Exploratory Study of the Hcci Engine Employing Exhaust Gas Recirculation

Sundar Lal, Devendra Singh, Ajay Kumar Sharma

***Abstract:** The primary aim of the present experiment is to study the productivity, emission behavior of the HCCI engine using exhaust gas recirculation at different flow rates under different load conditions on the controlled combustion of the HCCI diesel-fueled engine, to know the best performance and least emissions attainable and to further investigate the impact of the engine. Experiments have been performed for various percentages of exhaust gas recirculation with diesel fuel under load variations. These analyses of the EGR at varying load with the findings acquired are plotted and contrasted for the output and emission characteristics that have been carried out in order to identify the efficient operation of the diesel engine with the least environmental pollution.*

***Keywords:** CI, HCCI, EGR, SFC, brake thermal efficiency.*

I. INTRODUCTION

The concept of spark ignition and Compression ignition engine is quite old and the main principle has not been changed or modified from since long more than 120 years and it is not meeting the requirement of present situation because of lesser efficiency, increased fuel consumption and emissions. It is therefore very important to find an alternative to improve performance and reduce the environmental emissions of current engines. Homogeneous charge compression ignition (HCCI) is a new combustion technology that combines the key qualities of both the spark ignition (SI) and the compression ignition (CI) ignition, as a spark ignition engine that is well-mixed and as a compression ignition engine that has no compression ignition and thus no routing drops that contribute to higher fuel savings, high reliability, low NOx and particulates. It can be built as an example of the new engines because it provides a high fuel economy with improved performance and reduced emissions and particulate matter. The output and the emission characteristics have been carried out to identify the effective operation of the diesel engine with the least environmental pollution. Thomas Ryan et al. [1] studied HCCI mode 4-stroke diesel engines for a diverse variety of compression ratios from 7.5:1 to 17:1, and observed diesel seems to really be improperly adapted to HCCI due to evaporation difficulties for auto-ignition, pre-heated to 200^0C to evaporate fuel in the combustion chamber, and the compression ratio remained 6 to 8 to prevent extreme advance ignition. Aoyama et al. [2] contrasted HCCI to DDI and GDI (gasoline direct injection) – a certain framework and explored the impact of supercharging. Christensen et al. [3] observed that NOx emissions in the HCCI process rely on diesel fuel and that CO emissions are strongly reliant on complete combustion. Hyper charged experimented in HCCI with three different iso-octane, ethanol and CNG fuels with higher intake temperature resulted in lower CO emissions. Zhao et al.[4] experimented with the four-stroke HCCI gasoline engine through analytics and found that the hot recycled gas charge heating effect remained primarily essential to increasing auto-ignition timing and limiting combustion length. Gatellier and Walter[5] have achieved a fully developed a double diesel combustion called narrow-angle injection (NADI) in order to obtain minimum NOx and particulate matter emissions at partial loads. Narayanaswamy and Rutland[6] conducted numerical studies using a number of co strategies are implemented with GT-Power and reported that the impact of different EGR (extrinsic) rates on HCCI diesel mode activity concluded as ignition was briefly progressed in low EGR cases and started to delay with an increase in EGR percent. For the benefit of improving the principle of HCCI combustion in DI engines, Wanhuna Su et al. [7] studied the "Premixed Combustion" and "Lean Diffusion Combustion" by compound combustion technology. Mack et al. [8] with diethyl ether and ethanol blends Investigation of HCC combustion through both experimental and modelling approaches and the recorded DME led to further combustion. Kalghatgi et al.[9] illustrated that a CI engine loaded with gasoline was operating at full load in which heat transfer remained regulated by the primary fuel injection timing close the TDC. They proposed that the very same engine might be run in Hcci engines at small to medium levels utilizing inner EGR and that the engine might be initiated using just a spark ignition or energy light connection. Marcello canova [10] clarified that low NOx and particulate matter emissions during part load operation can be achieved by Co - op branded Compression Ignition. The HCCI combustion of traditional diesel engines can be accomplished by well before the load in the combustion chamber with a specialized fuel atomizer. Junjun[11] carried out an experimental study on the HCCI-DI diesel engine. In this research, N-heptane HCCI was injected into a single-cylinder diesel fuel direct injection (DI) configuration on a single-cylinder diesel engine and observed that NOx emissions reduced with minimal fuel spray.

