International Journal of Advanced Research in Engineering and Applied Sciences

ISSN: 2278-6252

ALTERNATIVE FUELS FOR HCCI ENGINE TECHOLOGY AND RECENT DEVELOPMENTS

G. Rajendra prasad*

S. Chakradhar Goud**

Dr. D. Maheswar***

Abstract: *Homogeneous charge compression ignition (HCCI) combustion is an alternative to current engine combustion systems and is used as a method to reduce emissions. It has the potential nearly to eliminate engine-out* NO_x *emissions while producing diesel-like engine efficiencies, when a pre mixture of gas-phase fuel and air is burned spontaneously and entirely by an auto ignition process.Due to the stringent emission norms, the research in the field of internal combustion engines in general and diesel engines in particular gathered huge importance and also increasing demand on fuel consumption. So high demands are placed on large gas engines in the areas of performance, fuel consumption and emissions. Homogeneous Charge Compression Ignition (HCCI) engines promise high thermal efficiency combined with low levels of nitric oxide and particulate matter emissions. However, due to the absence of an immediate means of triggering ignition, stable operation over a wide range of conditions and transient control have proven most challenging and have so far prevented commercialization by opening up new technical avenues, such as micro-hybridization and bio fuels. Most alternative fuel conversions involve reconfiguring a gasoline or diesel vehicle or engine to operate on natural gas, propane, alcohols, or on a blend of conventional and alternative fuels. Use of clean alternative fuels opens new fuel supply choices and can help consumers address concerns about fuel costs, energy security, and emissions. HCCI engines can operate on gasoline, diesel fuel, and most alternative fuels. HCCI combustion is achieved by controlling the temperature, pressure, and composition of the fuel and air mixture so that it spontaneously ignites in the engine. This control system is fundamentally more challenging than using a spark plug or fuel injector to determine ignition timing as used in SI and DI engines, respectively. The purpose of this study is to summaries the alternative fuel effect by adopting low-pressure injectors as an alternative for the HCCI engine combustion process.*

Keywords: *HCCI, combustion, fuel efficiency, pollutant emission, alternate fuels.*

*Associate professor, MNR college of Engg, Hyderabad, India

**Associate Professor, Progressive Engineering College, Bommalaramaram,A.P,India

***Professor & Principal, MNR college of Engg, Hyderabad

1. INTRODUCTION

The first inspirations for an engine that combined the best qualities of the diesel- and gasoline-powered engines-great fuel economy and low emissions, respectively-grew from observations by researchers over two decades ago that gas-powered engines often continued to run despite fouled spark plugs and engines. In a typical engine, fuel is burned to release energy for motion in an event called internal combustion. When this explosion can be set off rapidly and repeatedly, enough energy can be created to propel a car forward. In engines that run on gasoline, each combustion cycle usually consists of these steps: a mixture of fuel and air is taken into a cylinder or combustion chamber, compressed and ignited with a spark, which causes an explosion that drives the exhaust out of the cylinder and through the tailpipe. The well-mixed fuel blend burns more completely resulting in lower soot emissions. In addition, emissions of smog-forming nitrogen oxides (NOx) are relatively low because advances in techniques for recycling exhaust gas into the combustion chamber lowers the reaction temperature and reduces the formation of NOx. Any rogue emissions are scrubbed clear of the exhaust with catalytic converters. However, the fuel economy-the achievable miles per gallon-of this type of engine leaves much to be desired. The entire surface transport of India is based on petroleum fuel, but its availability is of growing concern. The production of domestic crude has been declining and the transport system has been increasingly dependent on imported crude oil to meet its needs. There is a growing concern that the world may run out of petroleum based fuel resources. All these make it imperative that the search for alternative fuels is taken in right earnest. Alternative fuels, particularly sustainable bio fuels, have been identified as one of the key elements in helping achieve this goal. Bio fuels derived from sustainable oil crops such as jatropha, camelina and algae or from wood and waste biomass can reduce the overall carbon footprint by around 80% over their full lifecycle. The information about alternative fuel vehicle and engine conversions where conversion systems modify vehicles and engines so that they can run on different fuels than the ones for which they were originally designed. Most alternative fuel conversions involve reconfiguring a gasoline or diesel vehicle or engine to operate on natural gas, propane, alcohols, or on a blend of conventional and alternative fuels. Use of clean alternative fuels opens new fuel supply choices and can help consumers address concerns about fuel costs, energy security, and emissions. An approach to making HCCI engines roadready is to build computer simulations of combustion under various conditions including the use of different fuels. To that end, researchers are developing chemical models for biodiesel from soy and canola as well as for ethanol and butane fuels. The structural features of these compounds determine the factors related to ignition like cetane number for diesel fuels or octane number for fuels used in spark-ignition engines. "There are no existing computer simulation models for the large molecules characteristic of biodiesel fuels, computational models can be used to predict HCCI ignition timings for any of these cases." An approach also made in the model development in performance of an HCCI engine from one combustion cycle to the next, able to, with models, capture this cycle-to-cycle coupling. This type of model informs the design of combustion control strategies because knowing what happened on a previous cycle determines how to adjust factors like the injection of fuel, air and exhaust for subsequent cycles thereby allowing for more efficient combustion. It's an interesting challenge and the benefit for both traditional gasoline engines and diesel engines really merits this level of attention."

