effect on engine efficiency. There has been some attempts in combustion phasing control of 13 RCCI engine . However, a controller which has the capability to optimize the operation of RCCI engine during its transients is yet to be designed. • Emission control: Emissions are a significant factor in RCCI engine operation and impose significant constraints on its operation. The necessity to meet the stringent EPA emission standards, requires optimal control of emission which can be achieved through model-based control strategies

- **2.1.Automotive HCCI Engine**

Fig.3 Automotive HCCI optical Research engine

The homogeneous-charge compression-ignition (HCCI) strategy has caught the attention of automotive and diesel engine manufacturers worldwide because of its potential to rival the high efficiency of diesel engines while keeping NO_x and particulate emissions extremely low. However, researchers must overcome several technical barriers, such as controlling ignition timing, reducing unburned hydrocarbon and carbon monoxide (CO) emissions, extending operation to high and low loads, and maintaining combustion stability through rapid transients.

HCCI engines can operate using a variety of fuels. In the near term, the application of HCCI in prototype automotive engines typically adopts mixed-mode combustion in which HCCI is used at low-to-moderate loads and standard spark-ignition (SI) combustion is used at higher loads. This type of operation using standard gasoline-type fuels requires a moderate compression ratio of 10:1 to 14:1 for SI operation and variable valve timing to achieve HCCI operation.

The CRF's automotive HCCI engine project comprises three parallel endeavors performed in collaboration with partners in industry, academia, and national labs: experimentally characterize in-cylinder processes including fuel-air mixing, ignition, combustion, and emissions to build our understanding of automotive HCCI combustion and facilitate its implementation; develop laser-based diagnostics capable of delivering the in-cylinder measurements required to characterize HCCI combustion; and develop, validate, and apply computational tools for simulating automotive HCCI combustion strategies including detailed fluid dynamics and chemical kinetics models.

The automotive HCCI engine lab houses a versatile light-duty engine designed to enable investigation of in-cylinder processes during HCCI operation. The automotive-sized engine (0.63 liters/cylinder) has a 3-valve pent-roof head and is equipped with extensive optical access for the application of advanced laser-based diagnostics, including a full height quartz cylinder and an optical piston. The air system provides intake pressures up to 2 bar and heating to 250 °C. These high

Intake temperatures allow investigations of HCCI operation with lower compression ratios (10:1 to 12:1). Alternatively, valve timings that retain large fractions of hot residual gases can be used to induce HCCI combustion. The engine is equipped with a centrally mounted gasoline-type direct injector, a port fuel injection capability, and a fully premixed fueling system, allowing investigations of both well-mixed and stratified HCCI operation.

As an example of current efforts, researchers have developed a new tunable diode laser diagnostic designed to capture time-resolved, spatially averaged measurements of CO in the engine. Such accuarate measurements are which needed for the investigation of recompression strategies in which exhaust valves are closed early to trap and recompress residuals in the cylinder.

Partial fuel injection during recompression is advantageous for rapidly controlling HCCI combustion phasing, and quantifying the extent of reaction of this fuel is a prime objective of the laser-absorption diagnostic. In other recent work, researchers have applied two-wavelength laser-induced fluorescence in the engine to simultaneously map both composition and temperature during recompression operation. Details of in-cylinder temperature distribution are important for understanding HCCI ignition and combustion performance.

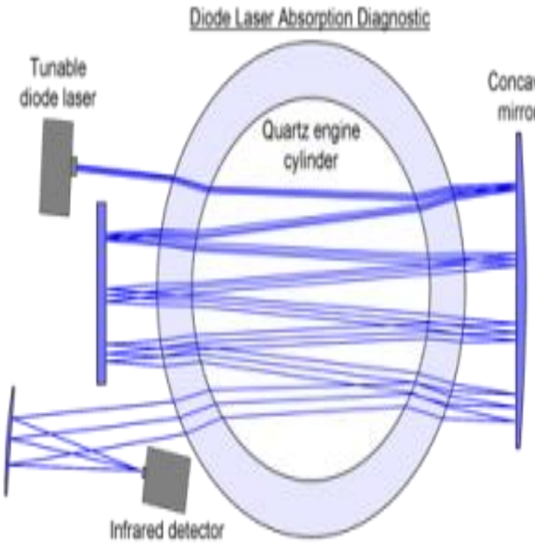

Fig.4 Reactivity Controlled Compression ignition (RCCI)

