Experimental Investigation on HCCI Engine using Exhaust gas recirculation

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***Abstract*— The burnt gases from exhaust is pumped back in to the intake manifold through suitable piping to dilute the air fuel mixture is the concept of EGR which reduces the Cycle Temperature due to high specific heat(Cp). Low cycle temperature results in lower combustion rate and peak pressure. Moreover lower peak pressure leads to less heat transfer which improves the efficiency. In the presented experiments an EGR loop has been used circulating the burnt gas from the exhaust back into the intake piping. When running the engine with high amounts of EGR it is necessary to use a back pressure valve in the exhaust pipe to force the exhaust gases into the intake pipe. The down side is that the pumping losses will increase. A heat exchanger is attached to the EGR valve in order to cool the burnt gases. The amount of EGR is calculated from the CO_2concentrations in the intake compared to the exhaust. Investigation is carried in two phases one is on EGR with different rates on CI engine and another is EGR on HCCI engine and comparison of results of effect of EGR on CI and HCCI Engine mode of operation.**

***IndexTerms*— CI, HCCI, EGR, SFC, brake thermal efficiency**

I. INTRODUCTION (HEADING 1)

The experimental investigation is carried out in two phases, in this first phase the kirloskar AV1 engine was operated with diesel fuel in conventional DI mode of operation through a warm up procedure and allowed to operate the engine with different load and constant engine speed. The mass of fuel consumption and specific fuel consumption of DI mode engine was found by taking the time taken for to consume the 10CC of fuel by stop watch. Manometer reading is noted for calculating volume of air sucked in to the engine cylinder. Similar, calculations were made for Mfc, Sfc and volumetric efficiency of the engine when it was operated at different load conditions. The performance engine like brake power, brake thermal efficiency, indicated power and mechanical efficiency is calculated from readings and emissions values of the DI mode engine Operation were noted and results are analyzed. In this second phase, DI mode engine was switch over HCCI mode engine operation by cut off the fuel to DI injector and allows the fuel to flow in the port fuel injector. In HCCI mode of operation the fuel is injected on the inlet air at intake manifold of the engine. The fuel is injected during the section stroke of the engine by port fuel injector. The fuel and air mixed together and formed homogeneous. Mixture before mixture enters to the combustion chamber. In both modes, experiments were conducted at variable load at rated speed 1500 rpm. The experimental investigation has been carried out for different load conditions with different EGR ratings. The performance and emission values of HCCI mode engine were recorded and obtained results are compared through graphs.

2. EXPERIMENTAL EGR SETUP

Figure 1.0 shows EGR setup with the engine

Table1. Properties of diesel fuel

Cetane number	53
Density at 300^0 C	836 kg/m3
Viscosity at 400^0 C	2.68 mm^2/s
Calorific value	42500 KJ/Kg

Table2: Engine specifications

Engine Type	4-stroke, single cylinder diesel engine, constant speed compression ignition Engine
Make	kirloskar av-1
Rated power	3.7 kw, 1500 rpm
Bore and stroke	80 mm×110 mm
Compression ratio	16.5:1
Cylinder capacity	553 cc
Dynamometer	electrical-ac alternator
Cylinder pressure	range:2000 psi or 140.000 bars
Orifice diameter	15 mm
Starting	auto start
Cooling	water cooled
Dynamometer	Eddy current dynamometer

3.0 EXPERIMENTAL ENGINE- HCCI MODE SETUP DETAILS

One of the combustion techniques is HCCI in which spontaneous ignition of charge takes place at multi points in the combustion chamber at high compression ratio with lean and dilute mixture of homogeneous charge.

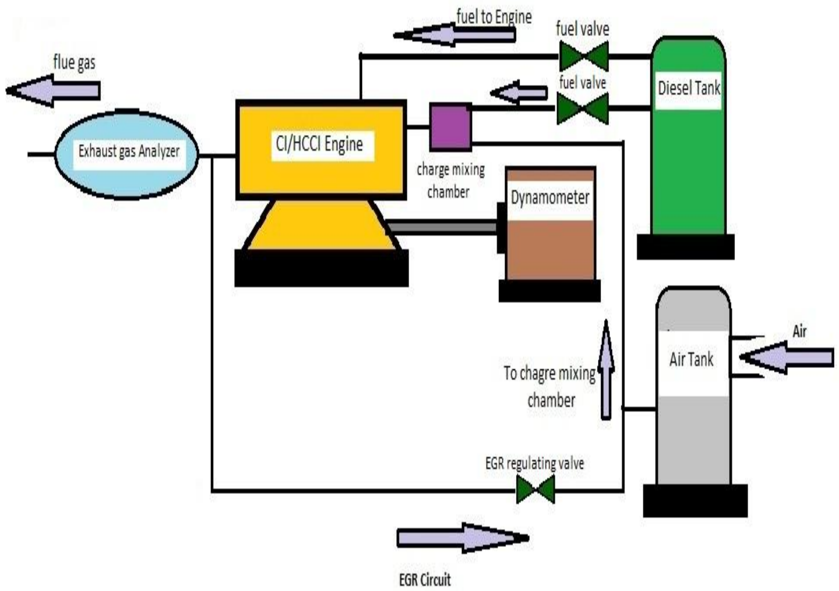


Figure 2.0SchematicdiagramofHCCI Engine experimental setup

Diesel-fueled HCCI combustion can be achieved in many ways.

- External mixture formation or port fuel injection,
- Early direct injection based on the combination of fuel bumping, small- diameter nozzle, narrow spray angle, and multiple injections,
- Late direct injection supplemented by a high level of EGR and high swirl ratio,
- Compound HCCI combustion with PFI combined with early direct injection.

In the present experimental investigation HCCI is achieved on a normal CI engine by implementing few modifications on the regular diesel engine.

