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Research Paper

A REVIEW ON METHODS OF HOMOGENEOUS CHARGE PREPARATION FOR HCCI MODE ENGINE

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Homogeneous charge compression ignition (HCCI) engine has ultra low oxides of nitrogen (NOx) and particulate matter (PM) emissions with significant improvement in brake thermal efficiency. There is many issues still need to be solved for the efficient operation of HCCI mode engine. The homogeneous air- fuel mixture preparation is the one of the primary issue to operate the HCCI mode engine. The HCCI engine uses lean homogeneous air-fuel mixture, the performance and emission characteristics of HCCI mode engine can be determined by percentage of air-fuel charge convert to homogeneous form before the start of combustion process. Therefore, percentage of homogeneous charge is only parameter to improve the performance and reduce the exhaust emissions from the HCCI engine. Many researchers have been trying to improve the HCCI engine operation with improve the percentage of homogeneous charge. This paper briefly discussed possibilities and methods of homogenous charge preparation in HCCI engine and discussed the merits and demerits of homogeneous charge preparation methods used by the researchers. And also reviews the impact of homogeneous air-fuel mixture on the HCCI engine performance and emission characteristics.

Keywords: Homogeneous charge compression ignition engine, Homogeneous charge preparation methods, External mixture preparation, In cylinder mixture preparation

INTRODUCTION

Homogeneously charged compression ignition (HCCI) is a promising engine combustion method between spark ignition (SI) and compression ignition (CI) Engines. HCCI combustion is a multipoint lean premixed auto-ignition process with no discernable flame propagation. In general, HCCI is largely controlled by chemical kinetics and less impacted by fluid dynamics (Thring R, 1989). As the HCCI engine has a nearly homogeneous charge, soot is significantly reduced, and NOx formation is relatively low compared to the CI engines (Ryan T W and Callahan T J, 1996). However, unburned hydrocarbon and carbon monoxide levels in

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HCCI are found to be higher than those in SI engines (Stanglmaier R H and Roberts C E, 1999). Despite the many advantageous features of HCCI combustion, difficulty in homogeneous charge preparation is the main issue to be resolved. Various homogeneous charge preparation of HCCI engines are being researched, such as port fuel injection (PFI), early direct injection (EDI) and late direct injection (Gray III A W and Ryan III T W, 1997; Stanglmaier R H and Roberts C E, 1999; Harada A *et al*., 1998). These schemes manipulate intake mixture properties; including inlet temperature (Tinlet), pressure (Pinlet), equivalence ratio (/) and exhaust gas re-circulation (EGR), so that auto-ignition occurs near the top dead center (TDC). Engine performances are found to be best when the SOC falls between 5 and 15 crank angle degrees (CAD) after TDC (Akhilendra P S and Agarwal A K, 2012; and Peng Z *et al*., 2005).

The start of combustion process is typically controlled by the air- fuel mixture. If the HCCI engine is using well mixed air-fuel charge, reduced the ignition delay period of the charge and combustion starts earlier with less combustion duration (Nathan S S *et al*., 2010). Therefore, well premixed air-fuel charge can increase the power output and reduce the emissions of PM, CO and NOx emissions. However if the HCCI engine operates with inhomogeneous charge, it shows the higher soot and HC emissions in the engine exhaust (Duc P M andWattanavichien K, 2007).

The rate of preparation of homogeneous charge can varied with inlet air temperature, air swirl, fuel properties, equivalence ratio and injector properties. Many researchers have been used all these methods to improve the rate of homogeneous mixture. While using high octane number fuels or duel fuel mode, enhance the air-fuel mixture as homogeneous form, it improve the engine power output. diesel with biogas fuelled HCCI engine has investigated by Ramesh *et al*. (Mohamed I M and Ramesh A, 2013). Here author used inlet air charge to create and improve the homogeneous mixture before the combustion take place. If increased the inlet air temperature can be vaporised the fuel within a short time of period between the fuel injection and combustion start. The rate of increasing the inlet air temperature should be limited, because higher inlet air temperature have been reduced the volumetric efficiency of the engine and reduced the engine power.