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II. EXPERIMENTAL SETUP

The engine selected for such a research investigation is four stroke single cylinder water cooled diesel engine of 1600 RPM constant speed compression kirloskar make av-type 3.7 KW rated power engine. It has a bore length of 80 mm and a stroke length of 110 mm with a cylinder size of 553 cubic centimeters. Its cylinder pressure range is 145 bar and is connected to the eddy current dynamometer that assess engine output and the next sensor to measure digital rpm.

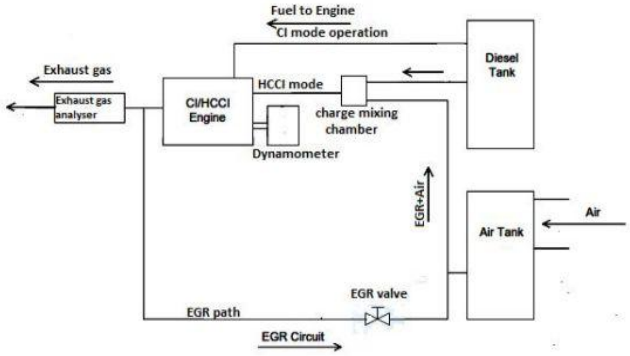

Fig. 1. Layout of engine block schematic

The above block diagram gives the exhaust from the engine re-circulated back in to engine and basic idea which is required to modify the existing CI engine; those modifications includes on the existing diesel fueled CI engine to operate on both CI mode using exhaust gas recirculation and also to operate on HCCI mode using exhaust gas recirculation.

III. MODIFICATION TO THE ENGINE

To run the CI engine on HCCI mode it require certain modifications for the existing engine is required which were undertaken to suit the requirement of experimentation. The following setting explains regarding modification stage wise. Several components of this EGR system is fabricated as per the suitability and requirement. (a) First modification is fitting of pipe line for the exhaust gas recirculation. (b) Second modification is arrangement of charge mixing chamber. And (c) Third modification is injecting the charge in to the inlet manifold. Figure 2 shows the schematic diagram of HCCI Engine experimental setup.

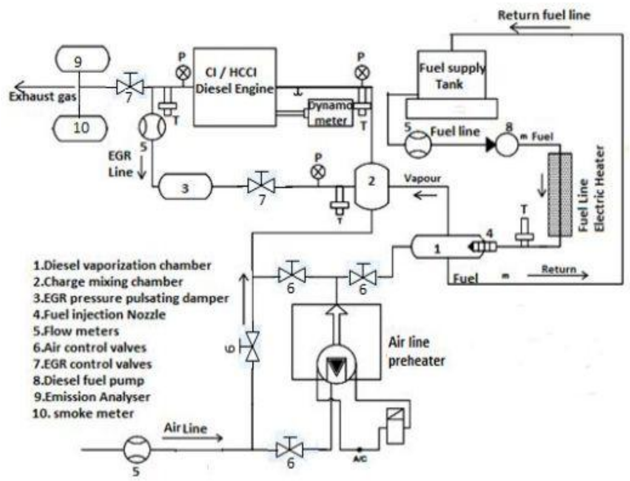

Fig. 2. Block illustration of the experimental procedure of HCCI Engine

IV. RESULT AND CONCLUSION

A. Comparison of engine performances of HCCI and CI

(1) Comparison of Brake Thermal Efficiency (η_{Bth}):

Brake Thermal Efficiency is a key factor for measuring the efficiency of the system under a given environment. The thermal output of the brakes under the HCCI and CI operating conditions at different brake powers is plotted and compared. In this relation, the brake power in kilowatts on the X-axis and the brake thermal efficiency on the y-axis are used. As shown in Figure 3 below the HCCI brake thermal efficiency is 8.29 per cent higher than the standard CI output until the BP is 59.28 per cent higher. The performance is equivalent to 71.58% of BP under these CI conditions. The performance of HCCI is reduced by 6.37 per cent at 83.33 per cent and 100 per cent BP.

