INVESTGATION ON IC ENGINE COMBUSTION WITH THE CONCEPT OF HCCI TECHNOLOGY

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Abstract

Many researchers have started by taking initiation to find the suitability for the reduction of fossil fuel combustion by the way of usage of bio fuels like bio-diesel to control the environment pollution but due to less calorific value of bio-fuels engine performance is not up to the expectation and started researches toward reduction of emission by technology changes, such as exhaust gas recirculation, engine modifications and catalytic after treatment.

Another way of alternative is by using non conventional source of energies like solar and wind power to reduce the usage of fossil fuels and to increase the availability in nature. At present in this direction also lot of researches are going on to bring down the unit cost production but it is unaffordable for the common man. For the use of common man because of high cost of unit production the other direction of research is started to improve the existing engine combustion technology because it is quite old principles have not changed from since long, with suitable modification in the design and combustion pattern. In this aspect it come researchers mind to change the heterogeneous combustion of CI engine by the way of introducing homogeneous combustion.Toburn the lean mixture in diesel engines homogeneous charge combustion is very efficient way to burn the lean mixture because of Homogeneous Charge Compress Ignition (HCCI) combustion system combines the SI engine and CI engine combustion advantages by using the concept of homogeneous charge combustion. Homogeneous Charge Compression Ignition (HCCI) is with least environmental pollution, because of least emissions from SI engine and more fuel efficiency from CI engine. Homogenous Charge Compressed Ignition. Improvement in fuel efficiency, combustion stability was observed when HCCI applied to two

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stroke engines and also observed the fuel efficiency of 50 % was improved in case of four store as compared to the SI engine .so this paper is focused on history and development of combustion technology of IC engines with its changes in combustion pattern.

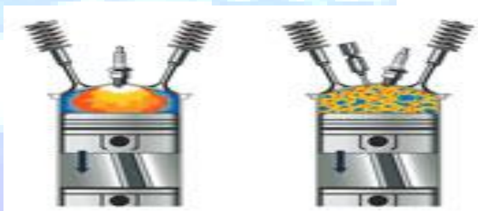
Keywords—IC engine, HCCI, CI Engine,SI Engine,Twostroke Engine, Four stroke Engine,VCR,VVT

I.INTRODUCTION

If we go in to internal combustion engines like petrol and diesel engines the basic principle of combustion not changed from since long. Otto cycle for petrol engines based on constant volume heat addition and rejection developed by N.A Otto Germany scientist in the year 1876 combustion is initiated by spark plug and Diesel cycle developed by German Engineer Rudolf Diesel in 1892 with the concept of compression ignition. These two cycles are successful for practical implementation even though it has less efficiency when compared with Carnot cycle. Carnot cycle is not a practical cycle but it will have high efficiency compared with the other cycles which was developed by Sadi Carnot, a French engineer in the year 1824 later on to get the same efficiency of Carnot tried with other cycles like Stirling and Ericsson cycles but these are not successes in practical application. So Otto (SI) and diesel (CI) cycles are come in to use.

SI engine combustion with the concept of homogeneous mixture, heterogeneous combustion, problem of detonation in end gas combustion, less thermal efficiency, throttling losses but in case of Two stroke engine unstable, irregular, incomplete part load combustion which is responsible excessive emissions of unburned hydrocarbons. CI engine combustion with the concept of heterogeneous mixture, heterogeneous combustion and with high NOx and particulates .In practical implementation SI and CI engines are having very less problems and convenient to use so focus is not given much for further modification by the researchers till the end of 1960s.significant research work was performed from the year 1960 to the end of 1970, Many studies were performed during this period by jo et al. to investigate the part load lean combustion of two stroke engine.

Present trend of increased fuel consumption, due to increased population, urbanization and transportation like electrical trains, automobiles. So consumption of fossile fuels increased year to year and fuel reserves are depleting in a faster rate. Most of the power getting from the thermal power station around 60% and hydraulic power is around 25% balance is from other sources like nuclear ,wind and solar power. it was observed the fuel consumption is increased by more than 10%in every year from last 7 years and giving more emissions, environmental pollution like HC,CO, NOx, soot and leading to global warming and acid rains. So this is the stage to control the emissions, global warming by implementing the advanced techniques to reduce the consumption. One of the advanced techniques is HCCI combustion concept. It is a form of internal combustion in which the Homogeneous Charge is compressed to the point of auto ignition. HCCI not completely the concept of SI engine and not completely the concept of CI engine but it incorporates the best features of both spark ignition (SI) and compression ignition (CI)concepts . HCCI as an SI engine, it mixes the charge well, which minimizes particulate emissions and as a CI engine, the charge is compression ignited, which leads to high efficiency because of no throttling losses.