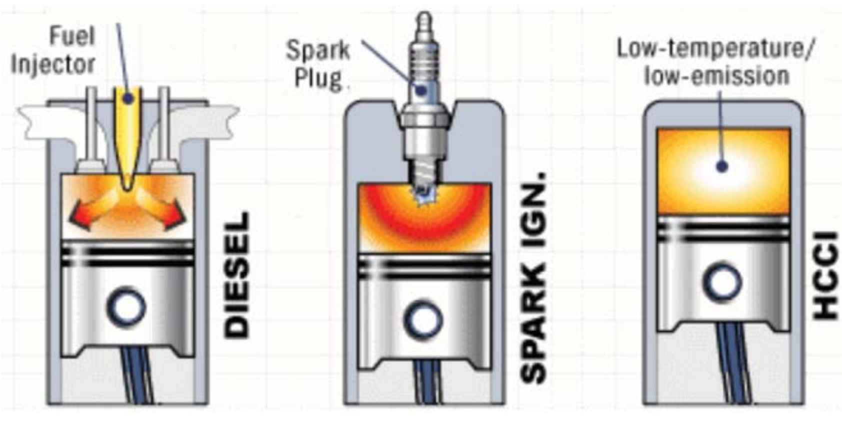
Intake air pressure boosting is a common way to improve the engine output power which is widely used in the high performance SI and CI engines applications. The effect of intake air pressure on the combustion characteristics and exhaust emissions of homogeneous charge compression ignition engine (Mustafa Canakci, 2012). The intake air is pressurized by using supercharger and turbocharger during suction stroke. The high pressurized inlet air can create the swirl inside the cylinder, and it enhances the vaporization of fuel and creates homogeneous mixture before the combustion start.

The fuel properties can governing the homogeneous charge preparation, the fuel viscosity and latent heat of vaporisation are play major roll for the homogeneous charge preparation (Iida N, 1997). The high viscosity fuels difficult to atomise and need more time to vaporise and form homogeneous mixture. Starck *et al*. (Starck L *et al*., 2010) investigated impact of fuel characteristics on HCCI combustion, performance and emissions. He concluded that a fuel having low cetane number and high volatility could improve the HCCI operating range of more than 30%. This paper is dedicated to review how the air-fuel mixture is created as homogeneous form and methods which are used in the HCCI engine for prepare the homogeneous mixture. Here also be discussed the merits and demerits of these methods and impact on HCCI engine performance and emissions.

HCCI ENGINE PRINCIPLE

HCCI is an alternative piston-engine combustion process that can provide efficiencies as high as compression-ignition, direct-injection (CIDI) engines (an advanced version of the commonly known diesel engine) while, unlike CIDI engines, producing ultra-low oxides of nitrogen (NOx) and particulate matter (PM) emissions (Dae Sik Kim andChang Sik Lee, 2006). HCCI engines operate on the principle of having a dilute, premixed charge that reacts and burns volumetrically throughout the cylinder as it is compressed by the piston. In some regards, HCCI incorporates the best features of both spark ignition (SI) and compression ignition (CI), as shown in Figure 1. As in an SI engine, the charge is well mixed, which minimizes particulate emissions, and as in a CIDI engine, the charge is compression ignited and has no throttling losses, which leads to high efficiency. However, unlike either of these conventional engines, the combustion occurs simultaneously throughout the volume rather than in a flame front. This important attribute of HCCI allows combustion to occur at much lower temperatures, dramatically reducing engine-out emissions of NOx (Suzuki H *et al*., 1997). Most engines employing HCCI to date have dual mode combustion systems in which traditional SI or CI combustion is used for operating conditions where HCCI operation is more difficult. Typically, the engine is cold-started as an SI or CIDI engine, then switched to HCCI mode for idle and low- to mid-load operation to obtain the benefits of HCCI in this regime, which comprises a large portion of typical automotive driving cycles. For high-load operation, the engine would again be switched to SI or CIDI operation (Suzuki H *et al*., 1997). Research efforts are underway to extend the range of HCCI operations.

