Performance Improvement and Effective Control of CO, NOx, Using Different Fuel Combination in IC Engines

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Abstract - Different intake valve timings and fuel injection amount were tested in order to identify their effects on exhaust emissions and combustion characteristics using variable valve actuation (VVA) in a Homogeneous Charge Compression Ignition (HCCI) engine. HCCI engine is a promising concept for future automobile engines and stationary power plants. Two-stage ignition process in a HCCI engine creates advanced ignition and stratified combustion, this makes ignition timing and combustion rate controllable. Meanwhile, the periphery of fuel-rich zone leads to fierce burning, which results in slightly high NOx emissions. The experiments were conducted in a modified single cylinder water-cooled diesel engine. In this experiment we use diesel, bio-diesel (Jatropha) and gasoline as the fuel at different mixing ratios. HCCI has advantages in high thermal efficiency and low emissions and possibly become a promising combustion method in internal combustion engines.

Keywords - HCCI, two stage ignition, NOx, bio-diesel, variable valve actuation

INTRODUCTION

In modern society internal combustion engine is the key in the entire transportation sector. Without the transportation performed by the millions of vehicles on road and at sea we would not have reached the living standard of today. The spark ignition, SI, and the compression ignition, CI are the two types of internal combustion engines. The petrol and diesel are at present the principal fuel for SI and CI engines. These fuels are in the verge of getting extinct and during combustion these fuels release substantial amounts pollutants into the atmosphere and creating the environmental related problems. The internal combustion engine is known as one of the major sources of air pollutants in the environment. The fuel oxidation process in the engine generates not only useful power, but also a considerable amount of pollutant emissions including Carbon Dioxide (CO2), Carbon Monoxide (CO), Unburned Hydrocarbon (HC), Nitrogen Oxides (NOx), and particulate matter. Reducing exhaust emissions and increasing the fuel economy of internal combustion engines are of global importance.

CO2 is mainly responsible for the global warming issue as it creates a reflective layer in the atmosphere that reflects heat from the earth back to the earth surface, increasing the earth’s average temperature over time. Carbon Monoxide (CO) is a very dangerous substance since it reduces the oxygen carrying capacity of blood stream. At low concentrations, CO inhalation can cause dizziness and nausea, while at higher concentrations it can be deadly (Dae Sik
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Kim, 2006). Unburned hydrocarbon emission, a result of incomplete combustion process, is a common source of respiratory problems. Particulate emissions or soot also causes some respiratory problems. Both unburned hydrocarbon and soot emissions have been linked to some cancers in several studies. High flame temperature generated during the combustion process is responsible for NOx formation which causes various health problems as well as contributing to acid rain and global warming issues.

The development of efficient internal combustion engines with ultra low emissions is necessitated by strict regulations on exhaust gas composition and fuel economy. Increasing concern over the potential global warming effects of major greenhouse gases from current fossil fuels coupled with a rapidly growing vehicle fleet around the world has intensified the uptake of alternative fuels and become an important area of research (Yap et al 2005).

Bio diesel is capable of solving the problems of fuel supply in a decentralized fashion and simultaneously help in reducing the environmental related problems (Kitae Yeom, 2006). Jatroba oil has been recognized as a major source to supply the declining fuel resources which could be used in I.C engines. Carbon dioxide is one of the major greenhouse gases. Although the burning of biodiesel produces carbon dioxide emissions similar to those from ordinary fossil fuels, the plant feedstock used in the production absorbs carbon dioxide from the atmosphere when it grows. Plants absorb carbon dioxide through a process known as photosynthesis which allows it to store energy from sunlight in the form of sugars and starches Lei Shi, (Yi Cui, 2006). After the biomass is converted into bio diesel and burnt as fuel the energy and carbon is released back into the atmosphere.

In parallel to this interest in alternative fuels, there has also been increased interest in Homogenous Charge Compression Ignition (HCCI) combustion. Homogeneous charge compression ignition (HCCI) technology, incorporating the advantages of both spark ignition and compression ignition, is a potential candidate for future ultralow-emission engine strategies (Jiang H, 2005). HCCI engines are being actively developed because they have the potential to be highly efficient and to produce low emissions. HCCI engines can have efficiencies close to those of diesel engines, with low levels of emissions of oxides of nitrogen (NOx) and particulate matter (PM). In addition, HCCI engines have been shown to operate with a range of fuels, e.g. natural gas, gasoline and bioethanol.

