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Experimental Evaluation of Performance and Emission Characteristics of Minimally Processed Ethanol Fuelled HCCI Engine

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Abstract

A well known bio-fuel ethanol has been investigated in this work in a HCCI mode. The engine chosen for the experiment is a single cylinder DI diesel engine modified to ignite minimally processed ethanol in a diesel engine under HCCI mode. As the ethanol has higher self ignition temperature the firing of ethanol in regular diesel engine by auto-ignition is not possible. Hence, suitable modification was made in the engine to ignite ethanol in the diesel engine like diesel fuel. The modified engine has on ECM controlled fuel spray and an air preheater in the suction side of the engine. The combined effort of the adiabatic compression in the engine and preheating of air ignites ethanol by auto-ignition and its timing of firing was precisely controlled by changing air intake temperature. This investigation revealed that the engine operated with minimally processed ethanol performed well with little loss of brake thermal efficiency, and, emitted comparatively lower emissions such as NO_x and smoke and proved that the ethanol is best suited fuel for HCCI operation. The water content present in the ethanol helped to control the timing of auto-ignition and helped to run HCCI engine smoothly.

Key words: HCCI, Ethanol, Air preheating, Performance, Combustion and Emission

Introduction
The increasing industrialization, ever increasing petroleum price, continuous release of green house gases by fossil fuel combustion, rapid addition of on road vehicles and

depletion of petroleum resources makes an intensive search for an alternative fuel. Many alternative fuels have been identified in the past and tested successfully in the existing engines with and without engine modification, but still each fuel has one or few undesirable fuel characteristics. This prevents the complete substitution of the existing by the alternative fuels. Also, many researchers have proved that the alternative fuels can serve as partial substitute for the existing fuels [7]. However, the various fuel admission techniques experimented earlier are giving good solution to apply larger fraction of alternative fuel in the existing engines.

Alternative fuels are broadly classified under two categories such as mineral based oils and biological based oils. The mineral based alternative fuels are non renewable and causing green house gas emission but biological based fuels are renewable and eco-friendly. The biological based alternative fuels called bio-fuels have been identified well before the exploration of the other promising alternative fuels [16].

In addition to that the engine fuels are classified under two categories. They are octane fuels and cetane fuels. Octane fuels are usable in spark ignition engines where as the cetane fuels are usable in compression ignition engines. Spark ignition engines, with precise control of air/fuel ratio is providing to be a clean low efficiency power source. Compression ignition engine is a very efficient power source but it suffers from higher NO_x and PM emission [13]. Today the application of diesel engine is widening. Hence, the diesel engines have been more targeted for emission of pollutants such as smoke and oxides of nitrogen. The smoke is produced due to the charge heterogeneity and oxides of nitrogen are produced due to higher cylinder temperature [9]. Hence, controlling cylinder temperature and maintaining charge homogeneity will lead to lower smoke and NO_x emissions.

HCCI combustion is a potentially attractive operating mode of internal combustion engines. It combines the advantages of both SI and CI engines. HCCI engine is a kind of engine which can accept any kind of fuel irrespective of its octane and cetane number. In HCCI combustion engines, the air fuel mixtures are compressed by piston motion. As a result, the mixture gets ignited by auto-ignition. The regular diesel engine used for diesel fuel operation is not suitable for auto-ignition of all kinds of fuel. Cetane fuels are relatively easier to auto-ignite in the regular diesel engine however the timing of auto-ignition needs to be controlled by some other means [13]. Several potential control methods have been proposed to control the HCCI combustion: varying the rate of exhaust gas recirculation (EGR) [25] , using a variable compression ratio (VCR) [3 &10] , and using variable valve timing (VVT) [24, 12] to change the effective compression ratio and/ or the amount of hot exhaust gases retained in the cylinder. However, the exhaust gas recirculation (EGR) and diluent admission are considered as the most common techniques to control the timing of auto ignition in various HCCI combustions. In EGR technique, either external EGR or internal EGR has been used to supply and mix burnt gases with fresh charge to change the timing of auto ignition. The EGR is a devise used to mix certain fraction of burnt gases into the fresh air inducted during suction stroke. These gases dilute the air fuel mixture and change the timing of auto-ignition. Similarly, in diluent admission method the inert vapours and gases (Which are not participating in combustion) are added to the fresh charge to change the timing of auto-ignition [2] [20].

Octane fuel HCCI combustion is very difficult even in high compression diesel engines because the heat produced by adiabatic compression is insufficient to auto-ignite the octane fuels [13]. Hence, these fuels require additional heat input or cetane improving additives to auto-ignite like cetane fuels.

Cetane improving additives are another method to use octane fuel in HCCI engines. In this method fuels having high cetane number are added or co-fired with octane fuel. This method also needs suction side air preheater for smooth running of engine. In addition to that this engine requires a control mechanism to control the timing of auto ignition as discussed in cetane fuelled HCCI engines.

Homogeneous Charge Compression Ignition (HCCI) engine is an engine which has an ability to accept all kinds of fuel irrespective of its octane and cetane number [6]. It has an ability to prepare charge outside the engine and combust the mixture by auto-ignition. The present work uses a minimally processed ethanol in the DI diesel engine under HCCI mode to study its feasibility of application, performance and emission characteristics. Ethanol is a renewable energy; it can be made from all kinds of raw materials such as sugar cane, molasses, cassava, sorghum, corn, barley, sugar beets, and waste biomass materials etc. by using already improved and demonstrated technologies. Ethanol has been widely used as fuel, mainly in Brazil, or as a gasoline additive for octane improvement and better combustion in USA and Canada. Ethanol has also been used as oxygen additive in diesel fuel to depress the soot and NO emissions [22]. Recently, since the fuel flexibility of HCCI combustion, neat ethanol HCCI combustion has also been investigated [4] [5] [6].

