Effect of Stratified Charge Compression Ignition on Emission and Power Output- A Review

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Abstract. The emissions from the vehicles causes for severe air pollution which resulted the development of stringent regulatory norms. Therefore there is a need of improvement in combustion phenomenon to decrease the NOx and PM, as they are directly dependent on combustion. To improve environmental conditions which are directly affecting human health, all automobile companies are endeavouring to satisfy strict emission standards. In this context stratified charge compression ignition (SCCI) engines seems promising and developing its application by incorporating the different types of combustion mode with the help of direct fuel injection and by ranging its capacity to full load condition. Alongside SCCI, a new concept of multi stage induction and Exhaust Gas Recirculation (EGR) can be incorporated in engine to reduce emissions, increase power output and efficiency. Various parameters have been considered to understand the combustion process for developing an engine to meet the requirements. The effect of different variables influencing the combustion process is highlighted.

Keywords: SCCI, Exhaust gas recirculation, emission.

1. Introduction

The challenges in today’s world in the fields of internal combustion engine are either the rapidly decreasing crude oil or air pollution from these engines. The concern of fuel scarcity may be reduced or eliminated with the help of alternative fuel, whilst emission is controlled through modification in operating cycles of engines. Therefore there is an increasing need of developing green and environment friendly technologies. Therefore there is continuous research on different methods or techniques which can improve air quality and reduce the consumption of fuel [1-3].

In the compression ignition engines the combustion characteristics includes the spray pattern, compression ratio, swirl, type of combustion chamber etc. are important parameters to decide the volume and nature of oxidation of fuel and so the emission. Combustion phenomenon in engines is more effective when the dilution of air-fuel mixture is taken place for its maximum limit [4-6].

The combustion systems which can be preferred are Low Temperature Combustion (LTC) technology and Stratified Charge Compression Ignition (SCCI). This technology has capacity to minimize NOx, soot emissions and particulate matter. The thermal efficiency increased with compared to conventional diesel engine. Although, researchers are facing some challenges like at minimum loads conditions one can get minimum efficiency of combustion. [6-10].

2. Key Points of SCCI
To get low temperature combustion in compression ignition engine, the very necessary requirements is formation of homogeneous mixture. This may be achieved through injecting the entire fuel ratio in all cylinders. The demand of LTC is increasing day by day; this is due to longer ignition delay and higher level of exhaust gas recirculation and less content of oxygen. However, to prepare uniform mixture in cylinder large level of turbulence is required [11].

Homogeneous charge compression ignition engines and low temperature combustion has its different advantages over the conventional engines. To incorporate the same advantages in conventional combustion system fuel was mixed stratification way, this technology is called Stratified Charged Compression Ignition (SCCI). SCCI technology is also called as compound HCCI which is based on stratification mixture of fuel. This technique includes all the advantages of HCCI combustion as well as LTC. By using this technique controlling of different parameters like combustion phasing and combustion rate are directly and easily controlled [12]. It is thus, observed that some amount of in-homogeneities will always remain in SCCI engine, while applying the different methods of mixture preparation. It also shows that uniform fuel air mixture cannot be achieved. By taking the base of stratification it is found that there are three major aspects which exist and are included in the cylinder i.e. fuel composition stratification, mixture concentration stratification and temperature field stratification.

Fuel composition stratification a means controlling the homogeneous charge and it is a very important parameter that can affect the auto ignition characteristics. It was found from the published studies that the combustion efficiency increased with increasing the level of fuel stratification. However, it was also concluded that higher level of stratification generate high NOx and reduced the combustion efficiency as well as power output. Letter investigation was carried out in a single cylinder engine with two Gasoline Direction Injection (GDI) to analyses the effect of stratification. Due to fuel stratification significantly increment in indicative mean effective pressure (IMEP) and emission especially at lean limits was found. Fuel stratification was proved to decrease the rate of pressure rise as well as sensitive to the local equivalence ratio. By implementing the fuel stratification SCCI combustion can be controlled [34-38] Increasing in mixture concentration stratification, auto-ignition advanced. The auto-ignition get also advanced by increasing the amount of fuel injected later in the cylinder. Mixture stratification plays an important role to predict the emissions of CO, unburned hydro carbons and soot. The emission of NOx is also affected by mixture concentration stratification [39].

3. Elementary principle of SCCI combustion

Figure 1 shows the basic concept of outline of fuel with its fuel design and its direction for SCCI combustion.
Figure 1. Elementary concept of outline of fuel with its fuel design and its direction for SCCI combustion. [12].

i. On the basis of operating parameters and selected fuels for test, the physical and chemical properties should be designed.

ii. Different methods or approach like injection of port fuel in direct injection combined with in-cylinder, injection mode, in-cylinder injection with multi hole and split injection, should be applied for selected fuel stratified concentration.

iii. The test fuels which have reverse chemical properties have to be taken that can be supplied as a port fuel injector as well as direct fuel injector.

iv. For controlling the combustion rate and peak combustion temperature, the controlled amount of exhaust gas recirculation should be used.