2. THE PROMISING HCCI TECHNOLOGY

Considering the type of engine; gasoline engine could operate cleaner than diesel engine, however diesel engine shows higher in thermal efficiency. This inspires the idea of hybrid among two common type of engine so far. It calls "HCCI" concept i.e. Homogeneous Charge Compression Ignition. However, HCCI combustion works with gasoline diesel and most alternative fuels, giving it a major advantage for future developments. In HCCI engines, the fuel and air are premixed to form a homogeneous mixture before the compression stroke. As a result, the mixture ignites throughout the bulk without discernable flame propagation due to occurrence of auto ignition at various locations in the combustion chamber (multi-point ignition). This may cause extremely high rates of heat release, and consequently, high rates of pressurization [3-5].

In HCCI engines, auto-ignition and combustion rate are mainly controlled by the fuel chemical kinetics, which is extremely sensitive to the charge composition and to the pressure and temperature evolution during the compression stroke, therefore HCCI combustion is widely assumed to be kinetically controlled [3, 6, 7]. The main objective of HCCI combustion is to reduce soot and NO_X emissions while maintaining high fuel efficiency at part load conditions [2, 8]. In some regards, HCCI combustion combines the advantages of both spark ignition (SI) engines and compression ignition (CI) engines [8, 9]. The results from experiment and simulation show that the HCCI combustion has a low temperature heat release and a high temperature heat release, and both heat releases occur within certain temperature ranges. The low temperature heat release is one of the most important phenomena for HCCI engine operation and the occurrence of it depends chemically on the fuel type [10-12].

However there are certain number of obstacles and problems in its application that have not been resolved. These problems are the control of ignition and combustion, difficulty in operation at higher loads, higher rate of heat release, higher CO and HC emissions particularly at light loads, difficulty with cold start, increased NO_X emissions at high loads and formation of a completely homogeneous mixture [13-15]. The lack of a well-defined ignition timing control has led a range of control strategies to be explored. Numerous studies have been conducted to investigate HCCI combustion control methods such as intake air preheating [14, 16, 17], Variable Valve Actuation (VVA) [4], Variable Valve Timing (VVT) [1], Variable Compression Ratio (VCR) [18] and EGR rate [10]. Moreover many studies also focused on the effects of different fuel physical and chemical properties to gain control of HCCI combustion [9, 19- 21].

HCCI engines can be considered as newcomers even though the research was initially by Onishiet al. in 1979, as reported in [22]. Investigators worldwide are developing HCCI engines as this technology has not matured sufficiently. They can be used in either SI or CI engine configurations with a high compression ratio (CR). HCCI engines work without the help of diesel injectors or spark plugs and can achieve high engine efficiency with low emission levels. General Motors Corporation (GM) has unveiled a prototype car with a gasoline HCCI engine and it was claimed that it could cut fuel consumption by 15% [23]. The engine is able to virtually eliminate NOx emissions and lowers throttling losses which assists better fuel economy [24].

A great deal of work has been done in recent years and the research area has extended to all aspect of the combustion process. It has been gradually presenting a picture of energy saving and cleaner exhaust emissions. Increasing environmental concerns regarding the use of fossil fuels and global warming have prompted researchers to investigate alternative fuels.

HCCI has high fuel flexibility and can be applied for a wide range of fuels with different octane/cetane numbers. The combustion process of a HCCI engine has little sensitivity to fuel characteristics such as lubricate and laminar flame speed. Fuels with any Octane or Cetane number can be burned, although the operating conditions must be adjusted to accommodate different fuels, which can impact efficiency. An HCCI engine with variable compression ratio or variable valve timing could, in principle, operate on any hydrocarbon or alcohol liquid fuel, as long as the fuel is vaporized and mixed with air before ignition. Besides gasoline[25] and diesel fuel [26], a variety of alternative fuels, such as methanol [27], ethanol [28,29], natural gas [30], biogas [31], hydrogen [32], DME [27] and their mixtures [33-35], including also gasoline and diesel mixtures and different mixtures of iso-octane with heptane [36], have been experimentally proved as possible fuels for HCCI combustion in both two-stroke and four-stroke engines.