In this work ethanol admission was provided by ECM controlled fuel spray and then combusted by auto-ignition with the help of air preheater. The results of the experiments proved that the engine performed well with little loss of thermal efficiency and emitted less NO_x and smoke compared to base fuel operation.

Abbreviations

TDC	Top dead center
EGR	Exhaust Gas Recirculation
HCCI	Homogeneous Charge Compression Ignition Engine
ECM	Engine Control Module
CI	Compression Ignition
CO	Carbon monoxide
HC	Hydrocarbon
NO_x	Oxides of Nitrogen
bTDC	before Top Dead center
aTDC	after Top Dead center
BTE	Brake Thermal Efficiency
BSU	Bosch Smoke Unit
DAQ	Data Acquisition System

Literature Review

Thring [21] used a labeco Cooperative Lubricant Research (CLR) engine and studied four stroke, diesel-fuelled, HCCI operations with control by varying the intake temperature and EGR fraction over a range of equivalence ratios. Thring, was the first person to call this type of combustion system as homogeneous charge compression ignition. Yanagihara [23], used a combination of early injection and late injection. Here, 50% of the fuel was injected at 13°CA (Crank angle) aTDC and the rest was injected during the early compression stroke. It resulted in gradual heat release beginning at 10°CA bTDC and extending upto 20°CA aTDC. The main combustion occurred after the second injection (20–25°CA aTDC), which significantly improved the combustion efficiency. HC emissions were about 5000 ppm to 2000 ppm and CO emissions were also high. NO_x and smoke levels were reported as very low. Shi Lei et al.[18], utilized the thermal energy of trapped exhaust gases to vaporize the fuel. Diesel was directly injected into the cylinder near intake TDC and valve overlap was adjusted to obtain a high internal exhaust gas recirculation. The effect of the engine load, speed, inlet temperature, external and internal EGR on HCCI combustion and emissions were studied.

Simescu et al.[19], conducted an experimental investigation of Premixed Charge Compression Ignition (PCCI)-DI combustion coupled with cooled and uncooled EGR in a Heavy Duty (HD) diesel engine. The study showed significant NOx reduction at light load conditions with upto 20% PFI (Port Fuel Injector). The study however showed that early PCCI combustion could adversely affect NO_x emissions by increasing in-cylinder temperatures at the start of diffusion combustion. The PCCI-DI combustion also showed increased Brake Specific Fuel Consumption (BSFC) and HC, CO and PM emissions.

Ryan and Callahan.[17], used an electronic port fuel injector located approximately 15 cm away from the intake valve in the upstream. This injector was used for injecting fuel into the intake air for HCCI mode of operation. The heated intake air and EGR allowed intake temperatures upto 240°C for fuel vaporization. The results showed that through controlled homogeneous charge compression ignition operation near zero smoke emission is possible. It was observed that HCCI operation was possible with compression ratio ranging from 8 to14, EGR rates from 30 to 60%, and air–fuel ratio from 12 to 28. From the experiments it was found that the best SOC (Start of Combustion) for HCCI fall in the range of 20° bTDC to TDC. Midlam - Mohler Shawn et al.[15], developed an atomizer for external mixture preparation and the authors have investigated the effect of uncooled EGR, Boost pressure, Air–fuel ratio, intake air temperature, swirl and engine speed on HCCI combustion.

Wet Ethanol

HCCI engines are inherently fuel flexible and can run on low grade fuels as long as the fuel can be heated to the point of auto ignition. In particular, HCCI engines can run on “wet ethanol’’, ethanol-in-water mixtures with high concentrations of water [11]. Considering that much of the energy required for processing fermented ethanol (from bio-sources, not from petroleum) is spent in distillation and dehydration. Direct use of wet ethanol in HCCI engines considerably improves the energy balance in favor of ethanol [8]. In a recent study, numerical predictions showed that a HCCI engine with efficient heat recovery can operate on a 35% ethanol in water mixture while achieving a high brake thermal efficiency (38.7%) and very low NO_x (1.6 parts per million, clean enough to meet any existing emissions standards). Direct utilization of ethanol at a 35% of volume fraction reduces water separation cost to only 3% of the energy of ethanol and co products (versus 37% for producing pure ethanol), and improves the net energy gain from 21% to 55% of the energy of ethanol and co products.

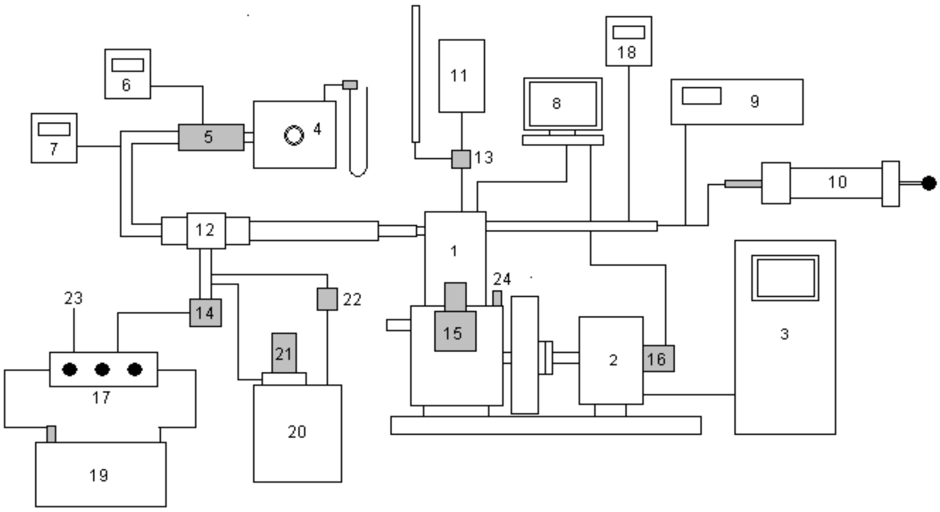
Previous studies have shown that water injection in an HCCI engine significantly delays combustion timing, thus increasing the required intake temperature for a specific operating point when compared to pure fuel. This method was found successful in terms of controlling the ignition timing. A later investigation found that a fuel-water mixture, or an emulsion, is more effective at retarding combustion timing and reducing pressure rise rates in comparison with separate injections. Lastly, a study by Megaritis et al [14]. used forced induction and residual gas through negative valve overlap (NVO) to run an HCCI engine on wet ethanol containing upto 20% water; the findings suggest increased air heating can extend the operating range of ethanol-in-water mixtures beyond the limitations of their experimental set-up.