Figure 1: Schematic Diagram of SI, CI and HCCI (26)



HOMOGENEOUS CHARGE PREPARATION

In diesel HCCI combustion, it is difficult to prepare homogeneous mixture because of the lower volatility, higher viscosity and lower resistance to auto-ignition of diesel fuel. First, elevated temperatures are required before significant vaporization occurs, making it easier to form a premixed homogeneous charge. Second, diesel fuel has significant cool-combustion chemistry, leading to rapid auto-ignition once compression temperatures exceed about 800 K (Suzuki H *et al*., 1998). This can lead to overly advanced combustion phasing and high combustion rates. Accordingly, the essential factor needed to achieve diesel HCCI combustion is mixture control, including both charge components and temperature control in the whole combustion history and high pre-ignition mixing rates.

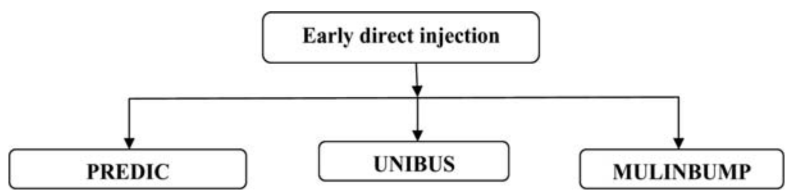
HOMOGENEOUS CHARGE PREPARATION STRATEGIES

The HCCI engine have the difficulties in the preparation of the homogeneous mixture, difficulties in control of the starting phases of combustion and control of the combustion rate, high hydrocarbon and CO emissions, and difficulties in extension of the load range. The strategies for mixture preparation are either in cylinder direct injection or external mixture preparation. Both the preparation methods have their own disadvantages that the external mixture has a low volumetric efficiency and in-cylinder mixture is prone to an oil dilution. This session describes the strategies and implementations of mixture preparation.

Premixed/Direct-injected HCCI Combustion

In premixed/direct-injected HCCI combustion, port injection was chosen for the main fuel supply to create a homogeneous charge, and direct fuel injection into the cylinder was used to change the concentration and position of local fuel-rich regions with the purpose of controlling HCCI combustion. A homogeneous charge compression ignition diesel combustion (HCDC) system, which is the earliest premixed/direct-injected HCCI combustion, has been proposed by Odaka *et al*. (Odaka M *et al*., 1999; Midlam-Mohler S *et al*., 2003; Guezennec Y *et al*., 2002; Midlam-Mohler S, 2004). In their system, most of the fuel was injected into the intake manifold to form a homogeneous pre-mixture in the combustion chamber and the premixture was ignited with a small amount of fuel directly injected into the cylinder. This system can reduce both NOx and smoke emissions better than ordinary diesel engines. Smoke is reduced near-uniformly as the premixed fuel ratio is increased.

Figure 2: Strategies for Early DI Mixture Preparation



Midlam-Mohler *et al*. (Aroonsrisopon T *et al*., xxxx; Berntsson A W and Denbratt I, 2004; Inagaki K and Fuyuto T, 2006) have also developed a premixed/direct-injected HCCI system. Port/manifold fuel injection is achieved using a low pressure atomizer system and direct injection is achieved using a high pressure injection system. The atomizer system delivers fuel as a premixed lean homogeneous mixture into the cylinder. At low loads, the main torque is from the homogeneous charge fuel and the direct injection fuel is mainly for ignition; at high loads, the maximum homogeneous charge fuel is used and direct injection fuelling is increased to full load. Small droplet size (<1 mm mean diameter) allows rapid evaporation during the compression stroke, removing the need for intake air heating. The results indicated that IMEP can be up to 4.7 bar by varying intake conditions in the speed range from 1600 to 3200 rpm. Furthermore, the mixed-mode HCCI combustion can achieve very low NOx and smoke emissions, less than 4 ppm and 0.02 FSN respectively.

