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Review on Effect of Exhaust Gas Recirculation (EGR) on Performance of Compression Ignition (CI) Engine and Homogeneous Charge Compression Ignition (HCCI) Engine

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ABSTRACT
Energy conservation is a trending topic in the world. But only saving energy is not the primary aim, there is a need for clean and efficient source of energy to reduce the pollution. Compression ignition engine is the preferred prime movers due t o excellent drivability and higher thermal efficiency. Even though it has many advantages, it also has major drawbacks as it produces higher level of NOx and smoke emissions which cause severe health issues to the living creatures. Exhaust gas recirculation (EGR) is found to be an effective method to control the level of NO_x and smoke emissions caused by the compression ignition (CI) engines. The EGR reduces the amount of NO_x and smoke emissions by decreasing the content of concentration of oxygen in the combustion chamber and also in the heat absorption. In order to get clean exhaust, many configurations have been proposed like high- and low-pressure loop EGR, as well as the hybrid systems. In order to reduce the higher level of NO_x and smoke particles, the EGR is implemented in homogeneous charge compression engine (HCCI) engine, which gives more promising result by reducing the pumping work and increasing the efficiency of the engine. Here we are studying in detail about the performance and the control of emissions in case of CI, HCCI and the implementation of EGR in the HCCI engine, and how it is useful to reduce the pollution content.

Keywords: *CI, emission, exhaust gas recovery, HCCI engines*

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INTRODUCTION

The demand and fame of the compression ignition (CI) engine is increasing as it provides better mileage and higher amount of power with less maintenance. Diesel engines are utilized for driving stationary/portable gear, and to produce power more financially than some other gadgets in this size range. The vast sale of diesel vehicles has been noticed in recent years. Air pollutants are a mixture of any materials into the atmosphere which will have threatening effects on humans. In recent years, because of globalization and mechanical advancement, transportation businesses are increasing quickly. Such enterprises are especially in charge of climatic contamination which is negative to human well-being and condition. Internal combustion engines are the primary power source for the vehicles utilized by transportation industries. Since all the diesels have high compression ratio which is responsible to achieve auto ignition and results in high expansion, the extra amount of the oxygen facilitates into the cylinder because of lean air fuel mixture. Thus great endeavors are being made to diminish the contaminations discharged from the exhaust without loss of power and fuel utilization [1–4]. HCCI innovation was defined to take out the downsides of traditional spark ignition (SI) and CI motors. HCCI is said to be the ideal combination of SI and CI motors [5]. Homogeneous charge compression ignition (HCCI) burning mode proposed by Onishi et al. [6] is a solid strategy that has been found to deliver low NO_x levels, close to zero residue and improved CO_2 emissions.

The ratio of mass of reused gases to the mass of engine intake is termed as exhaust gas recirculation (EGR). It is a highly efficient and broadly utilized method to control the development of the NO_x inside the combustion of IC engine. EGR is usually used to decrease NO_x in SI engines just as CI engines. This lessens the O_2 fixation and weakens the intake charge, and decreases the peak ignition temperature inside the burning chamber which will at the same time diminish the NO_x arrangement. It ought to be noticed that a large portion of the NO_x discharge happens lean blend limits when EGR is least successful [7]. The use of EGR in HCCI engine further reduces an excessive amount of NO_x from the engine.

ENGINE SETUP DETAILS

Schematic Diagram of Engine Setup Using EGR (Figure 1)

The EGR flow components, ducts and valves need to withstand the boost pressure. The area of duct from the motor exhaust to the inter-cooler ought to even be immune to exhaust temperatures that area unit usually during a variation of 200°–600°C. So to soak up the thermal enlargement and to endure the mechanical vibration, the duct ought to be created with versatile stainless steel bellows. Once EGR system is applied, the engine intake consists of contemporary air and reused exhaust gas. Exhaust gases were broached from piping and attached to recess inlet airflow movement; associate EGR management valve was provided during this pipe for EGR management. The exhaust gases were controlled by this valve and legitimately send to the intake manifold, upstream of blower or downstream of blower. Adequate separation for blending of outside air and exhaust gases were guaranteed. The proportion of recycled gases is usually pictured by associate EGR quantitative relation for the mass quantitative relation of recycled gases to the complete engine inlet [7–13].

