© 2018 IJSRSET | Volume 4 | Issue 8 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
International Journal of Scientific Research in Science, Engineering and Technology
DOI : 10.32628/IJSRSET23102171

Analysis of Emission In Hcci Mode Using Ion Sensor Technology On A Di Diesel Engine

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ABSCTACT

Experimental analysis was conducted to evaluate engine performance parameters such as brake thermal efficiency, specific fuel consumption, and in-cylinder pressure variations. Additionally, emission levels of nitrogen oxides (NOx), carbon monoxide (CO), unburned hydrocarbons (HC), and particulate matter (PM) were measured to assess environmental impacts. The results indicate that HCCI combustion significantly reduces NOx and PM emissions compared to conventional diesel combustion while maintaining competitive efficiency. The ion sensor effectively detected combustion phasing and enabled optimized control strategies for stable HCCI operation.

This research highlights the potential of ion sensor technology as a diagnostic tool for HCCI combustion, contributing to the development of cleaner and more efficient diesel engines. Future work may focus on refining combustion control strategies and integrating advanced fuel blends to enhance HCCI performance further.

Keywords : HCCI Combustion, Engine Performance, Ion Sensor Technology, Emission Reduction, Combustion Control

1. Introduction

The fact that ions are produced in flames has been known for many years. HCCI is a lean and low temperature combustion event, which leads to small quantities of ions being produced during the combustion event. Ion sensors using standard spark plugs are inexpensive sensors which are ideal for production engines. Currently combustion event in HCCI engines is measured using expensive pressure transducers which are impractical for production engines and thus making ion sensors a more likely candidate; however, the ion signal measured using ion sensors (spark plugs) is localized where the pressure signal is a global measurement (Mehresha P et al. 2005). Although the ion sensors are local measurement of the combustion event, the potential for control of combustion phasing is still valid.

1.1. WORKING PRINCIPLE OF HCCI ENGINES

HCCI is characterised by the fact that the fuel and air are mixed before combustion starts and the mixture auto-ignites as a result of the temperature increase in the compression stroke. Thus HCCI is similar to SI in the sense that both engines use premixed charge and similar to CI as both rely on auto-ignition to initiate combustion The concept of HCCI was initially investigated for gasoline applications in order to increase combustion stability of two-stroke engines. It is found that significant reductions in emissions and an improvement in fuel economy could be obtained by creating conditions that led to spontaneous ignition of the in-cylinder charge. The comparison between three modes of combustion is given in figure 1.1.

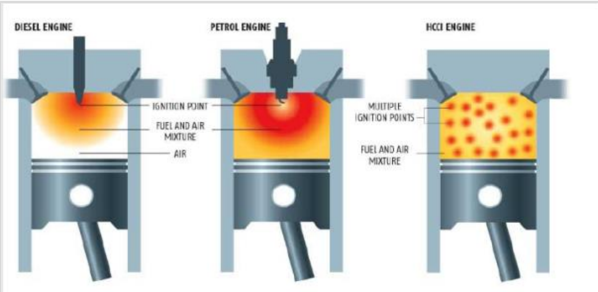

Figure 1.1 Three modes of Combustion

1.2. TYPES OF HCCI ENGINES

1.2.1. HCCI gasoline engines

HCCI mode of operation of gasoline engines was the first to be investigated in the idea of HCCI. This was mainly to improve the performance of 2 stroke gasoline engines from which the process was extended to 4 stroke gasoline engines as well. The technology has progressed to give better emission characteristics and considerable increase in efficiency of the engine. The auto ignition temperature of gasoline is in the range of 1000K to 1100K, a touch higher than diesel. The gasoline forms a homogenous charge with air in the carburetor but the heat of compression will not be sufficient to auto ignite the charge so to compensate this additional heater is normally attached in between the carburetor and the inlet manifold.

1.2.2. HCCI diesel engines

Higher part load efficiency and better emission characteristics of the HCCI engines directed the investigation to improve the low part load efficiency and heavy emissions of the diesel engines into HCCI mode of operation. The investigation started for heavy diesel engines which were then extended to all diesel engines. Now the research in concentrated on stationary engines as well. Diesel is better suited for this mode of compression than gasoline engines thanks to its lower flame point compare to gasoline. Pre-heating will be limited which will increase the efficiency of the engine.

1.3. COMBUSTION IN HCCI MODE OF OPERATION

Unlike in normal IC engines wherein the flame propagates from a spot of formation and the flame front travels the combustion in HCCI mode of combustion the combustion is a blast rather than flame propagation. HCCI combustion of diesel-like fuels displays a peculiar two-stage heat release. The first stage of the heat release is associated with low temperature kinetic reactions, and there time delay between the first and main heat releases. The low temperature heat release then triggers the high temperature heat release. Heat release from low temperature reaction relates to octane numbers of fuels. The lower the octane number is, the more obvious the heat release of low temperature reaction. For gasoline-like fuels (high octane numbers), heat release from low temperature reaction (first-stage heat release) is less compared with diesel-like fuels at the same condition.

2. EXPERIMENTAL SETUP

2.1 The existing four stroke single cylinder diesel engine of Kirloskar make has to be slightly modified with certain additional accessories to run as a HCCI engine. The schematic of the complete experimental setup is shown below.

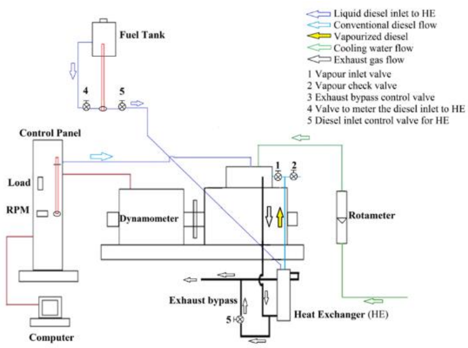

Figure 2.1 Schematic Diagram of the Experimental Setup.

The experiments will be conducted on a computerized single cylinder four stroke naturally aspirated direct injection water cooled diesel engine test rig. The engine is directly coupled to an eddy current dynamometer. The engine and the dynamometer are interfaced to a control panel which is connected to a computer. The software engine soft 2.4 records the engine performance and combustion characteristics.