By following all this steps the various difficulties which the SCCI facing can be minimize.

4. Effect of engine parameters on SCCI

Engine parameters play an important role for the improvement of engine performance. To get proper SCCI combustion port fuel injection is the best method which can be used in cylinder. Specifically, for achieving the controlled SCCI combustion phasing the early injection or port fuel injection plays a significant role due to its chemistry of fuel mixture concentration [13]. This happen because of amount of heat released at low temperature is proportional to equivalence ratio. Controlling of stratification mixture can be done by changing the injection timing within the cycle. Using this technique combustion phasing can also be managed. Along with, applying different fuel injection timing combustion duration for stratified mixture can be adjusted. Consequently, the duration of combustion increased and rate of pressure rise decreased in partial fuel stratification [14]. It is observed that indicated thermal efficiency of stratified compression charge ignition engine is lower than conventional combustion engine this is due to requirements of optimized combustion parameters such as phasing control, heat release rate and design of combustion chamber. So due to this reason challenges for achieving low level of NOx emission and maximum efficiency of stratified charged combustion engine is key issues. It has been detected, by varying the proportions of premixed fuel like n-heptane or iso-octane, the stratified temperature and proper mixture formed in cylinder as shown in figure 2. Moreover, fuel mixture stratification can be changed by varying the timing of fuel injection.
To increase the range of SCCI engine form lower load to higher load stratification of partial fuel in required. Due to stratification of partial fuel staged combustion can be achieved by decreasing the pressure rise rates.

4.1 Timing of Injection

Two stage gasoline direct injection technique is an effective method proposed by researchers for controlling the combustion rate, combustion phasing and preparing the homogeneous mixture for extending the working load of SCCI combustion [23]. By varying or changing the number of injection, width of injection pulse and dwell time for two nearer pulses, stratification of diesel fuel can be controlled using multi pulse fuel injection technology. With the help of two injections in single cycle, the fuel mixing can be improved. During first injection before TDC 80° and second injection after TDC 10°, smoke has been reduced. Using this technology thermal efficiency of SCCI engine can be reach up to the level of conventional diesel engine. Meanwhile other emission like NOx, Soot and PM also get reduced [24, 25].

Partial fuel injection method was used for achieving the homogeneous stratification mixture. In this method, injection of fuel taken place in two ways. Some amount of fuel injected in intake stroke and remaining fuel in compression stroke. It has been seen that while minimizing the rate of pressure rise and increasing the load capacity, productive potential are getting for partial fuel stratification during the SCCI combustion. It is also found that if amount of fuel stratified increased NOx emission will get increased [26]. For the closed valve injection, it has been found that maximum amount of the fuel strikes on the wall of port before entry of the cylinder so that details of injection do not matter. But during the open valve injection as the droplets enters into the cylinder the hydrocarbons (HC) emission increased. It concluded that closed valve fuel injection will be preferred and also suitable for the SCCI engines with port fuel injection system [23]. As per the stratified mixture concentration is concerned experiments showed that to increasing the load capacity of SCCI engine proper stratified mixture should be formed [21, 22].

Gasoline direct injection system showed a crucial role during the stratified combustion. Stability in combustion depends on fuel injection symmetrical or asymmetrical to the inlet port stratified mixture. Two GDI injectors also used for perfect combustion, in which one was used for preparing homogeneous charge combustion and second was employed directly into the combustion chamber for varying the stratified charge. They found enormous advancement in indicated mean effective as well as minimum amount of emissions while keeping operating range at lean limit [29-30]. They developed the components of fuel stratification with blending of diesel fuel and iso-octane. Diesel fuel was injected directly into the combustion chamber while iso octane injected into inlet port. Research reveals by changing the fuel ratios the ignition timing can be controlled for duel fuel stratified combustion [28].

4.2 Water Injection

There has been a long history of Water injection in the field internal combustion engines [17-19]. To lighten the effect of knock as well as for lower temperature and minimize the NOx emissions in SI combustion water injection has been used. [17]. This injection was previously investigated in different combustion techniques like Homogeneous charge compression ignition (HCCI) and Premixed Charge Compression Ignition (PCCI), but now it has also been investigated in Stratified charged compression ignition (SCCI) engine [20]. Experiment analysis was performed to get depth knowledge of with or without water injection in stratified charge compression ignition
It has been found that combustion rate is significantly increases in the range of 20 to 70 crank angle degrees before TDC for water injection as compared to without water injection [3]. Experiments were conducted on four-cylinder gasoline, SI 2.0L engine. Initially the direct water injection timing was 50 degrees before TDC. It has been found that as crank angle increased by 153 degree, water injection retarded combustion phasing to the point of misfiring [16]. It was found that by using this injection system there is incremental effect of 44% and 103% on CO emissions and unburned hydrocarbon respectively at 9.0 mg/cycle of water.