RCCI is a dual fuel engine combustion technology that was developed at the University of Wisconsin-Madison Engine Research Center laboratories. RCCI is a variant of Homogeneous Charge Compression Ignition (HCCI) that provides more control over the combustion process and has the potential to dramatically lower fuel use and emissions. RCCI uses in-cylinder fuel blending with at least two fuels of different reactivity and multiple injections to control in-cylinder fuel reactivity to optimize combustion phasing, duration and magnitude. The process involves introduction of a low reactivity fuel into the cylinder to create a well-mixed charge of low reactivity fuel, air and recirculate exhaust gases. The high reactivity fuel is injected before ignition of the premixed fuel occurs using single or multiple injections directly into the combustion chamber. Examples of fuel pairings for RCCI are gasoline and diesel mixtures, ethanol and diesel, and gasoline and gasoline with small additions of a cetane-number booster (di-tert-butyl peroxide (DTBP)).

RCCI allows optimization of HCCI and Premixed Controlled Compression Ignition (PCCI) type combustion in diesel engines, reducing emissions without the need for after-treatment methods. By appropriately choosing the reactivity's of the fuel charges, their relative amounts, timing and combustion can be tailored to achieve optimal power output (fuel efficiency), at controlled temperatures (controlling NOx) with controlled equivalence ratios (controlling soot). Key benefits of the RCCI strategy include:

- Lowered NOx and PM emissions
- Reduced heat transfer losses
- Increased fuel efficiency
- Eliminates need for costly after-treatment systems
- Complies with EPA 2010 emissions guidelines without exhaust after treatment

Example experimental engine results are shown in Figure 5

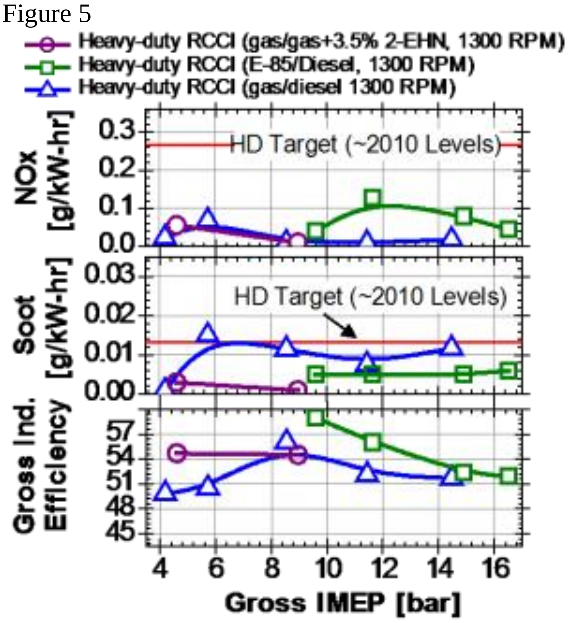

Figure 5: RCCI engine-out NOx, Soot and thermal efficiency in the ERC Caterpillar 3401 heavy-duty research diesel engine operating on a variety of fuel stocks, including gasoline/diesel. Indicted efficiencies as high as 59% achieved with E85/diesel. Note that emissions targets are met in-cylinder, without need for exhaust after-treatment.

Fuel Reactivity controlled RCCI combustion – HD Engines Hanson investigated the potential of controlling RCCI combustion strategies by varying the fuel reactivity. The parameters used in the study were steered from KIVA-CHEMKIN simulations made with a reduced PRF mechanism, which included injection timing, PFI fuel percentage and intake valve closing (IVC) timings. The engine experiments were conducted on the engine shown in Fig. 1 with a conventional common rail injector, and the results demonstrated control and versatility of dual-fuel RCCI combustion with proper fuel blends, SOI and IVC timings. The objective of the study was to explore fuel blending as a means for extending the RCCI operating regime.

To lower peak cylinder pressures and to aid in combustion phasing control, different methods of modifying IVC timings were implemented by Nevin et al., who used four different custom manufactured camshafts with IVC timings ranging from −143° aTDC (stock) to −85° aTDC in order to lower the effective compression ratio. The intake valve lift profiles are shown in Fig. 6. Initial CFD modeling results suggested that the IVC timing of −85° aTDC would be optimal, due to the resulting lower TDC temperatures and pressures. However, in the study of Hanson et al, IVC timings closer to those utilized in the production Caterpillar 3406 engine were investigated by using three camshafts with IVC timings of −85, −115 and −143° ATDC.