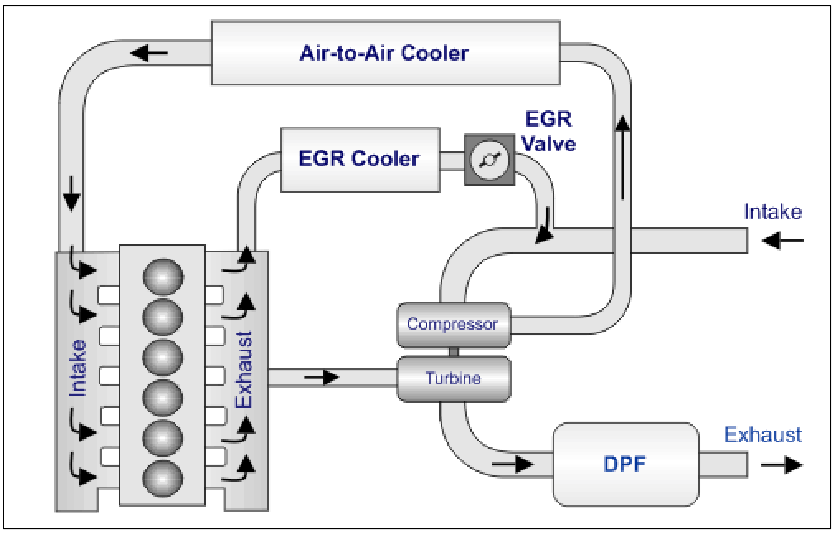

Fig. 1. *Schematic diagram of engine setup using EGR.*

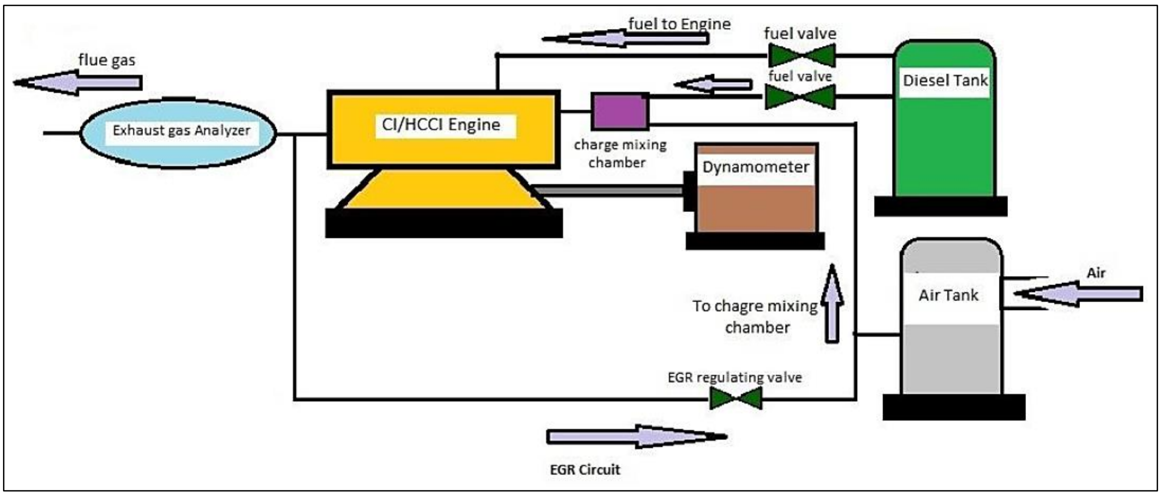

Fig. 2. *HCCI engine experimental setup [14].*

Experimental Engine: HCCI Mode Setup Details(Figure 2)

One of the burning procedures is HCCI in which unconstrained start of charge happens at multi-focuses in the ignition chamber at high pressure proportion with lean and weaken blend of homogeneous charge. In the current trial examination, HCCI is accomplished on an ordinary CI motor by executing couple of changes on the customary diesel motor. The air intake of the motor is connected with a carburetor similar to an SI engine. Diesel isn't provided at first through carburetor; the motor is begun as typical CI motor and permitted to keep running for quite a while with an appraised speed of 1500 rpm. The diesel is provided through the carburetor and the charge approaching in will be blended with diesel. Presently, the charge within the combustion chamber may be a homogenized charge, because the fuel may be already within, and therefore, the engine employed in the experiment is a consistent speed motor where the injection of fuel lowers, thanks to the governor action. Currently, the engine runs as an HCCI engine taking help of the pilot infusion through injector [14].