S.I Engine HCCI Engine

Left side figure shows combustion using the spark to ignite air fuel mixture. Right side figure shows the concept of HCCI which uses piston compression for a more complete ignition.

2. INVESTIGATIONS ON HCCI DEVELOPMENT

Many were involved in the development of the concept of combustion in different stages those are given below from the collected data of previous publications through literature survey.

- ATAC (Active Thermo-Atmosphere Combustion). Onishi et al.(1973) in two stroke engines
- Paul M.Najt and David E.Foster (1983) in four stroke engines – They used Iso-octane and Heptane as the fuel.
- R.H Thring (1989) HCCI in four stroke engine using gasoline and diesel fuels- suggested hybrid HCCI-SI engine

- Thomas ,Ryan et al. (1996) HCCI in four stroke engine using diesel for a wide range of Compression Ratio from 7.5:1 to 17:1
- Aoyama et al. (1996) compared HCCI with DDI and GDI (gasoline direct Injection)–same setup and investigated the effect of supercharging
- Christensen et al.(from 1998)super charging in HCCI with three different fuels (iso octane,ethanol and NG)
- Controlled auto ignition(CAI)combustion with fully variable valve train –Don law et al. and stated that the amount of internal EGR determines the combustion initiation point(Active valve Train was used)
- Jian Li et al. developed a multi cylinder CAI(controlled autoignition) gasoline engine and concluded that 5 to more than 30% reduction in fuel consumption and 90 to 99% reduction in NOX emissions.CO emissions are slightly lower than S.I engine HC emissions are 1.5 to 2.6 times of those from S.I combustion
- CAI combustion of gasoline and alcohol fuels was investigated by Aaron Oakley et al. and concluded that the combustion of alcohols leads to higher engine thermal efficiencies when compared to gasoline and suggested HCCI for part load operation
- George et al (2000) HCCI in four stroke S.I Engine with modifies valve timings
- Toru noda et al –Hydrogen fueled HCCI (Multi zone simulation)
- CAI combustion with fully variable valve train –Don law et al. and stated that the amount of internal EGR determines the combustion initiation point(Active valve Train was used)
- Toshiji et al. investigated the effect of A/F ratio and temp distribution in HCCI by modeling and concluded that pressure profiles depends on two factors

Onset timing of overall reaction of the cell

The magnitude of the time lag of ignition timings among cells

- Prediction of pre-ignition reactivity and ignition delayin HCCI Jincai Zheang et al. they used reduced chemical kinetic model and concluded that negative temp. coefficent. Affects the pre-ignition behavior
- Propane HCCI combustion model using sequential fluid mechanic chemical –kinetic model Salvador M et al. and they suggested that low swirl no cervices and hot walls reduces HC and CO emissions to near zero.

- Four stroke camless engine in HCCI mode using gasoline was experimented by Lucien et al. and they stated - CO,NOX and fuel consumptions were reduced at the same time the level of HC emissions are same when compared to S.I Engine operation
- Jian Li et al. developed a multi cylinder CAI(controlled autoignition) gasoline engine and concluded that 5 to more than 30% reduction in fuel consumption and 90 to 99% reduction in NOX emissions.CO emissions are slightly lower than S.I engine HC emissions are 1.5 to 2.6 times of those from S.I combustion
- Modeling of HCCI combustion and emissions using detailed chemistry william et al.they stated that the most of the CO emissions were formed from unburned fuel-air mix. Flowing from the boundary layer and cervice zones in to the high temp. parts of the cylinder during the expansion stroke.
- Satoshi et al experimented Natural Gas in HCCI engine (Using EGR for performance improvement).

They stated that EGR utilization increases the allowable engine load over 20 % without sacrificing the thermal efficiency and lowers Pmax dramatically

Onishi et al. who managed to get a part load stable two-stroke combustion process for lean mixtures in which ignition occurs without spark assistance. Remarkable improvements in stability, fuel efficiency, exhaust emissions, noise, and vibration were reported.

In 1983 Najt and Foster extended the previous work in two stroke engine to four-stroke engines and attempted to gain additional understanding of physics of HCCI combustion . They are the first to apply HCCI combustion concept in a four-stroke gasoline engine and they considered that HCCI is controlled by chemical kinetics, with negligible influence of turbulence and mixing.

Following figure shows first stage of the heat release curve is associated with low temperature kinetic reaction and the time delay between the first and main heat release is attributed to the negative temperature coefficient (NTC) regime, which locates between the two heat release stages (20, 23) in this negative temperature coefficient regime the overall reaction rate decreases though the in-cylinder temperature increases which leads to a lower reactivity of the system.

