

Performance and emission characteristics of HCCI Engine fueled with diesel and Ethanol Blend

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ABSTRACT

Alternate fuels have been used to fulfill the demand of fuel for engines used at various fields and also due to the decreasing petroleum fuel resources. Moreover the very low emissions norms have led to the experimentation, analysis and optimization of operating parameters of the engines run with these alternate fuels. Optimization of operating parameters to suit these alternate fuels have led to various new combustion techniques and one of these is HCCI. HCCI technique is a promising combustion mode with high efficiency and low emissions of NO_x and PM. This experiment's objective is to analyse the working of a single cylinder diesel engine under HCCI combustion mode using Ethanol, renewable fuel widely available from the agricultural wastes. The engine is run at its conventional mode and at HCCI mode with both Diesel HCCI and also Ethanol HCCI. The HCCI mode of engine operation involves different percentage HCCI as 10%, 20%, 30%, 40% and also 50% HCCI and observations carried out for the same. Ethanol with high octane number has higher volatility and hence tends to provide a much homogeneous mixture in HCCI mode improving BTE of the engine. Also the emissions using HCCI and Ethanol fuel are much lower as the ethanol fuel has no aromatic chain that causes soot formation and reduced NO_x emission. 50% Ethanol HCCI adaption provides the highest efficiency and also optimized emission like NO_x, HC and CO.

INTRODUCTION

Engines have been used in various fields and its field of application is still increasing with the passage of time. With the increased usage of the engines, fuel required is higher and so also the demand of petroleum fuels. Alternate fuels have been used to fulfil the demand of fuel for engines and also due to the decreasing petroleum fuel resources. Moreover the very low emissions norms have led to the experimentation, analysis and optimization of operating parameters of the engines run with these alternate fuels. Optimization of operating parameters to suit these alternate fuels have led to various new combustion techniques and one of these is HCCI. HCCI engines are operated with the compression ignition of homogeneous charge formed by premixed air and fuel mixtures through early injection onto the hot surface of a heated chamber known to be the vaporizer [3]. HCCI technology uses homogeneous charge inside the combustion chamber and this is obtained by premixing the air and vaporised fuel outside the combustion chamber.

HCCI has advantages like high efficiency, low NO_x, low particulate matter (smoke), ability to operate on a variety of fuels and also low exhaust temperature [1][3]. HCCI also has some challenges during its effective adaption. The main challenge during use of HCCI is to overcome the lack of controls for the combustion process. Hence a complete electronic control system is needed in case for effective adaption of HCCI technique. HCCI operating points are

unstable i.e., it is impossible to map an HCCI engine reliably. Small changes in any engine parameter, for example, intake temperature or coolant temperature, will have a large impact on the combustion timing. Thus, closed loop combustion control is necessary to guarantee correct combustion timing.

Ethanol when used in HCCI engine, the various properties like the volatility, low aromatic content high oxygen content etc. plays significant role in enhancing the combustion efficiency. The high volatility of ethanol enhances the tendency for the production of completely homogeneous mixture and thus there is no fuel rich zones formed in the combustion chamber [5]. But the ignition delay increases with the usage of ethanol as the auto- ignition temperature is higher. Hence an optimum preheating of the charge or a higher compression ratio of engine is needed to reduce the chemical delay period.

Salvador M. Aceves et al in their research paper have analysed experimentally a number of fuels and observed that HCCI has intrinsic fuel flexibility but the operating parameters like intake temperature and compression ratio are to be varied with respect to the fuel used. The octane rating of the fuel if high, then it needs preheating or higher compression ratio. As ethanol has a higher octane number it requires either preheating or a higher compression ratio for SOC [2]. Ludivine Pidol et al in their study observed that higher volatility due to ethanol blending results in improved mixing providing more homogeneous mixture, thus allowing reduced the injection pressure needed for fuel injection when used in an

HCCI engine. Whereas the same fuel when used in a conventional engine requires a higher injection pressure so as to atomize fuel for complete combustion [5]. Considering emissions, the lower aromatic content of the fuel signifies that the PM will be much lesser than compared to the conventional diesel usage as diesel has higher aromatic content than ethanol [4]. Also the NO_x emissions are lower with the Ethanol fuelled HCCI engine and there can be EGR effectively used with this fuel as due to its higher oxygen content in it [4] [5].