Experimentation Details

An analysis has been made on CI engine and HCCI mode, excluding EGR at various load conditions and including EGR at various burden conditions. At each load, the mass of fuel utilization and specific fuel utilization of DI mode motor were found by calculating the time taken for to devour the 10 CC of fuel by stopwatch. Pressure gauge reading is recorded for calculating the volume of air sucked into the motor chamber. Comparative calculations are made in order to get the engine performance like brake thermal efficiency, volumetric efficiency and the brake-specific fuel consumption (BSFC), and the results are plotted. In the next stage, HCCI mode engine was operated by switching it over DI mode by discontinuing the fuel to DI injector and allows the fuel to stream within the port fuel injector. In HCCI method of activity, the fuel is infused on the intake air at inlet manifold of the engine. The fuel is infused throughout the segment stroke of the motor by port fuel injector. The fuel and air combined and made uniform blend, before blend enters to the combustion chamber. In the two modes, tests were directed at variable burden at evaluated speed of 1500 rpm. The test examination has been completed for various burden conditions with various EGR appraisals. The performance and emission values of HCCI mode engine were recorded and the obtained results are compared through graphs [14].

RESULTS AND DISCUSSION

The results are noted and drawn below after performing sequence of trials on diesel-fuelled HCCI engine at different substations of EGR. The performance specifications such as brake thermal efficiency, volumetric efficiency, BSFC and exhaust gas temperature are plotted and compared with that under various conditions. The emission parameters are also plotted to find the rate of emission drawn under the following conditions. The results are as follows:

Impact of EGR on Brake Thermal Efficiency

Brake thermal efficiency is the essential to pass judgment on the execution of a motor under a specific condition. The brake thermal efficiency under various load conditions and the effect of EGR are shown below.

Figure 3(a) is the correlation of brake thermal efficiency between the ordinary CI, HCCI and EGR running state at numerous brake powers. In Figure 3(a, b), the execution of the HCCI and EGR is higher than the ordinary CI running conditions till 71% BP, but at higher burdens, the execution of both the conditions dropped than that of typical CI running conditions [14].

Figure 3(b) indicates the brake thermal efficiency of the engine and HCCI running conditions at different EGR values with respect to the typical CI. It is acquired that the performance goes higher with substitution of EGR till the load is 70%. At 18% EGR and 55% burden conditions, the brake thermal efficiency is 21% which is 25% above than that of the ordinary CI conditions. At higher burdens, the effectiveness drastically diminished from typical CI condition to 18% EGR substitution by 15% [14].

Figure 3(c) represents the brake thermal efficiency at CI, HCCI and typical EGR conditions are mapped in as bar graph at half and full burden conditions. The results and the charts represent the higher performance of HCCI at part burden than that of full burden conditions [14].

Volumetric Efficiency

Figure 4 represents the volumetric efficiency of the motor at different EGR substitutions at HCCI condition in comparison to that normal CI condition at part load and full load. It is obvious that the volumetric efficiency decreases with the increase in EGR substitution. Since, when the exhaust gas is re-circulated, gas is re-circulated, hence it provide the less space inside the cylinder for the fresh air intake. This is the cause for the decrease in the volumetric efficiency with EGR. The same way, the fuel entering the cylinder as the charge along with the inlet air takes away the room from the air and also has a negative effect on the volumetric efficiency [14].

Impact of EGR on Brake-Specific Fuel Consumption (BSFC)

BSFC is the parameter that indicates the specific amount of fuel that is consumed to produce a magnitude of power.