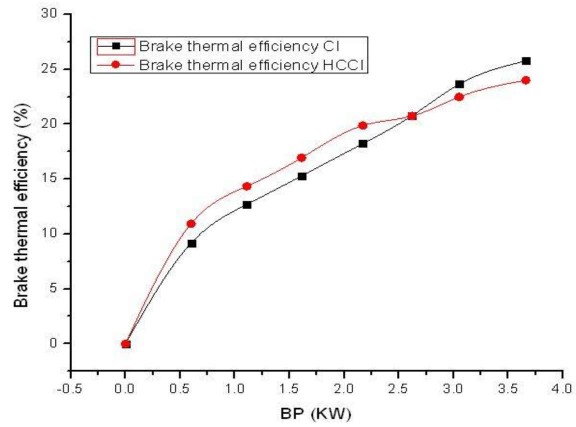

Fig. 3. Brake thermal efficiency Vs BP at CI and HCCI operations

Figure 4 shows the performance of the engine under CI and HCCI constraints at maximum load and part load. It is obvious that the thermal efficiency of the brake at part load is 7.80 per cent higher for HCCI than for CI, while at full load the result is different. Brake Thermal Efficiency of HCCI is less than 6.85 per cent of CI at maximum load.

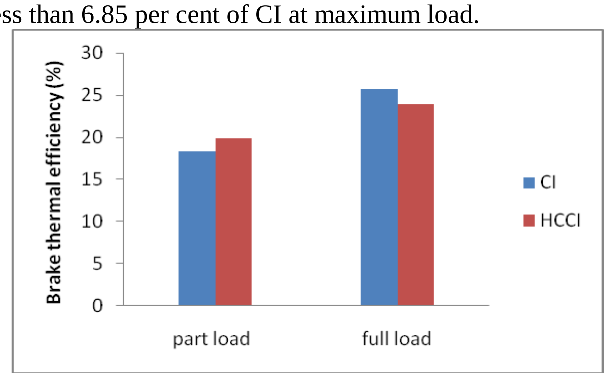

Fig. 4. Brake thermal efficiency Vs BP at CI and HCCI part and full load conditions

(2) Comparison of Volumetric efficiency (η_{Vol}):

As can be seen in Figure 5 the volumetric efficiencies of CI and HCCI are depicted and contrasted. A distinction is made between the volumetric efficiency of the CI condition and the HCCI conditions. It is evident that the volumetric efficiency of the engine is reduced when it is in HCCI condition compared to that of the CI condition by a mode value of 2.9 per cent.

As brake power increases the volumetric efficiency decreases for both HCCI and CI mode running of the Engine.

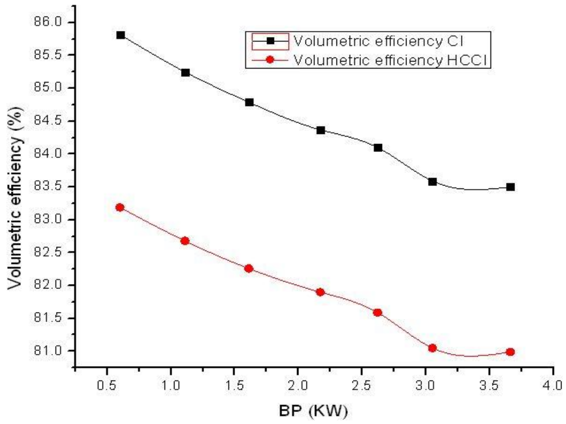

Fig. 5. Volumetric efficiency Vs BP at CI and HCCI conditions

Figure 6 shows the volumetric performance at part load and full load conditions relative to the CI and HCCI conditions. It is obvious from the graph that the volumetric efficiency of both loads declines in HCCI condition.