3. THE ANALYSIS OF ALTERNATIVE FUELS FOR HCCI ENGINE

Extensive experimental research shows that the engine exhaust emissions and fuel efficiency of modern diesel engines indicate several unfavorable conditions for biodiesel fuels when the engines are operated in conventional high temperature combustion cycles. The homogeneous charge compression ignition (HCCI) is an alternative combustion concept for internal combustion engines. The HCCI combustion engine offers significant benefits in terms of high thermal efficiency and ultra low emissions (NO_x and PM).Fuels can be described by various combinations of chemistry, boiling points, or physical Properties. The significance of kinetics in modelling advanced combustion modes like HCCI has been well-recognized. Overall, HCCI engine generally responded well to fuels of lower octane, higher sensitivity, lower aromatics and higher olefins, with boiling points in the lower range of those evaluated. One of the advantages of HCCI combustion is its intrinsic fuel flexibility. HCCI combustion has little sensitivity to fuel characteristics such as lubricate and laminar flame speed. Fuels with any octane or cetane number can be burned, although the operating conditions must be adjusted to accommodate different fuels, which can impact efficiency. The study focuses on to investigate the effect of different fuels used in HCCI on combustion characteristic. In order to study the fuel effect, a comparative study [37] was carried out with four types of fuel combinations to control the combustion process of HCCI engine. The fuels used were Gasoline (A-92, A-95, A-98), Diesel fuel (Diesel-45, Diesel-50, Diesel-55), Natural-Gas (NG), single-and dual-component mixtures of the gasoline and diesel primary reference fuels (iso-octane and n-heptane). Combinations between these fuels were used, such as: Natural-Gas with DME (Dimethyl Ether), gasoline with DME, diesel fuel or paraffin hydrocarbons with Natural-Gas.

3.1 combinations on the performance of HCCI - Effect of using different fuels.

The fuel mixture combinations are:

1. NG with DME	4. A-92 with DME	7. Diesel-50 with NG
2. A-98 with DME	5. C_nH_{2n+2} with DME , [n = 1-4]	8. Diesel-55 with NG
3. A-95 with DME	6. Diesel-45 with NG	9. C_nH_{2n+2} with NG, [n = 5-10]

Table 1. Properties of Fuels

Performance Attribute	Natural-Gas	DME	Diesel Fuel
Cetane Number, CN	<6	<55	40-55
Autoignition T oC	650	235	250
Stoichiometric A/F	16.86	9	14.6
Hu MJ/kg	49.9	28.8	42.5

Homogeneous mixtures of two different fuels, which have different ignition characteristics, were used in a compression ignition engine to control the ignition and to improve the thermal efficiency. By varying the composition of the fuel mixture, the ignition timing can be controlled as shown in the following Figures.

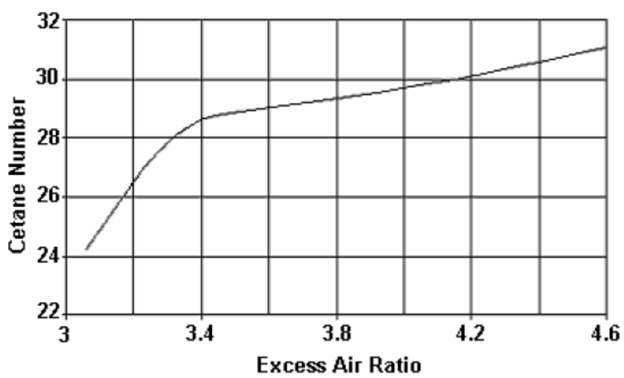

Fig 1 : Relation between CN and λ_{total} at Ta = 320 K, ε = 17.7 for maximum brake thermal efficiency (BTE).

The above Fig. shows that the Cetane Number of the mixture increase with increasing the total excess air ratio of Natural-Gas and DME, therefore, by controlling the fuel cetane number, we can control the combustion process of HCCI engine, and this will happen by using a combination of two different fuels. The combustion process of a homogeneous charge compression ignition engine is very sensitive to a substantial influence of a fuel cetane number on cycle indication parameters. A method for controlling physical and chemical composition of a fuel (a usage of a mixed two-component fuel with a component fraction changed in accordance with a known relationship, for example in dependence on mode parameters of an engine) was chosen as a basic operation method for a working process of HCCI engine.

Natural-Gas (NG) with Dimethyl Ether (DME)

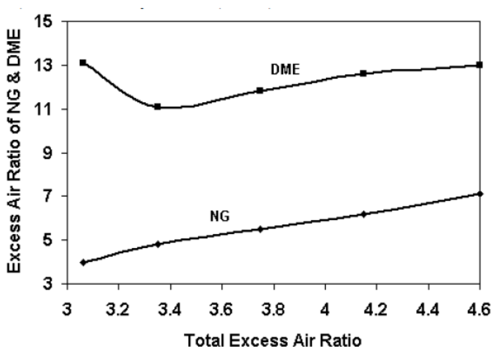

Fig 2 : Relation between total excess air ratio (λ_{total}) and excess air ratio of NG + DME

A-98 with DME

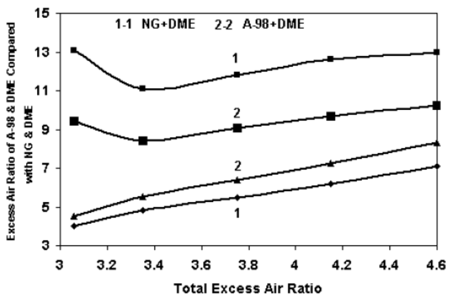

Fig 3 Relation between total excess air ratio (λ t_{otal}) and excess air ratio of NG + DME & A-98 + DME C_nH_{2n+2} with DME , [n = 1…4]