**EXPERIMENTAL SETUP**

In this study, an electrical dynamometer assembled on a four-cylinder and four stroke indirect injection diesel engine has been used. There are different thermo junctions and electrical units on the dynamometer and the engine. Circuits in all units have been connected to each other, and they have been controlled by a computer. In addition, there are two exhaust emission measurement systems working independently for ascertaining the levels of HC, CO, CO$_2$, and NOx respectively. In addition, an adjustment tool has been used to adjust the injection pressure.
Performance Improvement and Effective Control of CO\textsubscript{2}, NO\textsubscript{x}, Using Different Fuel Combination in IC Engines

**Engine specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore x Stroke</td>
<td>80 x 110 mm</td>
</tr>
<tr>
<td>Cubic Capacity</td>
<td>0.553 lit</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>16.5 : 1</td>
</tr>
<tr>
<td>Engine Wt. (dry) w/o flywheel</td>
<td>114 kg</td>
</tr>
<tr>
<td>Weight of flywheel</td>
<td>33 kg</td>
</tr>
</tbody>
</table>

Exhaust gas can be very hot if retained or re-induced from the previous combustion cycle or cool if re-circulated through the intake as in conventional Exhaust Gas Recirculation (EGR) systems. The exhaust has dual effects on HCCI combustion. It dilutes the fresh charge, delaying ignition and reducing the chemical energy and engine work. Hot combustion products conversely will increase the temperature of the gases in the cylinder and advance ignition.

**WORKING PRINCIPLE**

In this experiment we analyze the performance and emission characteristics using premixed charge compression ignition (PCCI) mode assisted with a secondary pilot injector as combustion initiator in HCCI engine.

The fuel is heated by means of a 1000 watts water bath provided with an electrical thermostat which enabled us to maintain the fuel at the desired temperature. The maximum fuel temperature that can be achieved using our set up is 75 deg c. In case of diesel we maintained the temperature at 55 deg c, and in case of bio-diesel we maintained the temperature at 75 deg c. The air is heated by means of 800 watts air heater placed in inlet manifold. The air temperature is maintained by means of an electrical thermostat to a maximum of about 80 deg c. The temperature history of the hottest (and close to adiabatic) portion of the core of the experiment is reproduced by the hottest zone. This part of the charge should be the first ignition site.

The fuel is injected in to manifold using an electronic fuel pump through a secondary fuel injector mounted on the inlet manifold whose spray angle is 30 deg c, the fuel line pressure is maintained at 6 bars. The current rating of the fuel injection pump that we have used is 20 ampere and that of the fuel injector is 0.3 ampere. The injection is controlled by electronic circuit having a limit switch with frequency of about 750 cycles per minute. The limit switch is actuated by means of a bolt attached to the inlet valve rocker; we effectively have utilized the 8 mm travel of the rocker arm for generating the electrical signal for initiating the injection during the suction stroke.
In its original form the HCCI uses a premixed air fuel mixture. This may be achieved through a port fuel injection. In place this; very early direct injection has also been used. Early direct injection in the combustion chamber, during the intake stroke or early part of the compression stroke, allows better fuel air mixing than a standard diesel combustion scenario. Direct injection also allows stratification of the in cylinder charge, and this offers means to realize stable and efficient combustion during transition from higher to lower engine load. It has been shown that for pure HCCI conditions were a completely pre mixed charge is used, fuel chemistry and gas mixture, temperature are the 2 major facts that determine the auto ignition process. Mixing and turbulence have a much lesser impact on the auto ignition. However, for “HCCI like” conditions like as direct injection, where a non homogeneous charge may be formed. The amount and rate of fuel air mixing may impact the ignition delay and start of combustion. The impact of the initial (i.e. at the end of the fuel injection or start of ignition dwell) temperature and fuel air distribution on ignition dwell was investigated. Various methods to prolong the ignition dwell were used, that inclined-variations in injection timing, EGR percentage, engine valve actuation and swirl ratio.

