# Experimental Investigation on Effect of Exhaust Gas Recirculation (EGR) on Biofuel-Diesel Fueled HCCI Engine using External Fuel Vaporizer

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## Abstract

Homogeneous charge compression ignition is new combustion concept, which is used to reduce the emissions and improve the engine performance parameters. HCCI combustion technology reduces $CO_2$ and $NO_x$ emissions also reduces exhaust gas temperature. In HCCI mode Combustion takes place at each and every place in combustion chamber so overall temperature inside the cylinder is reduced therefore $NO_X$ is reduced. In Exhaust Gas Recirculation (EGR) some amount of exhaust gas is recirculated inside the cylinder after passing through the EGR cooler. Partially cooled EGR is introduced in combustion chamber.$CO_2$ from the exhaust gas will absorb the heat of the combustion chamber and overall temperature inside the engine cylinder is reduced. HCCI and EGR combine together will reduce $NO_x$ and $CO_2$ meanwhile HC and CO increases. The engine is run at its conventional mode and at HCCI mode with both Diesel-Bio fuel HCCI. Percentage of HCCI is introduced according to energy input per second. From that engine runs at 10%, 30%, 50%, 70%, 90% HCCI. Simultaneously partially cooled EGR is introduced with 10%, 15% and 20%. Effect of HCCI and EGR is noted on engine performance parameters and emissions. The optimum condition is obtained at 20% EGR and 30% HCCI.

**Keywords- Diesel HCCI, EGR, Diesel vaporizer, Diesel Engine, Performance and Exhaust Emission analysis**

## I. INTRODUCTION

### *A. HCCI*

HCCI refers as homogeneous charge compression ignition. Homogeneous charge compression ignition is new combustion concept, which is an alternative to conventional spark ignition (SI) and compression ignition (CI) engine combustion concepts. HCCI engine incorporates the basic features of SI engines (premixed charge preparation) and CI engines (auto-ignition of the fuel at a certain pressure and temperature) hence, can be referred as hybrid of SI and CI engines. The fuel/air mixture does not rely on the use of a spark plug or direct injection near Top Dead Centre (TDC) to be ignited, overall lean mixtures can be used resulting to high fuel economy. Fuel vaporizer is required to vaporize the fuel. Mixing of fuel and air is taking place outside the cylinder in the intake manifold. From the conceptual point of view HCCI would allow drastic reduction of particulate matters (PM) and NOX emissions by two processes.

1) Formation of homogeneous mixture.
2) Auto ignition of homogeneous mixture.

In the HCCI engine the auto ignition occurs simultaneously across the combustion chamber. So no high temperature flame front will appear as in the case of SI engine. The absence of high temperature flame front will lead to negligible formation of $NO_X$. Moreover, the fuel rich zones are absent so soot formation are avoided. Because of less temperature inside the cylinder there may be high CO and HC emission but within the limit of CI engine.

### *B. Exhaust Gas Recirculation (EGR)*

Exhaust gas recirculation (EGR) is a technique by which a portion of engine's exhaust is returned to its combustion chamber via its inlet system. This method is designed to extract heat from the combustion process, thus lowering its temperature and reducing

NOx. This method also involves displacing some of the oxygen inducted into the engine with its fresh charge air, thus reducing the rate of NOx formation.
Percentage of EGR is defined as below: -

$$\%EGR=\frac{\text{Qair without EGR}-\text{Qair with EGR}}{\text{Qair without EGR}}$$

### *C. Biofuel*

Biofuels are fuels produced directly or indirectly from organic material – biomass – including plant materials and animal waste. Biofuels may be derived from agricultural crops, including conventional food plants or from special energy crops. Biofuels may also be derived from forestry, agricultural or fishery products or municipal wastes, as well as from agro-industry, food industry and food service by-products and wastes. Biofuels are divided in primary and secondary biofuels. In the case of primary biofuels, such as fuel wood, wood chips and pellets, organic materials are used in an unprocessed form, primarily for heating, cooking or electricity production. Secondary biofuels result from processing of biomass and include liquid biofuels such as ethanol and biodiesel that can be used in vehicles and industrial.