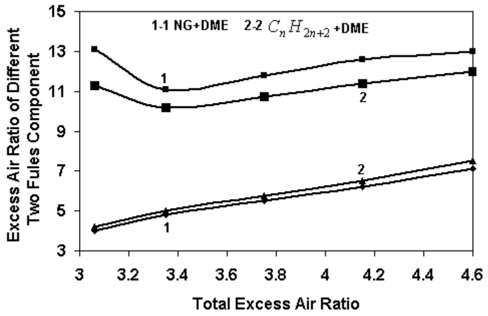

Fig 4 Relation between total excess air ratio (λ t_{otal}) and excess air ratio of NG + DME & CnH2n+2 + DME Diesel-45 with Natural-Gas

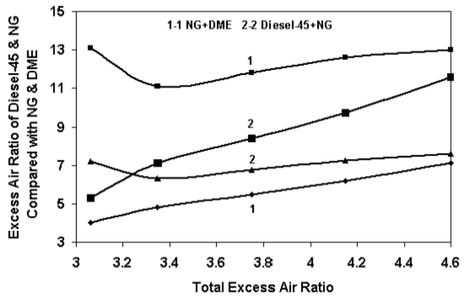

Fig 5 Relation between total excess air ratio (λ $_{total}$) and excess air ratio of NG + DME & Diesel-45 with Natural-Gas Diesel-55 with Natural-Gas

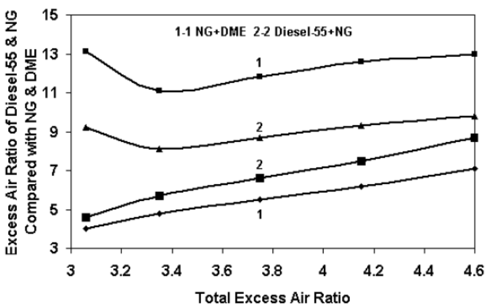

Fig 6 Relation between total excess air ratio (total λ) and excess air ratio of NG + DME & Diesel-55 with Natural-Gas $C_n H_{2n+2}$ with Natural-Gas, [n = 5…10]

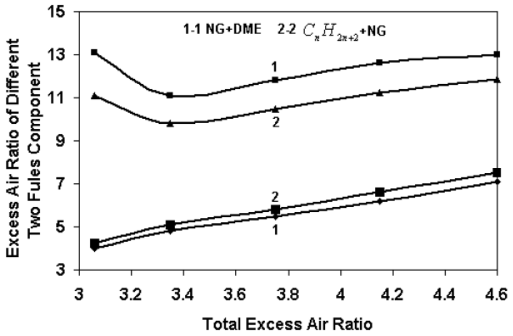

Figure 7 Relation between total excess air ratio (λ t_{otal}) and excess air ratio of NG + DME & $C_n H_{2n+2}$ with Natural-Gas .

As shown from the above Fig. that HCCI has been achieved with multiple fuels. Fuels with any Octane or Cetane number can be burned. It was shown that a tested engine can be used for realizing HCCI process with different components of a mixed fuel (a natural gas, a di methyl ether, benzenes with a different octane number, a diesel fuel, individual hydrocarbons providing range for changing Cetane number of a mixed fuel in limits of 24 - 31) and regulation relationships for these components providing maximum efficiency were used to improve the combustion behaviour, control the ignition timing and improve the thermal efficiency of the HCCI engine. Results analyzed that the possibilities of using fuels with different physical and chemical properties in HCCI engines to control the ignition timing and to control the combustion process. Homogeneous mixtures of two different fuels like Natural-Gas with Dimethyl Ether (DME), A-98 with DME, CnH_{2n+2} with DME, Diesel-45 with Natural-Gas and others, which have different ignition characteristics, are used in a compression ignition engine to control the ignition and to improve the thermal efficiency. By varying the composition of the fuel mixture, the ignition timing can be controlled. HCCI engines can operate using any type of fuel as long as the fuel can be vaporized and mixed with air before ignition [38].

Since HCCI engines are fully controlled by chemical kinetics, it is important to look at the fuel's auto ignition point to produce smooth engine operation. Different fuels will have different auto-ignition points . Fig.7 shows the initial intake temperature required for the fuel to auto ignites when operating in HCCI mode. It is clearly seen that methane requires a high intake temperature and high compression ratio to auto-ignite, as does natural gas because its main component (typically in a range of 75%-95%) is methane. It is easily adapted for use as a fuel due to its wide availability, economic and environmental benefits [39]. Its high auto-ignition point gives it a significant advantage over diesel-natural gas operation by maintaining the high CR of a diesel engine and lowering emissions at the same time[39-41]. It was found that methane is suitable for high CR engine operations[40] and results from a four stroke HCCI engine simulation have shown that methane did not ignite if the intake temperature was less than 400K with CR=15 [42]. where methane will only auto-ignite with intake temperature less than 400K when CR>18. If the Indicated Mean Effective Pressure (IMEP) is increased, it can reduce the intake temperature required on a HCCI engine. Increasing the CR has the same effect [43].