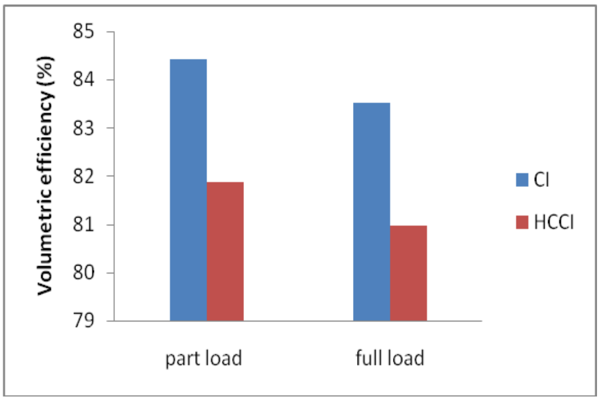

Fig. 6. Volumetric efficiency Vs BP at CI and HCCI part and full load conditions

(3) Comparison of brake specific fuel consumption (bsfc):

Figure 7 shows that the HCCI brake specific fuel consumption is 6.67 per cent lower than the BSFC of standard CI situations until the BP is 57 per cent lower. The performance is equivalent to 71.58% of BP under these CI conditions. At 8.33 per cent and 100 per cent BP, the performance of the BSFC is improved by 8.10 per cent for HCCI. At a lower load, the HCCI fuel consumption is lower than the standard CI engine, as the load raises the basic fuel consumption. It is clearly seen in Figure 7 above. It suggests that the higher load brake specific fuel consumption is higher for HCCI running mode compared to CI running mode.

Figure 8 shows the Brake specific fuel consumption of the engine at part and full load for HCCI and CI operating environment. It is evident that the real fuel consumption of the brake is lower for HCCI than for CI in part loading and the BSFC is higher for HCCI than for CI in full load condition.

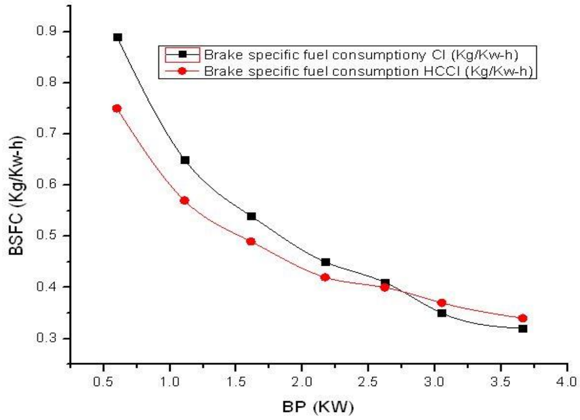

Fig. 7. Brake Specific Fuel Consumption Vs BP at CI and HCCI

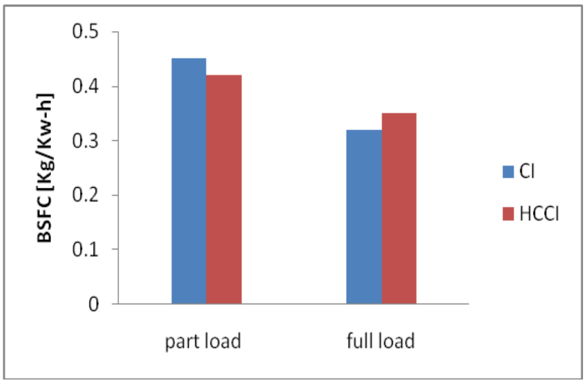

Fig. 8. BSFC Vs BP at CI and HCCI part and full load condition

B. Comparison of emissions of HCCI engine with ci engine

(1) Comparison of emissions of Nitrogen oxide (NO_X):

The figure 9 shows the oxide of nitrogen at HCCI and CI mode running. Emissions of HCCI engine is much lower than CI engine emissions. Experimental result is giving emissions of HCCI engine is 7.82% lower by median value than that of normal CI conditions. In CI condition curve shows performance starts deteriorating NOx starts increasing when load is increasing again it indicate at higher combustion temperature, when it exceeds 2000K and NOx formation is taking place, as a result NOx starts increasing.