Experimental Setup

The experimental setup consists of single cylinder water cooled DI four stroke diesel engine coupled with an eddy current dynamometer. It is capable of developing 4.4 kW at a constant speed of 1500 rpm. The inlet side of the engine is attached with series of instruments such as anti-pulsating drum, air heater, air temperature measuring device and fumigator. The outlet side of the engine is connected to exhaust gas temperature indicator, gas analyser and smoke sampler. The fuel admission side of the engine consists of an electronic injector. The electronic fuel injector is connected with necessary ECM and battery source. The system also consists of a low pressure fuel injection pump and relief valve to supply ethanol to the engine through low pressure fuel injector. This experimental setup also consists of diesel supply system and diesel consumption measuring instruments.

The experimental setup also consists of cylinder pressure measuring facility by piezo electric transducer and crank angle encoder to acquire cylinder pressure data with respect to crank angle.

The schematic of experimental setup used for this work is shown in Figure 1.



1. Diesel Engine, 2. Eddy current Dynamometer, 3. Dynamometer Control, 4. Anti pulsating drum, 5. Airpreheater, 6. Energy meter, 7. Inlet temperature indicator, 8. computer with DAQ, 9. Gas Analyzer, 10. Smoke sampling pump, 11. Diesel tank, 12. Ethanol injector assembly, 13. Three way cock, 14.Injector Solenoid, 15. Fuel Injection Pump, 16. Crank angle encoder 17. ECM, 18.Exhaust temperature indicator, 19. Battery, 20.Ethanol tank, 21.Low pressure ethanol injection pump, 22.Relief valve, 23.Input signal for ECM, 24.Inductive pickup for ECM operation

Figure 1: Experimental setup

Methodology

This work uses a minimally processed ethanol in the DI diesel engine under HCCI mode to study its feasibility, performance and emission characteristics. The engine was started using diesel fuel and kept under various load condition to obtain performance and emission readings. These readings were considered as base line readings and were subsequently used for comparison. The suction side of the engine consists of an ethanol spray and vaporizer, which slowly admits ethanol into the engine and converts the sole fuel engine into diesel-ethanol dual fuel engine. Further increase in ethanol admission led to misfiring of the mixture. Once the misfire identified, the air-heater attached in the suction side of the engine starts functioning and eliminates the misfiring. Subsequently, the admission of ethanol increases further and the heater is also tuned up in such a way to arrest any further misfiring. Under this condition, premixed ethanol-air mixture prepared by vaporizer is auto-ignited inside the engine. The heat required for auto-igniting ethanol air mixture is shared by adiabatic compression by engine and air heater attached in the suction side of the engine. This particular state of operation is termed as HCCI operation. Once the engine reaches the HCCI mode, the air intake temperature has been optimized. The same procedure was repeated for all subsequent load steps. For each and every load step, the optimum intake temperature, ethanol consumption, exhaust gas temperature, air inflow rate, emission parameters such as CO, HC, CO2, NOx and smoke were recorded and compared with the baseline operation.

Results and Discussions

This technique permits 100% diesel replacement by using ethanol after slight engine modification. The factors that prevent ethanol auto ignition in CI engine are its low cetane number and high self-ignition temperature. To overcome this, the in-cylinder temperature of the engine must be maintained well above the self-ignition temperature of ethanol. This can be provided by an air pre-heater housed in the suction side of the engine. Hence, the air enters the engine with sufficiently high temperature to enable auto-ignition of ethanol-air mixture. The heat required for auto-ignition of ethanol-air fuel mixture is provided by external heating and adiabatic compression in the engine. The detailed results of the HCCI operation is presented and discussed in this section to compare its performance and emission characteristic with base fuel operation.

Determination of Optimum Intake Temperature

As this method utilizes air preheater for assisting auto ignition, the optimum intake temperature must be identified for each load to get maximum performance. The air intake temperature used for steady running (without misfire) at each load was varied in steps of 5 on either sides of steady running temperature. At each intake temperature, the BTE of the engine was calculated. The intake temperature that gives maximum brake thermal efficiency was considered as the optimum intake temperature for that load condition as shown in the Figure 2. The same procedure was repeated for all subsequent load steps to find its optimum intake air temperatures. The optimum intake temperatures arrived by this method are 160°C, 145°C, 130°C, 115°C at 25%, 50%, 75%,100% load respectively.

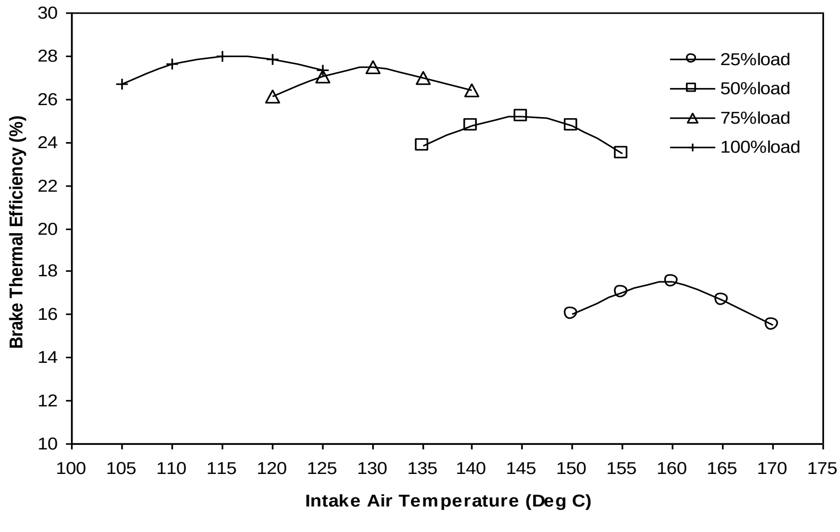


Figure 2: Variation of brake thermal efficiency with intake temperature at various loads for HCCI

Brake Thermal Efficiency

Figure 3 compares the brake thermal efficiency of HCCI mode with standard diesel operation. The brake thermal efficiency of HCCI mode is comparatively lower than standard diesel mode at all load conditions. This is due to the production of lower combustion temperature than the standard diesel operation at all loads. Usually, engine generates low combustion temperature at low loads and high combustion temperature at high loads. Hence, the heater requirement changes with respect to load. That is heater requirement is more at lighter loads and less at higher loads.