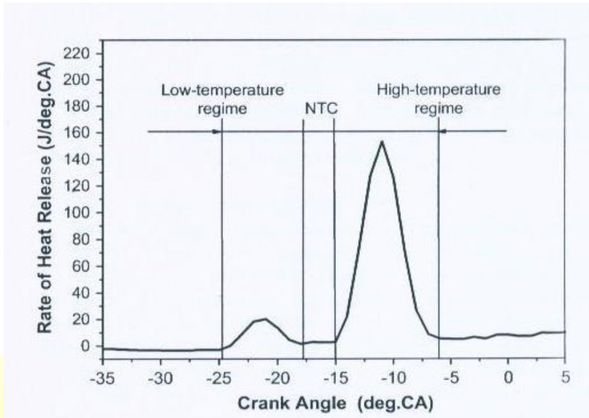


Fig1.n-heptane fuel heat release curve from HCCI combustion

Low temperature kinetics has been studied for some time, as this chemistry is responsible for knock in spark ignition engines heat release from low temperature reaction relates to octane numbers of fuels low octane number is the more obvious the heat release of low temperature reaction for gasoline like fuels (high octane number), heat release from low temperature reaction (first-stage heat release is less compared with diesel like fuel at the same condition. The heat release from low temperature reaction very less to obviously observe from heat release profiles at most conditions for gasoline like fuels. Research with the use of optical diagnostics has shown that HCCI combustion initiates simultaneously at multiple sides within the combustion chamber and there is no discern able flame propagation (14, 16).

3. COMPARISONS OF COMBUSTIONS

HCCI was identifies as distinct combustion phenomenon long ago, HCCI ignition occurs at many points simultaneously with no flame propagation. Combustion was described as very smooth, with very low cyclic variation.

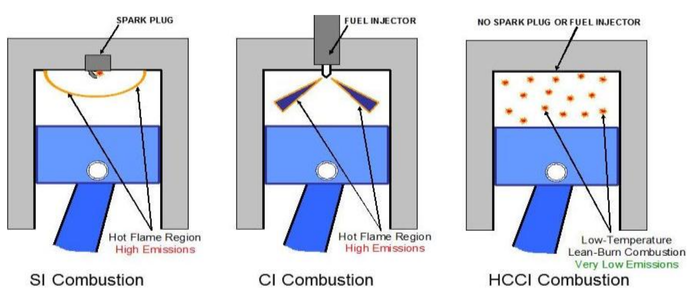


Fig 2: comparison of combustions

Homogeneous charge compression ignition (HCCI), which produces very less NO_X, and minimum PM emissions and high thermal efficiency by operating overall lean mixture. HCCI combustion has benefits like low NO_X emission and high thermal efficiency. However, this combustion mode can produce higher Unburned Hydrocarbons (UHC) and carbon monoxide (CO) emissions than those of conventional engines

In Spark ignition engines combustion timing is controlled by spark timing and in compression ignition engines is controlled by injection timing but in case of HCCI engine there is no direct method to control the start of combustion timing. Therefore, it is important to control the combustion for best fuel economy and lowest emissions. In controlling the temperature, pressure and composition of the in-cylinder mixture, the following parameters can be considered in combustion phase of the HCCI engine like fuel characteristics, intake air temperature, air–fuel ratio, fuel injection timing, multiple pulse fuel injections, engine speed. In addition, the engine performance is influenced by the injector spray geometry, exhaust gas recycling (EGR), variable valve timing, swirl ratio, supercharging, compression ratio, and the piston-cylinder

From HCCI engine principal it is important to realize mixture formation and the avoidance of fuel-wall interactions to achieve high fuel efficiency, reduce HC and PM emissions, and prevent oil dilution. HCCI engine have the potential for high efficiency like diesel, very low particulate emissions Ox and low cost because no high pressure injection system is required but the disadvantages is high HC and CO emissions, high peak pressure, high rate of heat release, reduced operating range, reduced power per displacement and difficulty in starting and controlling the engine. So this paper investigates the past as mentioned above from literature survey and current research done and considerable success in doing detailed modeling of HCCI combustion. Based on research papers it was observed that the implementation of HCCI to gasoline engines is constrained by many factors. The main drawback of HCCI is the absence of direct combustion timing control. Therefore all the right conditions for auto ignition have to be set in HCCI before combustion starts.