| *Fuel properties* | *Gasoline* | *Diesel* | *Butanol* |
|---|---|---|---|
| *Chemical formula* | $C_8H_{16}$ | $C_{12}H_{26}$ | $C_4H_9OH$ |
| *State* | *Liquid* | *liquid* | *Liquid* |
| *Octane rating* | *87-93* | *-* | *78* |
| *Cetane rating* | *-* | *40-55* | *-* |
| *Auto ignition temperature(ºC)* | *260* | *210* | *340* |
| *Flash point temperature(ºC)* | *-43* | *74* | *29* |
| *Boiling point temperature (ºC)* | *27-225* | *180-340* | *118* |
| *Stoichiometric ratio* | *14.7* | *15* | *11.2* |
| *Kinematic viscosity @ 30 ºC cSt* | *0.88* | *4* | *3.64* |
| *Calorific value (MJ/Kg)* | *47.3* | *45* | *33* |

## II. EXPERIMENTAL WORK AND METHODOLOGY

The engine used in the study was a vertical, single cylinder, water-cooled, four stroke diesel engine. The engine was coupled to an eddy current dynamometer to measure the engine output power. Burette was used to measure fuel consumption of diesel and weigh scale for measuring the amount of consumption in vaporizer system. Proximity sensor calibrated by digital tachometer is used to measure the speed of engine. The temperature was measured with the help of temperature sensor LM35. Exhaust gas analyzer is used for measuring HC (ppm), NOx (ppm), CO (% by vol.), $CO_2$ (%by vol.) and $O_2$ (% by vol.).

Fig. 1: Actual photograph of experimental setup.

*Table 1: Technical specification of the engine*

| Engine | Kirloskar |
|---|---|
| Dynamometer | eddy current, water cooled |
| Bore (mm) | 87.5 |
| Stroke (mm) | 110 |
| Displacement ($cm^3$) | 661 |
| Compression ratio | 17.5 |
| RPM | 1500 |
| H.P. | 5.2 |

The experimental setup consists of engine, fuel vaporizer, EGR cooler, fuel injection system, data acquisition system; and also emission measurement system. The modifications are done near the engine intake system.

The fuel vaporizer connects with engine intake system. Vaporizer consists of a main vaporizing chamber made of copper tube. Copper is selected as material of construction (MOC) due to its high thermal conductivity. External surface of the main vaporizing chamber is covered by an electric band heater (ceramic) to generate enough heat for vaporization of fuel. For the fuel supply, the fuel injection system of the HCCI engine consists of a fuel pump, fuel tank, fuel injector and an injector control circuit. Fuel pump supplies the fuel from the tank to the fuel injector. Fuel injector operates on a 12 V. When the receiver receives the optical rays passing through the window of the pulley and hence gives signal to the main injector to inject fuel for the defined time in to the vaporizer surface. The angle of injection can be varied by changing the position of the pulley window by rotating it and then fixing pulley with respect to TDC.