More reduction of volumetric efficiency due to high intake temperature, sluggish burning and reduced peak pressure are the other reasons for low brake thermal efficiency at all load conditions. However, better volatility and presence of more homogeneous mixture prevents loss of brake thermal efficiency at higher loads. The brake thermal efficiency of HCCI mode at full load is 28%, which is 1.5% lower than that of standard diesel operation.

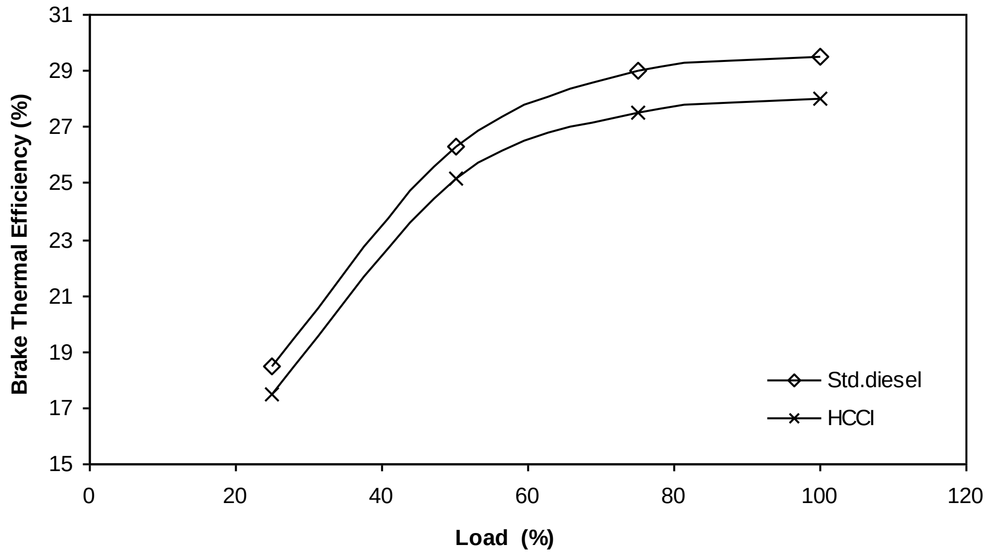


Figure 3: Variation of Brake Thermal Efficiency With Engine Load

Volumetric Efficiency

Figure 4 compares the volumetric efficiency of HCCI mode with standard diesel operation. At all loads, the volumetric efficiency decreases with respect to ethanol induction. The induction of ethanol displaces some of the air that would otherwise be inducted. This is the main reason for the lower volumetric efficiency.

It may be also noted that the volumetric efficiency is affected by the temperature of the retained exhaust gas. Generally, retained exhaust gas heats the incoming fresh air and lowers the volumetric efficiency. This is another important reason for decreasing trend of volumetric efficiency.

The lowest volumetric efficiency recorded in this mode is 83.2%. This is 6.8% lower than that of standard diesel operation.