Figure 5 represents the BSFC of the HCCI engine running conditions at different EGR substitutions with respect to the ordinary CI engine. It is acquired that the execution is running better with substitution of EGR till the burden is 70%. At 18% EGR and 55% burden conditions, the BSFC is 21% which is 25% plentiful amount of the ordinary CI conditions. At higher burdens, the effectiveness significantly expanded from ordinary CI condition to 18% EGR substitution by 5% [14].

Exhaust Gas Temperature Analysis

Exhaust gas temperature shown in Figure 6 provides qualitative information about the bulk peak temperature prevailing inside the combustion chamber. Injected fuel quantity, rate of EGR and infusion timing

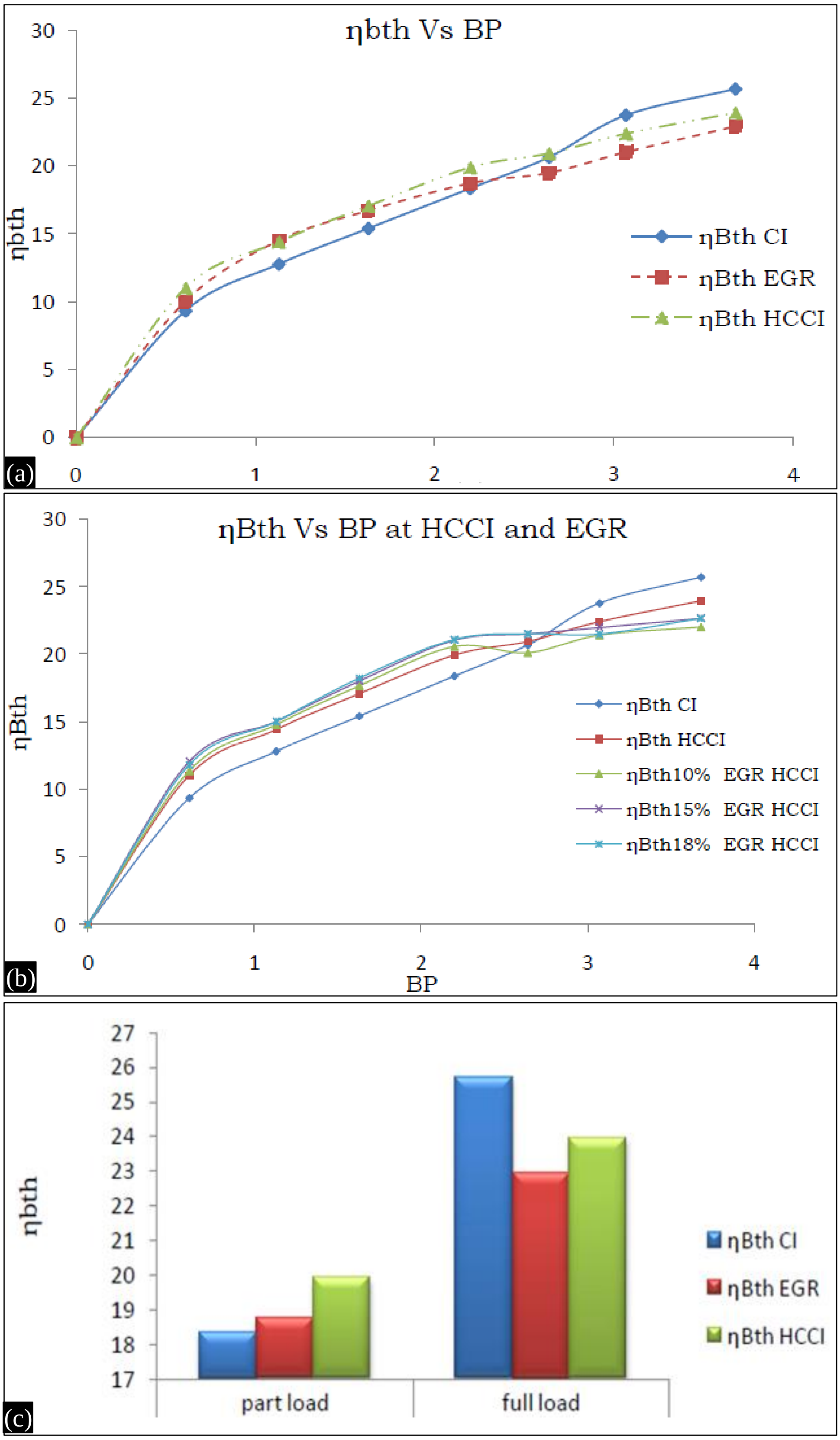

Fig. 3. *(a) ηBth vs. BP at CI, HCCI and EGR CI operations [14]. (b) ηBth vs. BP at CI and HCCI at various EGR operations [14]. (c) ηBth versus BP at CI and HCCI at various EGR operations [14].*