Foster *et al.* (Panão M R O and Moreira A L N, 2007) presented results pertaining to expanding HCCI operations by charge stratification achieved by both port and direct fuel injection. The stratification of the charge was altered in two ways, (a) by altering the ratio of direct injected fuel to fuel supplied to the intake system and (b) by retarding the injection timing of the DI injector. Stratified charge shows potential as a viable enhancement for HCCI combustion at the lean limit. The combustion becomes more stable with more stratified charge. Berntsson and Denbratt (Saxena Samveg, Schneider Silvan, Aceves Salvador, Dibble Robert *et al*., 2012) also investigated the control of HCCI combustion using premixed/ directed-fuel injection. In their experiments, port injection was used for the main fuel supply to create a homogenous air–fuel mixture. Engine experiments in both optical and traditional single cylinder engines were carried out with PRF50 as fuel. The amount of stratification as well as injection timing of the stratified charge was varied. The maximum rate of heat release depends on the amount of stratification – a larger amount gives a lower rate of heat release but the main heat release is advanced. Varied injection timing results in different phasing of the main heat release. The use of charge stratification for HCCI combustion can lead to a wider operating range, due to its effect on combustion phasing and rate of heat release. Increasing the stratification amount or late injection timing of the stratified charge can lead to an advanced CA50 timing and higher NOx emissions.

In the research mentioned above, the direct injected fuel is the same as the premixed fuel. In premixed/direct-injected HCCI combustion, these two fuels can also be different, and fuel characteristics can also be used to control combustion. In the system developed by Inagaki *et al*. (Kelly-Zion P L and Dec J E, 2003)., gasoline was supplied to the intake air port and diesel fuel was injected directly into the engine cylinder to act as an ignition trigger at timing before TDC. It was found that the ignition phasing of combustion can be controlled by changing the ratios of the two injected fuels, such that combustion proceeds very mildly. Spatial stratification of ignitability in the cylinder prevents the entire mixture from igniting instantaneously. The operable load range, where NOx and smoke emissions were less than 10 ppm and 0.1 FSN respectively, was extended up to an IMEP of 12 bar using an intake air boosting system together with dual fuelling.

Early Direct Injection HCCI

Because of the disadvantage of port fuel injection, an early direct injection approach towards achieving diesel-fuelled HCCI has been investigated. Compared with premixing in the intake port, this approach offers three potential advantages (Zhao F *et al*., 2003). 1) By injecting the fuel in the compression stroke, the higher in-cylinder temperatures and densities can help vaporize the diesel fuel and promote mixing. This allows cooler intake temperatures, reducing the propensity for early ignition. 2) With a carefully designed fuel injectors, the possibility exists to minimize fuel wall wetting that can cause combustion inefficiency and oil dilution. 3) In principle, only one fuelling system is required for both HCCI and conventional diesel operation. The main disadvantage of early DI for HCCI is that it is easy to produce wall wetting due to over-penetration of the fuel. Finally, it should be noted that controlling combustion phasing is still a critical issue for early-DI HCCI because injection timing does not provide an effective means of directly controlling combustion phasing as in conventional diesel combustion. Several different methods of early-DI HCCI have been investigated, including dual-injection techniques that combine early-DI HCCI with a conventional diesel Injection. Many combustion systems of early direct injection HCCI have been developed such as PREDIC (premixed lean diesel combustion)/MULDIC (multiple stage diesel combustion), UNIBUS and MULINBUMP, are shown in Figure 2 which are reviewed next.

PREDIC

One of the more significant efforts in early-DI HCCI is the work conducted at the New ACE Institute in Japan. Initial reports of this work by Takeda *et al*. (1996)and Nakagome *et al.* (1997) discussed various fuel injection strategies and results show that it is possible to achieve very low NOx and smoke emissions with this technique. However, similar to diesel-fuelled HCCI with port fuel injection, HC emissions were high and fuel consumption was significantly increased over conventional diesel combustion due to poor combustion efficiency and overly advanced combustion phasing. To minimize the over-penetration and wall wetting that can occur when fuel is injected well before TDC, when in-cylinder air densities and temperatures are low, three injectors were used in their study (one at the centre, and two on the sides) to control the injection timing and quantity of each injector independently. The double injectors mounted on either side of the cylinder, each with two sprays, were positioned so that the fuel sprays would collide in the middle of the chamber to limit wall wetting with very early injection. In addition, the nozzle hole diameter of the centre injector was reduced from 0.17 mm to 0.08 mm.