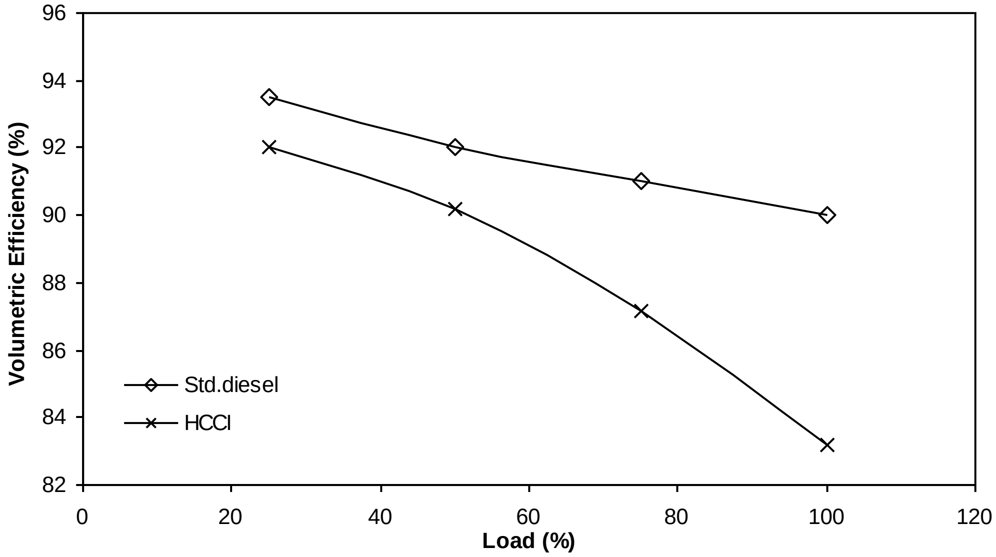


Figure 4: Variation of volumetric efficiency with engine load

Exhaust Gas Temperature

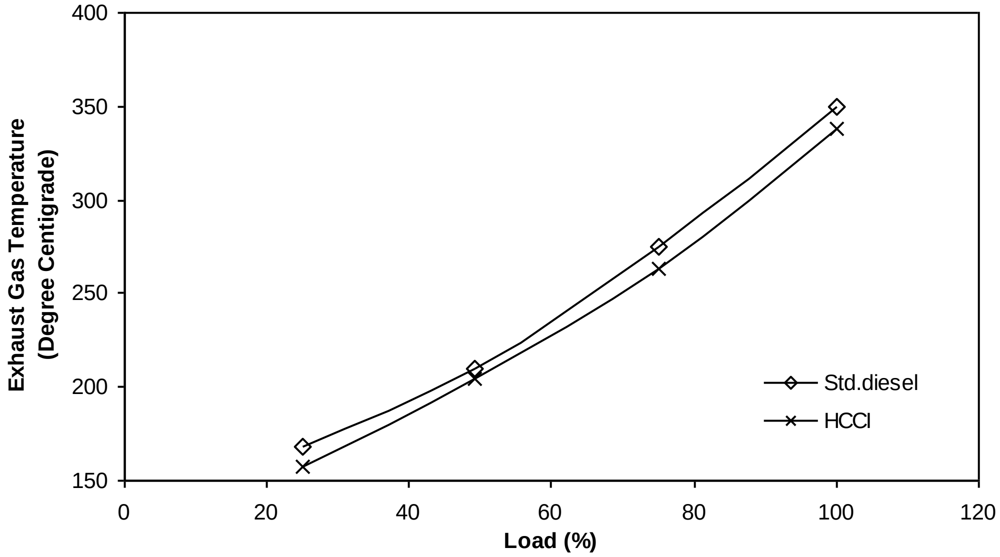


Figure 5: Variation of Exhaust Gas Temperature With Engine Load

Figure 5 compares the exhaust gas temperature (EGT) of HCCI mode with standard diesel operation at various load conditions. The EGT of HCCI mode is lower than that of standard diesel mode at all load conditions. This is due to lower combustion temperature caused by charge homogeneity, higher latent heat of vapourisation of ethanol and low flame temperature.

CO Emission

Figure 6 compares the CO emission of HCCI mode with standard diesel operation. The CO emission of HCCI mode is higher than that of diesel operation at all load conditions. In this case, as ethanol was inducted along with inlet air stream a considerable portion of air has been displaced and caused lower volumetric efficiency. Hence, the inducted fuel encounters a charge that has lower concentration of oxygen. This leads to incomplete combustion of charge and causing liberation of more CO. The quench layer of charge near the wall due to reduced flame speed could also be the other reasons for increased CO emission.

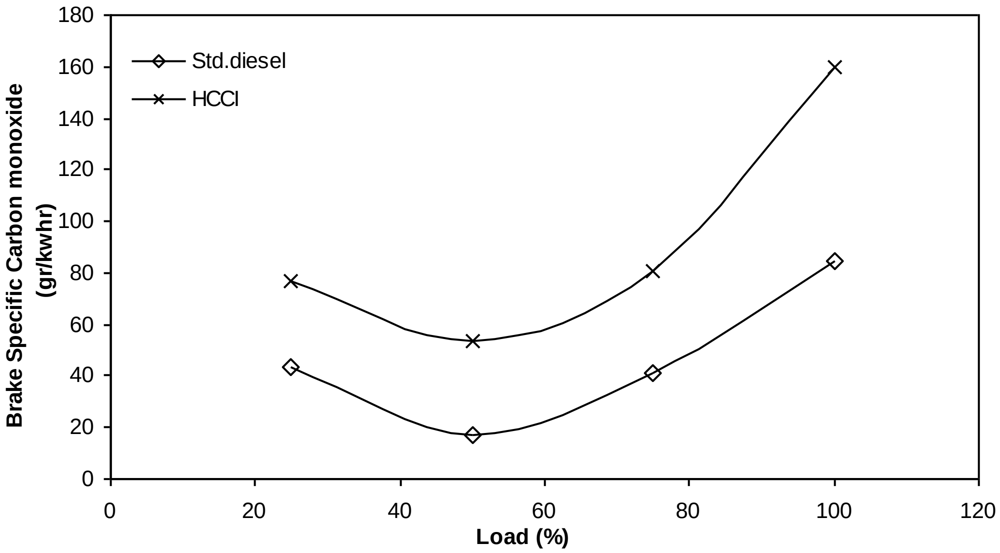


Figure 6: Variation of Brake Specific carbon monoxide emission with engine load

HC Emission

Figure 7 indicates the HC emission of HCCI mode at various loads. Usually at high loads, the quantity of fumigated fuel inside the cylinder is more. This absorbs a considerable portion of heat from the cylinder wall and keeps the charge relatively at low temperature. Hence, during combustion, the flame front propagating from the ignition centers do not extend to all regions of the cylinder and flame extinction occurs closed to the wall and causing liberation of more HC. This may be the main reason for more HC at higher loads.

The maximum HC emission observed at the time of full load is approximately 200 ppm higher than standard diesel operation.

