HCCI Technology: Challenges and control strategies

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***Abstract*- At present scenario emissions and fuel economy are the big issues related to the IC engines. There are too many researches are done to reduce or eliminate these emissions. HCCI (homogenous charge compression ignition) combustion is a new combustion technology with the help of this technology we can reduce the emission from CI engine and can also improve the efficiency of SI engine. Spark plug and fuel injector are not used in the HCCI engine to assist combustion process and combustion start in HCCI engine when fuel reached to its auto ignition temperature. This technology of combustion is efficient and produces less emission. In this research paper briefly describes working of HCCI engine, research work result, problem associated with HCCI engine and their possible solutions.**

***Keywards*- HCCI, Diesel fuelled HCCI, Gasoline fuelled HCCI**

I. INTRODUCTION

HCCI engine is introduced to reduce emissions from traditional IC engines. In SI engine during suction stroke charge is supplied by the carburetor so it is homogenous mixture and the problem faced by SI engine is knocking but in case of CI engine during suction only air goes in combustion chamber. During compression stroke near TDC fuel is sprayed by the injector that's why formed fuel air mixture is heterogonous. The problem with CI engine is NOx formation due to heterogeneous combustion [1,2].
To solve these problems researchers introduce a new technology i.e. HCCI engine. With help of HCCI combustion we can increase the efficiency and reduction in emissions [3]. CI engine have high efficiency and efficiency of HCCI engine is comparable to CI engine [4-6]. HCCI engine work on the principle of premixed homogenous charge compressed by piston until its temperature reach to auto ignition temperature. In HCCI combustion no flame front is formed the whole charge start burning spontaneously that's why ignition duration is reduced [1]. The main issues associated with HCCI engine are to control combustion, temperature and composition of charge. But at present all these issues are resolved by using electronic sensor and controller [7].

II. LITERATURE REVIEW

In past HCCI combustion was discovered for two stroke engine this research is done by onishi et. al in 1979. This new technology has been known as "active thermo atmosphere combustion (ATAC)". The problems with two stroke engine are high initial temperature at low and partial load conditions, tendency to knock (run on) while engine is stopped and high and high level of residual. Onishi utilized all these drawbacks in his new technology. In ATAC he worked on these two parameter high level of residual emission and initial charge temperature. He found during combustion there is no flame front propagation in chamber and spontaneous ignition of charge was observed that leads to reduction in emission and improved fuel economy [8]. After the onishi's research the same technology is demonstrated at Toyota [9].

Spectroscopic analysis on two stroke opposed piston engine is done by Noguchi et. al in 1979. From this analysis they found that there is pre ignition chemical reaction was occurred and that led to auto ignition. The burning rate in the combustion chamber is very fast and also noticed that these HCCI engine had low emission and better fuel economy [9].
HCCI technology was used in 4 stroke engine in 1983 by Najt and Foster. The study was done with blends of paraffinic and aromatic fuels over a range of different speed and different level of dilution. This analysis was done by considering that combustion is only controlled by chemical kinetics. According to their investigation it was concluded that HCCI combustion is controlled by the parameter temperature, pressure and composition of charge [10].
In 1989 further experiments is performed on the 4 stroke engine operated with fully blended gasoline and diesel fuel and suitable equivalence ratio and EGR were examined from this study concluded that low CR is necessary to use diesel as fuel otherwise auto ignition occurred to early stage of compression stroke [11].
In 1994 the experiments were performed on 2 stroke HCCI combustion and found that operating condition could be expanded by using methanol as a fuel [12]. In 1996 Thomas Ryan et. al performed study in 4 stroke engine using diesel fuel for the range CR 7.5:1 to 17:1. According to him diesel engine faces a problem while work on HCCI combustion that is less volatility of diesel. To remove this difficulty fuel was preheated to 200 C to evaporate fuel in intake manifold and CR will have to keep between 6 to 8:1 to avoid the possibility of advance auto ignition.
In 1996 HCCI engine DDI (diesel direct injection), GDI (gasoline direct injection) engines were compared at same setup for the optimum equivalence ratio. It was found that HCCI had lowest fuel consumption and less NOx emission. To increase engine output supercharging was also done. At the same time experiments were performed to optimize HCCI combustion by throttling either exhaust or inlet duct [13].
In 1998 Christensen et al. perform experiment on HCCI engine using three different fuel (isooctane, ethanol and CNG) along with supercharger. He states that operating limit of HCCI engine can be extended by using fuel stratification. According to Kontarkls