The air inlet of the engine is attached with a carburettor like an SI engine. Diesel is not supplied initially through carburetor; the engine is started as normal CI engine and allowed to run for some time with a rated speed of 1500 RPM. The diesel is supplied through the carburetor and the charge coming in will be mixed with diesel. Now, the charge inside the combustion chamber is a Homogenous Charge, as the fuel is already inside and the engine used in the experiment is a constant speed engine the injection of fuel reduces due to the governor action. Now the engine runs as a HCCI engine taking assistance of the pilot injection through injector.

4. EXPERIMENTATION DETAILS

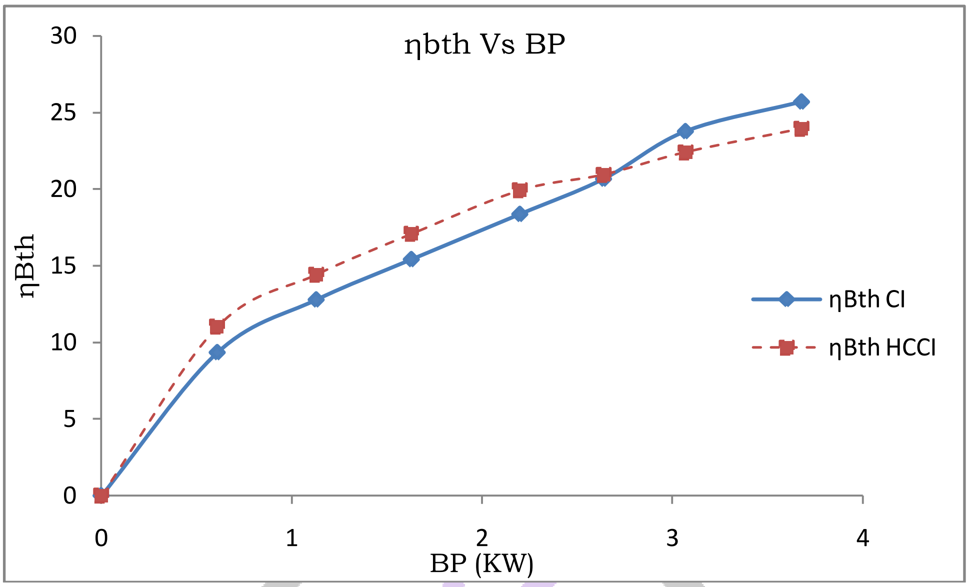
Experiments conducted with diesel fuel as follows.
i. On CI engine without EGR at different load conditions
ii. On CI engine with different EGR ratings at different load conditions
iii. On HCCI mode operation of CI engine without EGR at different loads conditions.
iv. On HCCI mode operation of CI engine with different EGR ratings at different loads.
At each load the mass of fuel consumption and specific fuel consumption of DI mode engine was found by taking the time taken for to consume the10CCoffuel by stop watch. Manometer reading is noted for calculating volume of air sucked in to the engine cylinder. Similar, calculations were made for Mfc, Sfc and volumetric efficiency of the engine when it was operated at different load conditions. The performance engine like brake power, brake thermal efficiency, indicated power and mechanical efficiency is calculated from readings and results are analyzed. In this second phase, DI mode engine was switch over HCCI mode engine operation by cut off the fuel to DI injector and allows the fuel to flow in the port fuel injector. In HCCI mode of operation the fuel is injected on the inlet air at intake manifold of the engine. The fuel is injected during the section stroke of the engine by port fuel injector. The fuel and air mixed together and formed homogeneous. Mixture before mixture enters to the combustion chamber. In both modes, experiments were conducted at variable load at rated speed 1500 rpm. The experimental investigation has been carried out for different load conditions with different EGR ratings. The performance and emission values of HCCI mode engine were recorded and obtained results are compared through graphs.

5. EXPERIMENTAL RESULTS

The significant results are drawn after conducting series of experiments on diesel fuelled HCCI engine at various substitutions of EGR. The performance parameters; brake thermal efficiency, volumetric efficiency, Brake specific fuel consumption are plotted and compared with that under various conditions. The drawn results are as given below;

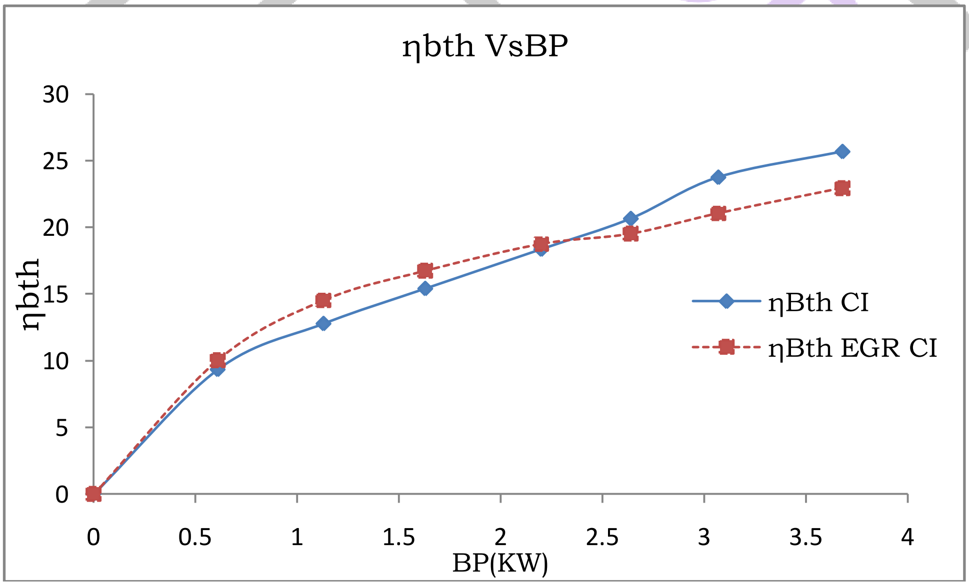
5.1 Brake Thermal Efficiency (η_{Bth}):

Brake thermal efficiency is the important parameter to judge the performance of an engine under a particular condition. The brake thermal efficiency under the condition HCCI under various EGR conditions is mentioned below.