EXPERIMENTAL SETUP AND RESEARCH METHODOLOGY

The engine used in the study was a vertical, single cylinder, water-cooled, four strokediesel engine. The engine was coupled to an eddy current dynamometer to measure the engine output power. Burette was used to measure fuelconsumption of diesel and weigh scale for measuring theamount 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 analyser is used for measuring HC (ppm),NO(ppm), CO (%vol.), CO₂ (%vol.)and O₂ (% vol.).

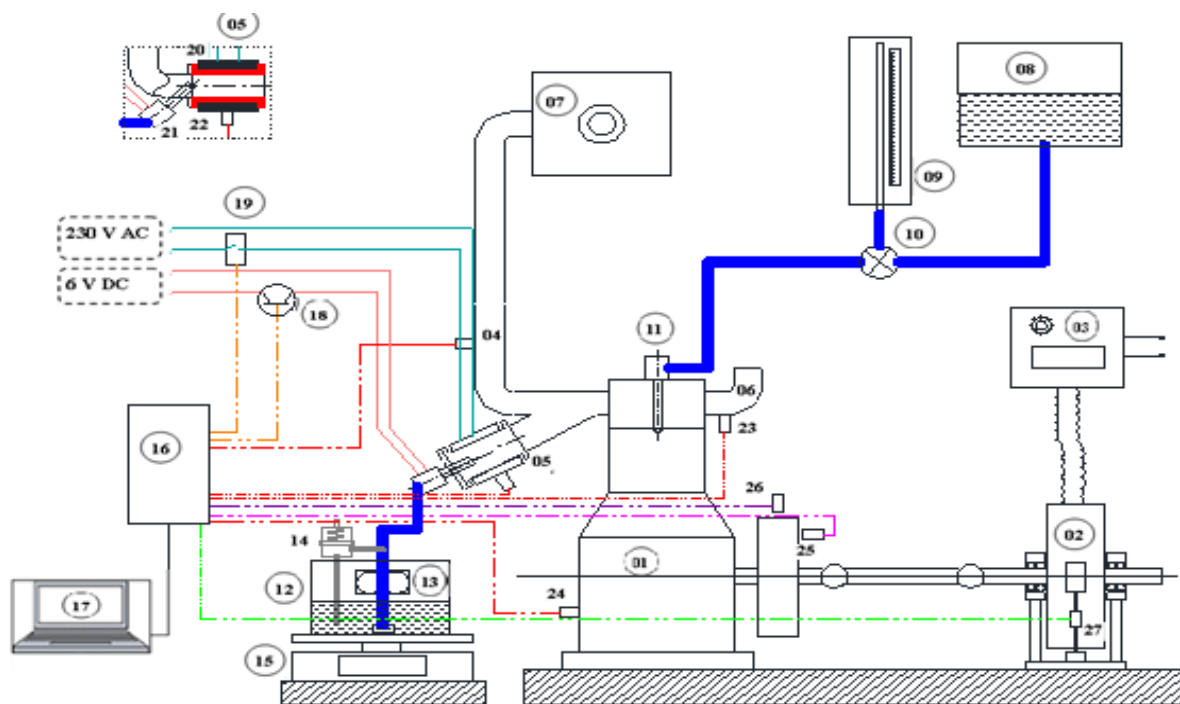
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The experimental setup consists of engine, fuel vaporizer, fuel injection system, data acquisition system; and also, emission measurement system. The modifications are done near the engine intake system. Figure 1 shows schematic diagram of modified HCCI engine experimental setup.

