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Research Directions for Homogenous Charge Combustion Ignition Engine

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Homogenous Charge Combustion Ignition Engine (HCCI) technology is an advanced engine technology developed in 1989. Several attempts are being made for the performance improvement and field applications of HCCI engines. Simulation models and laboratory experiments confirm that the HCCI technology is superior to the conventional IC engines. However, the HCCI research is in nascent stage today. Focused research is required to bring this technology in commercial use. This paper aims to investigate the future directions for study of Homogenous Charge Compression Ignition engines. Review articles from last ten years were studied in detail. The conclusions and future directions suggested by all papers are critically examined, tabulated and analysed. Common conclusions are separately presented and the specific conclusions of the papers are compared so as to develop a methodology to carry out further research in the field of Internal Combustion engines.

***Keywords*:** Intake Manifold, CI engine, CFD Analysis

1. Introduction

First practical internal combustion engine was developed in 1860. This engine made use of coal-gas air mixtures as fuel. However this engine had efficiency close to 5%. In 1867, Nicolaus Otto and Eugen Langen had developed an engine working on premixed fuel and air mixture working on 4 strokes. These engines had efficiency close to 11%. [1]. Since then the highest thermal efficiency was close to 28%. Researches are being performed all over the world to improve the efficiency and reduce the emssions from the engines.

The basic concept of HCCI was proposed by Onshi et al in 1989.The air and fuel are mixed external to the combustion chamber of engine and mixture is auto ignited by compression. This concept overcomes the basic drawbacks of CI and SI engines and produces very less emissions. This is advanced engine technology and it has got the potential to solve global emission problem.

2. Discussions on Previous Research Work on HCCI

On the basis of review of literature, engines can be classified on the basis of fuel injection techniques as shown in fig.1. Compression Ignition (CI) engines and Spark Ignition (SI) engines are two major types developed in late 1900s. In CI engines, the fuel is directly or indirectly injected (DI/IDI) in the engine cylinder by a fuel injector and mixture is ignited by compression. While in Spark Ignition engines, the air and fuel is mixed externally and the charge is ignited by spark plug. HCCI engine is combination of SI and CI engine. The air and fuel are mixed prior to combustion and charge is ignited by compression pressure. The HCCI engine can be categorized into Direct Injection, Port Fuel Injection (PFI), Dual Fuel Injection and Common Rail Direct Inection (CRDI). The DI/IDI strategy is incorporated by changing the fuel injection timing. This can be achieved by either advancing or retarding the fuel injection timing. Injection is done more than once, either early or late, changing the spray cone angle etc. This sub divides the strategy into Premixed Lean Diesel Combustion (PREDIC), Uniform Bulky Combustion System (UNIBUS), Multi Phase Injection with Bump Combustion Chamber (MULTI BUMP), Narrow Angle Direct Injection (NADI), Homogenous Charge Intelligent Multiple Injection (HIMICS), Multiple stage Diesel Combustion (MULDIC). The Port Fuel Injection is done either in the engine intake or in a pre-chamber. This facilitates proper mixing of air and fuel. In some cases, charge inducted is at higher temperature and pressure.

Port fuel Injection when incorporated with HCCI is called Premixed Charge Compression Ignition (PCCI).It is further classified based on the fuel used. The dual fuel injection strategy makes use of two injectors. High reactivity fuel is injected by DI and low reactivity fuel is injected by PFI. These types of engines are called Reactivity Charged Compression Ignition (RCCI) engines.

The review articles published in different journals from 2009 onwards are discussed in this paper. Mingfa et al [2] observed five challenges for the use of HCCI engine. Firstly the difficulty in combustion phasing control, secondly noise levels are high and UHC and CO emissions are also seen to be higher, thirdly the load and operating range is limited, fourthly the inability of engine starting in cold start conditions and finally mixture is never homogenous in nature. Various strategies had been adopted for the control of Diesel fuelled HCCI engines is summarised in Table 1. Early injection techniques in combination with different injection timings at different spray angles with multiple spray nozzle design were attempted. In most cases, HC and Soot were seen to be increased. Control of NOx emissions still remains a problem even if early direct injection techniques are adopted.