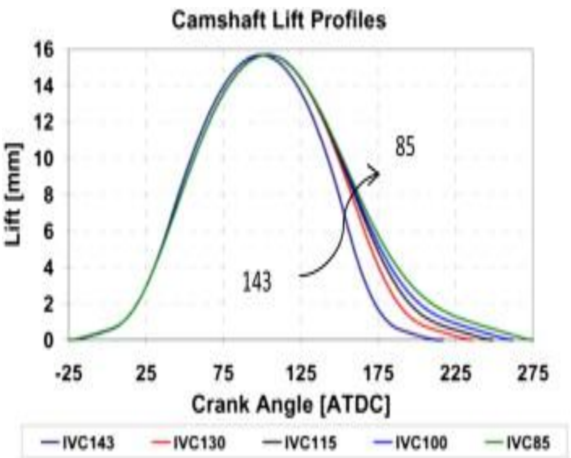

Fig. 6 Intake valve lift profiles for custom camshafts

III. HCCI/CAI ENGINES

Stringent emission standards and the need to reduce greenhouse gas, CO2 emissions from vehicles has led to intensive research on new combustion systems namely, the homogeneous charge compression ignition (HCCI) or controlled autoignition (CAI) engines. These combustion concepts have the following features; HCCI/CAI involves autoignition of very lean homogeneous mixtures of fuel and air so that the combustion temperatures are low. Due to low combustion temperatures NOx formation is negligibly small. NOx formation is two orders of magnitude lower than those from the current SI and CI engines Very little soot is formed as the homogeneous charge is burnt. High fuel efficiencies similar to DI diesel engines can be obtained as very lean mixtures are burned. The first attempts to utilize HCCI/CAI combustion were made to control irregular and misfiring combustion in 2-stroke SI engines at light loads by Japanese researchers during late 1970s. Autoignition of the homogeneous charge was obtained by retaining large amounts of hot residual gas containing partially oxidized hydrocarbons and active chemical species in the cylinder. Honda motors applied this form of combustion on a motorcycle engine prototype during mid-1990s, which was termed as ‘Active Radical Combustion (ARC)’. Fuel economy improvements of about 30% and HC reduction of 50% were obtained compared to normal 2-stroke engine operation. The autoignition of lean homogeneous charge has been called by a variety of names such as Active Thermo Atmosphere Combustion (ATAC), Premixed Charge Compression Ignition (PCCI), Premixed Lean Diesel Combustion (PREDIC), Active Radical Combustion (ARC), Controlled Autoignition (CAI), Homogeneous Charge Compression Ignition (HCCI) etc

3.1. HCCI v/s CAI

Application of autoignition of lean homogeneous charge has been studied in the conventional gasoline as well as diesel engines. The processes adapted to auto-ignite homogeneous charge and the objectives of its application to SI and CI engines are somewhat different In the gasoline engines, external heating of intake charge or use of hot residual gas has been employed to cause controlled autoignition of high octane gasoline or natural gas –air mixtures. Therefore, the auto-ignited combustion process when applied to gasoline engines has been termed as controlled autoignition (CAI). The main objective of CAI application to the gasoline engines is reduction in fuel consumption and NOx emissions. In the conventional diesel engines, the fuel air mixture is heterogeneous and compression of air to high temperature is used to auto-ignite diesel fuel. The diesel fuel has low self-ignition temperature. In application of this concept to diesel engines, the main approach is to premix as much fuel as possible before autoignition without encountering negative effects of auto ignition on combustion parameters and emissions. Autoignition may be caused by other forms of heating of fuel-air mixture in addition to compression heating. This process when applied to diesel engines is usually called as homogeneous charge compression ignition (HCCI). The main objective of HCCI application in the diesel engines is to reduce NOx and particulate emissions. It may be noted that fundamentally the HCCI and CAI processes are the same

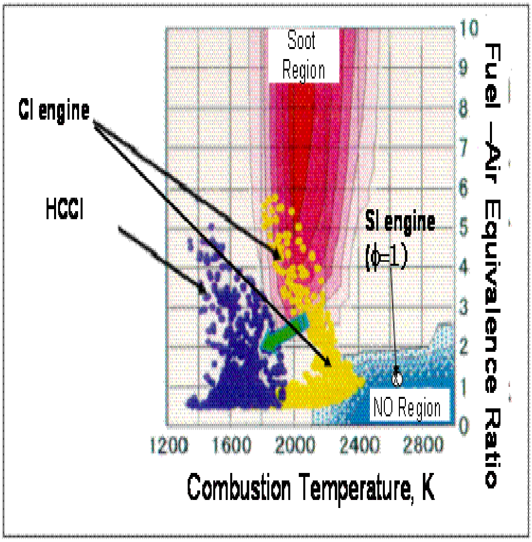

Fig 7. The Fuel –air equivalence ratio –Temperature diagram for hydrocarbon -air mixture conditions for formation of soot and NOx. The conditions of normal SI and CI engine operation and target regionfor HCCI/CAI for low NO and soot formation are shown.