The engine soft measures and calculates the parameters in every 3 seconds and the parameters which are used in the proposed work are brake thermal efficiency, brake specific fuel consumption, volumetric efficiency etc. The input parameters that are required are calorific value and density of the fuel.

The engine specifications are given in table.

Engine	4 stroke single cylinder CI engine
Make	Kirloskar
Power	5.2 KW @ 1500 RPM
Bore X Stroke	87.5 X 110 mm
Compression ratio	17.5:1
Connecting rod length	234mm
Dynamometer type	Eddy current with load cell
Load measurement	Strain Gauge load cell
Water flow meter	Rotameter
Fuel and air flow measurement	Differential pressure unit
Speed measurement	Rotary encoder
Interfacing	ADC card PCI 1050

2.2. EXPERIMENTAL TEST RIG

The engine test rig consists of a single cylinder, four stroke, direct injection, water cooled 5.2 kW output CI engine mounted on a vibration damping platform. The four stroke “TV1” model Kirloskar engine was directly coupled to an eddy current dynamometer. The test rig is provided with necessary equipment that measured combustion and performance parameters along with pressure and various temperatures accurately.

The setup has an independent panel box consisting of air box fuel tank manometer, fuel measuring burette and engine indicator. An independent coolant system which consists of a pump and rotameters are provided. The pump sucks in water from the sump in the laboratory and circulates into the cylinder jackets and dynamometer and the pressure sensor. Two rotameters measure the flow rate of water into the dynamometer and the engine. This custom made setup enables to measure the BP, IP, Friction power, BMEP, IMEP, brake thermal efficiency BSFC and A/F ratio.

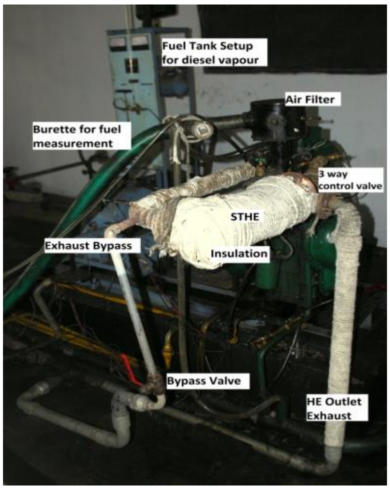

Figure 2.1 Experimental Setup for Vapour Induction

3. METHODOLOGY

3.1. The experiments have to be done according to the following experimentation matrix.

Variables	Type of variables	Details of Variables	Remarks
Independent	Fuels Used	Diesel,	
	Load (%)	25,50,75 and 100	
	Injection Pressure(bar)	180,200 & 220	
	Injection Timings (deg. bTDC)	27.5,29.5 & 31.5	
	% Diesel Vapour Induction	0 to 100%	
	Bias Voltage	50 to 150 V	
Dependent	Brake Thermal Efficiency (%)	25%, 50%, 75 % and 100% Load	
	Ion Current	25%, 50%, 75 % and 100% Load	
	Emissions - CO,HC,CO_2,NO_x and Smoke Opacity	25%, 50%, 75 % and 100% Load	
	Cylinder Pressure(bar)	25%, 50%, 75 % and 100% Load	
	Heat Release Rate(J/deg. CA)	25%, 50%, 75 % and 100% Load	

4. RESULTS AND DISCUSSION

4.1. EMISSION CHARACTERISTICS

The combustion performance of the engine was assessed by calculating and comparing the brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC). Exhaust engine temperature variation was also taken as one performance parameter. The variation of exhaust gas temperature with the increasing amount of diesel vapour induction was plotted.

4.1.1. Unburnt Hydrocarbons

Unburnt hydrocarbons are result of incomplete combustion (which can be caused due to lack of air). As the CI engines work in lean mixture they emit comparatively low amount of UBHC (less than 100 ppm) when compared to SI engines. As HCCI engines run of leaner charge it is expected that the HC emissions will reduce. But this is not the case. A slight increase in HC emissions were observed though the increase was only marginal.

As the engine approach HCCI mode of operation there is a decrease in in-cylinder temperature as shown above. This is one of the reasons for the increase in HC emissions. Another reason can be as the homogenous charge is compressed there is a chance that the fuel gets into the crevices and minute cracks in the engine cylinder. These fuel molecules will be kept away from air required for their proper combustion. The variation in HC emissions as the engine approaches HCCI mode of operation is shown.

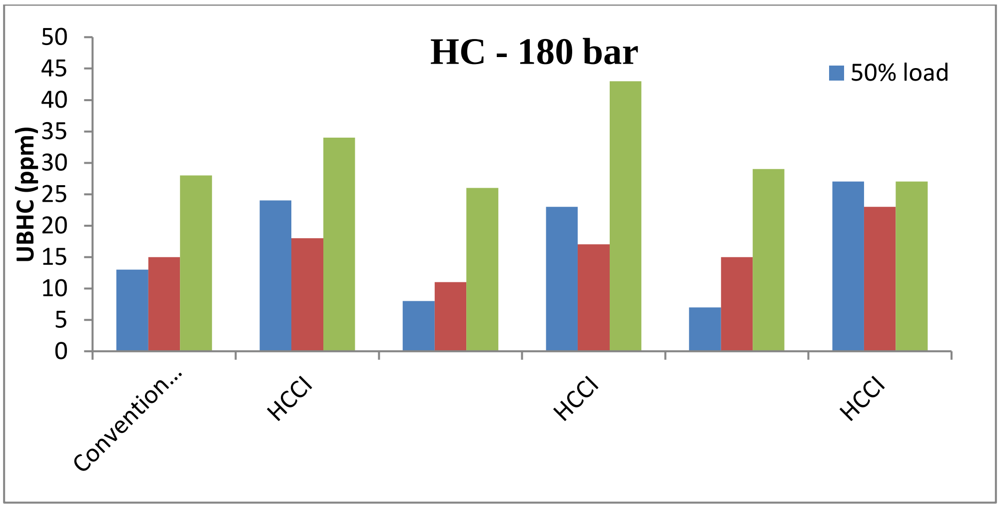

Figure 4.1.1 UBHC emissions for conventional and vapour induction mode at different injection timings at 180 bar