The number of holes was also increased from 6 to 16 and some tests were carried out using a centre injector with 30 holes at various angles. Using this injection method, the engine could be operated with PREDIC. To overcome significant over-advanced combustion, special fuel blends with cetane numbers of 19 and 40 were developed and tested, along with changes in the intake temperature and compression ratio. A subsequent study (Harada A *et al*., 1998) reported the development of a swirling-flow pintle-nozzle injector that produces a more uniform mixture and reduces wall wetting (as measured by reduced lube-oil dilution), thereby improving combustion efficiency.

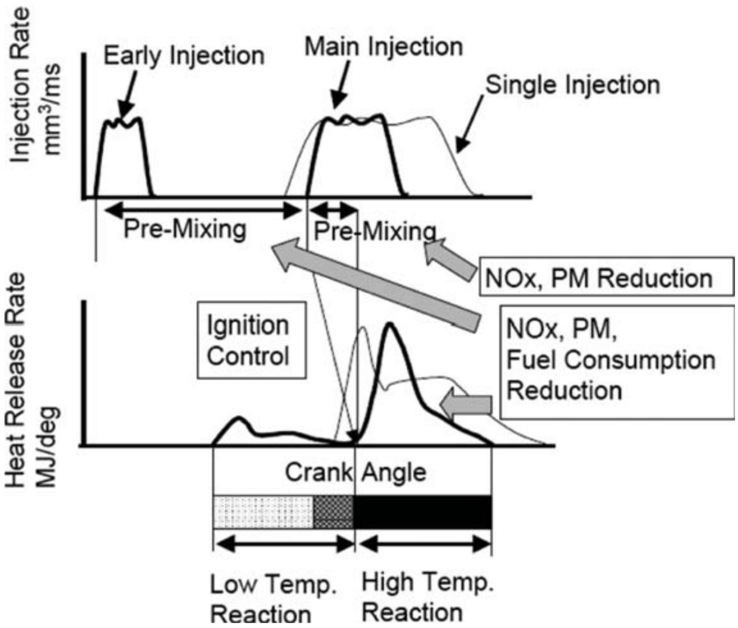
In an attempt to achieve higher power densities, this early-DI work was expanded to include a second fuel injection near TDC (Hashizume T *et al*., 1998). This was accomplished by using the dual side-mounted, impinging-spray injectors to produce the lean premixed charge, whilst a centre-mounted injector was used to inject additional fuel near TDC. Approximately half of the fuel was injected in each stage, which was near the maximum amount of premixed fuel that could be used without causing knock. Various combinations of injection timings (for both stages) and fuel CN were used to optimize performance and emissions. Since the second stage burns similarly to conventional diesel combustion, NOx and PM emissions were much higher with this approach than those obtained with pure HCCI.

However, NOx was reduced to about half that of conventional diesel combustion without a significant increase in fuel consumption. Smoke emissions also decreased, but HC emissions were higher. In order to solve the problem of high HC and CO emissions during HCCI operation, Akagawa H *et al*. (1999) investigated the effects of EGR rate and oxygenated fuels on fuel consumption and the effects of the top-land crevice volume on HC and CO emissions and on adhesion of fuel on the walls. They also investigated double injections, the first earlier injection to form a homogeneous and lean mixture, and the second later one for conventional combustion. Much higher loads were found possible whilst achieving low NOx emissions but this was accompanied by an increase in fuel consumption. Multiple injections were also investigated by Morita *et al*. (2000) and further developed by Nishijima *et al*. (2002), investigating the effects of split injections and water injection. Split injections reduced HC and CO emissions but unfortunately increased NOx emissions.

UNIBUS

Yanagihara H (2001) have also applied HCCI combustion with diesel fuel (Toyota UNIBUS). As described by Yanagihara, the engine operates in UNIBUS mode up to about half load and half speed. As with other DI HCCI techniques, mixture preparation is a key issue. Yanagihara et al. used piezo-actuator injectors with pintle type injector nozzles to reduce the spray penetration in an attempt to limit the over-leaning of the charge. The technique involves a combination of an early injection (around 50º BTDC) and a late injection (about 13º ATDC). The majority of data presented in the paper were taken with 12:1 compression ratio, presumably to avoid overly advanced combustion of the premixed fuel. The investigations examined the impact of the injection timing, level of fuelling, EGR rate and double injections on emissions, torque, instantaneous heat release and load. These results were compared with conventional diesel combustion with the same injector. Low levels of fuelling and low injection pressures were thought to be most appropriate to limit wall wetting and knocking with this particular