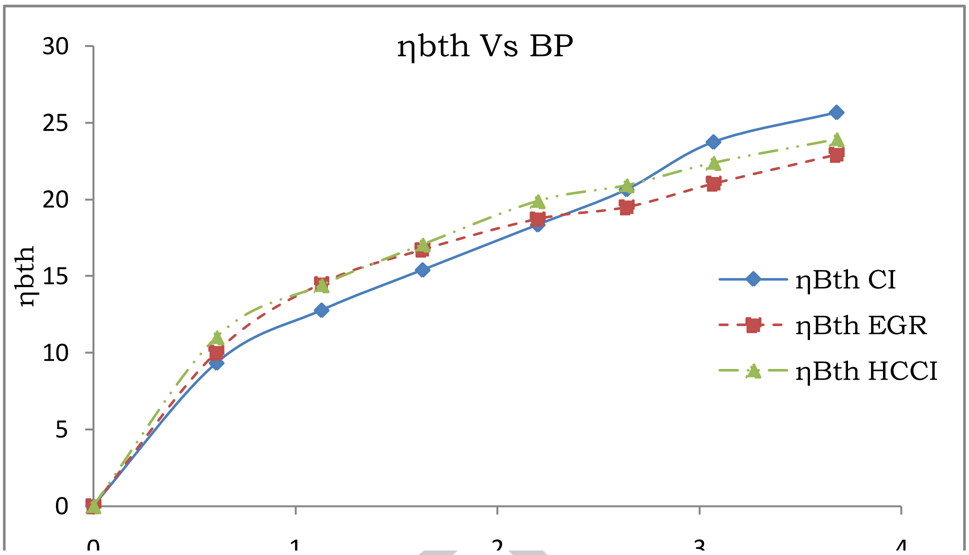
Graph 1: η_{Bth} Vs BP at CI and HCCI operations

As shown graph1 the brake thermal efficiency of the HCCI is 12% higher than the efficiency of normal CI conditions till the BP is 57%. At 71% of BP the efficiency is equal for that CI conditions. At 85%and 100% BP the efficiency is decreased by 8%.



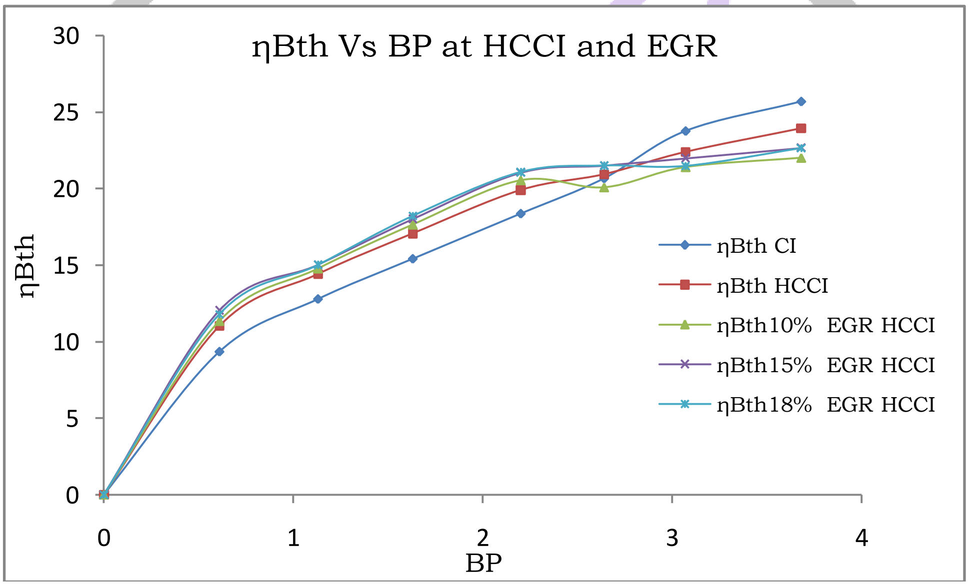
Graph 2: η_{Bth} Vs BP at CI and EGR CI operations

As shown graph 2 the brake thermal efficiency of the EGR is 9% higher by mode value than the efficiency of normal CI conditions till the BP is 57%. At 71% of BP the efficiency is equal for that CI conditions. At 85%and 100% BP the efficiency is decreased by 8%.



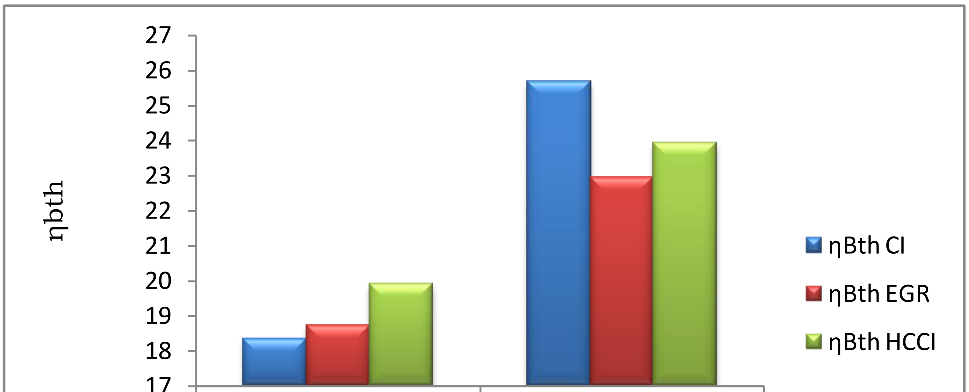
Graph 3: η_{Bth} Vs BP at CI, HCCI and EGR CI operations

The graph 3 is the comparison of brake thermal efficiency between the normal CI, HCCI and EGR running conditions at various brake powers. As mentioned in the comments of for graph 1 & 2 the performance of the HCCI and EGR are better than the normal CI running conditions till 71% BP but at higher loads the performance of both the conditions dropped than that of normal CI running conditions.