From the literature identified the Four main areas of timing control they are one is thermal control through exhaust gas recirculation (EGR) second is variable compression ratio (VCR), third is variable valve timing (VVT), and fourth is fuel injection systems and fuel mixtures(additives). To investigate HCCI Combustion Process a detail CFD (Computational Fluid Dynamics) approach will be used to limit the drawback of HCCI Engine

3.0 DEVELOPMENT OF HCCI ENGINES

3.1 Two stroke HCCI Engine

The main problems of the two-stroke engines are unstable, irregular, and incomplete part load combustion which is responsible for excessive emissions of unburned hydrocarbons so to overcome the problems Lots of studies were performed from the end of the 1960s to the end of the 1970s by Jo et al. to investigate the part load lean two-stroke combustion. He found that the irregularities of the combustion and the auto ignition were considered as the weak points of the two-stroke engine could be effectively controlled and successfully concluded by the innovative work it was published with his colleague, Onishi et al. who managed to get a part load stable two-stroke combustion process for lean mixtures in which ignition occurs without spark assistance. Remarkable improvements in stability, fuel efficiency, exhaust emissions, noise, and vibration were reported. Onishi and his colleagues named this new combustion process “ATAC” (Active Thermo-Atmosphere Combustion).

Another paper concerning two-stroke auto-ignition was published in 1979 [8]. Noguchi and his colleagues named this auto-ignition combustion the TS (Toyota-Soken) combustion process. They also concluded that TS combustion occurred similarly without flame front while showing great efficiency and low emissions. They were one of the first to suggest that active radicals in residual gases could play an important role in the auto ignition process.

In the late 1980s, Duret tried to apply Onishi’s pioneering work to DI two-stroke engines for improvement of part load emissions. For this purpose, he investigated the idea of using a butterfly exhaust throttling valve as previously shown by Tsuchiya et al. in a carburetted engine. The first application of ATAC auto ignition with direct fuel injection engine was then described in 1990.

CFD calculations showed that by regulating the introduction of intake flow by the use of exhaust control valve [6] the mixing between the residual gas and fresh intake air may be precisely regulated

Until mid-1990s this research work was further developed and the interest of using transfer port, throttling to even better control the degree of mixing between the fresh charge and the reactive residual hot gas was demonstrated [4].

The first prototype of two stroke direct injection automotive engine using the transfer port throttling technique for better controlling the degree of mixing between fresh and reactive residual gas was presented by Duret and Venturi in 1996. Considering the benefits of combining direct injection with HCCI, this engine was easily able to meet the European emissions standards valid up to the year 2000 with 20% more fuel economy improvement compared to its four strokes without after treatment counterpart of equivalent power output [6].

So In this period “Ishibashi” investigated the possibility of using the auto ignition in two-stroke motorcycle engines. He showed that possible to control the amount of active residual gases in the combustion chamber as well as in cylinder pressure before compression by using a charge control exhaust valve it was. He named this process as “Activated Radicals (AR) combustion process. AR prototype400 cc Honda EXP-2 was prepared for the Grenada-Dakar rally 1995 and performed very well particular to their high fuel economy compared to the four-stroke motorcycles. This work was further developed up to the first industrial application of AR combustion in production in a Japanese motorcycle model in 1996 and in a European scooter model in 1998 [6].

A new prototype engine named as 2/4 SIGHT which was developed by Ricardo in 2008 which uses HCCI concept. This gasoline engine concept uses novel combustion, boosting, control, and technologies of valve actuation to enable automatic and seamless switching between two- and four-stroke operations, An engine equipped with this new system is capable of running on either the 2-stroke or 4-stroke engine cycle, with the aim of delivering significant performance and fuel economy improvements, allowing their V6 test-bed to be downsized from 3.5 liters to 2.0 liters for producing the same power output. This aggressive downsizing leads reduction of fuel about 27% in fuel economy and lowered the emissions significantly.

As reported by Lotus in 2008 recent HCCI engine was [9]. a single-cylinder research engine named as " omnivore" has been built, with loop scavenging and direct injection with the ability to vary geometrically the compression ratio from 8 : 1 to 40 : 1 or from 6.4 : 1 to 24.4 : 1 on a trapped basis (after exhaust port closure). Blundell et al. and Turner et al. have published this engine data showing very low emission levels and a minimum part-load indicated a specific fuel consumption of 0.218 kg per kW h using gasoline and 0.217 kg per kW h using E85. The engine was designed to be able to operate in HCCI modes and is intended to explore reduction and the ability to operate on alternative alcohol-based fuels and gasoline, allowing flexible fuel vehicle operation.

3.2 Four stroke HCCI Engine

In 1983 Najt and Foster extended the previous work on two-stroke engines [8] to four-stroke engines and attempted to gain additional understanding of the underlying physics of HCCI combustion. They are the first to apply HCCI combustion concept in a four-stroke gasoline engine. In this work they considered that HCCI is controlled by chemical kinetics, with negligible influence of turbulence and mixing. By means of heat release analysis and cycle simulation, they conducted experiments using PRF fuels and intake preheating. They pointed out that HCCI combustion process was governed by low temperature (less than 950°K) hydrocarbon oxidation kinetics. Also they concluded as HCCI combustion is a chemical kinetic combustion process controlled by the temperature, pressure, and composition of the in-cylinder charge.