Fuel Vaporizer System

Schematic diagram of fuel vaporizer system is shown in figure 2(a). The fuel vaporizer connects with engine intake system as shown in figure 2(b). Technical specification of fuel vaporizer is shown in table 2. 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 TTL. 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.



(1)Diesel Engine ;(2)Eddy Current Dynamometer; (3)Excitation control Rheostat; (4)Air Inlet; (5)Fuel Vaporizer; (6)Exhaust Gas Outlet; (7)Air Surge Tank with anemometer; (8)Diesel Fuel Tank; (9)Burette; (10)Three Way valve; (11)Convectional Diesel Injector; (12)Fuel Tank for fuel vaporizer; (13)Fuel Pump; (14)Pressure Regulating Valve; (15) Weighting Scale; (16)High speed Data Acquisition System with injector control module; (17)Computer; (18)MOSFET for Injector control; (19)Relay for heater supply control; (20)Heater Tube; (21)Fuel Injector; (22)&(23)Thermocouple; (24)Temperature Sensor LM- 35; (25) High precision crank position sensor;(26)Tachometer;(27)Load cell.

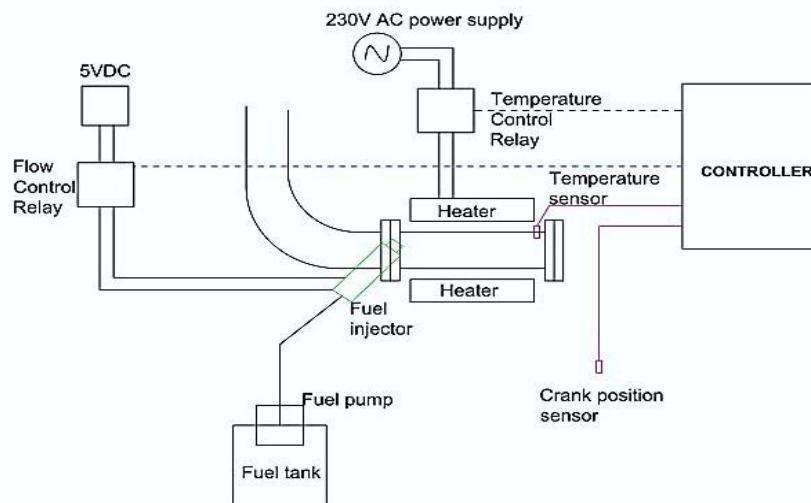
Fig. 1: Schematic diagram of HCCI engine Experimental Setup

Table 1: Technical Specification of Fuel Vaporizer

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

Table 2: Fuel Property

Properties	Diesel	Ethanol
Density (gm/cc)	0.830	0.810
Boiling point, °C	180-340	78.37
Calorific Value, kJ/kg	42,000	29860
Flash point, °C	55	171.1
Autoignition Temp. °C	210	368
Cetane number	51	8
Octane number	Lower than Ethanol	109
Vaporization temp. °C	Higher than Ethanol	77.86
Stoichiometric air-fuel ratio	14.7	9

**Fig 2. Schematic diagram of fuel vaporizer****OBSERVATION**

The fuel used in the experiment, Diesel and Ethanol are of different calorific value and hence Specific Fuel Consumption is not considered. Instead of BSFC, Brake Specific Energy Consumption (BSEC) is considered during the experimental observation. The Specific energy consumption follows a curve similar to the SFC and the only difference is that it provides a clear view of the performance when fuels of different calorific value are considered. The Brake Specific Energy Consumption increases with increase in HCCI percentage at loads below the rated load as shown in the graphs considered. But at higher loads i.e., near rated load, the HCCI BSEC approaches values lower than that of the conventional diesel specific energy consumption (SEC). Thus, the energy consumed to generate unit brake power is lower for HCCI engine at load approaching the rated load value. The lowest BSEC at rated load is attained for 50% Ethanol HCCI as seen in figure 4.