However, the intake temperature required for hydrogen is lower than that for natural gas in HCCI engines without increasing the IMEP or the CR [44]. This is due to hydrogen having a lower density than natural gas. Hydrogen can operate as a single fuel in a HCCI engine but it works in an unstable condition and is prone to generate knocking [45]. It has the highest diffusivity in air, about 3-8 times faster, which leads to fast mixing [41] and the intake charge can be considered homogeneous when mixed with air[47]. Its net heating value is almost 3 times higher than diesel (119.93 MJ/kg compared to 42.5 MJ/kg) with a high self-ignition temperature to initiate combustion (858 K) [45]. Hydrogen and natural gas are mainly used as fuel additives or even as a single fuel in IC engines due to their practicality and availability. Car manufacturers are producing cars powered by fuel-cells(using hydrogen), as well as engines operated with compressed natural gas (CNG). They are purposely built to reduce emissions and be more economical than gasoline and diesel. Iso-octane is used as a surrogate fuel for gasoline in engine experiments while n-heptane is used for diesel[46]. Hydrogen and natural gas are mainly used as fuel additives or even as a single fuel in IC engines due to their practicality and availability. Car manufacturers are producing cars powered by fuel-cells(using hydrogen), as well as engines operated with compressed natural gas (CNG). They are purposely built to reduce emissions and be more economical than gasoline and diesel. Iso-octane is used as a surrogate fuel for gasoline in engine experiments while n-heptane is used for diesel[47]. Alcohol-derived fuels, as shown in Fig. 12, are not widely used due to their complexity to produce.HCCI engines have some features of both spark ignited (SI) engines and Diesel engines. HCCI engines, like SI engines, are generally premixed and very lean at fuel-air equivalence ratio, <0.5; thus they produce very low NOx and particulate matter (PM) emissions. Yet, HCCI engines typically have high compression ratios, leading to high efficiency similar to that found in Diesel engines.

In an SI engine, the combustion event is initiated by a spark, and the timing of the spark is routinely adjusted by an onboard computer called an electronic control unit (ECU). Similarly, the combustion event in a Diesel engine is initiated by injection of the Diesel fuel and the injection time and duration is variable. However, the HCCI engine does not have a spark plug or direct fuel injection; the combustion event occurs when the cylinder contents are hot enough (approximately 1000-1200 K) for a long enough time (order ~ 1 millisecond). The effect of biodiesel content on HCCI engine performance and emission characterization has been studied where combustion experiments are performed in a two cylinder engine, in which one cylinder operates in HCCI mode while other operates in a conventional diesel engine cycle.

The basic requirement of the HCCI engines of homogeneous mixture of fuel and air is fulfilled by port fuel injection strategy, in which an external mixing device is used for fuel vaporization. This fuel vaporizer provides highly premixed charge of fuel and air. HCCI engine is operated with various blends of biodiesel (B20, B40, B60 and B80) and 100% biodiesel (B100). Experimental results of engine tests included combustion and exhaust composition at different engine load and speed conditions. A partial flow dilution tunnel is used for particulate sampling, which are further analyzed for various metal concentrations in biodiesel HCCI particulates vis-à-vis diesel HCCI particulates.

4. SUMMARY

The Volkswagen Golf 2012 satisfies the lust for performance and stability of the drive with its inbuilt technology that’s an appropriate remedy for all types of engine wants. the ability to the Golf Volkswagen is delivered by a 2.0 liter turbocharged four-cylinder that’s capable of deployed a horsepower of 266. Emptor will are confronted with the selection of either choosing a conventional six-speed manual transmission and VW’s DSG dual-clutch automated manual. the quality all wheel drive permits for a sure-footed handling and thus ensures a snug drive. However, the all wheel drive has been reworked for livelier response and to form all the ability go rearward straightforward. With a sharper handling and quicker acceleration, the Volkswagen Golf 2012 could be a much-desired machine that’s positively price investment. The 2012 Golf Volkswagen also will expertise the HCCI engine. HCCI engine could be a petrol engine that behaves a lot of sort of a diesel engine. The behavior of the engine depends on compression primarily needed for bound conditions. The 7-speed DSG can mark the prevalence of the Golf Volkswagen 2012 engine. The automotive has 3 wheelbases, namely, short for the hatchbacks, midsize for Jetta, Tiguan and Golf Variant and Long for Touran and Tiguan XL. The capability to carry baggage is additionally probably to travel up accordingly. The 2012 Golf can have a baggage capability of 405 litres. Surprisingly, Mazda is passing on today's popular trend of downsized, turbocharged engines—say, a 1.4-liter turbo instead of this 2.0-liter. The company says the next generation of gasoline engines, which will employ HCCI (Homogenous Charge Compression Ignition)—essentially firing a gasoline engine like a diesel, without using the spark plugs—will erode the benefits of downsized engines. Smaller engines reduce pumping losses by operating at a higher load (the throttle is open further) more often. In the same way, HCCI engines will have to flow more air to realize the fuel-saving, lean-combustion benefits of that cycle. Mazda claims that if it downsized the Sky family of engines they wouldn't be able to flow enough air for HCCI without upsizing once again. Plus, as Mazda rightly points out, adding a turbocharger and an intercooler is quite a pricey proposition.