In relation to the HCCI engine is combustion phase control. Hot residual gas supplies heat to the combustion chamber and promotes HCCI combustion. This hot residual gas can be controlled by a variable valve timing (VVT) device. Moreover, the VVT device can improve volumetric efficiency by varying the intake valve’s open and close timing.

**Injection Timing**

Circumference of the flywheel : 126.5 cm
Radius of the flywheel : 20.13 cm

The experiment is conducted with different fuels at different mixing ratios at the primary and secondary injectors; the order of fuel injection is as follows,

**Mode 1: Diesel conventional**

In this mode the experiments are conducted with only primary injection. The diesel is only used as a fuel for combustion. The pilot injector is closed in this mode; there is no fuel supply through pilot injector. This experiment measures the emissions and fuel consumption with conventional mode, with preheating of the air before supplying the air in to combustion chamber.

**Mode 2: Bio-diesel conventional**

In this mode Bio diesel (Jatroba oil) is used as a fuel instead of diesel in mode

**Mode 3: Diesel Diesel PCCI-DI combustion**

In this mode of experiments both primary injector and pilot injector are used to supply the fuel in to the combustion chamber. Diesel is used as a fuel in both the injectors. Pilot injector supplied the diesel in to combustion chamber before the actual injection of the diesel in to combustion chamber through primary injection port. The emissions and fuel consumptions are measure in this mode. The PCCI was created by the supplying the fuel through pilot injector after the piston reaching the Bottom dead centre.

The procedure followed in mode three has also been followed for the other modes of experiments given below.

**Mode 4: Bio-diesel Bio-diesel PCCI-DI combustion**

**Mode 5: Diesel Bio-diesel PCCI-DI Combustion**

**Mode 6: Bio-diesel Diesel PCCI-DI combustion**

**Mode 7: Diesel Petrol PCCI-DI combustion**

**Mode 8: Bio-diesel Petrol PCCI-DI combustion**

The suction stroke duration is for 219 deg
The exhaust stroke duration is for 219 deg
The inlet valve opens 4.5 deg before TDC during exhaust stroke
The inlet valve closes 34.5 deg after BDC during compression stroke
The exhaust valve opens 34.5 deg after BDC during expansion stroke
The exhaust valve closes 4.5 deg after TDC during exhaust stroke
The manifold injection starts 61.239 deg after TDC during the suction stroke
The manifold injection closes 51.239 deg before BDC during the suction stroke
The injection duration is for 87.52 deg during suction stroke, for about 2/5 of the suction stroke.

The injection rate is maintained at 7.2 ml/min during the injection duration

RESULTS AND DISCUSSION

Effect of load on Exhaust gas Temperature

The effect of load on the exhaust gas temperature is measured by thermocouple attached with the outlet manifold. The variation of temperature with the increase of load for all the cases is measured. Figure 2 shows that the variation of temperature with increase of load for the conventional mode with diesel, bio diesel and HCCI with the Diesel: Diesel and Biodiesel: Biodiesel mode.

![Fig. 2 Comparison between conventional and HCCI methods](image)

The exhaust gas temperature is increased with the increase of load for all the cases. This could be due to more amount of fuel combustion inside the combustion chamber at higher load as compared to lower load and complete combustion of the fuel. Within the four modes the exhaust gas temperature from conventional diesel mode is higher than the other modes and Biodiesel: Biodiesel mode is lower than the other modes for all the load conditions (Lei Shi, 2006).

As compared to conventional modes with diesel and biodiesel modes the diesel and biodiesel with HCCI modes produced lower temperature. For the maximum load conditions the exhaust gas temperature from the diesel, bio diesel, Diesel: Diesel, Biodiesel: Biodiesel are 315, 306, 278 and 270°C respectively.