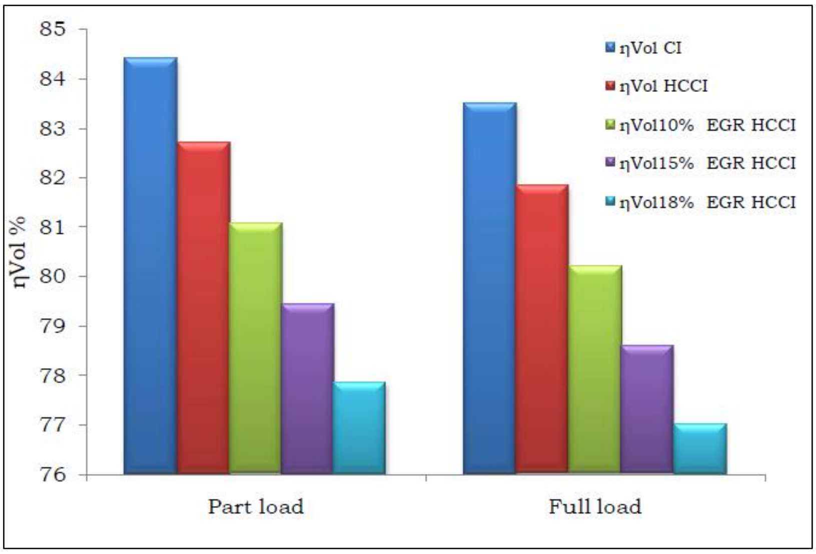

Fig. 4. *ηvol at CI and HCCI at various EGR substitutions [14].*

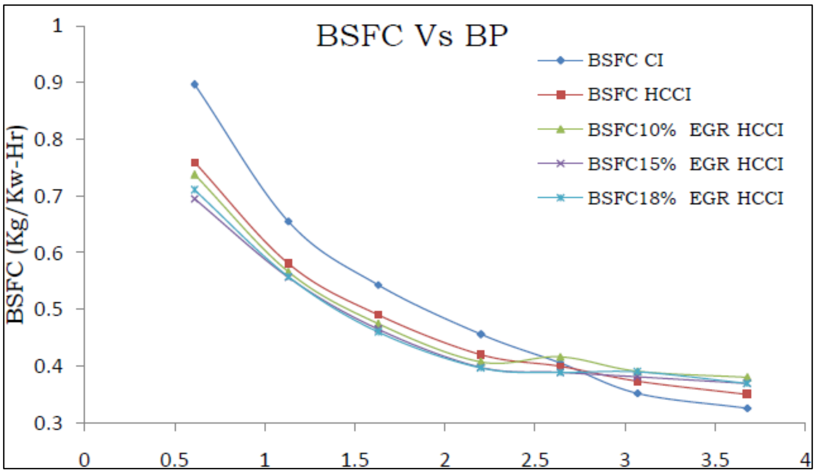

Fig. 5. *BSFC versus BP at CI and HCCI at various EGR substitutions [14].*

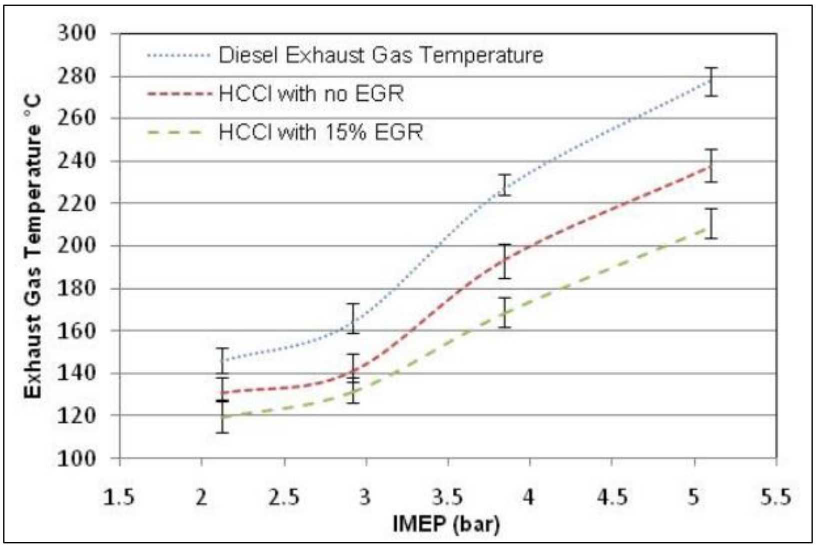

Fig. 6. *Exhaust gas temperature in HCCI combustion and EGR [15, 16].*

are few important factors which affect the exhaust gas temperature. In HCCI burning, exhaust gas temperature is altogether lower than ordinary diesel combustion (CI) due to homogeneous charge combustion. Exhaust gas temperature increments with expanding engine burden because of the presence of wealthy combustible blend, while it lowers with a growth in EGR due to mixture dilution. At higher EGR conditions, non-responsive idle vaporous species, for example, CO_2 and water vapors, which have moderately higher warmth limit, contrasted with different constituents of the exhaust gas, consumed the burning created heat and lessened the mass in-chamber temperature. At higher burdens, EGR turns out to be less powerful because of moderately bigger addition in mass in-chamber temperature. Heat created throughout higher burden conditions is essentially higher when contrasted with heat-absorbing limit of the non-receptive vaporous species (Figure 5) [15, 16].

Emission Inspection

It describes the variation in mass emission of different species (NO_x, HC, CO and smoke) in exhaust gas. The trials were performed for all loads with 15% EGR and without EGR and compared with baseline diesel engine operating in conventional CI combustion mode.

Emission of Carbon Monoxide (CO)