Figure 3: UNIBUS Combustion Strategy



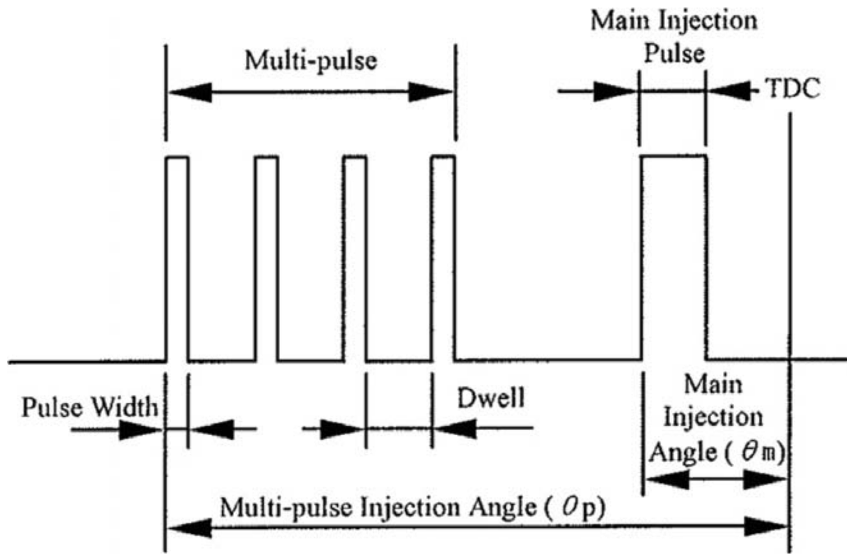
injector nozzle.

A luminous flame is not observed, due to the negligible PM available for oxidation, and confirmed by low PM emissions. The use of EGR is also discussed, and a 60% EGR level is shown to be effective for delaying the HCCI combustion by about 7deg crank angle. A dual-injection strategy has also been developed, with 50% of the fuel introduced in a second injection at 13º ATDC. The second injection significantly improves the combustion efficiency of the early-injected fuel, reducing HC emissions from 5000 ppm to 2000 ppm and CO emissions from about 8000 ppm to 2000 ppm (Hasegawa R and Yanagihara H, 2003). Therefore, fuel combustion from the second injection can be considered as a trigger for a portion of the heat release from the early-injected fuel. Although the second injection increases NOx emissions above the near-zero levels for early injection alone, they are still very low for a diesel engine. Further studies (Najt P E and Foster D E, 1983) were then carried out looking at the possibility of using a second injection closer to TDC to trigger the combustion, which reduced the NOx benefits but also the fuel consumption penalty.

MULINBUMP

Su *et al*. (*et al*., 2003; 2004; 2005) proposed a compound diesel HCCI combustion system – MULINBUMP, combining premixed combustion with ‘‘lean diffusion combustion’’. The premixed combustion was achieved by the technology of multi-pulse fuel injection. The start of pulse injection, injection pulse number, injection period of each pulse and the dwell time between the injection pulses were controlled. The objective of controlling the pulse injection was to limit the spray penetration of the pulse injection so that the fuel will not impinge on the cylinder liner, and to enhance

Figure 4: Multi-pulse Injection of MULINBUMP



the mixing rate of each fuel parcel. The last or main injection pulse was set around TDC. A flash mixing technology was developed from the development of a so-called BUMP combustion chamber, which was designed with some special bump rings. The combustion of fuel injected in the main injection proceeds at much higher air/fuel mixing rate than in a conventional DI diesel engine under the effect of the BUMP combustion chamber, which leads to ‘‘lean diffusion combustion’’.