Work of Najt and Foster is further extended by Thring on four-stroke engines in 1989, by examining the performance of an HCCI engine operated with a full-blended gasoline. The operating regime of a single-cylinder engine was mapped out as a function of air fuel equivalence ratio, EGR rate, and compression ratio.

Studies have shown that it is possible to achieve high efficiencies and low emissions by using lean mixtures at high compression ratio on four-stroke engines. In case of four-stroke , a quite number of experiments have been performed on combustion of HCCI and studied, with single cylinder engines, which normally do not provide brake thermal values. However, Stockinger demonstrated brake thermal efficiency of 35% on a 4-cylinder 1.6 liter engine with brake Mean Effective Pressure (bmep)at 5 bar. Later studies have shown brake thermal efficiencies above 40% at 6 bar BMEP.

4.0 RECENT ANALYSIS OF HCCI ENGINES

Recent analyses of HCCI engines have used detailed chemical kinetics codes in either single-zone mode or multiple-zone model. It is assume that the combustion chamber is a completely -stirred reactor with uniform temperature, pressure and composition in Single-zone models. Single zone model is applicable to homogeneous charge engines which analyze, predict start of combustion with good accuracy where mixing is not a controlling factor. Beginning conditions of the compression stroke is known, and then can be used to evaluate ranges of operations for different fuels and conditions but a single- zone model is not considering the effect of temperature gradients inside the cylinder. The assumption of uniform charge temperature inside the cylinder results in all the mass igniting at the same time when the ignition temperature is reached. Therefore, a single-zone model under predicts the burn duration, and also over predicts peak cylinder pressure, NOx and is unable to predict the combustion efficiency. HC and CO emissions result from mass in cervices and boundary layers that are too cold to burn to completion. A multi-zone model can take full account of temperature gradients inside the cylinder, and therefore can do a much better job at predicting peak cylinder pressure, NO_X and burn duration, and can generate predictions for HC and CO emissions. These benefits are obtained at the cost of a much-increased time for computation compared with a single- zone model. Multidimensional CFD models have the highest potential for predicting realistic results when the geometry of the combustion chamber is resolved in full detail, in combination with a detailed chemistry approach to model combustion. The CHEMKIN chemistry solver is integrated into the KIVA code for solving the detailed chemistry during multidimensional engine simulations. The KIVA code provides CHEMKIN the species and thermodynamic information o9f the computational cells, and the CHEMKIN code returns the new species information and energy release after solving the chemistry. The chemistry and flow solutions are then coupled.

5.0 REASONS TO GO FOR THE DEVELOPMENT

a. Advantages

- In order to achieve particularly favorable NOx emissions and soot
- The combustion always occurs with excess air, just as with the diesel engine, which also has a positive effect on the specific fuel consumption
- Relative to SI gasoline engines, HCCI engines are more efficient, approaching the efficiency of a CIDI (compression ignition direct injection) engine.

b. Improved Efficiency

- Elimination of throttling losses.
- High compression ratios
- Shorter combustion duration (No Flame front, so distance to travel)
- Fuel-Flexibility

C. Emissions

- HCCI engines also have lower engine-out NOx.
- HCCI engines have substantially lower emissions of PM.
- The low emissions of PM and NOx in HCCI engines are a result of the dilute homogeneous air and fuel mixture. The charge in an HCCI engine may be made dilute by being very lean by EGR.

6.0 CHALLENGES OF HCCI COMBUSTION

The main objective of HCCI combustion is to reduce soot and NO_X emissions while maintaining high fuel efficiency at part-load conditions in HCCI engines, the mixture auto-ignites in multiple spots and then is consumed quickly without discernible flame propagation. The mixture is both lean and homogeneous so that little NOx and soot are formed. However, there are still challenges associated with the success fuel operation of HCCI engines. The challenges include the control of the ignition and combustion facing, reduction of high HC and CO emissions and the utilization of EGR, etc. Nonetheless, the fundamental understanding of the combustion process in HCCI engines is still limited, and there has been increasing number of research papers on HCCI. The challenges are as follows.

6.1. The difficulty in combustion phase control

One of the principle challenges of the HCCI combustion is the control of the combustion phasing. Unlike conventional combustion a direct method for controlling the start of combustion is not available. Auto ignition of the fuel-oxidizer mixture is influenced by the properties of the mixture and by the time temperature history to which it is exposed, instead of start of combustion supposed to be established by the auto-ignition chemistry of the air fuel mixture. Hence, combustion phasing of HCCI engines is affected by the factors like auto ignition properties of the fuel, fuel concentration, residual rate and possibility, reactivity of the residual, mixture homogeneity, compression ratio, intake temperature, latent heat of vaporization of the fuel, and engine temperature, heat transfer to the engine and other engine dependent parameters.