The biggest challenge of HCCI in gasoline engines is controlling the combustion process. With spark ignition, the timing of the combustion can be easily adjusted by the power train control module, with control of the spark event. That is not possible with HCCI's flameless combustion.[48] The mixture composition and temperature must be changed in a complex and timely manner to achieve comparable performance of spark-ignition engines in the wide range of operating conditions. That includes extreme temperatures--both hot and cold--as well as the thin-air effect of high-altitude driving. To overcome this, designers could use an engine that uses gasoline but switches between spark ignition and diesel-style compression ignition when required, reports (subscription required).If successful, Bosch estimates that a gasoline engine with HCCI and existing technologies such as turbo charging and stop-start systems could be up to 30 percent more fuel efficient than a conventional engine of the same performance. Its first prototype engine will be a 2.0-liter GM Ecotec unit fitted with a supercharger, a turbocharger, direct fuel injection, a stop-start system, variable valve timing, and HCCI compatibility. Researchers hope their prototype will be as powerful as GM's 3.6-liter V-6 but with the 30 percent target for a reduction in fuel consumption.

Unfortunately, the technology still appears to be in its early days as the prototype engine won't be completed until sometime in 2014, meaning any commercial release may not appear until closer to the end of the decade. It is expected that the vehicle density will increase significantly in coming future, therefore more strict emission regulations has to come. It is very important to make the compulsory use of the control techniques in the vehicles to meet the emission standards. The future study to be focused be on the development of alternative diesel emission control techniques based on the future Indian emission standards.

Many challenges remain before HCCI engines are practical. One of the major challenges of HCCI is controlling the combustion timing. Combustion timing is defined as the crank angle at which 50% heat release occurs, often called CA50. Each stroke of the piston in the cylinder occurs over 360 crank angle degrees. The point of peak compression is called top dead centre (TDC) and engine timings are referred to in times of degrees after top dead centre (ATDC). Another issue for HCCI engines is that pressure rise occurs very rapidly, because auto ignition occurs nearly simultaneously throughout the combustion chamber. This rapid pressure rise can lead to noise, and potentially damaging knocking conditions within the engine. By avoiding the detrimental effects of rapid pressure rise, an increase in the power output of HCCI engines can be achieved. Better understanding of the HCCI combustion process can be greatly aided by exploration of the chemical processes occurring in the combustion process, such as the effect of fuel structure on combustion timing. It is possible to observe combustion characteristics of the fuel-in-air charge by collecting exhaust samples at different combustion timing. Combustion timing is determined by a number of different parameters, such as equivalence ratio, intake manifold pressure, and intake manifold temperature. The primary influence on combustion timing is the intake manifold temperature of the fuel-in-air mixture inducted into the engine combustion chamber. HCCI research has continued over the past 15 years. 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 iso-propyl nitrate, dimethyl ether (DME), di-tertiary butyl peroxide (DTBT) etc.. 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 behaviour 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. 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. An HCCI engine with VCR or VVT could, in principle, operate on any hydrocarbon or alcohol liquid fuel, as long as the fuel is vaporized and mixed with the air before ignition. The importance of turbulence/chemistry interactions on the global ignition event and emissions in HCCI engines has been demonstrated using multidimensional simulations. For lean, low-temperature operating conditions, engine-out NOx levels are low, NOx pathways other than thermal NO are dominant, engine-out NO 2/NO ratios are high, and in-cylinder in homogeneity and unmixed unless must be considered for accurate emissions predictions. Combustion timing is determined by a number of different parameters, such as equivalence ratio, intake manifold pressure, and intake manifold temperature. The primary influence on combustion timing is the intake manifold temperature of the fuel-in-air mixture inducted into the engine combustion chamber. Devices such as electrical heaters, heat exchangers, and exhaust gas recirculation (EGR) control the intake manifold temperature(Tin).The composition of the fuel also plays a major part in the ignition process, as different fuels possess different auto ignition characteristics. Yet still the study should focus more on the technical feasibility of burning blends of natural gas, hydrogen, and DME to improve engine performance, efficiency, and emissions .

REFERENCES

[1] K. Yeom, J. Jang, Ch. Bae, "Homogeneous charge compression ignition of LPG and gasoline using variable valve timing in an engine,'' International Journal of Fuel, 86, 494-503, 2007.

[2] L. Xingcai, H. Yuchun, Z. Linlin, H. Zhen, "Experimental study on the auto-ignition and combustion characteristics in the homogeneous charge compression ignition (HCCI) combustion operation with ethanol/nheptane blend fuels by port injection,'' Fuel, 85 , 2622–2631, 2006.

[3] A. C. Alkidas, “Combustion advancements in gasoline engines,’’ International Journal of Energy Conversion and Management, 48, 2751- 2761, 2007.

[4] C. S. Daw, R. M. Wagner , K. D. Edwards, J. B. Green, “Understanding the transition between conventional spark-ignited combustion and HCCI in a gasoline engine,’’ Proceedings of the Combustion Institute, 31, 2887–2894, 2007.