For HCCI, the brake thermal efficiency of conventional diesel engine is higher than both the diesel and Ethanol HCCI at lower loads. As the curve approaches the rated load, the Brake thermal efficiency of HCCI engine takes a leap and tends to be higher than that of the conventional diesel

efficiency. This leap is higher for 50% HCCI where the efficiency of HCCI engine running with 50% HCCI is higher than that of conventional diesel and also diesel HCCI. The Brake thermal efficiency at rated load is the highest for Ethanol HCCI as shown in the graphs. When various percentages of HCCI are considered, the highest efficiency is for 50% Ethanol HCCI as seen from figure 5.

The volumetric efficiency decreases with increase in Load and this is due to the fact that the engine cylinder temperature during suction is higher for higher load conditions. With increase in HCCI, the volumetric efficiency decreases which is due to the displacement of the part of air by the vaporized fuel during the suction stroke. The higher the percentage efficiency, higher is the volume displaced. Thus, volumetric efficiency decreases with increase in HCCI as in figure 6.

The hydrocarbon emission is observed with different load conditions as in figure 7 and it represents the variation of HC emission with the increase in load from 0% to 100% at every 20% load increase. HC emission decrease with increase in load denotes a much complete combustion taking place in the engine combustion chamber. For HCCI engine the HC

emission increases with the increase in percentage HCCI. The lowest emission is observed for 10% HCCI and the highest for 50% HCCI. This is a known effect of an HCCI engine where tends to increase the HC emission.

Figure 8 represents the variation of NO_x emission with the increase of load from 0% to 100% at every 20% load rise. Also, the effect of percentage HCCI is considered, with observations carried out at 10%, 30% and 50% HCCI. The NO_x emission is

observed to be increasing with load and this is due to the rise in combustion temperature favoring the NO_x formation. The NO_x emission is lower for HCCI engine than the conventional engine for lower loads. At higher load conditions the Ethanol HCCI emissions maintains its lower pace, but the NO_x emissions of diesel HCCI increases and is higher than that of conventional Diesel HCCI NO_x emission. The least NO_x emission is attained at higher Ethanol HCCI percentage i.e., 50% Ethanol HCCI.