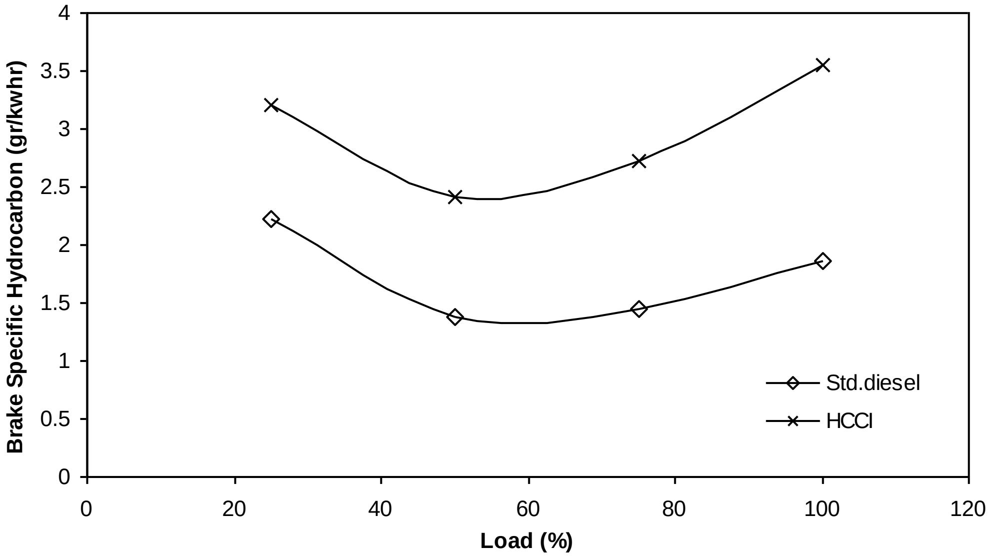


Figure 7: Variation of Brake Specific Hydrocarbon emission with engine load

NO_x Emission

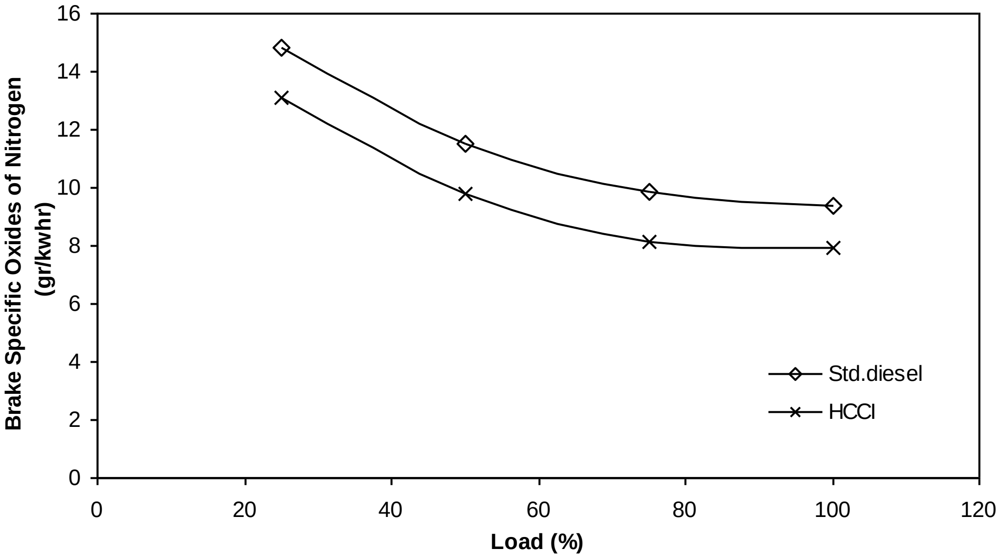


Figure 8: Variation of Brake Specific Oxides of Nitrogen emission with engine load

Figure 8 compares the NO_x emission of HCCI mode with standard diesel operation. From the figure it is observed that the NO_x emission of HCCI mode is lower than standard diesel operation at all loads. Usually, the production of NO_x is more associated with the intake charge temperature and the availability of oxygen. It also varies exponentially with combustion temperature [1]. The production of lower combustion temperature as a result of sluggish combustion and lower concentration of oxygen are the main reasons for liberation of lower NO_x compounds. The maximum NO_x emission observed from HCCI mode was 905 ppm. The NOx emission from HCCI mode is approximately 200ppm lesser compared to standard diesel operation.

Smoke Intensity

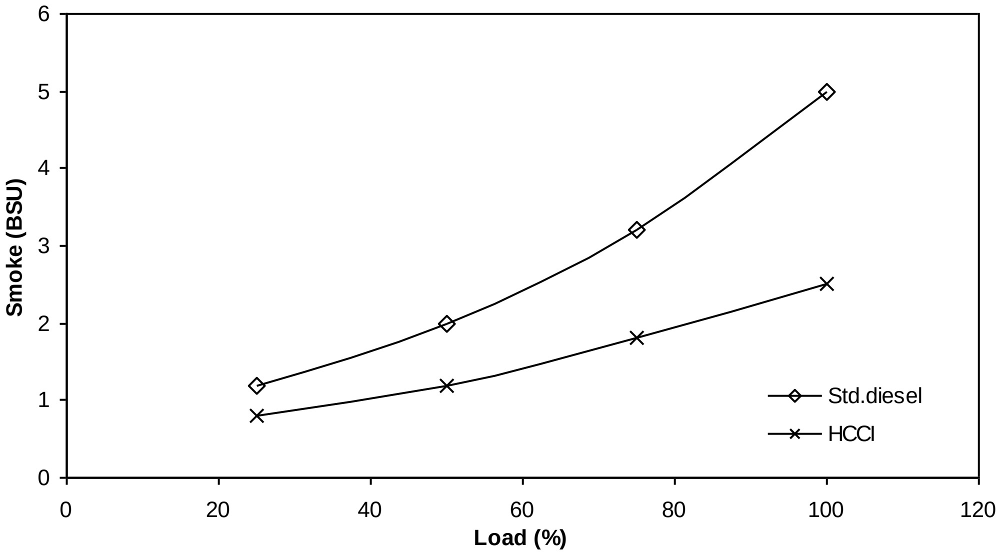


Figure 9: Variation of Smoke Intensity With Engine Load

Figure 9 compares the smoke intensity of HCCI mode with standard diesel operation. It shows lower smoke for HCCI operation than that of standard diesel operation at all loads. More specifically, at lower loads very low smoke levels were observed. This is attributed to reduced amount of diffusion burning and soot free combustion of ethanol that has been homogeneously mixed with air. Generally, high volatile fuels evaporate rapidly and leaving fewer chances for production of smoky exhaust. The same trend is observed in all loads. However, at higher loads a slight increase in smoke level was observed. This is due to combustion of more fuel in less oxygen environment. The maximum smoke level observed from the HCCI mode is 2.5 BSU, which is 50% lower than the reference fuel.