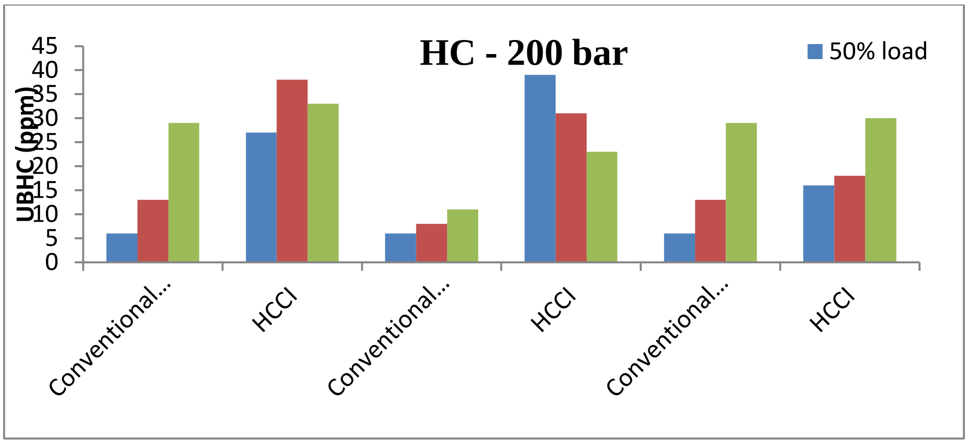

Figure 4.1.2 UBHC emissions for conventional and vapour induction mode at different injection timings at 200 bar

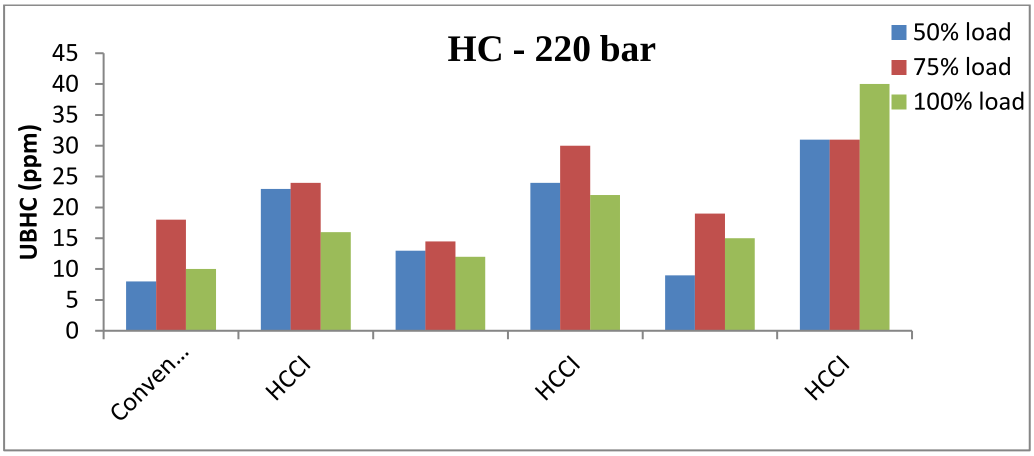

Figure 4.1.3 UBHC emissions for conventional and vapour induction mode at different injection timings at 220 bar

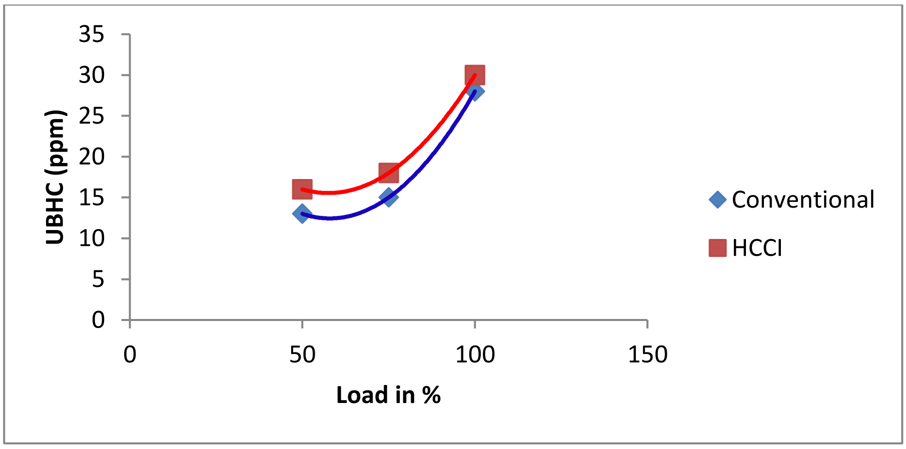

Figure 4.1.2 UBHC emissions at optimized vapour induction mode and conventional diesel injection mode at different loads

4.2.1. **Carbon Dioxide**

Carbon dioxide is generally a non-polluting component of the CI engine emissions. Its presence in the exhaust is taken as a measure of the completeness of combustion as ideally, combustion of hydrocarbons should produce only carbon dioxide and water. It was seen that the carbon dioxide content in the exhaust decreased marginally indicating signs of incomplete combustion.

As the engine approached HCCI mode of operation there was a decrease in in-cylinder temperature as shown in figures 4.12 and 4.13. This is one of the reasons for the decrease in carbon dioxide emissions. Another reason can be as the homogenous charge is compressed there is a chance that the fuel gets into the crevices and minute cracks in the engine cylinder. These fuel molecules will be kept away from air required for their proper combustion.

The variation in carbon dioxide emissions as the engine approaches HCCI mode of combustion are shown.