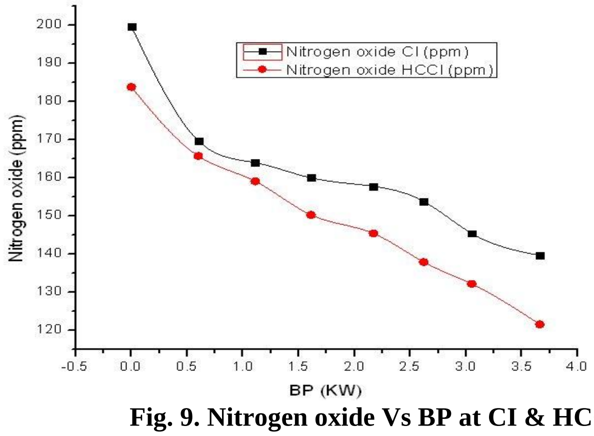

Fig. 9. Nitrogen oxide Vs BP at CI & HCCI

The figure 10 shows NOx emissions at part and full load conditions, there is a clear drop of the NOx emissions with the use of the HCCI technique.

At part load NOx emissions of NOx is 158 .3PPM and at full load is 140.6 for CI mode running and for HCCI at part load is 146.3 PPM and at full load is 122.5 PPM .It is clear from the results for both HCCI and CI conditions NOx emissions are reducing at full load condition.

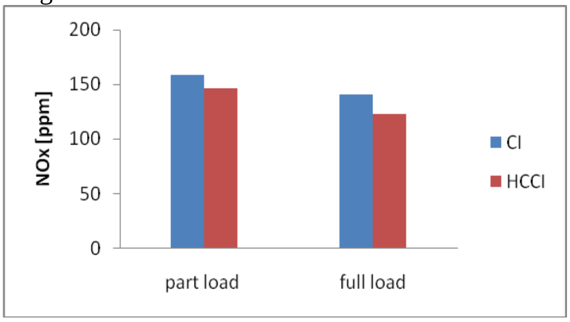

Fig. 10. Nitrogen oxide Vs BP at CI & HCCI part and full load condition

(2) Comparison of emissions of carbon monoxide (CO):

The figure 11 shows the CO at HCCI and CI. At HCCI condition the CO is 3.96% less than that of the CI conditions for both HCC and CI emissions of CO are decreasing with increase of brake power till 66 % load and then after with increase of brake power CO emissions are increased by 12%.

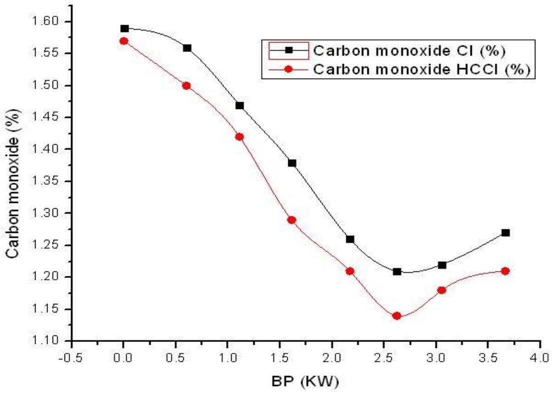

Fig. 11. Carbon monoxide Vs BP for CI and HCCI

The figure 12 shows the emissions at part and full load conditions, there is a clear drop of the CO emissions with the use of the HCCI technique at part load. At full load condition for HCCI there is a rise of CO. It indicates at full load condition combustion is incomplete in HCCI condition and useful amount of fuel energy in the form of carbon monoxide leaving in to atmosphere through exhaust gas. This can be minimized by taking exhaust gas recirculation and by re-burning of CO.

(3) Comparison of emissions of carbon dioxide (CO_2):

As shown Figure 13 the CO_2 emissions of the HCCI is 5% lower by median value than that of normal CI conditions. As break power increases the emissions of carbon dioxide increases for both HCCI and CI condition of the engine. CO_2 emissions are higher for HCCI and starts decreasing at peak load as compared with CI condition, it shows at peak load formation of CO and HC are taking place in HCCI condition.