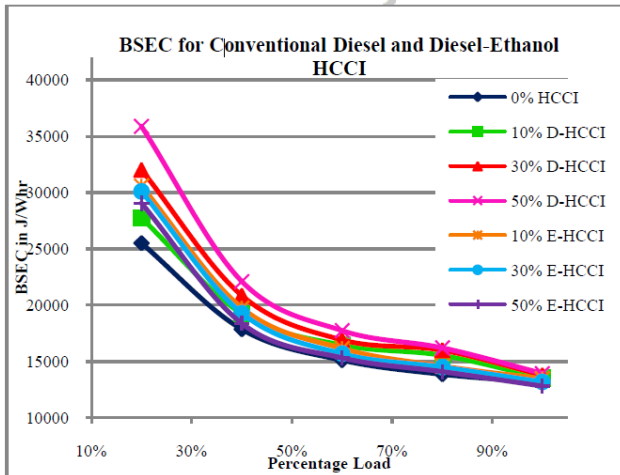


Fig 4. Effect of Percentage HCCI on BSEC

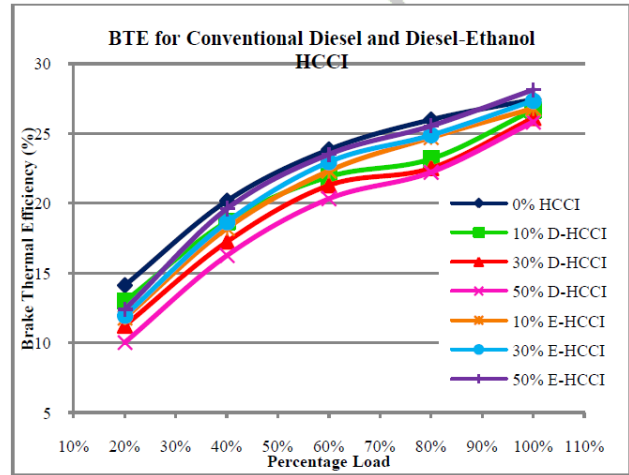


Fig 5. Effect of Percentage HCCI on BTE

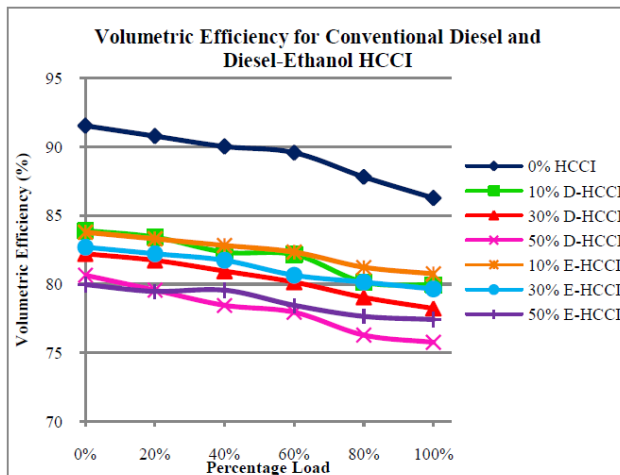


Fig 6. Effect of Percentage HCCI on Volumetric Efficiency

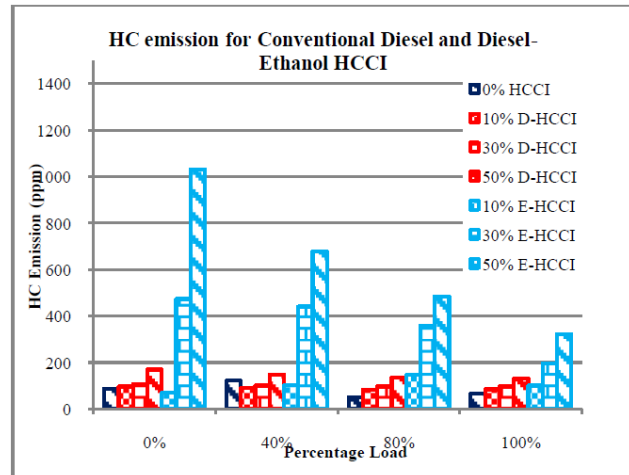


Fig 7. Effect of Percentage HCCI on HC Emission

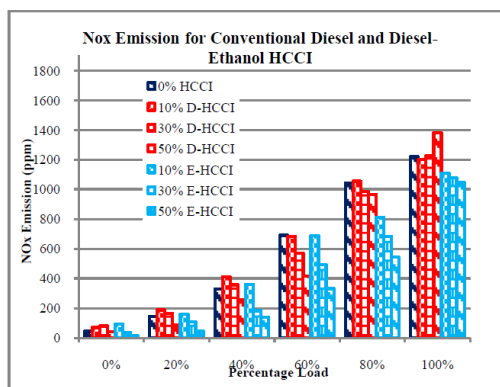


Fig 8. Effect of Percentage HCCI on NO_x Emission

RESULT AND CONCLUSION

- Specific energy consumption decreases with increase in HCCI percentage and also the Brake Thermal Efficiency increases with increase in percentage HCCI. The highest brake thermal efficiency is attained for 50% Ethanol HCCI.
- The Volumetric efficiency is reduced with Ethanol HCCI percentage increase. But Ethanol has oxygen molecule in it. And this provides excess oxygen needed during combustion.
- NOx emission adapts a reducing curve with percentage HCCI increase. The least NOx emission occurs for 50% ethanol HCCI.
- The emissions like HC and CO increases. The HC emission is about three times higher than that of the conventional diesel HC emission. CO emission is higher only at low loads. At nearly rated load, the CO emission rise is the lowest.
- These observations lead to the conclusion that 50% Ethanol HCCI leads to the highest performance with lower emissions and hence is most suitable when compared to the conventional diesel system.

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