Figure 7 shows the comparison between CO mass outflow for normal CI and HCCI burning modes. Excessive CO discharge is found as one of the significant downsides of HCCI burning. Like HC outflow, main consideration which adds to higher CO discharge is low ignition temperature because of burning of moderately leaner homogeneous blend. The intermediate product obtained by burning of CO cannot be completely oxidized to CO_2 at lower temperature. Level of CO discharge diminishes with expanding IMEP because of generally higher burning temperatures at higher burdens. Mass discharge of CO in HCCI ignition is a lot higher when contrasted with CI burning mode. Excessive EGR levels, which are needed for burning control in HCCI ignition, further lessen the peak in-cylinder temperature [15].

Emission of Hydrocarbon (HC)

Figure 8 demonstrates the HC mass emission from the HCCI ignition at different EGR states alongside CI burning. HC discharges in CI burning mode are essentially lesser than that of HCCI mode. It occurs essentially because of generally deficient burning of fuel at lower top-chamber temperature and homogeneous ignition of lean blend. Considerable measure of homogeneous blend stays caught in hole volume closer to cylinder wall, which is produced in the exhaust stroke in the event of HCCI burning, prompting excess HC and CO emissions. This type of emission sources is practically not there in normal CI engines. Expanding EGR rate improves the HC discharge level because of two reasons. First, the distribution of some unburned HC with exhaust gas prompts decrease in by large HC outflows. The second is the decrease in top in-barrel ignition temperature, which prompts increment in HC outflows. Generally, the impact of expanding EGR on HC profile demonstrates the improvement in mass emission of HC for all IMEP states [15, 16].