et al. (2000) the effect from spark assistance decreases with decreasing equivalence ratio and can be used low to about 0.333 equivalence ratio.
An alternative solution to extending operating the range is to operate the engine in a 'hybrid mode' where the engine operate in HCCI mode at low, medium and cruising loads and switches to spark ignition (SI) mode or diesel mode at cold start, idle and higher load [54] (Milovanovic et al. 2005). In 2007 research [14] demonstrated the relevance of motion planning in the control of the coupled air path dynamics of turbocharged diesel engine using EGR [15].

III. HCCI WORKING

HCCI technology was discovered about 30 years ago [8]. HCCI is a combustion technology to achieve high efficiencies and low NOx level as compared to compression ignition direct injection engine [4]. PM emission is also reduced by using EGR with HCCI [16].
HCCI technologies include the best feature of both SI and CI engine. In the HCCI engine fuel and air are premixed and send to cylinder and this mixture is compressed to auto ignition temperature as a result the temperature increases in the compression stroke [17]. Thus HCCI engine is similar to SI in the sense that homogenous mixture is used and similar to CI as both depend on auto ignition to initiate combustion [6].
In HCCI engine there is no flame front formation and combustion start throughout the volume and whole mixture burn at same time [19]. In HCCI engine no flame front is formed due to which lower gas temperature achieve thus NOx formation reduces [20]. High CR and high intake temperature is required to get homogenous spontaneous ignition of mixture [18]. Combustion in HCCI engine is fully controlled by chemical kinetics rather than spark and injection timing [19, 20].
To control combustion various advances made an intake air charge, EGR and varying CR [6]. Homogenous mixture can be prepared either internally or externally. Fuel is directly injected to combustion chamber with the help of cylinder injector during internal homogenous charge preparation in the engine intake manifold. Electronic controlled injector is used for external homogenous charge preparation [1].

IV. ADVANTAGES

The advantages of using HCCI technology in IC engines-

1. With the help of HCCI engine we can achieve up to 15% fuel saving because these have lean mixtures and also lower peak temperature leads to lower emission compare to SI engine.
2. In HCCI engine there is no throttling losses, high CR and shorter combustion duration which leads to high efficiency [19,21].
3. It can operate wide range of fuel like diesel, gasoline and biofuels [19, 22].
4. It can use in any engine configuration automobile engine, stationary engine, heavy duty engine or small sized engine [4, 23, 24].
5. Less green house gas emissions observed with the HCCI technology.
6. Emission of NOx and PM is reduced while using HCCI technology.

V. DISADVANTAGES

There is some drawbacks associated with HCCI technology which are described below-

1. High level of UHC and CO emission is observed and also knocking tendency under certain condition is observed [2, 25, 26].
2. High cylinder peak pressure creates a noise and also damage engine [2, 25, 27].
3. The combustion phase of HCCI engine is difficult to control.
4. Smaller power range

VI. CHALLENGES FOR HCCI TECHNOLOGY

Before implementing the benefits of the HCCI combustion it has to overcome some barriers. These barriers are described below-

6.1 Combustion phase control

In conventional engines, combustion phase or ignition timing is directly controlled by spark timing in SI engine or by fuel injection timing for CI engine. In HCCI engine ignition timing is controlled by auto ignition that is more challenging. The main combustion is controlled by auto ignition which is effected by few factors compression ratio, degree of mixture homogeneity, intake temperature, engine speed, amount of EGR, engine temperature, residual rate, wall temperature – pressure, combustion duration and fuel auto ignition chemistry and other factor [28-30]. Engine efficiency and power output is mainly depend combustion control if combustion occur too early, power drop in term of efficiency and damage to engine occurs if combustion occur too late, chance of misfire increases[31-34].