![Fig. 3 Comparison between different fuels in HCCI mode](image)

Figure 3 shows that the variations of exhaust gas temperature with the increase of load for the HCCI mode with different primary and secondary fuel supply. Within these the biodiesel and petrol are used with primary and secondary fuels produced lower exhaust gas temperature as compare to other three cases (Diesel: Biodiesel, Biodiesel: Diesel, Diesel: Petrol). The HCCI with different fuels for primary and secondary fuels produced lower exhaust gas temperature as compared to conventional mode and HCCI mode with the same fuel for primary and secondary fuels.
Effect of load on Hydro carbon in Exhaust Gas

Figure 4 Comparison of hydrocarbon emission between conventional and HCCI methods

The hydrocarbon emission from all the modes is observed with different load conditions. Figure 4 represents the variation of HC emission with the increase of load from 0% to 100%. The study found that the HC emission from conventional diesel mode is higher than the other modes and also the HC emission from HCCI mode is lower than the conventional mode. The HC emission increased with the increase of load for conventional mode and decreased with the increase of load for HCCI mode. Within the HCCI mode the HC emission from BD:BD mode is observed as lower value compared to D:D mode for all the load conditions.

For the conventional mode the HC emission increased from 55 ppm to 108 ppm when the load is increased from 0% to 100%. For the same load interval for BD:BD the HS emission is observed with the decrement from 24 ppm to 11 ppm.

Figure 5 shows that the variation of HC emission with the increase of load for HCCI mode with different fuel as a primary and secondary fuels. For all the cases of HCCI mode the HC emission decreased with the increase of load. Within all HCCI modes D:BD produced lower HC emissions and BD:D mode produced higher HC emissions (Dae Sik Kim, 2006).

Effect of load on NOX Emission in Exhaust Gas

The Nox emission is measured with all the modes of the operations in this study. Figure 6 shows that the Nox emission from the conventional mode with diesel and biodiesel and HCCI with the same fuel for both the primary and secondary injections. In conventional mode lower Nox emission is observed for bio diesel based experiment for all the load conditions as compared to diesel base operations. The HCCI mode operations produced lower Nox emissions as compared to conventional mode of operations, this could be due to lower and uniform temperature inside the combustion chamber during combustion process due to uniform mixing of the fuel with air inside the combustion chamber.

For the HCCI mode the NOx emission shows that Biodiesel:Petrol and Diesel:Petrol combinations generate very low Nox emission as compared to other cases of HCCI mode of operations. The NOx emissions are observed as more are less same value for all load conditions.

Figure 5 shows that the variation of NOx emission with the increase of load for HCCI mode with different fuel as a primary and secondary fuels. For all the cases of HCCI mode the NOx emission decreased with the increase of load. Within the HCCI modes D:BD produced lower NOx emissions and BD:D mode produced higher NOx emissions (Dae Sik Kim, 2006).
these two cases for all the load conditions (Yap. D, 2005). The Nox emission increased from 15 to 330 ppm and 19 to 342 ppm for Diesel:Petrol and Biodiesel:Petrol mode respectively, when the load is increased from 0 to 100% (shown in Figure 7).

The SFC is found to be lower value in conventional mode as compare to HCCI mode for all the load conditions. This could be due to secondary fuel supply in the case of HCCI mode operation as compare to conventional mode in which only primary fuel is supplied. Figure 8 shows, the specific fuel consumption with the increase of load for conventional and HCCI mode with same type of fuel and Figure 9 shows the SFC for different fuels. The study also found that at higher load conditions the specific fuel consumption is observed as same value for all the cases.

**Effect of load on Brake Thermal Efficiency**

The variation of brake thermal efficiency with the variation of fuel in the conventional diesel engine is identifies by diesel and bio diesel as a fuel in a conventional mode and Diesel: Diesel, Biodiesel: Biodiesel as a fuel in the HCCI mode with same fuel for primary and secondary injection. The brake thermal efficiency is measured with the increase of load from 20% to 100% of the load condition with the increase of every 20% load. Figures 10 and 11 indicates that the variation of brake thermal efficiency with the increase of load (Yap. D, 2005).

The study found that for all the modes of operations the brake thermal efficiency increases with the increase of load. In the case of diesel and bio diesel with the conventional mode operation the brake thermal efficiency increased from 10.9 to 31.26% and 11.75 to 33.39% respectively
when the load increased from 20% to 100%. For the same fuels the HCCI mode of the operations produced higher thermal efficiency as compared to its conventional mode, this could be due to lower combustion temperature and complete conversion of energy available in the fuel in to useful form in the case of HCCI mode of operation as compared to conventional mode of operation. The brake thermal efficiency with different fuel as primary and secondary fuel operations in the HCCI mode is represented in Figure.