The characteristics of auto-ignition and rate of heat release of the premixed fuel of multi-pulse injection were investigated, being one of the more important aspects that affect engine emissions. By advancing the start timing of multi-pulse injection, noisy auto-ignition can be avoided, but over-advancing of the start timing will lead to over-mixing, resulting in higher total hydrocarbon (THC) emissions. The results also show that in the compound combustion mode, the fuel proportion of multi-pulse injection should be high, under the condition of no noisy auto ignition, which is helpful in the reduction of NOx emissions. Small amounts of fuel in multi-pulse injection offer no benefits to NOx emissions reduction, but worsen smoke emissions.

Compound combustion technology has potential in realizing HCCI combustion at rather wide operating conditions of a diesel engine. The basic idea of the MULINBUMP compound combustion system is: 1) at low loads of a diesel engine, there is control of the HCCI combustion process by the multi-pulse fuel injection strategy, which can achieve very low NOx and PM emissions (<10 ppm); and 2) at medium and high loads, the strategy of combining premixed combustion with ‘‘lean diffusion combustion’’ is applied. The mixing rate of fuel and air is improved by combining a high mixing rate combustion chamber with a super high injection pressure, thus achieving rapid mixing. Over the full load range of a diesel engine, the best injection modes can be obtained at different conditions by controlling multi-pulse injection, thereby clean and high efficiency combustion of the diesel engine can be achieved over the full load range. To date, the IMEP of compound combustion has reached 0.93 MPa.

Narrow Angle Diesel Injection

A narrowing of the spray cone angle is commonly used to reduce the fuel wetting on the piston head surface and cylinder wall. The use of a narrow fuel injector nozzle spray cone angle to avoid spray–wall interactions at the early injection timings shows promise for achieving HCCI combustion while maintaining a relatively high efficiency (Walter B and Gatellier B; 2003; Shimazaki N *et al*., 2003; Mueller C J *et al*., 2004; Duret P *et al*., 2004). In the research of Kim and Lee (2007), two injector nozzles with different spray cone angles (156 deg and 60 deg) were used to examine the potential of HCCI combustion. The compression ratio of the test engine was reduced from 17.8:1 to 15:1 to prevent the immoderately advanced ignition of the pre-mixture formed by early injection. The results showed that in the case of the conventional diesel engine, the IMEP was decreased rapidly as the injection timings were advanced beyond 20º BTDC and indicated specific fuel consumption (ISFC) were also deteriorated. In the case of advanced injection timing between 30ºand 50º before the TDC, the IMEP was approximately half of that attained under the conventional diesel combustion with the injection timing near the TDC. Injecting the fuel at very early timing helps to create HCCI combustion. However, injecting too early leads to poor fuel evaporation and piston bowl spray targeting issues. At that condition, the fuel–air mixture is formed at the outside of the combustion chamber and the deteriorated combustion efficiency can be expected. Moreover, due to the shifting of combustion event to earlier side, this causes the increase of negative work during compression stroke.

These trends are regarded as typical problems of early injection HCCI engine that lower the thermal efficiency and increase the incomplete combustion products such as the HC and CO emissions. In contrast, the ISFC indicated a modest decrease in the IMEP although the injection timing was advanced to 50–60º BTDC in the case of a narrow spray angle configuration. This reveals that the narrow angle concept was effective in maintaining the high ISFC and IMEP when the fuel was injected at an early timing for HCCI combustion. In addition, the IFP has developed a combustion system able to reach near-zero particulate and NOx emissions while maintaining performance standards of the DI Diesel engines, especially in terms of output power and torque. This dual mode engine application called NADI (narrow angle direct injection) applies homogeneous charge compression ignition at part load and switches to conventional Diesel combustion to reach high and full load requirements. Therefore, it can be concluded that the narrow spray cone angle injector can reduce the wall wetting problem and avoid an out of bowl injection when the fuel was injected at an early timing for HCCI combustion.

Late Direct Injection HCCI

One of the most successful late injection DI HCCI systems for achieving diesel-fuelled HCCI is the MK (modulated kinetics) combustion system developed by the Nissan

Motor Company. The principles of this late injection HCCI combustion process are described by Kawashima *et al*. (1998) and Kimura *et al.* (1999). In order to achieve the diluted homogeneous mixture required for HCCI, a long ignition delay and rapid mixing are required. The ignition delay is extended by retarding the injection timing from 7ºBTDC to 3º ATDC and by using high levels of EGR, sufficient to reduce the oxygen concentration to 15–16%. Rapid mixing was achieved by combining high swirl with toroidal combustion-bowl geometry. The operating range for the first generation MK system was limited to about one-third of peak torque and half speed. In the MK mode, NOx emissions were reduced substantially (to about 50 ppm) without an increase in PM. Combustion noise was also significantly reduced. In addition, it should be noted that with this late-DI HCCI technique, combustion phasing is controlled by injection timing, which is an advantage over port fuel injection and early-DI HCCI techniques.