6.2 High level of Noise, UHC and CO emissions

During compression stroke the instantaneous heat release which is caused by auto ignition of whole homogenous charge. This instantaneous heat release is the main cause of abrupt pressure rise and high level of noise which may cause a severe damage to the engine. So controlling this sudden heat release is extremely important. The acceptable pressure rise limit is 8 bar/ CA for noise [35]. The basic reason for UHC and CO is incomplete oxidation of fuel. Valve overlapping, crevice volume present in the combustion chamber and wall deposits absorption are the other reasons for UHC and CO [36].

6.3 Operation range

Another obstacle in HCCI engine to successful commercialization in the market is the limited operation range. To get full advantages of HCCI engine it is important to extend the range of operation [37, 38]. Controlling the ignition timing over a

range of load and speed is a difficult task [37, 38]. At extremely low loads, due to lack of ignition energy to auto ignite the lean mixture, auto ignition become difficult at extremely high load also limited by knocking phenomenon [28]. Hence, the domain of operation of HCCI engine is in limited range.

6.4 Cold start

In the winter season or geographically cold region cold start become a challenge for HCCI engine. Because the compressed charge loose more heat to the wall at cold start operation [39]. This problem can be overcome by starting the engine by the conventional mode for a short warm up period and then switch to HCCI mode.

6.5 Homogenous charge preparation

The homogenous charge preparation is the main factor to increase fuel efficiency and reduce emissions like HC and PM [40]. HCCI combustion phase is also controlled by auto ignition reaction and mixture homogeneity has an effect on auto ignition reaction. For a low volatility fuel like diesel it is very difficult to prepare a homogenous mixture. In IC engines, the time for preparation of a homogenous mixture is very short because of short span of thermodynamic cycle time [41]. The degree of homogeneity of fuel is greatly improved by only by increasing the time for mixture preparation.

VII. PROPOSED SOLUTION TO CHALLENGES

Following are the proposed solutions for various challenges in HCCI technology:

7.1 Combustion phase control

The change in the temperature history of the mixture is one of the solutions to control the combustion timing. VVT (variable valve timing) method or trapping residual/ exhaust gas [42-44], fixing the injection timing to inject inside the cylinder [49-51], variable CR method [38, 45, 46], modulating the intake temperature [4, 52, 53], the variable amount of EGR method [44, 47, 48], by injection of water [45] or varying the temperature of coolant [54].

7.2 High level of noise

Three main cylinder pressure derived metrics have been applied to solve this problem. For example the peak pressure rise rate (PPRR) [55], combustion noise level (CNL) [58, 59] and ringing intensity (RI) [55-57, 21].

7.3 Range of operation

Several methods are adopted to enlarge the domain of operation for HCCI engine. For enlarging high load region, boosting intake air [45], using a residual gas trapping method with cooled EGR or using two stroke operation in two stroke/ four stroke witching engine [60] may be solutions to these problems.

7.4 Cold start

One of the solutions is starting the engine in a conventional mode and then switching to the HCCI mode after a short warm up period. Other solutions are using glow plugs, using different fuel or fuel additives, increasing CR with variable CR or VVT or using spark assisted compression ignition [61].

7.5 Homogenous charge preparation

Low temperature combustion (LTC) was employed in many combustors such as IC engine and gas turbine, mainly to decrease NOx emission because they are responsible for the formation of peroxy acetyl nitrate. Other steps are like fuel injection in a highly turbulent port flow for gaseous and highly volatile fuels [45, 62] or early in-cylinder injection with sophisticated fuel injector for diesel fuel can be taken for solve this problem.

VIII. CONCLUSION

HCCI combustion process is totally different from the SI and CI engine because of no flame propagation. Chemical kinetic has a dominating role in HCCI combustion. This new concepts of engine has higher thermal efficiency, lower emissions and lower fuel consumption. HCCI engines are cheaper than conventional engine because of their simple construction. HCCI engine is an alternative strategy when CI engines cannot achieve future NOx and PM standards. Difficulties associated with the HCCI engine like combustion phase control, cold start, homogenous charge and extending range of operation has to be overcome for the successful operation of HCCI engine.

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