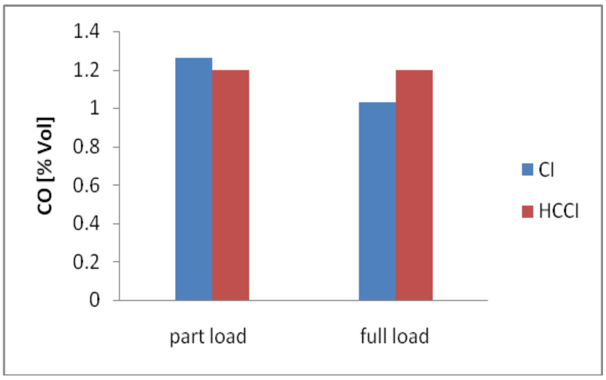

Fig. 12. CO Vs BP for CI and HCCI part and full load condition

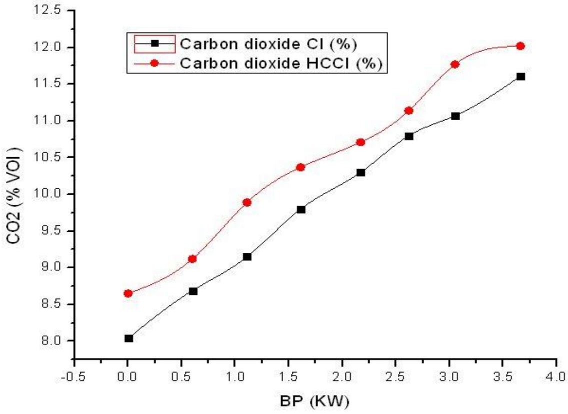

Fig. 13. CO_2 Vs BP at CI and HCCI

There is a clear drop of CO_2 emissions with the use of the CI condition because emissions of CO decreasing for HCCI and CI with the increase of brake power and CO_2 emissions are increasing up to 65.6 % of brake power then after emissions CO increasing and CO2 emissions are decreasing.

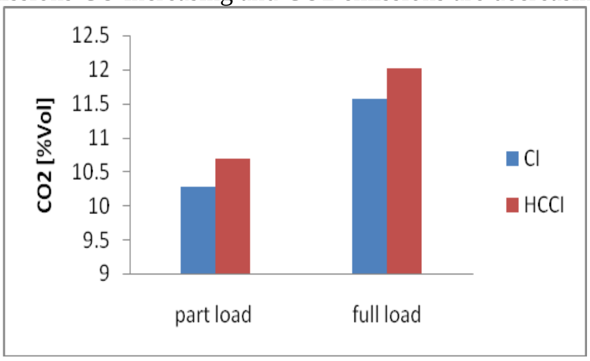

Fig. 14. CO_2 Vs BP at CI and HCCI part and full load condition

C. HCCI emissions using exhaust gas recirculation

(1) Comparison of emissions of nitrogen oxide (NO_X):

Figure 15 shows a clear picture of the NO_X emissions at all the 3 test conditions. EGR dilute the air fuel mixture and reduces the in cylinder temperature this lower temperature reduces the formation of NOx. The NOx emission of normal CI is higher than the HCCI mode running. The NOx emission of EGR-CI is lower than the NOx emissions of normal CI condition.

The NOx emission of HCCI condition is almost near to the EGR-CI condition and it is decreasing with increasing the brake power at higher load. At higher load NOx emissions of EGR-CI and HCCI are lower than the normal CI running condition.