The HCCI/CAI combustion process has two main steps:

(i) Preparation of lean premixed, homogeneous fuel-air mixture, and

(ii) Autoignition leading to combustion of lean premixed charge.

Different approaches have been investigated to accomplish the above steps leading to HCCI/CAI Combustion

IV. CHALLENGES OF HCCI COMBUSTION

In spite of several inherent advantageous features of HCCI combustion, there are some unresolved issues that have kept the HCCI engine from being applied in commercial engines. The most difficult hurdle is the control of ignition. The control of ignition is principally more problematic as compared to the direct control mechanism such as spark plug or fuel injector used in SI and CI engines respectively to control the ignition timing. In HCCI mode, the ignition is controlled by the charge mixture composition and its temperature history. The main challenges of HCCI combustion are stated as follows:

4.1The Difficulty In Combustion Phasing Control

Unlike conventional combustion mode as in SI and CI engines, the HCCI combustion lacks in direct method for controlling the combustion. In fact, in HCCI the start of combustion depends upon the auto-ignition chemistry of the mixture, which therefore is affected by the properties and the time-temperature history of the mixture. Therefore, the combustion phasing in HCCI engines is influenced by the several factors like auto ignition properties of the fuel, fuel concentration, residual rate and possibly, reactivity of the residual, homogeneity of the mixture, compression ratio, intake temperature, latent heat of vaporization, engine temperature, heat transfer to the engine and other engine dependent parameters.

4.2 High Levels Of Uhc & Co Emissions

HCCI combustion generates inherently lower NOx and PM emissions at low loads but comparatively higher HC and CO emissions at low to medium loads as well as high NOx at high loads. In this mode a large fraction of the in-cylinder fuel is accumulated in the cylinder crevice region during the compression stroke and is therefore remains unburned. Furthermore, the larger part of this unburned fuel still remains unburned when it re-enters into the cylinder during the expansion stroke, as the temperature of the burned gas is too low. This leads to considerable increase in both HC and CO emissions as compared to the conventional combustion. Besides, the maximum temperature of the burned gas is not high enough (lower than 1400K or 1500K) to oxidize the CO to CO2 at low loads and hence the combustion efficiency

4.3 Range Of Operation

HCCI combustion performs satisfactorily only in the limited operating range. In this mode, controlling the ignition timing over the full range of speed and load is a challenging issue. The range of operation depends mainly on the auto-ignition properties of the fuel, engine geometry and the operating parameters. Part /light load operation suffers from the lack of sufficient ignition energy to auto-ignite the lean mixture at the end of the compression stroke. In addition, UHC and CO emissions also increase at part load operation due to insufficient combustion efficiency. Furthermore, the high load operation is typically limited by very high rate of pressure rise during combustion and therefore resulting engine knock

4.4 Cold Start Capacity

The HCCI ignition is very sensitive to the intake charge temperature and the small variations change the combustion phasing considerably. Furthermore, the initial temperature required to obtain auto-ignition condition changes with fuel properties and the operating conditions. HCCI engine will face a major problem in firing during cold start operations, as the temperatures are very low and the heat transfer to the cold combustion chamber walls is high. This problem can be overcome by starting the engine in a conventional mode and then switching over to the HCCI mode after a short warm-up period Homogeneous Charge Compression Ignition (HCCI) Combustion Engine

4.5 Homogeneous Mixture Preparation

Effective mixture preparation and avoiding fuel-wall wetting is the key to obtain high fuel efficiency, reduce HC and PM emissions and prevent oil dilution. Even for moderately volatile fuels like gasoline, wall wetting may adversely affect the HC emissions. This is specifically important for the poor volatile fuels like diesel. Mixture homogeneity affects the auto-ignition reactions, which control the combustion phasing. NOx emissions have found to be lower, even if there is some degree of in homogeneity in the mixture

4.6 Abnormal Pressure Rise With Noise

In HCCI mode, due to simultaneous auto-ignition of the whole homogeneous charge in the compression stroke, the heat release is instantaneous, which results in sudden rise in temperature followed by the abrupt rise in pressure leading to high levels of noise. Furthermore, at higher loads the rate of pressure rise can be so high that it may increase the engine noise considerably. If this condition is allowed to continue, then it may cause severe damage.