Graph 4: η_{Bth} Vs BP at CI and HCCI at various EGR operations

The graph 4 plots the brake thermal efficiency of the engine a HCCI running conditions at various EGR substitutions compared to the normal CI. It is inherited that the performance is going better with substitution of EGR till he load is 70%. At 18% EGR and 55% load conditions the brake thermal efficiency is 21% which is 25% more than that of the normal CI conditions. At higher loads the efficiency dramatically decreased from normal CI condition to 18% EGR substitution by 15%.



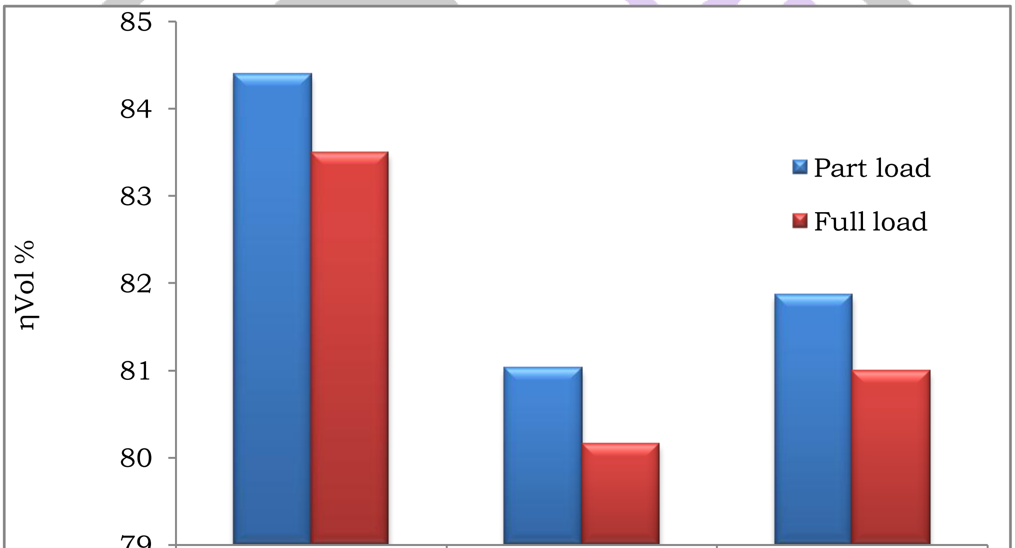
	part load	full load
ηBth CI	18.36	25.69
ηBth EGR	18.74	22.94
ηBth HCCI	19.91	23.94

Graph 5: η_{Bth} Vs BP at CI and HCCI at various EGR operations

Brake thermal efficiency at CI, HCCI and normal EGR conditions is plotted in as bar chart at 50% load and 100% load conditions. The values and the charts show the better performance of HCCI at part load than that of full load conditions.

5.2 Volumetric efficiency (η_{Vol}):

Volumetric efficiency is the measure of breathing capacity of the engine under a particular condition; better volumetric efficiency implies to better burning of fuel and reduced combustion residuals.

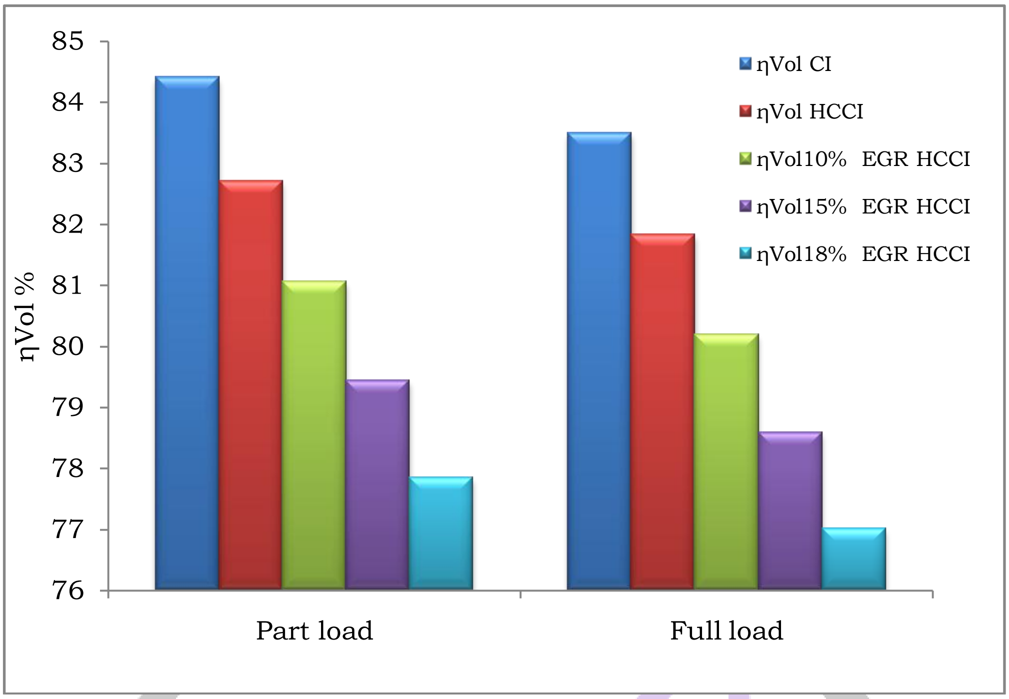


	ηVol CI	ηVol EGR	ηVol HCCI
Part load	84.4	81.024	81.868
Full load	83.5	80.16	80.995