Table1: Control strategies

Strategy Adopted	**Methodology**	**Comments**
Premixed Lean Diesel Combustion (PREDIC)	The fuel injection time and quantity is varied by use of one fuel injector at centre and two more fuel injectors from one side.	Nox reduced, Smoke reduced, HC increased
Uniform Bulky Combustion System (UNIBUS)	Piezo-actuator injectors with pintle-type injector nozzles were used. The technique involves a combination of an early injection (around 50 BTDC) and a late injection (about 13 ATDC)	Reduce wall wetting, prevents over-leaning of mixture, low PM emission
Multi Phase Injection with Bump Combustion Chamber (MULTI BUMP)	To achieve ‘lean Diffusion Combustion’ a Bump Combustion Chamber is used in this technique. The injection is done with help of pulses. The time of start of pulse, period of spray, the quantity of fuel and time of dwell of spray are optimised for suitable spray penetration to avoid wall impingement.	Noisy auto-ignition avoided, high fuel consumption, increases smoke emissions, Nox unchanged
Narrow Angle Direct Injection (NADI)	Two injectors are used with spray cone angles of 156^{o} and 60^{o}, Compression Ratio=15:1 and Exhaust Gas Recirculation was also used.	It solves the problem of wall of combustion chambers and piston getting wet because of excessive spray penetration.
Homogenous Charge Intellegent Multiple Injection (HIMICS)	First injection takes place at commencement of compression stroke; second injection takes place just before TDC.	Lesser emissions of Soot and NOx, But emissions of HC and CO was found to be higher.
Multiple stage Diesel Combustion (MULDIC)	Direct injection takes place commencement of compression stroke, second injection takes place just before TDC.	Reduce Nox, Soot in limits
Partially Premixed Compression Ignition (PCCI)	Fuel injection in fuel intake, with or without EGR, with or without turbo charging	Limited in part load operation, more HC and less Nox

Mingfa et al. [2] also investigated the articles on Gasoline fuelled HCCI engines. It was concluded that the high octane fuels cannot be easily auto ignited by compression. Port fuel injection can be beneficial due to longer mixing time between fuel and air. Adoption of Direct Injection can result in better combustion phasing control. Charge inducted at higher pressure showed better performance. Use of EGR, Variable CR and modified fuels serves as useful method to control combustion in gasoline fuelled HCCI engines. Mingfa et al. [2] presented the findings of articles on optical diagnostic tools used for combustion visualisation.

Gaurav Dwivedi et al [3] studied the articles on use of Bio-fuels in IC engines. It was concluded that bio-diesel can be a potential alternative for use fossil fuels. Emssions of NOx and HC was greatly reduced due to use of Bio-diesel fuelled IC engine. Pravin Kumar et al [7] investigated the use of Bio-diesel in HCCI engines with different strategies like late direct injection with EGR, EGR used with LTC, bio-gas and bio-diesel with DI engine, Bio-diesel with por fuel injection and external fuel vaporiser, changing injection timimg and prssure with diesel and bio-diesel etc. LTC helped to reduce UHC and CO with bio-diesel but still contributed to higher emissions. Higher emissions were reported because of use of early or late injection strategies used with bio-diesel.

Various strategies for control of HCCI engines have been developed over the years. The summary of these strategies have been enlisted in the flowchart. The early and late direct and port fuel injection strategies have already been discussed in table 1. Reitz et al, Paykani et al and Wang et al [4][5][6] studied the articles related to the development of RCCI engines.

3. Significant Findings of Literature Review

The significant findings of the previous research work are shown in table-2. Table-2 also highlights the directions for future work in HCCI technology.

Table 2: Significant findings of the previous research work

Article	Significant findings	Future Directions
[2]	The mixture preparation can be improved by two methods 1) By modifying the rate of mixing of fuel and air which can be done by increasing the pressure of intake air, by enhancing fuel injection pressures, by making use of smaller holes of nozzles, modifying combustion chamber geometry, and by energy utilization of spray wall impingement and multi-pulse fuel injection based on modulating injection mode.	Dual fuel mode can be a beneficial alternative for HCCI operation. The effects of turbulence on fuel/air/ EGR mixing and combustion processes are needed to be studied further. A great deal of work is also necessary to understand the auto-ignition chemistry of practical fuels at a fundamental level. Optical diagnostics can be useful in developing the models that predict HCCI combustion.
[3]	Bio-diesel is a potential alternative fuel since it reduces the dependency on fossil fuels. The percentage of sulphur is very less in diesel which is another major advantage. Higher cetane of biodiesel implies its much improved combustion profile in an internal combustion engine. The pollutant component from exhaust is also decreased by using biodiesel.	Use of Bio-diesel in diesel engine reduces emissions of NOx, CO and HC. But PM is observed to be increased in many cases. Exhaust gas temperatures are also reduced. EGR reduces emission of NOx. But the use of EGR upto 30% is desirable. The focus of work from onward should be development of 100% biodiesel. Higher cetane number fuel can serve better combustion efficiencies.