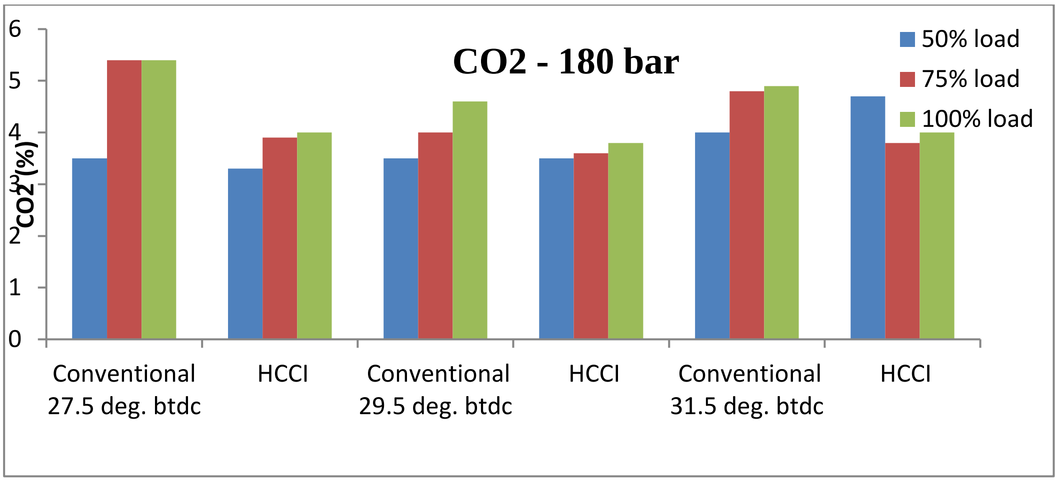

Figure 4.2.1 CO_2 emissions for conventional and vapour induction mode at different injection timings at 180 bar

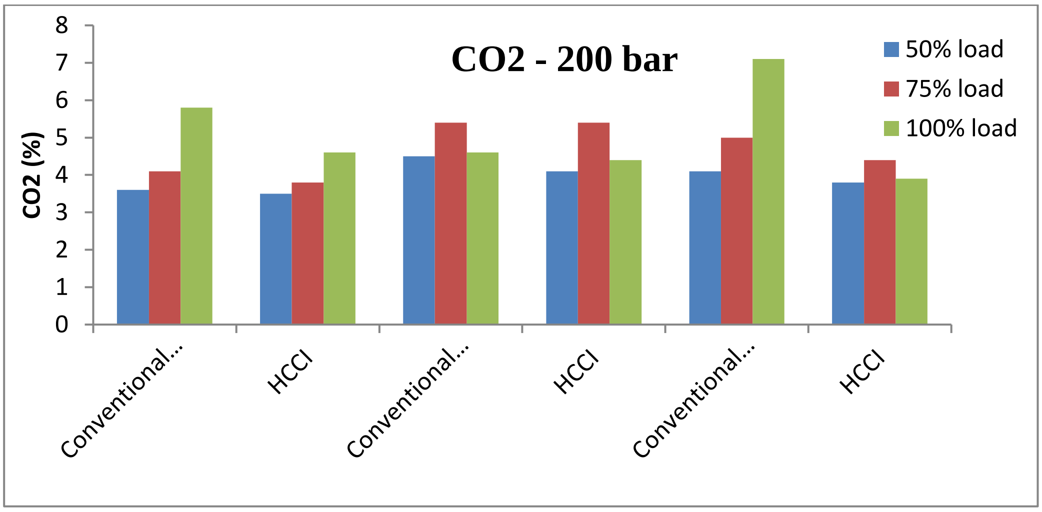

Figure 4.2.2 CO_2 emissions for conventional and vapour induction mode at different injection timings at 200 bar

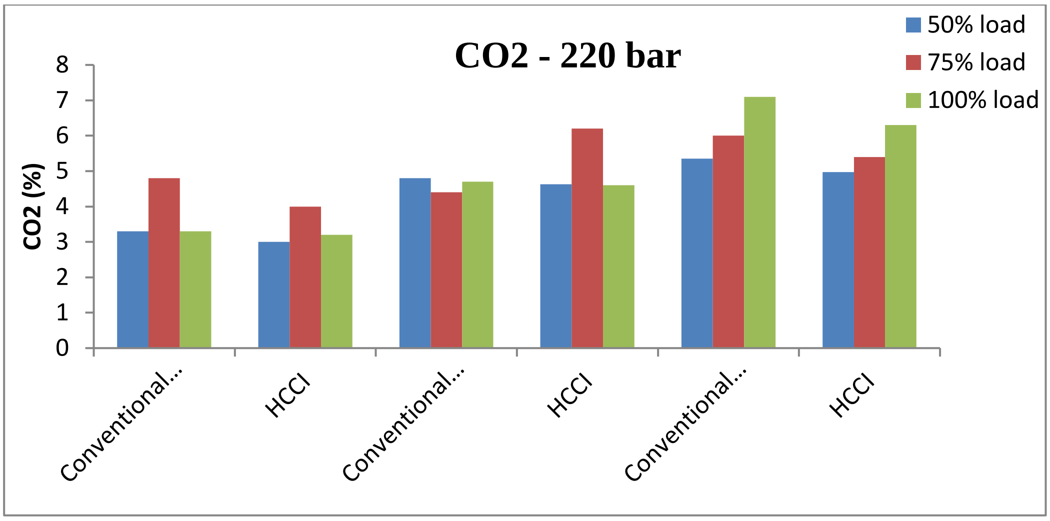

Figure 4.1.3 CO_2 emissions for conventional and vapour induction mode at different injection timings at 220 bar

4.3.1. **Carbon monoxide**

Carbon monoxide is the toxic byproduct of all hydrocarbon combustion. This is the result of incomplete combustion as enough oxygen would not be present for the carbon monoxide to be converted into carbon dioxide which is harmless.