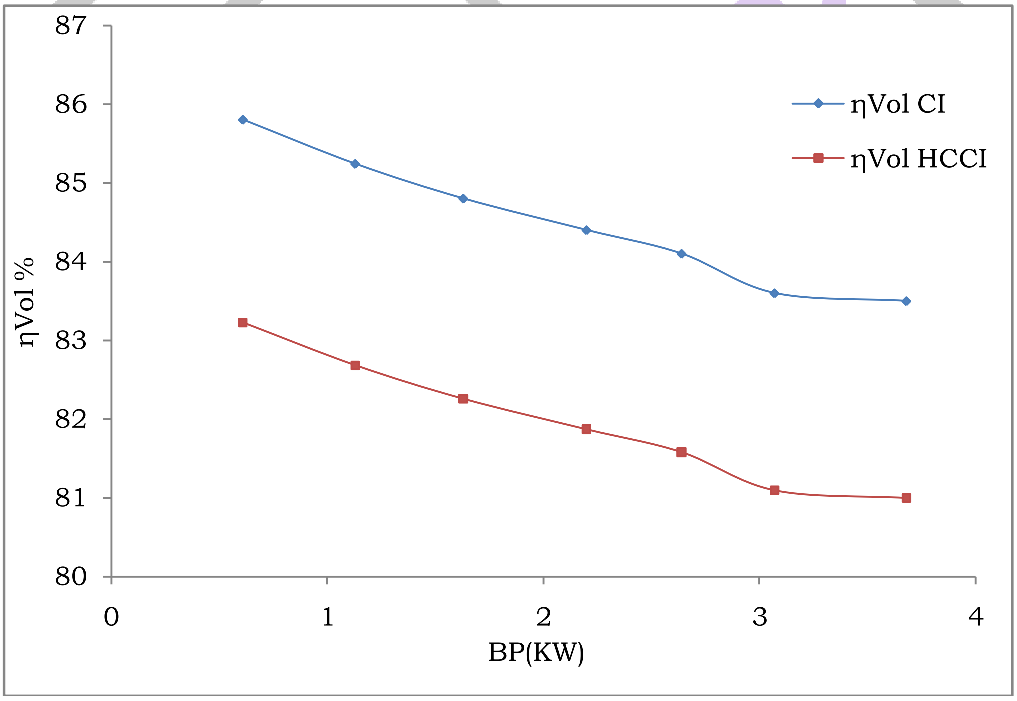
Graph 6: η_{vol} at CI, CI EGR and HCCI conditions

Graph 6 shows the volumetric efficiency of the engine at the three test conditions at part load and full load conditions. When the exhaust gas is re circulated it consume the space inside the cylinder Levin less room for the fresh inlet air. 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 the negative effect on the volumetric efficiency. The above reasons satisfy the values in the graph 6 and graph 7.

The graph 7 shows the volumetric efficiency of the engine at various EGR substitutions at HCCI condition in comparison to that normal CI condition at part load and full load. It is evident that the volumetric efficiency decrease with the increase in EGR substitution. The reason given in the above paragraph clearly justifies the trend of graph 7.