Fig. 2: Fuel vaporizer

Fig. 3: EGR cooler

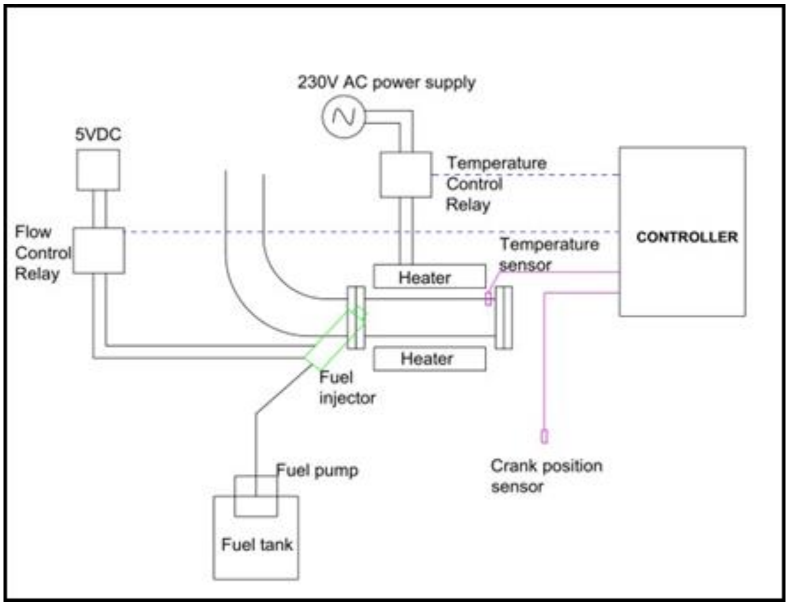



Fig. 4: Schematic diagram for Fuel vaporizer

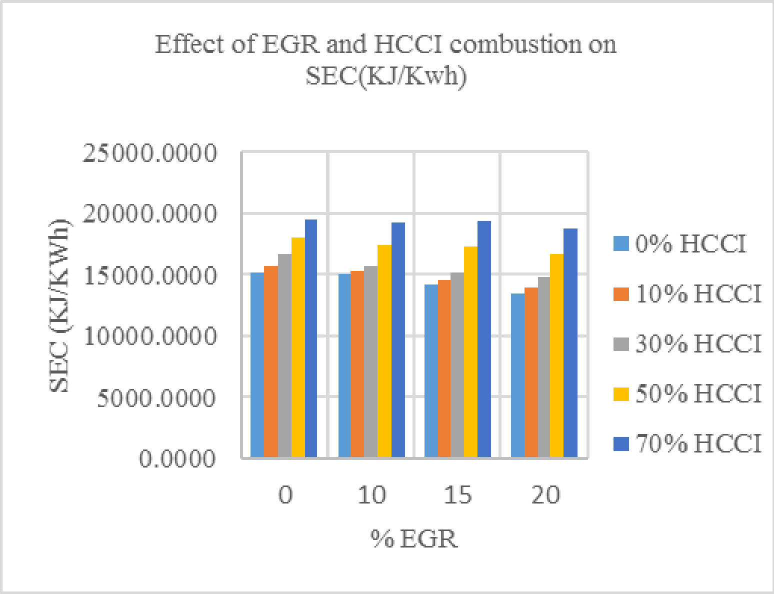
*Table 2: Technical specification of fuel vaporizer*

| | |
|---|---|
| *Heater power* | *500 W* |
| *Vaporizing chamber diameter* | *38 mm* |
| *Vaporizing chamber length* | *150mm* |
| *Fuel injection pressure* | *5.0 bar* |