It was seen that the carbon monoxide emissions increased as the engine approached HCCI mode of combustion. As the engine approached HCCI mode of operation there was a decrease in in-cylinder temperature. This is one of the reasons for the decrease in carbon dioxide emissions and subsequent increase in carbon monoxide emission. Another reason can be as the homogenous charge is compressed there is a chance that the fuel gets into the crevices and minute cracks in the engine cylinder. These fuel molecules will be kept away from air required for their proper combustion. The variation in carbon monoxide emissions as the engine approached HCCI mode of combustion at 200 bar injection pressure are shown in figures is the optimized injection pressure for vapour induction, the graphs are plotted at this pressure varying injection timing showing how CO emissions vary as engine approached HCCI mode of combustion. The trend showed CO increases at first but with vapour induction it was becoming steady. This is because homogeneity of the mixture prevents fuel rich areas thereby reducing CO emissions.

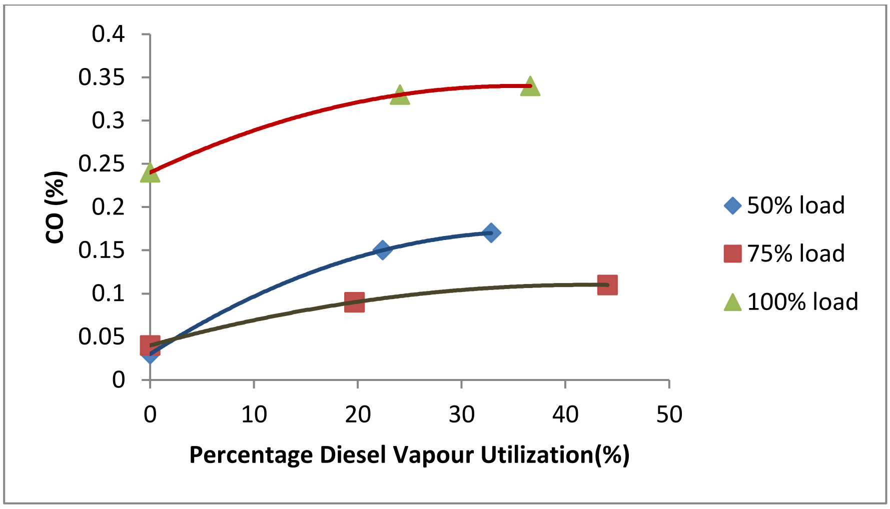

Figure 4.3.1 Effect of vapour induction on CO Emissions at 27.5 deg. btdc and 200 bar injection pressure

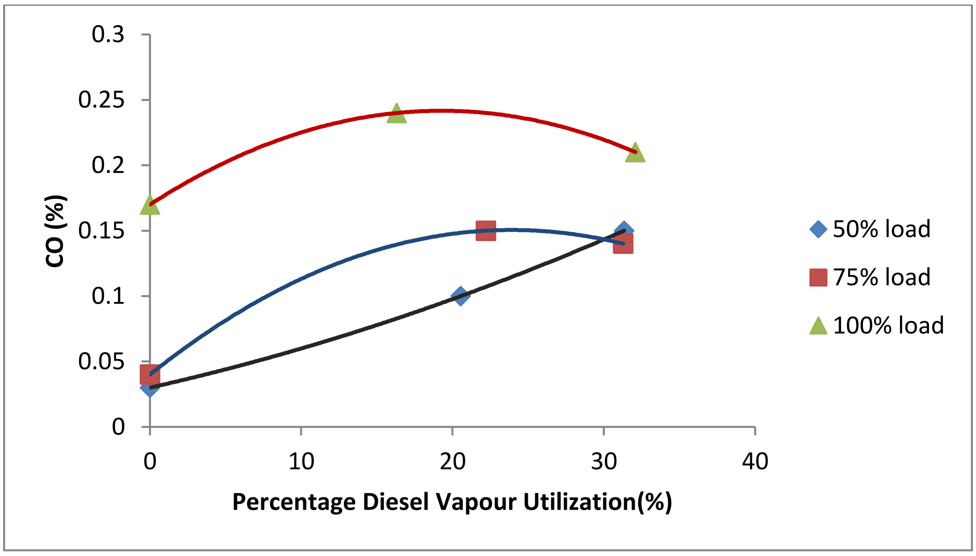

Figure 4.3.2. Effect of vapour induction on CO Emissions at 29.5 deg. btdc and 200 bar injection pressure

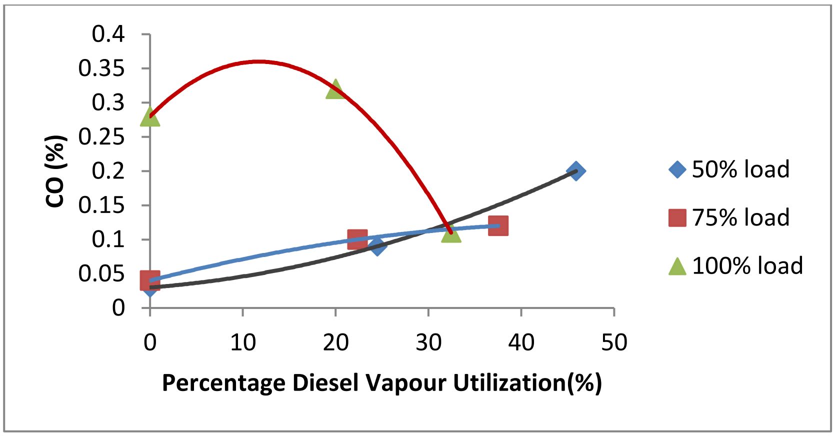

Figure 4.3.3. Effect of vapour induction on CO Emissions at 31.5 deg. btdc and 200 bar injection pressure

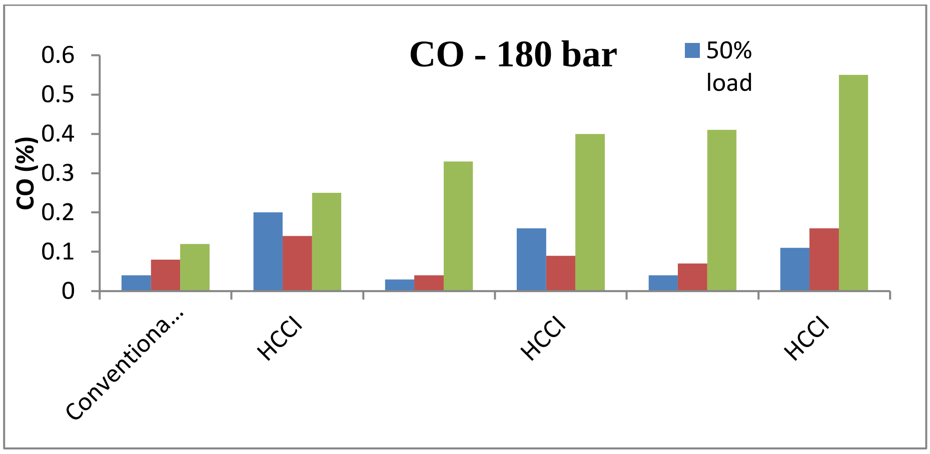

Figure 4.3.4. CO emissions for conventional and vapour induction mode at different injection timings at 180 bar.