[4]	RCCI is a promising strategy. High Gross Thermal Efficiency was observed with gasoline and diesel fuelled HCCI engines for a wider range of load conditions. Heat transfer losses were greatly reduced which resulted in higher thermal efficiency in HD engines. Use of additive increase GIE by 1%.Natural gas/diesel serves very low NOx and Soot emissions.	Use of Natural gas in RCCI can be a potential alternative. Engine parameters are needed to be further optimised for efficient operation of dual fuel RCCI engines. The after treatment devices are needed to be modified to operate on lower exhaust gas temperature which is a challenge. Further experimentation is needed to be carried out to increase the feasibility of this technology use in commercial sector.
[5]	**RCCI** gives higher GTE, Low H-T losses, HC and CO emissions increased, Nox very less, fuel Flexibility**.** **RCCI with alternative fuels**: Hydrated ethanol gives higher GIE and very low NOx. Methanol increases BTE but high diesel consumption. Natural Gas serves higher combustion duration thus less PRR observed. Short squish distance and large bowl volume reduces HC.	A heat transfer losses are needed to be reduced in RCCI. This will increase the combustion efficiency. To increase the operating range of a great deal of work is being carried out. A common strategy of control over RCCI engine is needed to be explored further. Design of squish and piston bowl volume can be further explored. Turbo-charging can be a good option to increase the amount of air available for combustion and volumetric efficiency can also be increased.
[6]	For RCCI engines, the stable operation can be achieved by high charge reactivity under low load conditions. On the contrary Peak Pressure Rise rate can be suppressed by use of low charge reactivity. The most effective way of controlling the HCCI combustion is to stratify the charge.	The charge reactivity and stratification can be controlled by making use of different reactivity fuel in the DI and PFI injectors. Lesser UHC and CO can be achieved by controlling the timing of DI and ratio of DI/PFI. The operating range can be extended by optimising type of fuel used and fuel injection strategy adopted.
[7]	**Bio-diesel in CI**: reduces CO, HC, emissions but increases NOx emissions. Auto-ignition control can be done by charge composition and Time-Temperature History**.** **For HCCI operation**: Various early and late injection techniques like PREDIC, UNIBUS etc reduce wall wetting but NOx remains a problem	The operating range of HCCI combustion can be extended by SCCI. Very low NOx and smoke emissions can be achieved by Premixed/direct-injected HCCI. It can also lead to wider operating range of HCCI combustion.The increase in ignition delay period and decrease in overall combustion temperature using Low Temperature Combustion (LTC) can reduce the emissions of NOx and soot.
[8]	**Bio-diesel in CI engines**: Reduces CO, HC, PM emissions but increases Nox. BSFC and BTE are close to conventional diesel. EGR decreases NOx but smoke, HC and CO emissions increases. **HCCI operation** reduces NO_X and PM but HC, CO increases.	CRDI can be potential option. Achievement of homogenous mixture preparation is necessary. Optimization of engine operating parameters can be suitably carried out by making use of RSM technique. This will also reduce down the amount of actual experimentations.

	Manifold injection provides homogeneous mixture in HCCI engines but SOC control is difficult. Higher EGR extends the auto ignition time.	

Conclusions and Future Research Directions

The following conclusions can be drawn after critical examination of the published literature on HCCI technology.

- Great deal of work is needed to be carried out in understanding the physics of combustion and emission. The Chemical Kinetic Mechanisms are able to predict the combustion of low carbon compounds like Methane, ethane, propane, iso-butane etc. But the combustion of practical fuels like Gasoline and Diesel is still not predictable.
- CI engines are needed to be modified to HCCI engine operation to overcome its basic drawback of high soot and NOx emissions.
- Low Temperature combustion (LTC) strategies like HCCI, PCCI, SCCI and RCCI have got the potential to reduce exhaust gas emissions and increase thermal efficiency.
- RCCI strategy would succeed only if a novel design of engine is developed which is optimised to overcome all drawbacks of its operation.
- Late and early injection techniques are not the most promising techniques for the performance and emission improvements in HCCI engines.
- PCCI technique has limited range of operation.
- Mechanical fuel injection is needed to be replaced by electronic fuel injection. Common Rail Direct Injection (CRDI) can be a potential injection strategy for diesel fuelled HCCI.
- Low Temperature Combustion strategy combined with Bio-diesel, controlled EGR and High injection pressures can be useful.
- Use of gaseous fuel, Squish and Bowl volume design modification, optimisation of ratio of port injected and directly injected fuel, high injection pressure for DI, controlled EGR combination in RCCI seems to be a promising option to address all the issues.

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