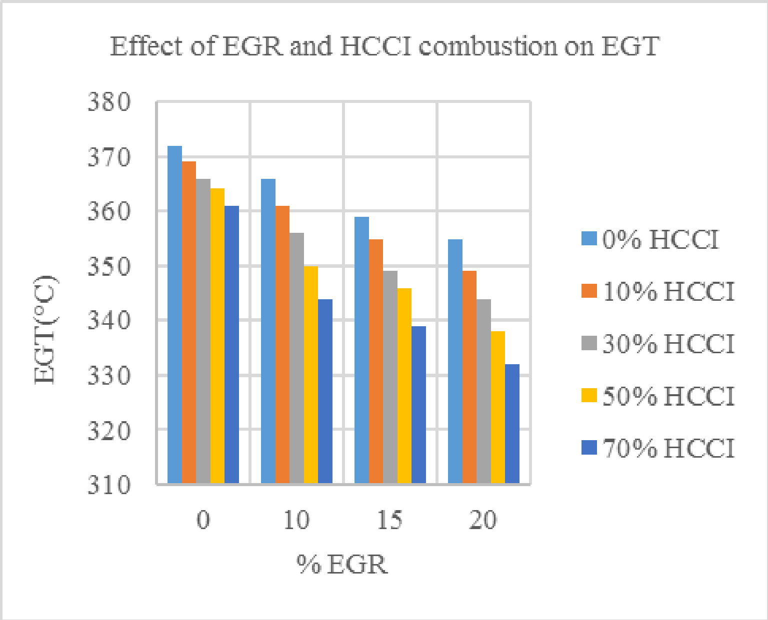
## III. RESULTS AND DISCUSSION

### A. *Engine Performance Parameter for Conventional Diesel and Diesel Butanol HCCI with EGR*

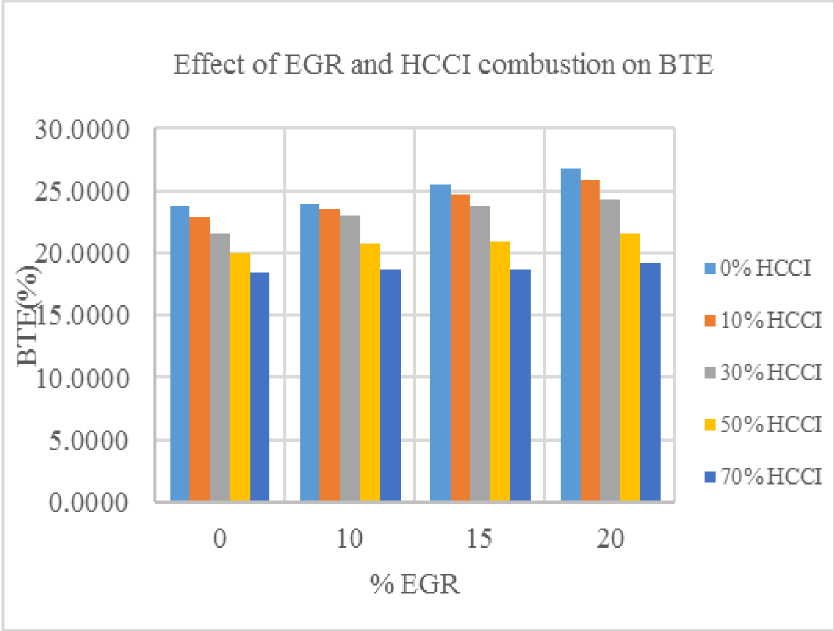
#### 1) *Specific Energy Consumption*



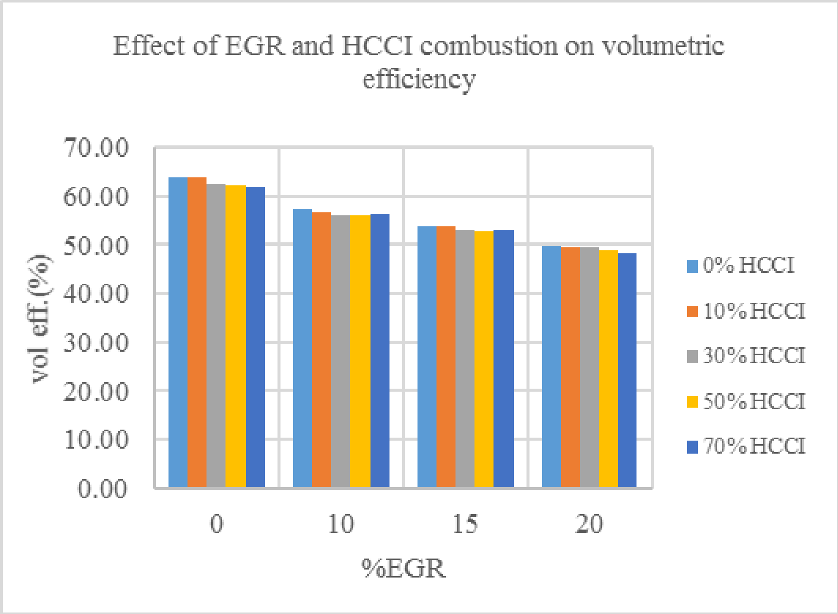

#### 2) *Exhaust Gas Temperature*



*3) Brake Thermal Efficiency*



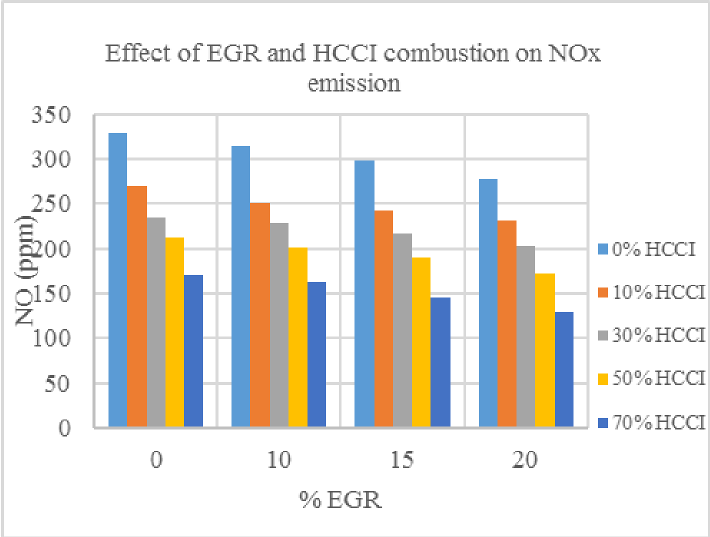

*4) Volumetric Efficiency*



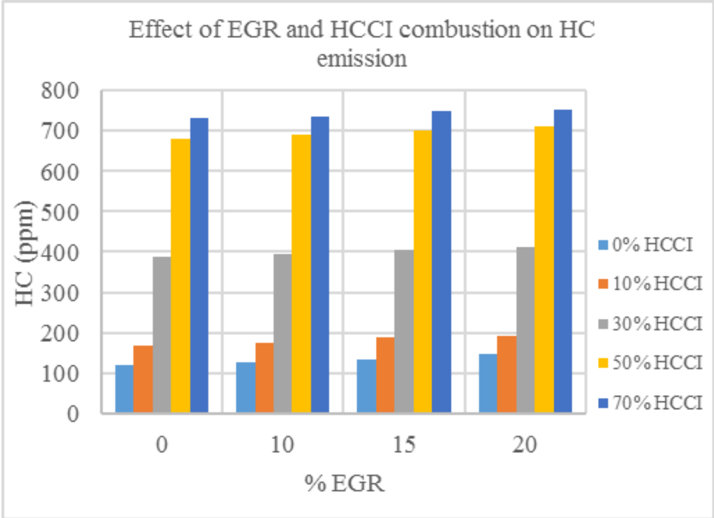

– As the load increase the specific energy consumption decreases. When HCCI percentage increases specific energy consumption increases as energy input at higher load increases. As EGR percentage increases the specific energy consumption decreases slightly at every load. At the higher load amount of fuel supplied is higher and oxygen availability is less therefore A/F ration changed and increases the specific energy consumption. The lowest specific energy consumption is at 20% EGR. Exhaust gas temperature decreases with increases in HCCI percentage and EGR. EGR rate increases the brake thermal efficiency slightly compared to conventional diesel engine. The possible reason for that is the reburning of the hydrocarbons recirculated with the exhaust gas. When the exhaust gas is recirculated the sufficient amount of oxygen is available for the combustion of unburnt hydro carbons therefore less amount of fuel is burned. Volumetric efficiency decreases with increases in load. If percentage of HCCI and EGR increases volumetric efficiency decreases because some amount of intake is replaced by some amount of vaporized fuel and exhaust gas.