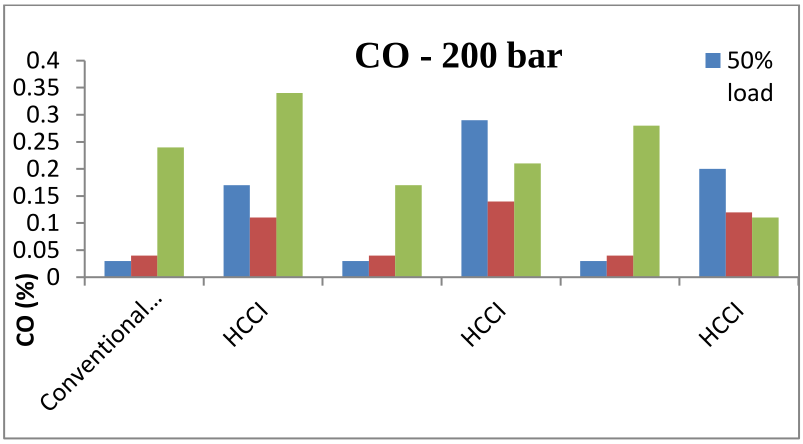

Figure 4.3.5. CO emissions for conventional and vapour induction mode at different injection timings at 200 bar.

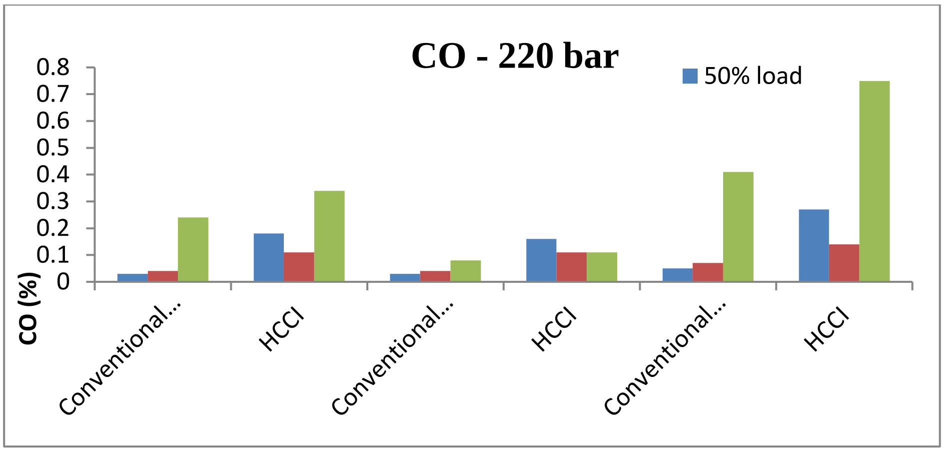

Figure 4.3.6. CO emissions for conventional and vapour induction mode at different injection timings at 200 bar.

4.4. Nitrogen Oxides

Nitrogen oxides are among the major pollutants in engine exhaust. They have far-reaching effects and remain in the atmosphere for a long time. One of the major reasons for developing HCCI mode of combustion is reduction of nitrogen oxide emissions. Different mechanisms explain the formation of NOx in engines. One of the major parameters that controls formation of NOx is in-cylinder temperature. NOx formation starts as the in-cylinder temperature reaches near 1800 K and it increases much with increase in temperature. HCCI mode of combustion helps in reducing the peak temperature inside the cylinder and thereby reduces thermal NOx considerably.

One another factor that controls NOx formation is residence time. As HCCI employs an explosion by production of many autoignition spots, the residence time will be less and hence lesser NOx production.

It was seen that the NOx emissions started to decrease as more and more vapour was inducted. However, after some point of induction a further increase in vapour induction caused a decrease in engine performance. Further addition of vapour caused the following situations at different loads.

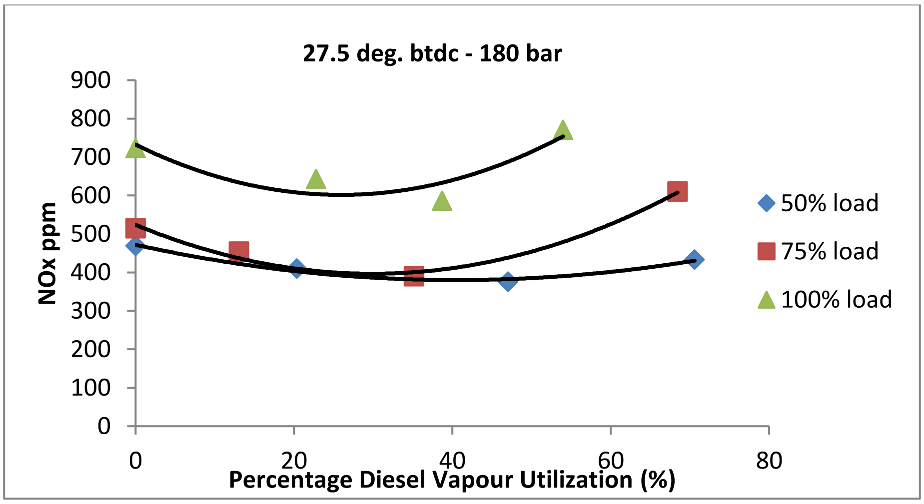

Figure 4.4.1 NOx variation with vapour induction at 27.5 deg. btdc and 180 bar injection pressure.