6.2. High level of UHC and CO emissions

all homogeneous charge combustion ignitions, during compression stroke a significant portion of the in-cylinder fuel is stored and escapes combustion, and also the burned gas temperature is very low it cannot to consume much of the unburned fuel when it re enters in to the engine cylinder during the expansion stroke which causes increase in noise, unburned hydrocarbons and carbon monoxide emission. This is one more challenge to HCCI engine operation. This results in significant increase in both HC and CO emissions relative to conventional combustion. In addition, the temperature of peak burned gas is are too low (lower than 1400K or 1500K) to complete the conversion of CO in to CO_2 by completing the reaction at low loads, and the combustion efficiency deteriorates [19] this loss of combustion at the lightest loads rates the pressure rise so more the engine noise increases significantly if left unchecked it may damage engine [18]

6.3. Operation range

Adding the problems to the above, another fundamental barrier in HCCI development is extending the operating load range whilst maintaining the full HCCI benefit it is as important as the auto ignition process. In addition to expanding the HCCI operation to higher load, very light load operation is also limited, because there is insufficient thermal energy to trigger auto ignition of the mixture late in combustion stroke. More over with low exhaust gas temperature at neat idle operation, excess emissions of CO and HC in combination, makes the combustion mode less appealing from combustion efficiency and exhaust emissions perspectives.

6.4. Cold start

the heat loss from the compressed charge to the cold combustion chamber walls is too high because of operation temperatures are very low at the time of cold start, so the HCCI engine starting will face a major difficulty, so the engine may have to be started in a conventional mode after a short warm-up period then switched to the HCCI mode. Therefore maintaining real homogeneous combustion after the cold start also be a real challenge. Cold starts are an area where much more developmental efforts are required in HCCI operation. Obviously, HCCI benefits in fuel efficiency and emissions is as important as extending the HCCI operations to high loads.

6.5. Homogeneous mixture preparation

For achieving the higher fuel efficiency, effective mixture preparation, avoiding fuel/wall interactions are crucial for achieving high fuel efficiency and also at the same time reducing HC and PM emissions for preventing oil dilution. Fuel impinging on the surfaces of the combustion chamber has been proven disadvantageous to HC emissions even for moderately volatile fuels such as gasoline [20]. Mixture of homogeneity has an effect on auto ignition reactions that control the HCCI combustion phasing [21] and there is significant evidence that low NOx emissions can be produced even with some degree of mixture in homogeneity within the combustion chamber. Homogeneous mixture preparation is most difficult for fuels with reduced volatility such as diesel, which requires elevated intake air temperatures for low smoke operation when port-injected.

7. SOLUTIONS PROPOSED FOR THE CHALLENGES

A. Controlling of HCCI ignition timing

For controlling HCCI combustion timing several strategies have been investigated, and extending the load range with various levels of success. Most of these strategies can be divided into the broad categories of mixture dilution, Modifying fuel properties, fast thermal management and in-cylinder direct fuel injection. Many studies investigating HCCI control employ more than one method due to the complicated and highly coupled nature of the HCCI combustion problem.

7.1. Mixture dilution for HCCI control

High intake charge temperatures and a significant amount of charge dilution must be present to achieve HCCI combustion. To initiate and sustain the chemical reactions leading to auto ignition processes in cylinder gas temperature must be sufficiently high and to control runaway rates of the heat releasing reactions substantial charge dilution is necessary. These requirements in both cases can be realized by recycling the burnt gases within the cylinder.

One of the HCCI combustion phasing control approach is to advance or retard combustion timing by diluting the cylinder mixture. Najt and Foster showed that HCCI combustion in a four-stroke engine could be controlled by introducing re-circulated exhaust gas into the cylinder intake mixture. Christensen and Johansson showed combustion timing to be slower with higher amounts of EGR.

Within the engine cylinder while processing the presence of the recycled gases have a number of effects on the HCCI combustion and emission. The temperature of the intake charge increases owing to the heating effect of the hot burnt gases when hot burned gases are mixed with cooler inlet mixture of fuel and air. This is often the first case for HCCI combustion with high octane fuels, such as gasoline and alcohols. The second case is, some of the inlet air replaces by introduction or retention of burnt gases in the engine cylinder and hence reduces the oxygen concentration (especially with the EGR). Oxygen present in the air is reduction due to the presence of burnt gases which causes the dilution effect. Third case may be with burnt gases, the total heat capacity of the in-cylinder charge will be higher; it is mainly due to the higher specific heat capacity values of carbon dioxide (CO_2) and water vapor (H_2O). The rise in the heat capacity of the cylinder charge is responsible for the heat capacity effect of the burnt gases. Finally, combustion products present in the burnt gases can participate in the chemical reactions leading to auto ignition and subsequent combustion.