### B. *Engine Performance Parameter for Conventional Diesel and Diesel Butanol HCCI with EGR*

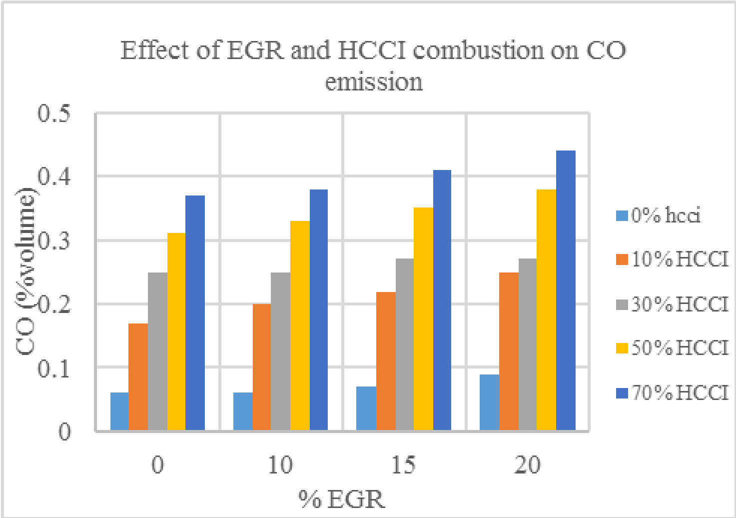
#### 1) *NOx Emissions*



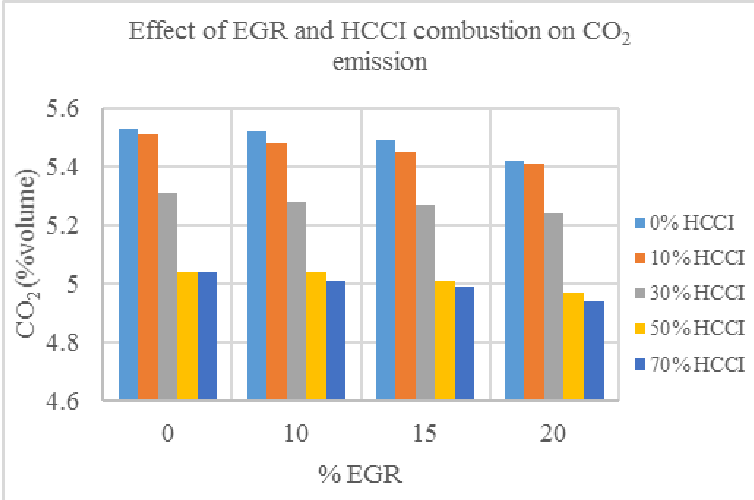

#### 2) *HC Emissions*




#### 3) *CO Emission*



*4) $CO_2$ Emission*




- In the conventional diesel engine as the load increases the NOx emission increases. If percentage of HCCI is considered the NOx emission reduces. The main reason is homogeneous mixture inside the cylinder and less availability of oxygen. When partially cooled EGR is introduced the NOx reduces significantly. The main reason for that is less availability of oxygen and lower flame temperature in the combustible mixture. As the load increases HC emission reduces which shows the complete combustion inside the engine. If percentage of HCCI increases HC emission increases. Moreover, partially cooled EGR also increases HC emissions. As the load on the engine increases CO emission decreases due to complete combustion and oxidation of CO into $CO_2$. As the percentage of HCCI and EGR increases CO emission increases. As the load on the engine increases $CO_2$ emission increases which indicates complete combustion and complete oxidation of C into $CO_2$. As the HCCI and EGR percentage increases $CO_2$ emission decreases.

## IV. Conclusion

- Specific energy consumption increases with increases in HCCI rate and decreases with increase in EGR rate. Brake thermal efficiency decreases with increases in HCCI rate and increases with EGR rate. Highest brake thermal efficiency is for 30% HCCI and 20% EGR.
- Volumetric efficiency decreases with HCCI rate and further decreases with EGR rate compared to conventional diesel engine.
- NOx emission reduces significantly with increase in HCCI rate and EGR rate compared to conventional diesel engine.
- CO and HC emissions increase with increase in HCCI rate and EGR rate compared to conventional diesel engine.$CO_2$ emission decreases with increase in HCCI rate and EGR rate.

Above observations lead to the conclusion that 30% HCCI and 20% EGR leads to the lowest emissions and highest engine performance parameters compared to conventional diesel engine.

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