4.7. Prompt Response Of Cycle Transient

HCCI suffers with a real-time, fast-response control system to tackle the challenges of maintaining required ignition timing during the transient operation, in which the engine speed and load fluctuates rapidly

4.8. Engine Control Strategies And Systems

Still a lot of work is required to be done for developing a new methodology for feed-back and closedloop control of fuel and air systems, suitable control theory and control arithmetic, advanced combustion sensors and next-generation software and hardware accustomed for HCCI combustion in order to optimize the combustion process over full range of load and speed ranges

4.9. Cylinder To Cylinder Variation

Most of the theoretical and experimental work has been done on single cylinder engine. So, when HCCI was used in multi-cylinder engines, the ignition timing and combustion rate vary significantly due to variations in residual gas fraction, intake charge temperature, mass and composition of the fuel and air charge because of the structure and length of the manifolds. Hence, misfire may occur in certain cylinders and knock in other cylinders. Therefore, effort is required to be done for suitable designing of multi-cylinder engines to maintain precise uniformity of flows in every cylinder

4.10. Accurate Chemical Mechanism And Precise Combustion Model

A multi-dimensional CFD model coupled with detailed chemical kinetics is required to be developed in order to fastly and inexpensively evaluate the engine geometry and combustion systems and therefore to accurately predict the features of HCCI combustion.

V. RESULTS AND DISCUSSION

Low Temperature Combustion investigations carried out on the ERC and ORNL engines described above over wide ranges of operating conditions are reviewed. The use of CFD modeling to guide the experimental work is also discussed.

5.1. Dual Fuel Hcci And Pcci Combustion Using In-Cylinder Fuel Blending

The potential of controlling premixed charge compression ignition (PCCI and HCCI) combustion strategies by varying fuel reactivity was investigated by Kokjohn et al. In-cylinder fuel blending was proposed as the fuel delivery and blending strategy to adjust the fuel reactivity on a cycle-to-cycle basis by changing the injected quantities of gasoline and diesel fuel to optimally accommodate engine load and speed changes. A preliminary experimental study at an engine load of 6 bar IMEP was performed in the HD engine using port fuel injection of gasoline and direct injection of diesel fuel near BDC using a low pressureGDI injector. The operating conditions are given in TableIII. Fig 8.shows the cylinder pressure and heat release rates over an EGR sweep at 6 bar IMEP and 1300 rev/min. The simulations were run from IVC to EVO using a two-dimensional sector grid representation of the combustion chamber. At IVC a homogeneous mixture of iso-octane, *n*-heptane, residuals/EGR, and air was assumed. The simulations captured the combustion characteristics reasonably well. However, the peak cylinder pressure and AHRR were slightly over predicted due to the neglected spatial in homogeneity in fuel/EGR/air mixture. But, the results were extremely useful to provide guidelines for the selection of combustion strategies, as described next.

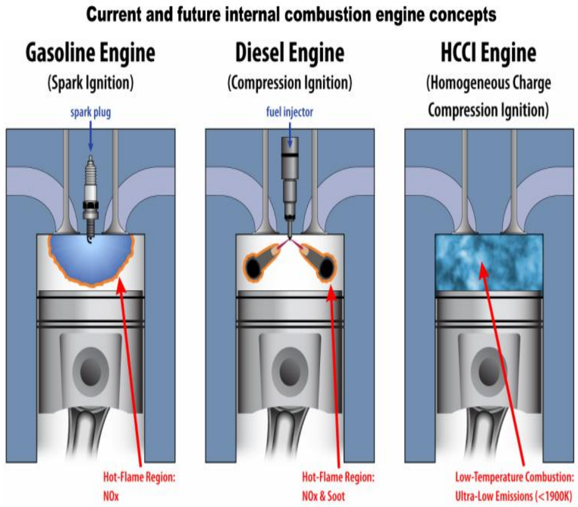

Fig 8 Current and Future Combustion engine concepts

Table III. HD Engine operating conditions for dual fuel study

Nominal IMEP	6 bar				
Engine speed	1300 rev/min				
EGR rate (%)	0	7	11	17	25
Equiv. ratio	0.3	0.32	0.34	0.36	0.4
Intake Temp.	*32 °C*				
Intake press.	1.38 bar				
Total fuel	67 mg/cycle				
Gasoline by mass	61%				
Gasoline by energy	61.4%				
Mass of diesel fuel	26.1 mg/cycle				
Mass of gasoline	40.9 mg/cycle				
Diesel Injection pressure	100 bar				
Diesel SOI	−140 °aTDC				
Diesel injection duration	13.7 °CA				