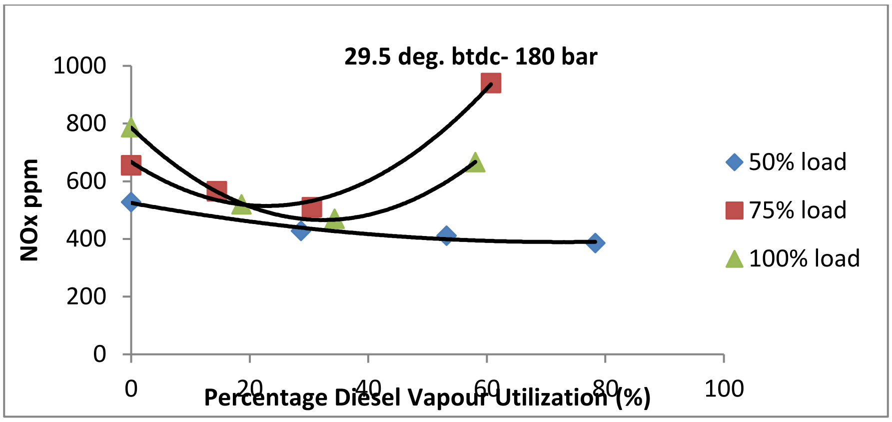

Figure 4.3.2 NOx variation with vapour induction at 29.5 deg. btdc and 180 bar injection pressure.

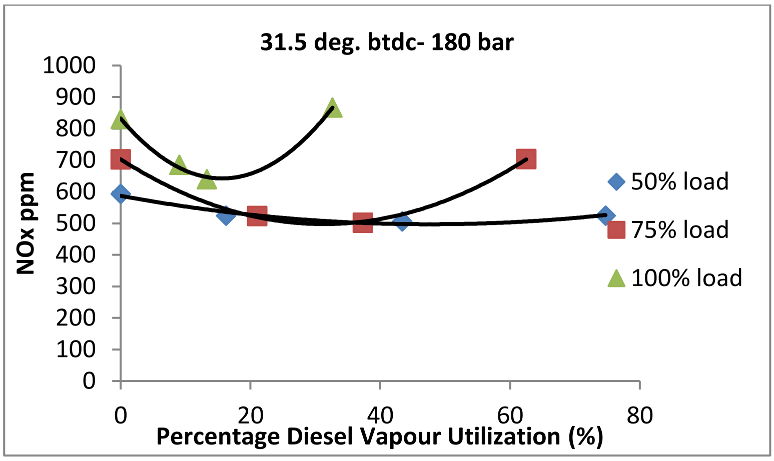

Figure 4.3.3. NOx variation with vapour induction at 31.5 deg. btdc and 180 bar injection pressure.

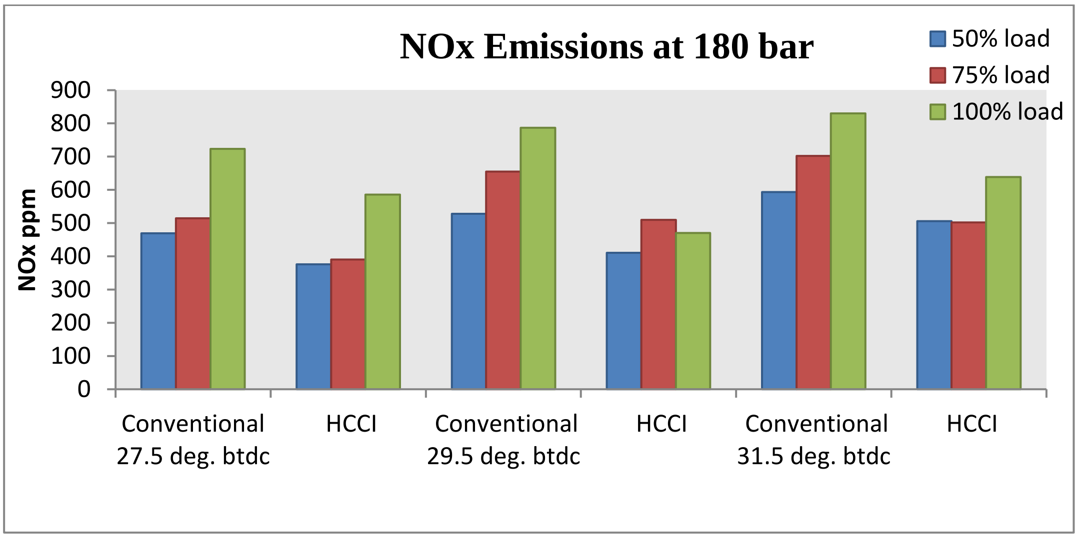

Figure 4.3.4. NOx emissions for conventional and vapour induction mode at different injection timings at 180 bar.

4.4. Smoke Opacity

The variation of smoke opacity for Conventional diesel combustion and vapour induction mode at varied injection timings and injection pressures are discussed here. Smoke emissions are reduced at higher loads with the introduction of vapour. However, at 50% full load conditions, the introduction of vapour produced more smoke on average. An overall reduction of smoke by 48% was observed with the use of vapour induction. This may be due to decreasing temperature and at higher loads mixture becomes more homogeneous.