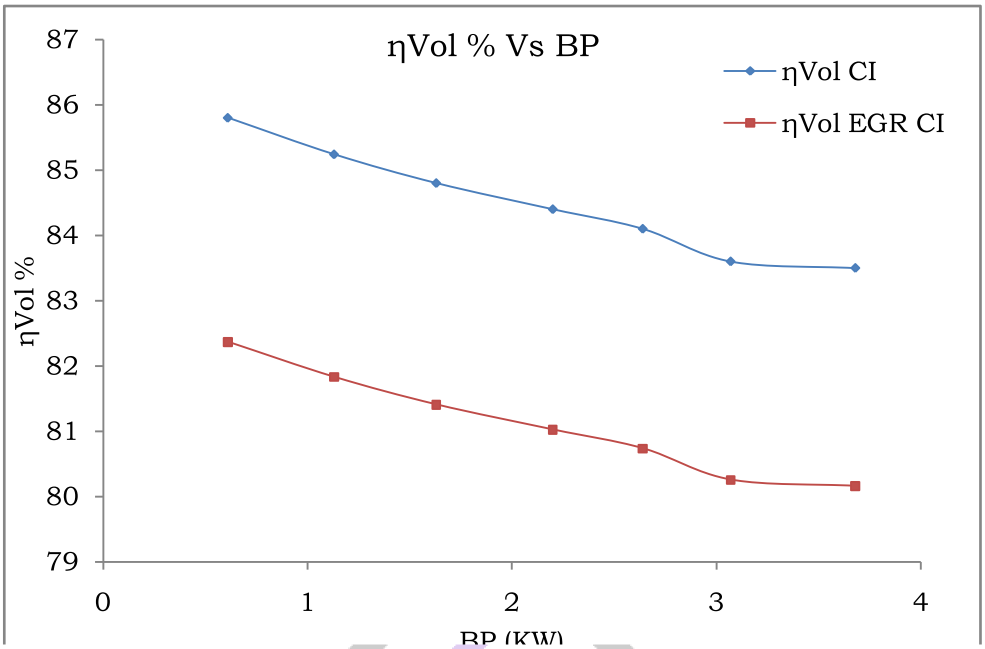


Graph 7: η_{vol} at CI and HCCI at various EGR substitutions

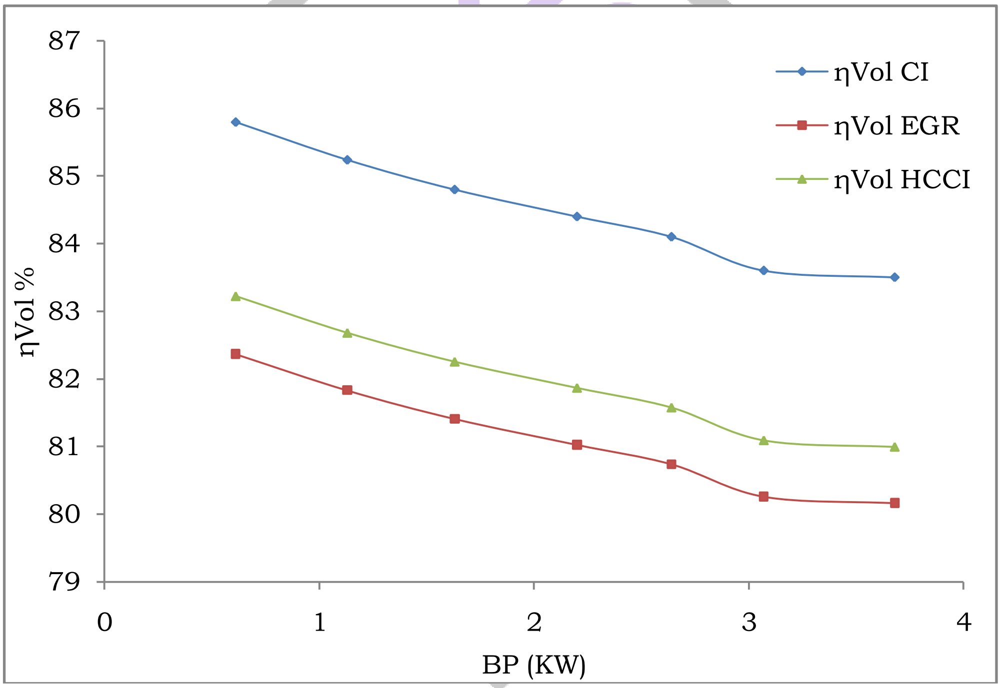


Graph 8: η_{vol} Vs BPat CI and HCCI conditions

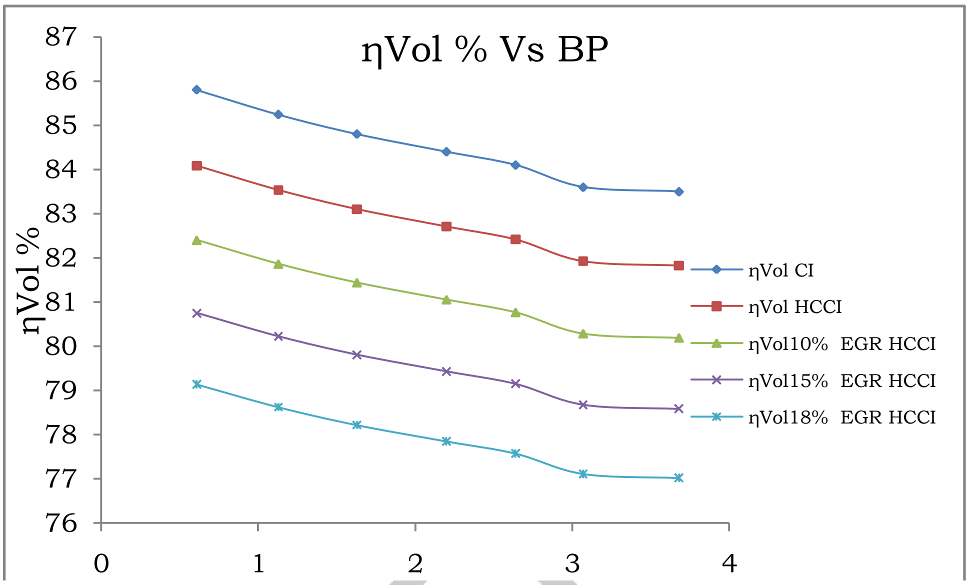
As shown in above graph the volumetric efficiencies of CI condition and HCCI condition are plotted and compared. In graph 9 the comparison is between volumetric efficiency of CI conditions and the EGR substitution at CI conditions. In graph 10 all the three conditions are compared and it is clearly seen that the volumetric efficiency deceases from normalcy running condition to the HCCI condition.



Graph 9: η_{vol} Vs BPat CI and CI EGR conditions



Graph 10: η_{vol} Vs BPat CI, CI EGR and HCCI conditions

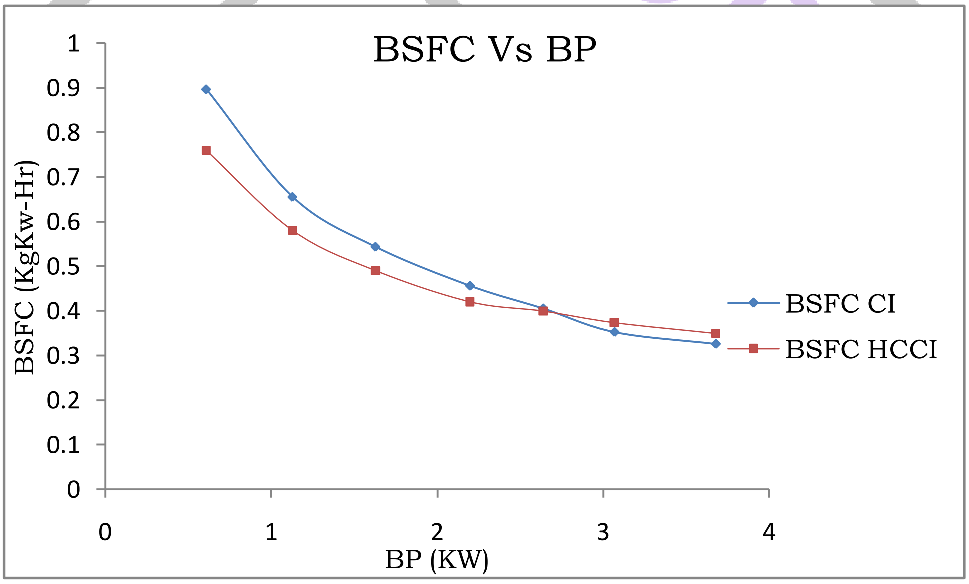


Graph 11: η_{vol} Vs BPat CI, HCCI at various EGR conditions

The graph 11 shows variation of volumetric efficiency at CI, HCCI and EGR HCCI conditions. There is a drop of 9%i the volumetric efficiency from the normal CI running conditions to 18%EGR HCCI conditions.