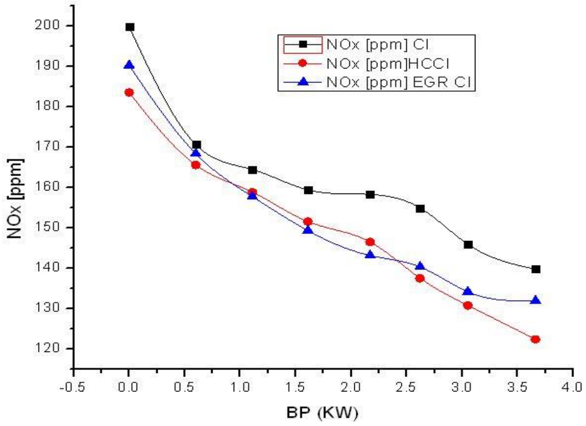

Fig. 15. NOx Vs BP at CI, EGR CI & HCCI

Following figure shows the comparison of NOx emissions by taking brake power on x-axis and NOx emissions on y-axis for test conditions of normal CI, HCCI and substitutions of10%, 15% and 18% EGR for HCCI condition. From experimental results it shows for all conditions with increasing brake power the emissions of NOx is decreasing but problem to increase further flow rate of EGR (more than 18%) at higher loads delay in combustion and higher smoke emissions are observed. So comparisons are made with the limit of 18% flow rate of EGR supply to the engine for both HCCI and CI conditions.

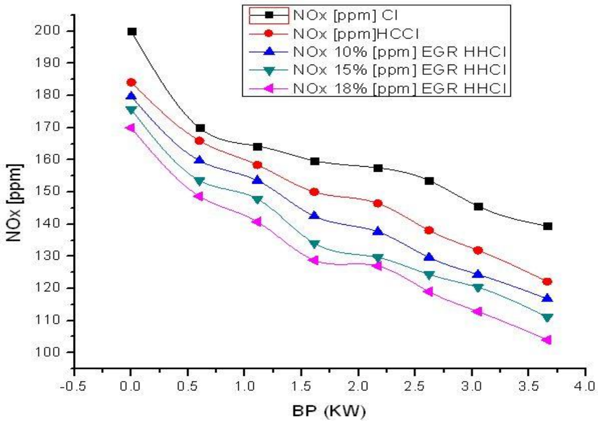

Fig. 16. NOx Vs BP at CI & various EGR HCCI

(2) Comparison of emissions of carbon monoxide (CO):

Figure 17 shows the comparison of CO emissions for the three test condition of CI, HCCI and EGR-CI. CO emission of CI is higher than the emission of EGR-CI and HCCI and EGR-CI is higher than HCCI condition. From the experimental results Carbon monoxide emissions of HCCI engine is compared with normal CI, EGR-CI engine and found the emissions of HCCI is 7.8% lower by median value than that of normal CI conditions. HCCI enables well mixed and even combustion results in CO less burning of fuels.

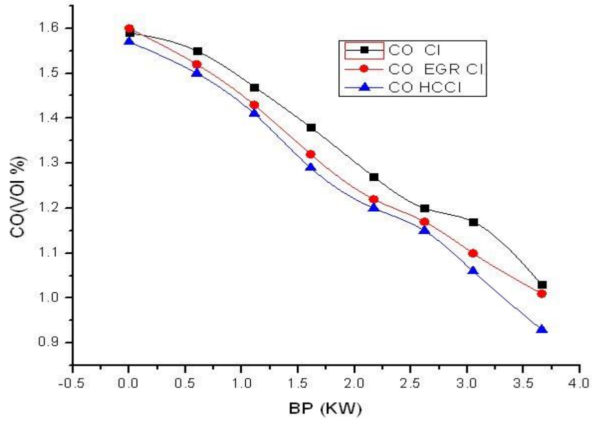

Fig. 17. CO Vs BP for CI, HCCI and EGR C

The figure 18 shows variation of CO at CI, HCCI and EGR-HCCI and HCCI using 10%, 15% and 18% of exhaust gas recirculation. The CO emissions are higher for CI engine as compared with HCCI engine. With the increased flow rate of exhaust recirculation from 10% to 15% and then from 15% to 18% on EGR-HCCI engine it was observed the emissions are reducing for all test conditions. On overall the CO emissions of CI.HCCI and EGR-HCCI at different substitutions of exhaust gas recirculation is decreasing with the increase of brake power to a certain extent and with minor deviation again it is decreasing. CO emissions are higher for 10 % EGRHCCI and there is a drop of 10 % CO emissions from the normal CI running conditions to 18% EGR- HCCI conditions.