4.3 Pressure Rise Rate (PRR)

One more important parameter which needs to be considering while doing the investigation on SCCI combustion is rate of pressure rise. This is used to define the higher limit of SCCI combustion. Increase in the pressure of combustion chamber the NOx and smoke formation reduces because of dilute mixture. With the help of split injection method, the mean effective pressure decreases with no changes in NOx and smoke formations.

Figure 3 represent the relation between maximum of pressure rise rate and position of crank angle with respect to different equivalence ratio. It is observed from the figure that maximum rate of pressure rise has been increased for richer fuel air mixture and it decreased as the mixture becoming leaner. It is also observed that for every intake air temperature the rate of combustion has been very high. It can be noticed from the figure that position of crank angle for maximum rate of pressure rise shifted towards constant fuel air ratio as the inlet air temperature increased [2].

**Figure 3** Maximum pressure rise rate at different equivalence ratio [2].
Experiments were performed on a single cylinder, four stroke stratification charge engine with direct injection spark ignition system. They used methanol fuel for their study. It has been observed that at maximum load and engine speed the pressure rise and break thermal efficiency decreased by 60% and 6% respectively. It has also been observed that break thermal efficiency of methanol fueled engine increased 18% at minimum load by reducing the value of compression ratio from 16 to 14. [4]. It is proved that the stratification has a capacity to change the pressure rise rate increasing or decreasing it meanwhile allowing the improvement in output of SCCI combustion. It is found that stratified fuel can also increase the combustion efficiency at low load.
conditions [8,9].

4.4 Effect of NOx

NOx emission directly depends on the injection timing by using different fuel quantities. In conventional combustion engine, the NOx emission is around 30-35 ppm, but using the split injection method, the NOx emission is limited to 22 ppm that is much lower than the conventional combustion engine. But overall pressure is increased, and it affects the fuel quantities. Once the fuel quantity increases, the mean effective pressure simultaneously increases. HC emission is a function of the fuel injection timing for different fuel quantities injected per stroke [19]. It has been found from that the concentration of NOx get minimum for the homogeneous charge while operating on multiple fuel injection system. This is due to there has been early injection in different form which increased the intensity of mixing until the second stages of injection starts. Which in turn reduce the formation of NOx maintain the temperature within the limit. HC emission can be controlled easily by using PFI system in SCCI engines [20].

5. Challenges of SCCI Combustion

In stratified charge compression ignition engine, as the mean effective temperature decreases, UHC and CO emissions simultaneously increases compared to conventional engines because of the lean mixture or the high exhaust gas recirculation rates. In split injection method, one portion is the induction of fuel in suction line that has challenges as diesel can’t be vaporizes at normal conditions. The turbocharger has the capacity to increase the fuel pressure and temperature, but it is not sufficient to vaporize the fuel. The solution to it is to install a heat exchanger or EGR or both depending on operating conditions, which will increase the temperature of the incoming air sufficiently for the rapid vaporization of fuel. As an alternative to it, the fuel itself can be heated to the boiling point by the help of EGR.

6. Conclusion

Stratified charge compression ignition provides an effective advantage for improvement of thermal efficiency of internal combustion engines. Stratified Charge Compression Ignition (SCCI), technology can be considered as extended part of Homogeneous Charge Compression Ignition (HCCI) engine. In SCCI concept of combustion by varying different operating or design parameters of combustion like, port fuel injection, EGR, fuel management and component design, the overall performance of combustion and mixture preparation can be achieved. The SCCI concept has the advantage of both the HCCI and LTC combustion technology, by controlling can be done directly or flexibly on combustion phasing and combustion rate. Moreover, by using suitable fuel physical and chemical properties and management of design parameters like port fuel injection, split injection and EGR combustion of SCCI can be controlled. The typical feature of all such advanced combustion technique before ignition occurs is preparing of homogeneous mixture or stratified mixture. It is concluded that Hydrocarbons (HC) and Carbon oxide (CO) are less as differentiate to homogeneous charge compression ignition engine. NOx emissions are drastically reduced from conventional internal combustion engine but higher that HCCI engine. Moreover it is noted that using higher stratified charge leads to significance increment in NOx emissions.
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