Emissions of Nitric Oxide (NO_x)

Nitric oxide (NO) and nitrogen dioxide (NO_2) are the most dangerous contaminations transmitted by diesel motors and are assembled as NO_x. Excessive in-cylinder temperature and existence of climatic nitrogen in the new admission air are the two positive conditions needed for NO_x deposition. Predominantly, NO_x development happens throughout post-burning responses, when restricted temperatures because of heterogeneous ignition surpass the critical temperature for NO_x arrangement and atoms of oxygen and atmospheric nitrogen begin joining. In the event of HCCI burning, homogeneous charge gives a constant ignition and henceforth mass temperature is constrained, which conveys ultra-low NO_x. Presentation of EGR gives effective outcomes and further decreases NO_x level because of decrease in temperature (Figure 9) [15, 16].

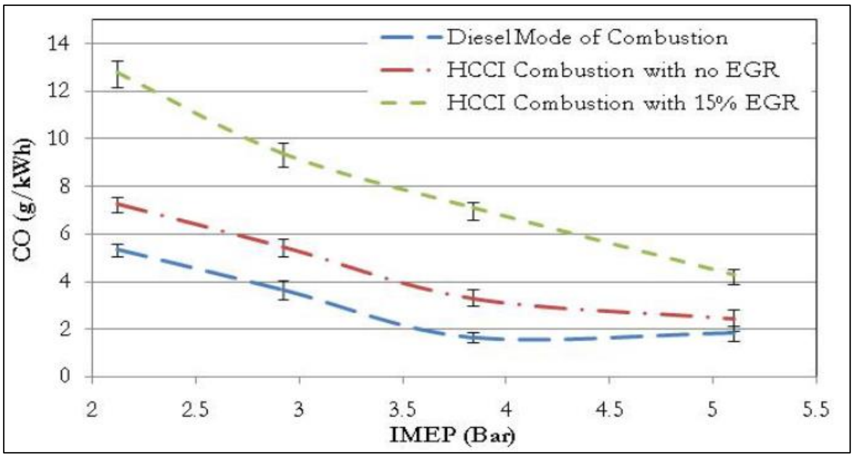

Fig. 7. *Carbon monoxide in HCCI combustion and EGR [15].*

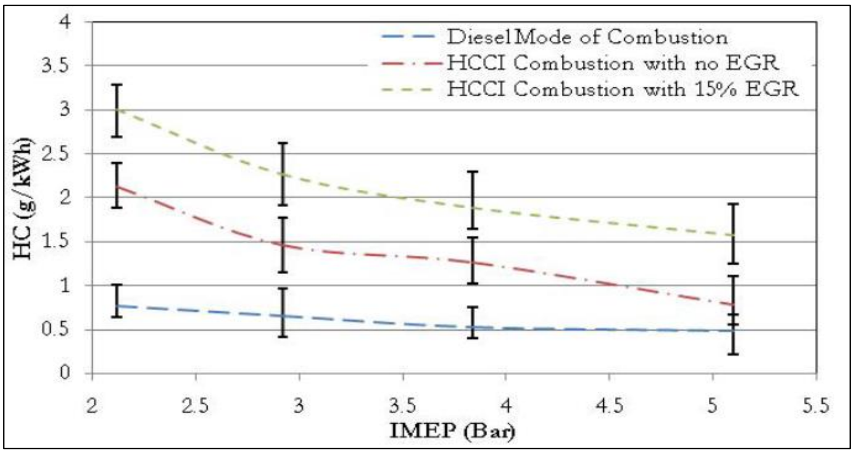

Fig. 8. *Unburned hydrocarbon in HCCI combustion and EGR [15, 16].*

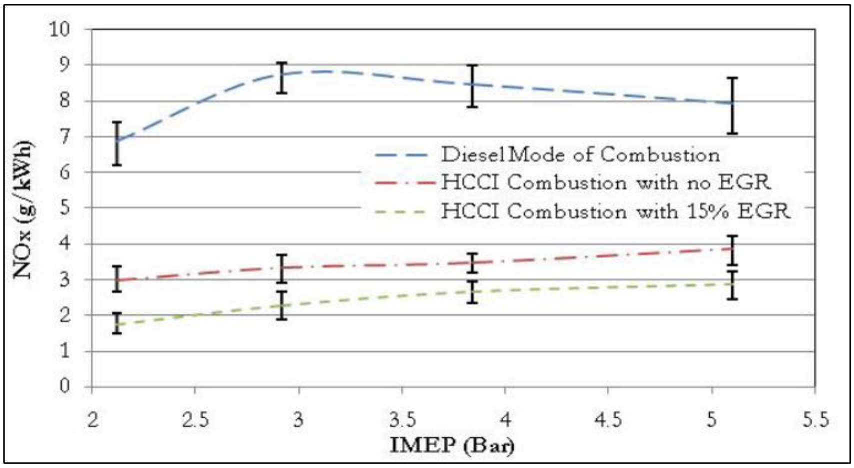

Fig. 9. *Oxides of nitrogen in HCCI combustion and EGR [15, 16].*

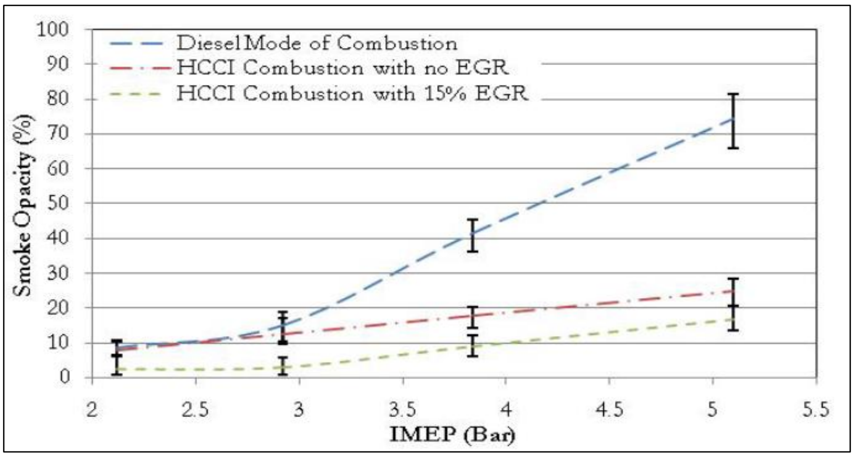

Fig. 10. *Smoke opacity in HCCI combustion and EGR [15].*

Smoke Opacity Inspection

Low smoke discharge is another vital favorable position of HCCI burning. Quantity of smoke is a roundabout pointer of PM (particulate matter) and ash outflow level in the exhaust. Diesel particulates comprise burning created carbonaceous material with higher boiling point natural species dense and ingested onto its surface. For the most part, smoke is estimated as far as smoke opacity. Smoke/particulate development is straightforwardly influenced by the blend quality and its burning. Non-homogeneous blend experiencing heterogeneous burning gives higher smoke/particulate arrangement because of the essence of confined fuel-rich zones, while homogeneous charge gives more preferable smoke features.