[5] X. Lü, L. Ji, L. Zu, Y. Hou, C. Huang, Z. Huang, “Experimental study and chemical analysis of n-heptane homogeneous charge compression ignition combustion with port injection of reaction inhibitors,’’ International Journal of Combustion and Flame, 149, 261-270, 2007.

[6] J.J. Hernandez, J. Sanz-Argent, J. Benajes, S. Molina, “selection of a diesel fuel surrogate for the prediction of auto-ignition under HCCI engine conditions,’’ International Journal of Fuel,87, 655–665, 2008.

[7] X. C. Lu¨, W. Chen, Z. Huang., “a fundamental study on the control of the HCCI combustion and emissions by fuel design concept combined withcontrollable EGR. Part 2. Effect of operating conditions and EGR on HCCI combustion,’’ International Journal of Fuel, 84, 1084-1092, 2005.

[8] M. Yao ,Z. Chen,Z. Zheng,B. Zhang,Y. Xing., “Study on the controlling strategies of homogeneous charge compression ignition combustion with fuel of dimethyl ether and methanol,’’ International Journal of Fuel, 85, 2046-2056, 2006.

[9] J. Ma, X. Lü, L. Ji, Z. Huang, “an experimental study of HCCI-DIcombustion and emissions in a diesel engine with dual fuel,’’ International Journal of Thermal Sciences, 47, 1235-1242, 2008.

[10] L. Shi, Y. Cui, K. Deng, H. Peng, Y. Chen., “ study of low emission homogeneous charge compression ignition (HCCI) engine using combined internal and external exhaust gas recirculation (EGR),’’ International Journal of Energy, 31, 2665–2676, 2006.

[11] A. Dubreuil, F. Foucher, Ch. Mounaı¨m-Rousselle, G. Dayma ,Ph. Dagaut, “HCCI combustion: Effect of NO in EGR,’’ Proceedings of the Combustion Institute, 31, 2879-2886, 2007.

[12] M. Sjoberg, J. E. Dec, “Comparing late-cycle autoignition stability for single- and two-stage ignition fuels in HCCI engines,’’ Proceedings of the Combustion Institute, 31 , 2895–2902, 2007.

[13] N.K. Miller Jothi, G. Nagarajan, S. Renganarayanan, “LPG fueled diesel engine using diethyl ether with exhaust gas recirculation,’’ International Journal of Thermal Sciences, 47, 450-457, 2008.

[14] D. S. Kim , Ch. S. Lee, “ improved emission characteristics of HCCI engine by various premixed fuels and cooled EGR,’’ International Journal of Fuel,85, 695–704, 2006.

[15] X. C. Lu¨, W. Chen, Z. Huang, “A fundamental study on the control of the HCCI combustion and emissions by fuel design concept combined with controllable EGR. Part 1. The basic characteristics of HCCI combustion,’’ International Journal of Fuel, 84, 1074-1083, 2005.

[16] J. Chang, Z. Filipi, D. Assanis, T-W Kuo, P. Najt, R. Rask., “Characterizing the thermal sensitivity of a gasoline homogeneous charge compression ignition engine with measurements of instantaneous wall temperature and heat flux,’’ International Journal of IMechE, 2005.

[17] P. Yaping, T. Manzhi, G. Liang, L. Fafa, L. Hua , G. Yingnan, “Study the ethanol SI/HCCI combustion mode Transition by using the fast thermal management system, ’’Chinese Science Bulletin, vol. 52, no. 19 , 2731-2736, 2007.

[18] J. Olsson, P. Tunestal, B. Johansson, S. Fiveland, R. Agama, M. Willi , D. Assanis,“Compression Ratio Influence on Maximum Load of a Natural Gas Fueled HCCI Engine,’’ SAE, 02P-147, 2002.

[19] M. Canakci, “An experimental study for the effects of boost pressure on the performance and exhaust emissions of a DI-HCCI gasoline engine,’’ International Journal of Fuel, 87, 1503-1514, 2008.

[20] K. Inagaki, T. Fuyuto, K. Nishikawa, K. Nakakita, I. Sakata, “combustion system with premixture-controlled compression ignition,’’R&D Review of Toyota CRDL Vol.41 No.3, 2006.

[21] A report to the U.S. Congress, “Homogeneous Charge Compression Ignition (HCCI) Technology ’’, 2001.

[22] M. F. Yao, Z. L. Zheng and H. F. Liu, "Progress and recent trends in homogeneous charge compression ignition (HCCI) engines," Prog Energy Combust Sci, vol. 35, pp. 398-437, Oct 2009.

[23] A. S. Premier. (2007, May 17,2010). HCCI could cut fuel consumption by 15%. Advanced Materials and Processes, P. 27.SREC2010-F2-2 8

[24] A. S. Premier. (2004, May 17, 2010). And they're not hybrids: HCCI engines could bring breakthrough fuel efficiency. Machine Design (21),43-44.