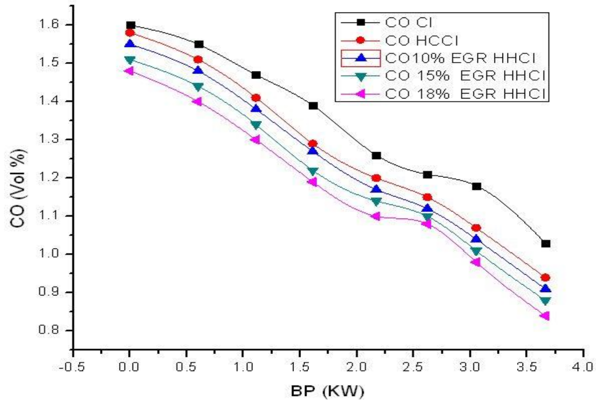

Fig. 18. CO Vs BP for CI and various EGR HCCI

(3) Comparison of emissions of carbon dioxide (CO_2):

Figure 19 shows a clear picture of the CO_2 emissions are increasing for all the three test conditions with increase of brake power and CO_2 emissions are higher for HCCI condition then CI, EGR-CI condition. The figure 20 shows variation of CO_2 at CI, HCCI and EGR-HCCI and also with substitution of 10%, 15% and 18% of EGR on HCC conditions. CO_2 emissions are higher for 18 % EGR substitution on HCCI and it is lower for normal CI condition than HCCI condition. With the increase of brake power emissions of CO_2 are increasing and at peak load there is a drop of 10% the CO_2 emissions at peak load conditions to 18% EGR- HCCI conditions, this is where the emissions of CO and HC are increasing at peak loads .i.e when CO_2 emissions are decreasing CO, HC are increasing. The curve is dropping down at higher loads which is shown in figure 20.

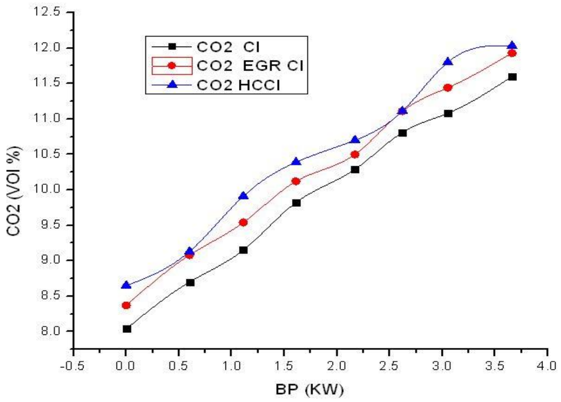

Fig. 19. CO_2 Vs BP at CI, EGR CI and HCCI

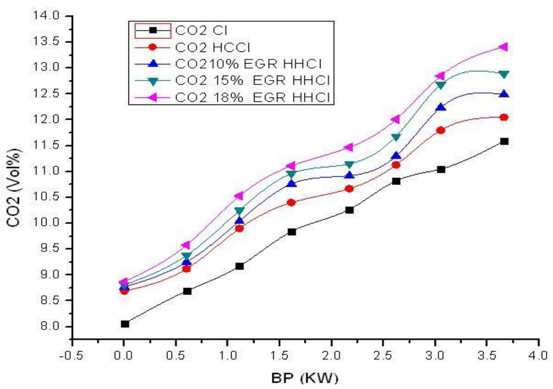

Fig. 20. CO_2 Vs BP at CI, EGR HCCI

V. CONCLUSION.

1) The decrease in BSFC demonstrates the enhanced efficiency of the HCCI engine at load condition using exhaust gas recirculation.
2) The NOx emissions decreases with the use of EGR, at 18% EGR on HCCI mode, NOx emissions are much lower than normal CI and EGR-CI modes.
3) At part load of HCCI mode CO emissions are lower by median value than normal CI condition. With the substitution of 18% EGR on HCCI condition at part load there is a drop of 10% CO emissions.

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