Peak Pressure and Rate of Pressure Rise

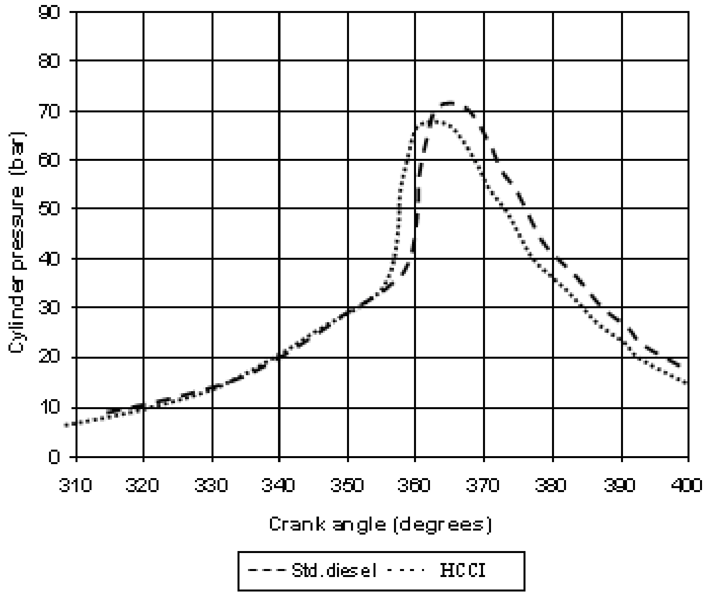


Figure 10: Variation of Cylinder Pressure With Crank Angle At Full Load

Figure 10 compares the cylinder pressure diagram of the HCCI mode with that of the standard diesel operation at full load. From the figure, it is observed that the peak pressure of HCCI mode is lower than standard diesel operation. The maximum cylinder pressure for the HCCI mode of operation is 64bar, which is 3 bar lesser than for the standard diesel operation. This is the main reason for lower BTE of the HCCI mode.

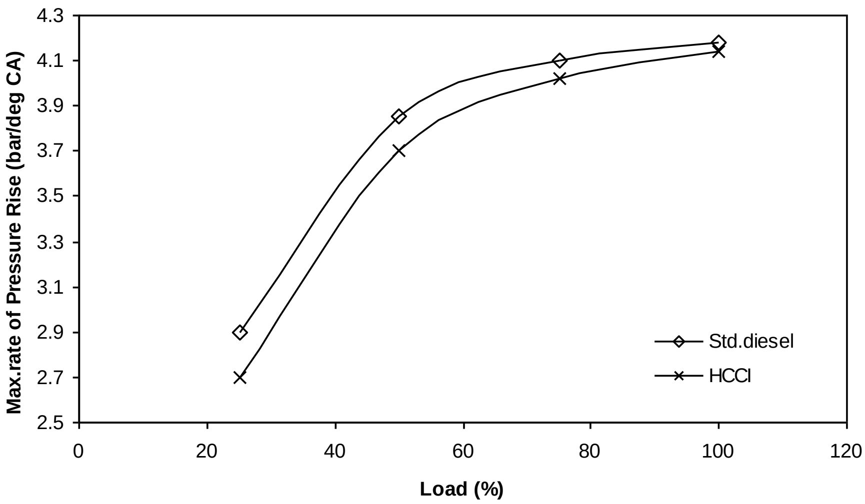


Figure 11: Variation of Maximum Rate of Pressure Rise With Engine Load

Figure 11 indicates the variation of rate of pressure rise with engine load. From the figure it is observed that the rate of pressure rise of HCCI mode is lower than standard diesel at all load conditions. The production of lower combustion temperature and lower volumetric efficiency are the main reasons for the lower rate of pressure rise of HCCI mode at all load conditions. This is the main reason for lower brake thermal efficiency, lower EGT, lower NOx and lower smoke emission.

Net Heat release rate

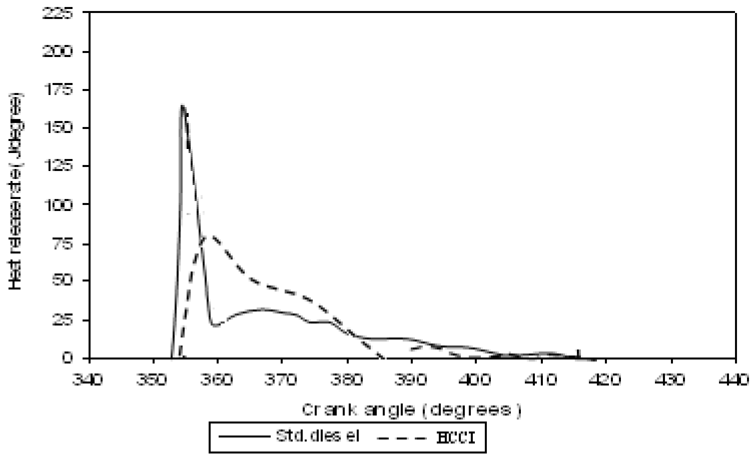


Figure 12: Variation of Net Heat Release Rate With Crank Angle At Full Load

From the figure 12, it is observed that the standard diesel operation has two phases of combustion viz. The premixed phase of combustion and the diffusive phase of combustion, but, in HCCI mode the first phase of combustion is not visible and it combusts like the combustion happening in SI engines. This is a proof for the operation of HCCI mode. This is mainly due to combustion of premixed homogeneous mixture by auto ignition method. The duration of combustion of HCCI mode is shorter than standard diesel mode and the peak heat release rate of HCCI mode is shorter than standard diesel mode. Hence, the HCCI mode offers lower cylinder pressure, lower brake thermal efficiency, lower NO_x and lower smoke emission.

Conclusion

The experimental investigation conducted using ethanol in HCCI mode yielded the following major conclusions to find the suitability of application of ethanol in HCCI mode. This investigation also revealed the performance and emission characteristics of ethanol in HCCI mode of operation.