Figure 10 represents essentially lesser smoke levels for HCCI combustion mode with respect to CI combustion mode. It is mostly because of fully lack of fuel-rich zones on account of homogeneous blending of air and fuel. Smoke opacity increments with expanding motor burden in both CI just as HCCI burning mode, anyway the rate of increment is a lot higher in CI when contrasted with HCCI ignition mode. The use of EGR further diminishes smoke level in HCCI combustion [15].

CONCLUSION

The brake thermal efficiency of the engine is increased due to HCCI and also because of the addition of EGR under the part load. Once the full load condition is applied, the values change drastically and the brake thermal efficiency is noted higher at the CI engine compared to that of EGR and HCCI engine. The volumetric efficiency is more in CI engine compared to that of HCCI engine and it decreases further expanding the quantity of EGR. The BSFC is better in HCCI engine compared to CI engine and it increased by increasing the percentage of EGR till the part load, but at 100% load is applied, the efficiency seems to be better in HCCI at 5% of EGR but further expanding the quantity of EGR will decreases the BSFC. The exhaust gas temperature is lower in HCCI engine with EGR than that of CI engine. One of the drawbacks found in HCCI engine with EGR is the higher emission of CO and HC compared to the ordinary CI engine. The main advantage of implementation of EGR in HCCI engine is found to be reducing the highly dangerous pollutant NO_x at ultra-low level compared to that of CI engine. Even the application of EGR in HCCI results in reduced smoke capacity.

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