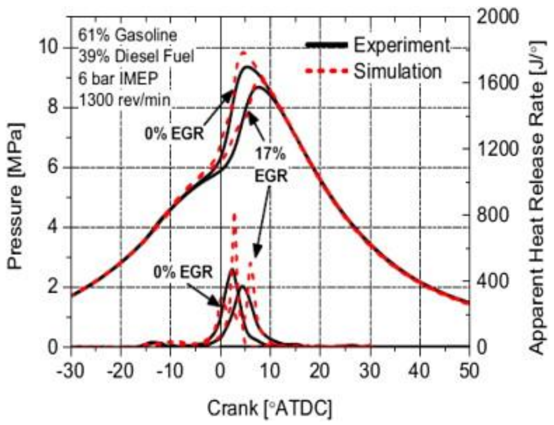

Figure 9. Possible Temperature Distribution in a Low CR Engine and with High Temperature Gradients through an Arbitrary Line in the Combustion Chamber: Black Lines indicate the Increase in Temperature per Δt; Yellow Arrow indicates the Magnitude of Temperature Increase due to Compression; Red Arrow indicates the Magnitude of Temperature Increase due to Diffusion from the Burned Gases.

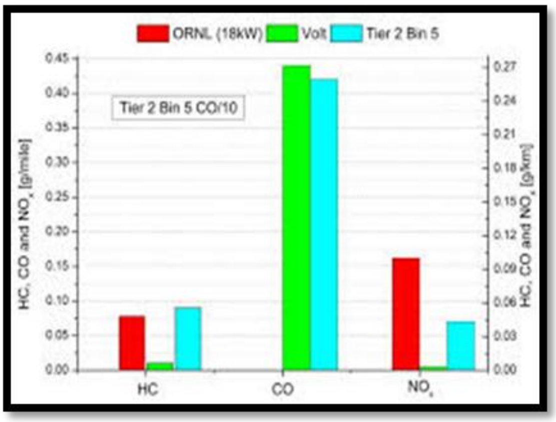

Fig.10. Balanced combustion phasing and load over all

VI. CONCLUSION

The HCCI combustion engines have the potential to reduce the NOx and PM emissions simultaneously, while maintaining the thermal efficiency close to that of conventional diesel engine. But in HCCI combustion there are many challenges such as the difficulty in combustion phasing control, misfire at low and knocking at high loads, cold start problem, difficulty in homogeneous mixture preparation, high rate of pressure rise and high level of noise, high level of HC and CO emissions etc. The homogeneous mixture preparation and autoignition control are the main issues of the HCCI combustion. In HCCI combustion reduction in NOx and PM emissions simultaneously is made possible by eliminating high-temperature and fuel-rich zones respectively due to lean or diluted mixture obtained through effective homogeneous mixture preparation. Auto-ignition control in HCCI leads to achieve higher thermal efficiency. Port fuel injection (PFI), in-cylinder direct injection and PFI combined with direct injection strategies among others are employed for homogeneous mixture preparation The mixture reactivity can be altered by fuel blending, fuel modification or EGR, whereas the time-temperature history of the mixture can be changed by modulating intake temperature, adjusting in-cylinder injection timing, variable compression ratio, variable valve timing and EGR. Furthermore, HCCI combustion as a whole can be controlled by designing and managing the fuel properties appropriately through cetane number, octane number, molecular structure, oxygen content, latent heat of evaporation and boiling and distillation. LTC and SCCI combustion concepts can be regarded as the extension of HCCI combustion concept.Dual fuel reactivity controlled compression ignition combustion in HD and LD diesel engines was focused on, due to its demonstrated superior control, compared to other strategies with discussion of the operating range, thermal efficiency and emission benefits. Experimental work on a single-cylinder HD diesel engine with the dual fuel strategy and a "single fuel" strategy (with the use of an additive) were presented, including low load to high load operation. Next, RCCI combustion in LD and HD engines was compared and combustion in an LD multi-cylinder diesel engine was discussed. Finally, RCCI combustion in an LD single-cylinder engine was reviewed.

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