In the case of HCCI with different fuel as primary and secondary fuel supply, the diesel and petrol are used with primary and secondary fuel produced higher brake thermal efficiency as compared to other mode of operations. The diesel as a primary fuel and biodiesel as a secondary fuel produced lower brake thermal efficiency. The magnitudes of brake thermal efficiency with all the load conditions for different mode of operations are presented in Figure 12. The study identified that for all the load conditions the Diesel: Diesel and Diesel: Petrol combinations under HCCI mode of operations produced maximum thermal efficiency. The lower thermal efficiency is observed for Diesel conventional and Diesel: Biodiesel HCCI mode.

**Effect of load on Carbon Dioxide**

The effect of load on the CO2 emission with the conventional mode and HCCI with same type of fuel is shown in Figure 13 and for different fuels in Figure 14.

The study found that CO2 emission from diesel with conventional and HCCI mode are higher than the biodiesel with conventional and HCCI mode. This could be due to the variation of the chemical characteristics of the diesel with bio diesel. The CO2 increased from 3 to 6.3% and 2.5 to 4.9% for diesel and biodiesel respectively when the load is increased from 0% to 100%. For the same load conditions the CO2 emission is observed with 2.7 to 5.7% and 1.8 to 4.8% respectively for diesel and biodiesel with HCCI mode respectively. The CO2 emission from diesel with HCCI mode is higher than the biodiesel with conventional mode (Lei Shi, 2006).
Effect of load on Carbon Monoxide Emission

The variation of CO emission with the variation of load for all the modes of operations in this study is representing in Figure 15 and 16. The study found that there is no variation of CO with the increase of load for all the HCCI mode of operation with different fuel as a primary and secondary fuel except Diesel: petrol mode. In the case of conventional mode of operation the CO emission initially increased with the increase of load, then further increase of load decreased the CO emission. Within all HCCI modes the Biodiesel: Biodiesel mode produced very low amount of CO emission as compared to other cases of HCCI modes (Lei Shi, 2006).

CONCLUSION

The exhaust gas temperature from HCCI mode is lower than the conventional mode of operation. Within the HCCI mode with different fuel combinations the biodiesel and petrol are used as a primary and secondary fuels respectively produced lower temperature than the HCCI with other combination of fuels.

The study found that the HC emission decrease with the increase of load for HCCI mode with all the type of fuels. But in the case of conventional mode the HC emission increased with the increase of load. The lower HC emission is observed for diesel and biodiesel as a primary and secondary fuel respectively.

The lower NOx emission is observed for all the HCCI mode of operation as compare to Conventional mode. Within the all HCCI mode of operations diesel and petrol as a primary and secondary fuel produced lower NOx emission.

The Specific fuel consumption decreased with the increase of load for all the mode of operations. The lower specific fuel consumption is observed for diesel and petrol as a primary and secondary fuel respectively.

The brake thermal efficiency from Diesel and petrol as a primary and secondary fuel in the HCCI mode is higher than the other mode of operations with different fuels.
The study observed that the CO₂ emission from HCCI mode is lower than the conventional mode this could be due to complete combustion of fuel inside the combustion chamber. Within the all HCCI mode the diesel and petrol as a primary and secondary fuel produced lower CO₂ emission.

There is no change in the CO emission with the increase of load in the case of HCCI mode with different fuel combinations. The use of biodiesel reduced the CO emission as compare to other cases.

The study concludes the emission from HCCI mode is lower than the conventional mode but the specific fuel consumption varied with different combination of fuel in HCCI mode. The Diesel and petrol as a primary and secondary fuel is better than the other fuel combinations in view of both environment and fuel consumption point of view.

REFERENCES

Nomenclature
HC 1 Hydro carbon emission from conventional mode combustion, ppm
HC 2 Hydro carbon emission from PCCI-DI mode combustion, ppm
NO 1 Oxides of nitrogen emission from conventional mode combustion, ppm
NO 2 Oxides of nitrogen emission from PCCI-DI mode combustion, ppm
CO 1 Carbon mono oxide emission from conventional mode combustion, %
CO 2 Carbon mono oxide emission from PCCI-DI mode combustion, %
CO 2 1 Carbon mono oxide emission from conventional mode combustion, %
CO 2 2 Carbon mono oxide emission from PCCI-DI mode combustion, %