7.2. EGR strategy of fuel modification

One of the strategies of fuel modification is introduction of EGR and addition of EGR into intake is the most practical means of controlling charge temperature in an HCCI engine. It has been well confirmed that hot EGR enhances combustion in 4 stroke HCCI engines mainly due to the higher temperature of resulting intake mixture, rather than existence of active radicals. In addition to the thermal effects, the inserted gases contained in the EGR can be used to control the heat release rate due to its impact on chemical reaction rates, which can be delay the auto ignition timing, reduce the heat release rate, and thus lower peak cylinder pressure.

There are many other possibilities for HCCI engine control; these include variable compression ratio, variable valve timing, operation with multiple fuels, and thermal control. Out of these options, thermal control is inexpensive to implement and purely based on technologies familiar to manufacturers and may be most acceptable if demonstrated to be satisfactory.

7.3 Fast thermal management for HCCI control

The controlling technique which involves in rapid changing of intake change temperature to control the combustion of HCCI is fast thermal management. Many studies have indicated that HCCI combustion timing is sensitive to intake air temperature. Haraldsson et al. and Yang et al. suggested the use of two air streams and regaining heat from exhaust gases to heat one of the air streams. By mixing two air streams, one direct from atmosphere and the other heated by exhaust gases, it is possible to control the temperature of the final intake air stream (each stream with independent throttles for mixing). Both studies with and without mixing observed the ability of the FTM system to control the combustion phasing of HCCI combustion. One of the studies by Yang indicates that while FTM is effective to control combustion phasing in HCCI engines, the "thermal inertia" of the system makes cycle by cycle temperature adjustment difficult, which in turn complicates the control of HCCI combustion during transients. This lag in achieving the desired HCCI combustion phasing was also observed by Haraldsson research, although in his study.FTM was presented as an acceptable alternative to use variable compression ratio in closed loop control of HCCI combustion.

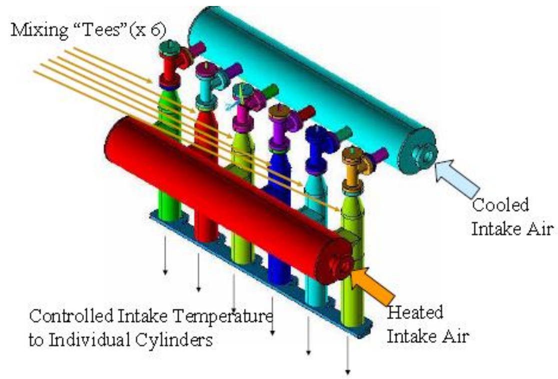


Figure3: fast thermal management

B. Thermal control system:

Thermal control consists of a pre-heater to increase fuel-air mixture temperature and a supercharger to increase mixture density and also an intercooler to decrease mixture temperature. The ultimate resulting system has five independent control parameters which are given under:

- One is equivalence ratio,
- Second is fraction of EGR,
- Third is Intake pressure,
- Fourth is pre-heater effectiveness, and
- Fifth is Intercooler effectiveness.

These parameters can be tuned to meet the load demands while obtaining auto ignition at the desired time and meeting the constraints of maximum pressure and NO_X emissions.

Due to the fact that the HCCI mixture is not burned by a discernible flame, the physics of flow-combustion interactions in a typical burning flame are considered to be absent. However, experiments still indicated the local fluctuations recorded by fuel in homogeneity. The features of in homogeneity could become important in the high EGR cases. In fact, it has not been successful to use chemical kinetics alone to simulate the combustion by assuming a uniform temperature distribution, i.e., the single-zone model. The high temperatures in the center of the chamber are responsible for the ignition. To account for the temperature stratification, a multi-zone model was used which divided the entire mixture into several groups. The effects of engine flow field on combustion are still not considered. On the other hand, due to the possible in homogeneity in mixture and temperature distribution, it has been suspected that the turbulence also has effects on the combustion rates. It is still a question whether the mixture is completely homogeneous and the turbulent mixing has no effect on the heat release rates.