In the development of a second-generation system, several modifications were made to expand the range of MK operation to higher loads and speeds (Kimura S *et al*., 2003). Since more fuel must be injected at higher loads, a high pressure common-rail fuel system was used to provide high injection pressures at all speeds to reduce fuel injection duration. The ignition delay was increased by reducing the compression ratio to 16:1 and adding EGR cooling to reduce the intake temperature (Yap D *et al*., 2006). To minimize the potential for liquid fuel impingement on the piston bowl wall, the piston bowl diameter was increased from 47 to 56 mm. This change significantly reduced HC emissions under cold-engine conditions. The results show that the second-generation MK system can be used over the entire range of everyday driving, indicating that the engine met the second-generation targets of about half load and three-quarters speed. NOx emissions are stated to be reduced by 98% compared with conventional operation without EGR, whilst PM emissions are similar to the conventional engine.

More recent work by Kawamoto *et al.* (2004) proposed the use of higher CN fuel, which went against other HCCI operating requirements, but was recommended to reduce HC emissions under cold start conditions. The major advantage of the MK combustion system is illustrated by its ease of implementation because it does not require additional or different hardware. Equally, its operation with conventional hardware did not affect negatively the engine's specific power output. However, the injection timing retard and lower compression ratio lead to a deterioration of cycle efficiency and higher unburned HC emissions.

CONCLUSION

Homogeneous charge compression ignition engines have ultra low NOx and PM emissions without affect the engine efficiency. However HCCI mode engines have some challenging issues to operate the HCCI mode engine efficiently. The preparation of homogeneous charge is the one of the major problem in HCCI engine operation. In this review, discussed and conclude the methods which are used to prepare the homogeneous charge and analysed the effect on HCCI engine performance and emission parameters.

In port fuel injection, the fuel is injected on fresh inlet air at intake manifold. The fuel and air are having enough time to mix and form homogeneous charge before take the combustion process. It can be reduced both NOx and particulate matters emissions. The port injection method is also have the some disadvantages due to the early injection the misfire may occur, it can be reduced engine power output and increased HC and smoke emission.

The early direct injection method is used to overcome the disadvantage of port injection method. The early DI method can increased the in cylinder temperature and reduced the ignition delay. The main disadvantage of early DI for HCCI is that it is easy to produce wall wetting due to over-penetration of the fuel. Finally, it should be noted that controlling combustion phasing is still a critical issue for early-DI HCCI because injection timing does not provide an effective means of directly controlling combustion phasing as in conventional diesel combustion. Several different methods of early-DI HCCI have been investigated, including dual-injection techniques that combine early-DI HCCI with a conventional diesel Injection. Many combustion systems of early direct injection HCCI have been developed such as PREDIC (premixed lean diesel combustion)/MULDIC (multiple stage diesel combustion), UNIBUS and MULINBUMP.

One of the most successful injection system is late injection DI HCCI systems for achieving diesel-fuelled engine. The principles of this late injection HCCI combustion process are described by Kawashima *et al*. (1998) and Kimura *et al*. (1999). In order to achieve the diluted homogeneous mixture required for HCCI, a long ignition delay and rapid mixing are required. The ignition delay is extended by retarding the injection timing from 7º BTDC to 3º ATDC and by using high levels of EGR, sufficient to reduce the oxygen concentration to 15–16%. Rapid mixing was achieved by combining high swirl with toroidal combustion-bowl geometry. The operating range for the first generation MK system was limited to about one-third of peak torque and half speed. In addition, it should be noted that with this late-DI HCCI technique, combustion phasing is controlled by injection timing, which is an advantage over port fuel injection and early-DI HCCI techniques.

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