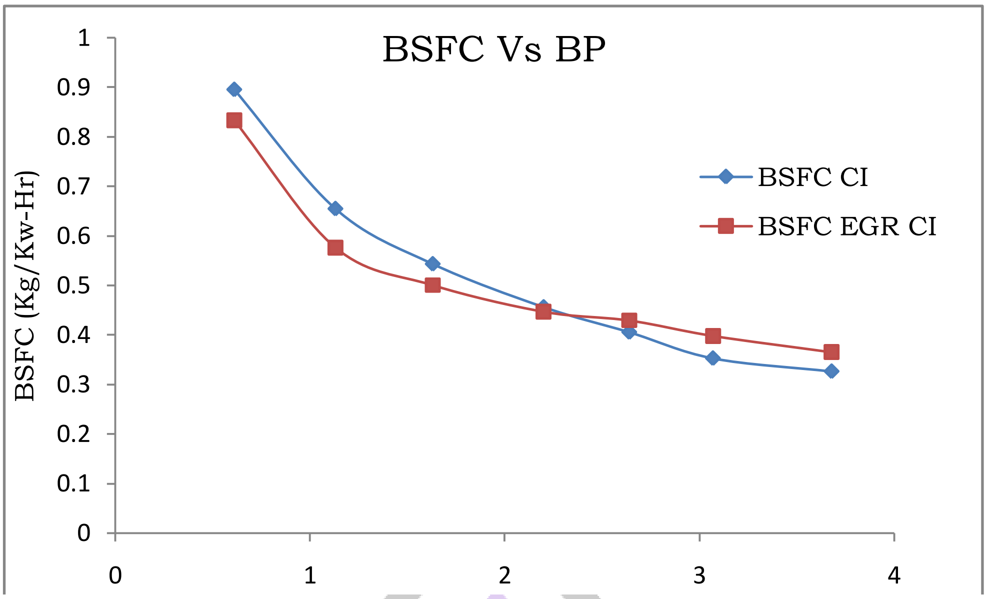
5.3 Brake Specific Fuel Consumption (BSFC):

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



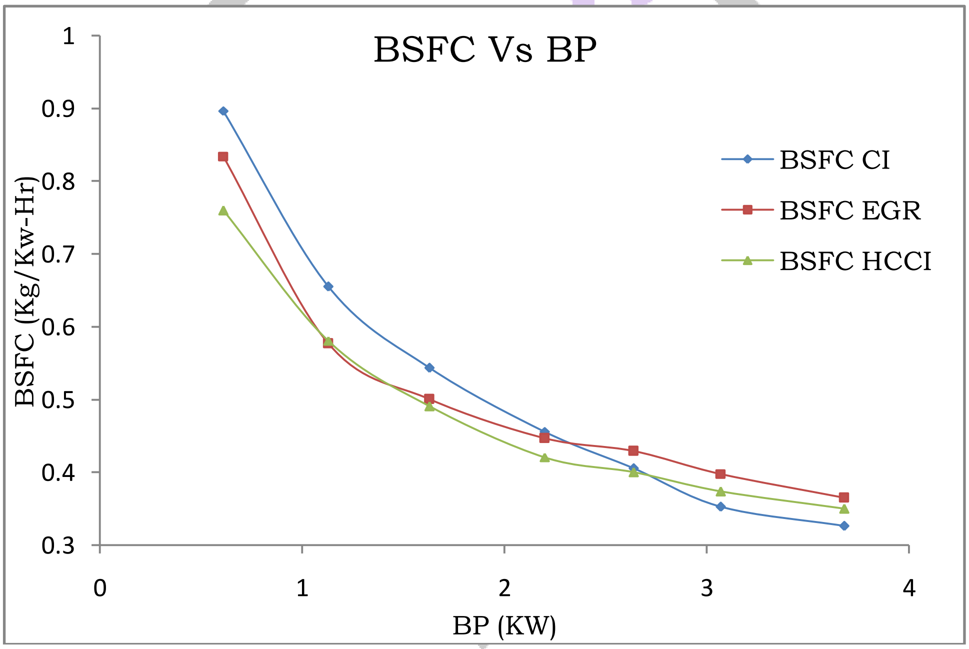
Graph 12: BSFC Vs BP at CI and HCCI

As shown graph12 the BSFC of the HCCI is 6% lower than the BSFC of normal CI conditions till the BP is 57%. At 71% of BP the efficiency is equal for that CI conditions. At 85% and 100% BP the efficiency is increased by 4%.



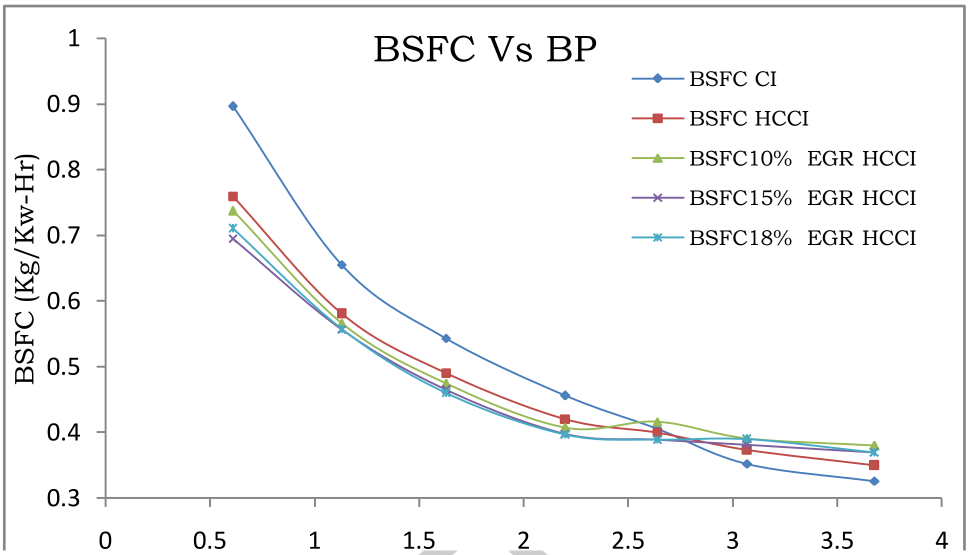
Graph 13 : BSFC Vs BP at CI and EGR CI

As shown graph 13 the BSFC of the EGR is 4% lower by mode value than the BSFC of normal CI conditions till the BP is 57%. At 71% of BP the BSFC is equal for that CI conditions. At 85%and 100% BP the efficiency is decreased by 2%.