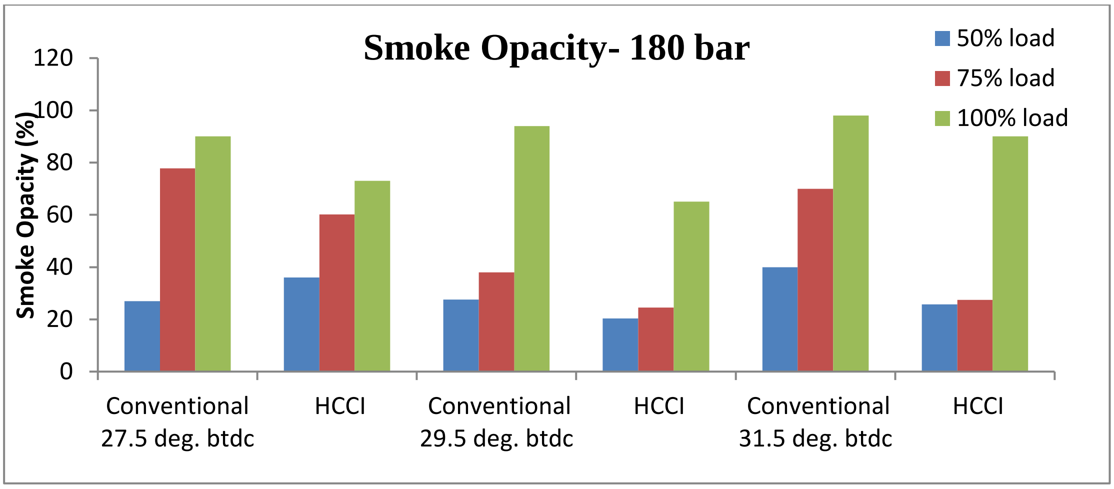

Figure 4.4.1 Smoke Opacity for conventional and vapour induction mode at different injection timings at 180 bar.

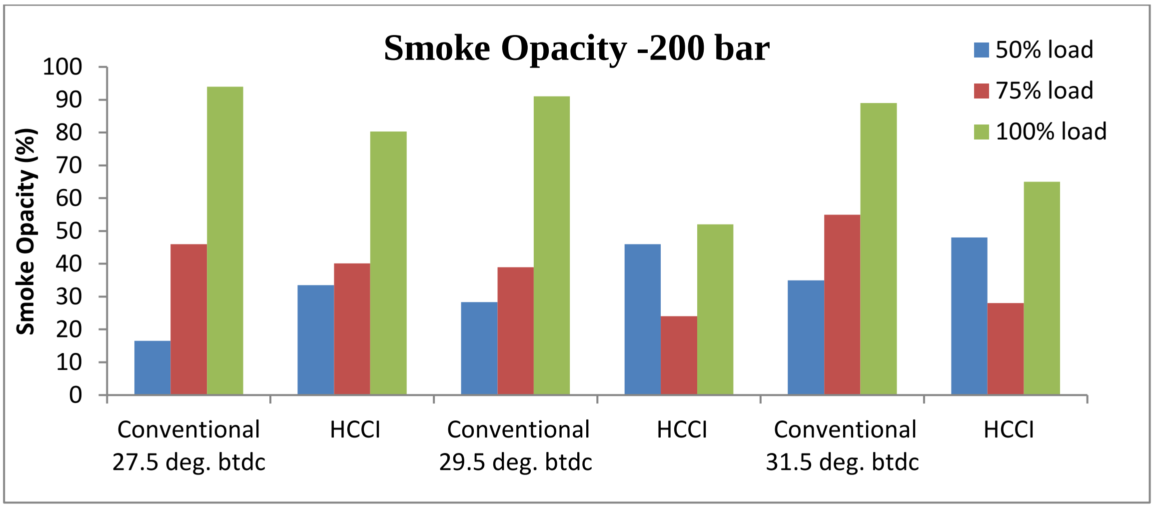

Figure 4.4.2 Smoke Opacity for conventional and vapour induction mode at different injection timings at 200 baR.

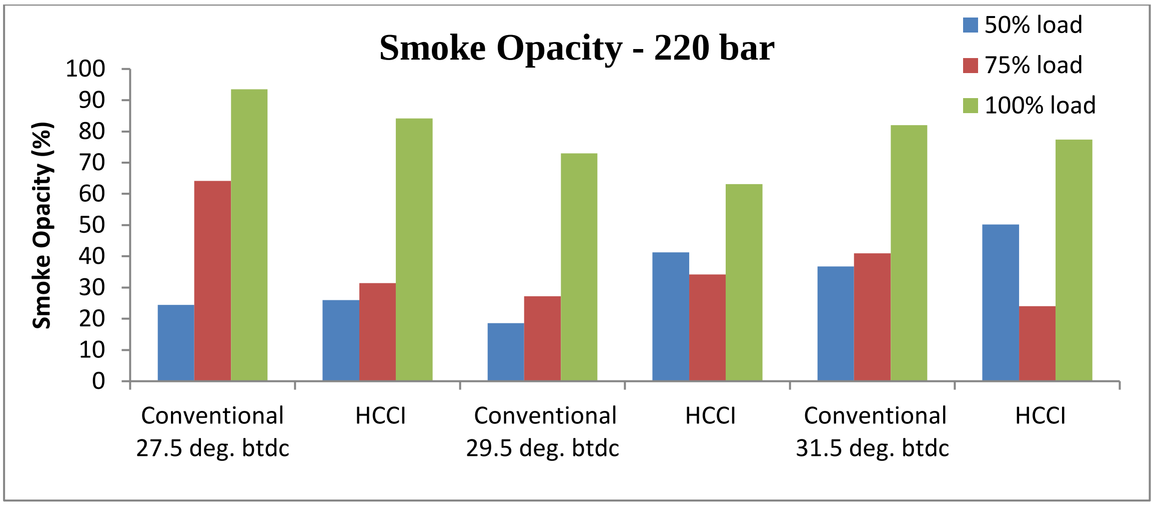

Figure 4.4.3 Smoke Opacity for conventional and vapour induction mode at different injection timings at 220 bar

5. CONCLUSION

The investigation was focused on the effect of diesel vapour induction on the engine performance and to try and achieve HCCI mode of combustion in the engine. The injection timings and injection pressures were varied and tests were conducted at 50%, 75% and 100% load conditions to find out the optimum conditions for vapour induction. The performance and emission study of the engine was done at each test condition and as described in the previous chapters favourable conditions were found out. It was found that the operation of engine using diesel vapour depends on a variety of parameters. For different load conditions the vapour produced from heat exchanger was successfully utilized for combustion.

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