7.4. Starting System

HCCI engines are often difficult to start. At cold start, the compressed gas temperature in an HCCI engine is reduced because the charge receives no preheating from the intake manifold and the compressed charge is rapidly cooled by heat transfer to the cold combustion chamber walls. Without some compensating mechanism, the low compressed charge temperatures could prevent an HCCI engine from firing. A common approach has been to start the engine in spark ignition mode or diesel mode and transition to HCCI mode after warm-up. However, success full transition typically required advanced engines equipped with variable compression ratio (VCR) or variable valve timing (VVT), which may be expensive or difficult to implement for heavy duty engines. In practice operation in SI mode requires equivalence ratio of 0.6 -0.65 or greater (Flynn et al. 2000).which is high enough to damage the engine if thermal auto ignition or knock occurs during the transition. Instead of attempting to start the engine in SI mode and transition to HCCI mode, a brand new approach is used to start the engine directly in HCCI mode by preheating the intake with a gas fired burner. This was easy to implement by adding a burner to the pre-heater. The burner is run for a period of time (30 minutes) until the pre-heater reaches a high temperature (300°C).At this condition, running the intake charge through the pre heater while simultaneously spinning the engine with an air starter is enough to achieve HCCI ignition. After ignition, combustion is self sustaining and the burner can be turned off, as the intake gases are heated by the hot exhaust. The burner is a source of emissions and a consumer of fuel, and as such in a practical deployment of an HCCI engine for stationary power generation. This would have to be considered as a contributor to the overall system emissions and fuel consumption.

7.5Compression ratio

Christensen et al. of his several investigations express the Compression ratio as an effective means to achieve HCCI combustion control. Through his studies demonstrated that regardless of fuel type used increasing the compression ratio from 9.6: 1 to 22.5: 1 had a strong influence on ignition timing and assists in decreasing the necessary intake charge temperature. Hiraya et al. also reported the effect of compression ratio through his studies from 12: 1to 18.6: 1 on setting of combustion. Both of their studies on a gasoline HCCI engine showed that higher compression ratios allowed for lower intake charge temperature and higher intake density for higher output. Furthermore, higher compression ratio contributed to higher thermal efficiency. And also the study done by Iida also has confirmed that change in compression ratio has a strong influence on HCCI combustion on-set. Their results also showed that compression ratio has a greater effect on HCCI combustion on-set compared to changes in either intake charge temperature or coolant temperature.

Olsson et al. investigated the influence of compression ratio on a natural gas fuelled HCCI engine. In his experimental study the test engine had a secondary piston whose position can be varied to attain variable compression ratio (VCR). In their tests, the compression ratio was modified (21: 1, 20: 1, 17: 1, and 15: 1) according to the operating condition to attain auto ignition of the charge close to TDC. This VCR engine has shown the potential to achieve satisfactory operation in HCCI mode over a wide range of operating conditions by using the optimal compression ratio for a particular operating condition. The study also showed that higher compression ratio gives the maximum pressure rise for early combustion timing and a reverse effect was seen with delayed combustion on-set.

8.0 LIMITATIONS

- Inability to control the combustion initiation
- Problems in controlling the rate of combustion over the whole speed and load range
- Requirements of some external setups to preheat the air
- Depending on the method used to facilitate HCCI combustion, strong cycle-to-cycle variations can occur. This poses a control problem, but is also a threat for the HCCI combustion
- The HCCI engine has relatively high friction losses due to the low power density.

• if misfire occurs, the gas mixture during the next cycle will be too cold for auto-ignition to occur (unless intake air heating is used) and the engine will stop

9.0 PARTIAL HCCI (PHCCI)

• In Partial HCCI mode the engine is cold-started as an SI or CI engine, then switched to HCCI mode for idle and low- to mid-load operation to obtain the benefits of HCCI in this regime. For high-load operation, the engine would again be switched to SI or CI operation.

• The future of HCCI looks promising especially with partial HCCI mode.

Major companies such as General Motors, Mercedes-Benz, Volkswagen and ford have invested on research of HCCI technology. General motors' company released a test vehicle named as Saturn Aura by using PHCCI technology and the test vehicle is on the road and open Vectra with PHCCI technology is on going under the progress for test conditions. Mercedes-benz released Dies-otto with PHCCI Technology and this is also on the road for test conditions and another company like Volks wagen with the name of Touran with CCS (combined combustion spark), GCI(gasoline compression Ignition) technology are under progressing. Ford company also developing the HCCI technology which is under progressing.

10.0 CONCLUSION

By this time market should have been introduced by many HCCI engines for practical use because of several challenges as mentioned above in the combustion, the engines have not up to the level of matching in cost to release in the market and still it is in undergoing research stage only.

The technical challenges facing HCCI combustion both in gasoline and diesel HCCI, owing to the lack of direct control over the start of ignition and the rate of heat release, their operational range is limited and less optimized combustion phasing. HCCI combustion technology and its future research and application should be considered as part of an effort to achieve a step change in combustion in lowering temperature of combustion for wide range of operating conditions. The future Combustion process of IC engines converges towards combustion of premixed compression ignition, while direct injection and turbo charging will become a norm on such engines. Therefore it may be our futuristic with more flexible engine with realistic possibility with their real-time control and to come in to the practical use as fully flexible engine to convert the chemical energy from any type of fuel into mechanical work through premixed auto-ignited low-temperature combustion [6].

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