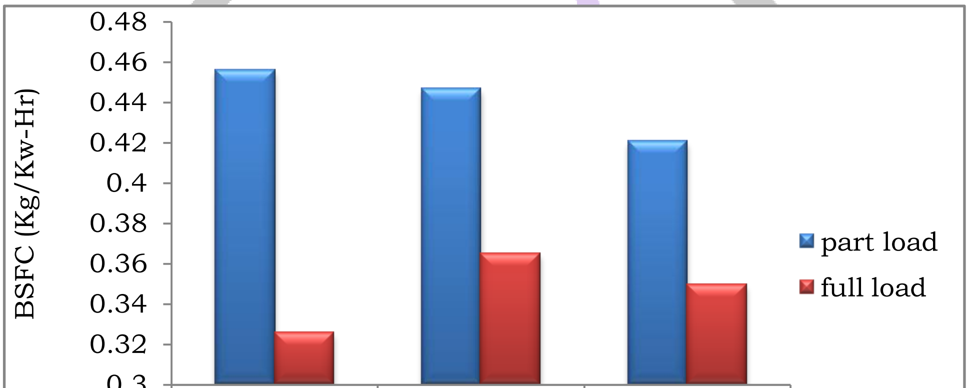
Graph 14: BSFC Vs BP at CI, CI EGR and HCCI

The graph 14 is the comparison of BSFC between the normal CI, HCCI and EGR running conditions at various brake powers. As mentioned in the comments of for graph 12 & 13 the performance of the HCCI and EGR are better than the normal CI running conditions till 71% BP but at higher loads the performance of both the conditions dropped than that of normal CI running conditions.



Graph 15: BSFC Vs BP at CI and HCCI at various EGR substitutions

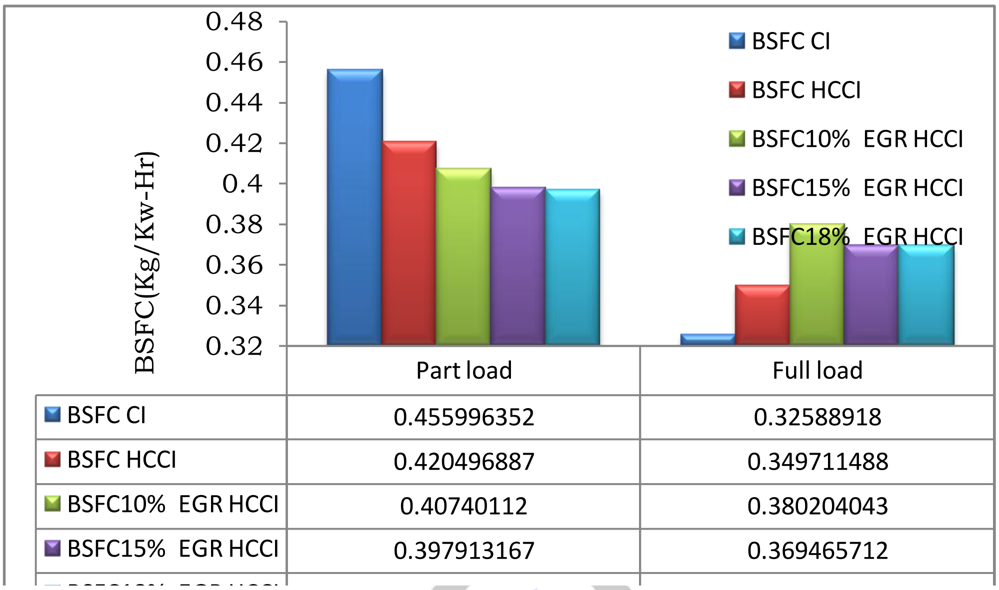
The graph 15 plots the BSFC of the engine a HCCI running conditions at various EGR substitutions compared to the normal CI. It is inherited that the performance is going better with substitution of EGR till he load is 70%. At 18% EGR and 55% load conditions the BSFC is 21% which is 25% more than that of the normal CI conditions. At higher loads the efficiency dramatically increased from normal CI condition to 18% EGR substitution by 5%.



	BSFC CI	BSFC EGR	BSFC HCCI
part load	0.455996352	0.446749895	0.420496887
full load	0.32588918	0.364956104	0.349711488

Graph 16: BSFC at CI, EGR CI and HCCI

The BSFC at CI, HCCI and normal EGR conditions is plotted in as bar chart at 50% load and 100% load conditions. The values and the charts show the better performance of HCCI at part load than that of full load conditions.



Graph 17: BSFC at CI, HCCI and various EGR conditions

The Graph 17 presents the BSFC of all the test conditions at part load and full load, it is clear that the BCSFC is lowest for the 18%EGR HCCI conditions at part load but the condition at the full load is totally different that the BSFC for the 18% EGR HCCI is second highest where the 10% EGR HCCI shows the first highest.

6.0 CONCLUSIONS

Significant conclusions are drawn after analyzing the results obtained from the experimental and computational trails under various conditions of HCCI and EGR. The conclusions are as;

- The brake thermal efficiency of the engine is increased due to the HCCI and also due to addition of EGR till the Load is 60%. Further load application decreases the brake thermal efficiency. With EGR substitution on HCCI condition the brake thermal efficiency has increased by 12% at 18% EGR substitution at HCCI condition.

- The volumetric efficiency of the engine has decreased by HCCI and EGR substitution. The volumetric efficiency has gone down by 8 % when compared to that of normal CI conditions.
- The BSFC of the HCCI is 6% lower than the BSFC of normal CI conditions till the BP is 57%. At 71% of BP the efficiency is equal for that CI conditions. At 85% and 100% BP the efficiency is increased by 4%. the BSFC of the EGR is 4% lower by mode value than the BSFC of normal CI conditions till the BP is 57%. At 71% of BP the BSFC is equal for that CI conditions. At 85%and 100% BP the efficiency is decreased by 2%. It is inherited that the performance is going better with substitution of EGR till he load is 70%. At 18% EGR and 55% load conditions the BSFC is 21% which is 25% more than that of the normal CI conditions. At higher loads the efficiency dramatically increased from normal CI condition to 18% EGR substitution by 5%.

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