[25] Jacques L., Dabadie J., Angelberger C., Duret P., Willand J., Juretzka A., Schaflein J., Ma T., Lendresse Y., Satre A., Schulz C., Kramer H., Zhao H., Damiano L., Innovative Ultra-low NOx Controlled Auto-Ignition Combustion Process for Gasoline Engine: the 4-SPACE Project. SAE Technical Paper Series 2000, SAE 2000-01-1837.

[26] Ryo H., Hiromichi Y., HCCI Combustion in DI Diesel Engine. SAE Technical Paper Series 2003, SAE 2003-01-0745.

[27] Zheng Z., Yao M., Chen Z., Zhang B., Experimental Study on HCCI Combustion of Dimethyl Ether (DME) / Methanol Dual Fuel. SAE Technical Paper Series 2004, SAE 2004-01-2993.

[28]Yap D., Megaritis A., Wyszynski M. L., An Investigation into Bioethanol Homogeneous Charge Compression Ignition (HCCI) Engine Operation with Residual Gas Trapping. Energy & Fuels 2004, 18, 1315-1323.

[29] Yap D., Megaritis A., Wyszynski M. L., An Experimental Study of Bioethanol HCCI. Combustion Science and Technology 2005 (subm Feb).

[30] Jun D., Iida N., A Study of High Combustion Efficiency and Low CO Emission in a Natural Gas HCCI Engine. SAE Technical Paper Series 2004, SAE 2004-01-1974.

[31] Wyszynski M. L., Megaritis A., Karlovsky J., Yap D., Peucheret S., Lehrle R. S.,Xu H., Golunski S., Facilitation of HCCI Combustion of Biogas at Moderate Compression Ratios by Application of Fuel Reforming and Inlet Air Heating. Journal of KONES Internal Combustion Engines 2004, 11, (3-4).

[32] Stenlåås O., Christensen M., Egnell R., Johansson B., Mauss F., Hydrogen as Homogeneous Charge Compression Ignition Engine Fuel. SAE Technical Paper Series 2004, (04SFL-229).

[33]Chen Z., K., M., O., M., Y., T., Experimental Study of CI Natural-Gas/DME Homogeneous Charge Engine. SAE Technical Paper Series 2000, SAE 2000-01-0329.

[34] Masahiro S., Masato K., Ali M., Kiyoshi K., Shingo E., Knock Characteristics and Performance in an SI Engine With Hydrogen and Natural-Gas Blended Fuels. SAE Technical Paper Series 2004, SAE paper No. 2004-01-1929.

[35]Toshio S., Yoshitaka O., HCCI Combustion of Hydrogen, Carbon Monoxide and Dimethyl Ether. 2002, SAE 2002-01-0112.

[36] Christensen M., Hultqvist A.□ Johansson B., Demonstrating the Multi Fuel Capability of a Homogenous Charge Compression Ignition Engine with Variable Compression Ratio. SAE Technical Paper Series 1999, SAE Paper 1999-01-3679.

[37] S. V. Gusakov, Mahmoud Mohamed El-Ghobashy El-Hagar, Thermal Engineering and Internal Combustion Engine Department Fuel requirements for HCCI engine operation "design of the high thermal efficiency HCCI engine running on DME".

[38] Antunes JMG, Roskilly AP. The use of H2 on compression ignition engines. In: Third European congress on economics and management of energy in industry, 6th–9th April 2004.

[39] Karim GA. Hydrogen as a spark ignition engine fuel. Int J Hydrogen Energy 2003:28:569–577.

[40] J.M. Gomes Antunes, R. Mikalsen, A.P. Roskilly ,Sir Joseph Swan Institute for Energy Research, Newcastle University, United Kingdom. An investigation of hydrogen-fuelled HCCI engine performance and operation

[41] S. Aceves and D. Flowers, "Engine shows diesel efficiency without the emissions," ed: Lawrence Livermore National Laboratory, 2004.

[42] R. G. Papagiannakis and D. T. Hountalas, "Combustion and exhaust emission characteristics of a dual fuel compression ignition engine operated with pilot Diesel fuel and natural gas," Energy Convers Manage, vol. 45, pp. 2971-2987, Nov 2004.

[43] P. M. Duc and K. Wattanavichien, "Study on biogas premixed charge diesel dual fuelled engine," Energy Convers Manage, vol. 48, pp. 2286- 2308, Aug 2007.

[44] N. Saravanan and G. Nagarajan, "An experimental investigation on hydrogen fuel injection in intake port and manifold with different EGR rates," Energy Environ, vol. 1, pp. 221-248, 2010.

[45] S. B. Fiveland and D. N. Assanis, "A Four-Stroke Homogeneous Charge Compression Ignition Engine for Combustion and Performance Studies," SAE Paper 2000-01-0332, 2000.

[46] J.-O. Olsson,et al., "Compression Ratio Influence on Maximum Load of a Natural Gas Fueled HCCI Engine," SAE Paper 02P-147, 2002.

[47] J. M. G. Antunes, R. Mikalsen and A. P. Roskilly, "An investigation of hydrogen-fuelled HCCI engine performance and operation," Int J Hydrogen Energy, vol. 33, pp. 5823-5828, Oct 2008.