1. The brake thermal efficiency in HCCI mode is 1.5% lower compared to standard diesel operation at full load.

2. The volumetric efficiency of HCCI mode is comparatively 6.8% lower than that of standard diesel operation.
3. The NO_x emission of the HCCI mode is 200 ppm lower than that of standard diesel operation
4. The smoke emission of HCCI mode is 50% lower than standard diesel operation.
5. Simultaneous reduction of NO_x and smoke has been achieved in this method.
6. HCCI mode emits more CO and HC at all load conditions than that of standard diesel operation. However, it is inevitable in case of fumigation mode of fuel admission.

From the above investigation it is concluded that ethanol is a fuel best suited for HCCI operation as little effort was required to control the timing of auto-ignition.

References

[1] Barata, M. "Performance and Emissions of a Dual Fuelled DI Diesel Engine", SAE 952364, pp. 16-19, 1995.

[2] Christensen M, Johansson B, Homogeneous charge compression ignition engine with water injection. SAE Technical Paper No.1999-01-0182, 1999.

[3] Christensen Magnus, Hultqvis Anders, Johansson Bengt. Demonstrating the multi fuel capability of a homogeneous charge compression ignition engine with variable compression ratio. SAE 1999-01-3679.

[4] Christensen Magnus, Johansson Bengt, Einewall Patrick. Homogeneous charge compression ignition (HCCI) using isooctane, ethanol and natural gas – a comparison with spark-ignition operation. SAE 972874.

[5] Christensen Magnus, Johansson Bengt, Amne ´ us Per, Mauss Fabian. Supercharged homogeneous charge compression ignition. SAE 980787.

[6] De Caro PS, Mouloungui Z , Vaitilingom G. Interest of combining an additive with diesel–ethanol blends for use in diesel engines. Fuel 2001; 80(4):565–74.

[7] Devan, P. K. and Mahalakshmi, N. V. "Combustion, Emission and Performance Characteristics of Diesel engine Fuelled with Eucalyptus oil with an Ignition Enhancer", International Journal of Green Energy, Energy and Environment, Vol. 1, No. 1, pp. 40-49, 2010.

[8] Flowers DL, Aceves SM, Frias JM, Improving ethanol life cycle energy efficiency by direct utilization of wet ethanol in HCCI engines. SAE Technical Paper No.2007-01-1867, 2007.

[9] Ganesh D, Nagarajan G, Homogeneous Charge Compression Ignition (HCCI) Combustion of Diesel fuel with External Mixture formation. Energy, Vol.35, 2010, pp.148-157.

[10] Haraldsson G , TunestaPer, Johansson Bengt, Hyvo ¨ nen Jari. HCCI combustion phasing in a multi cylinder engine using variable compression ratio. SAE 2002-01-2858.

[11] Hunter Mack J, Salvador M. Aceves, Robert W. Dibble, Demonstrating Direct use of Wet Ethanol in a Homogenious Charge Compression Ignition (HCCI) Engine. Energy, Vol.34, 2009, pp.782-787.

[12] Kontarakis George, Collings Nick, Ma Tom. Demonstration o f HCCI using a single cylinder four-stroke SI engine with modified valve timing. SAE 2000-01-2870.
[13] Lu Xingcai, Hou Yuchun, Zu Linlin, Huang Zhen, Experimental study on the auto-ignition and combustion characteristics in the homogeneous charge compression ignition combustion operation with ethanol/ n-heptane blend fuels by port injection. Fuel 85 (2006) 2622–2631
[14] Megaritis A, Yap D, Wyszynski ML, Effect of water blending on bioethanol HCCI combustion with forced induction and residual gas trapping. Energy, Vol.32, 2007, pp.2396-2400.
[15] Midlam-Mohler Shawn, Guezennec Yann, Rizzoni Giorgio, Mixed mode diesel HCCI with external mixture formation. DEER 2003 News report, 26 th August 2003.
[16] Robert Last, J., Micheal Kruger and Manfred Durnholz, "Emissions and Performance Characteristics of a 4- Stroke, Direct Injected Diesel Engine Fuelled with Blends of Biodiesel and Low sulfur Diesel Fuel", SAE Trans., 950054, pp. 1-13, 1995.
[17] Ryan III TW, Callahan TJ, Homogeneous charge compression ignition of diesel fuel, SAE Paper No.961160, 1996.
[18] Shi Lei, Cui Yi, Peng Kangyao, Chen Yuanyuan, Study of low emission homogenous charge compression ignition (HCCI) engine using combined internal and external exhaust gas recirculation (EGR). Energy, Vol.31, 2006, 2665-2676.
[19] Simescu Stefan, Fiveland Scott B, Dodge Lee G, An experimental investigation of PCCI-DI combustion and emissions in a heavy duty diesel engine, SAE Paper No.2003-01-0345, 2003
[20] Steinhilber T, Sattelmayer T, The effect of water addition on HCCI diesel combustion. SAE Technical Paper No.2006-01-3321, 2006.
[21] Thring RH, Homogenous charge compression ignition (HCCI) engines. SAE Paper No.892068
[22] Xing-cai L u ¨, Jian-guang Yang, Wu-gao Zhang, Zhen Huang. Effect of cetane number improver on heat release rate and emissions of high speed diesel engine fuelled with ethanol–diesel blend fuel. Fuel 2004;80(14–15):2013–20.
[23] Yanagihara H, Ignition timing control at Toyota "unibus" combustion system. A new generation of engine combustion process for the future. Proceedings of the IFP international congress, 2001, pp.34-42.
[24] Yang Jialin, Culp Todd, Kenney Thomas. Development of a gasoline engine system using HCCI technology – the concept and the test results. SAE 2002-01-2832.
[25] Zhao H, Peng Z, Ladommatos N. Understanding of controlled auto ignition combustion in a four-stroke gasoline engine. J Automobile Eng 2001; 215:1297–310.