Journal of Energy Technologies and Policy
ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online)
Vol.2, No.2, 2012

An Experimental Investigation of Performance and Emission in Ethanol Fuelled Direct Injection Internal Combustion Engines with Zirconia Coating

M. Velliangiri and A. S. Krishnan
Department of Mechanical Engineering,
Coimbatore Institute of Technology, Coimbatore, India -641 014.

Abstract

This article presents the experimental investigation of use of neat ethanol (95% Ethanol +5% water) as a fuel in a four stroke single cylinder engine as regards to performance and emission characteristics. Two different ignition modes viz. (i) High Compression (16.5:1) Spark Ignition with high-pressure manifold injection of ethanol and (ii) Ultra High Compression (44.4:1) Compress Ignition with Direct Injection of ethanol have been experimentally analyzed with and without zirconia surface coating. As a benchmark, the results have been compared with data from the same engine run with diesel as fuel. In the first mode, the brake thermal efficiency with ethanol as fuel was found almost equal to that of diesel. However, the emissions were found to be significantly lower. In the second mode, the brake thermal efficiency was found to fall in between the diesel and ethanol manifold injection modes of operation. More significantly, the cost of running the engine was found to be lower than the operating cost incurred by using diesel. This assumes importance in the wake that ethanol can be obtained from non-fossil resources.

1.0 INTRODUCTION

Ethanol is an alternative fuel resulting in less greenhouse gas (GHG) emissions than gasoline [1]. The key environmental benefit of ethanol is that, unlike gasoline and diesel, its consumption does not significantly raise atmospheric levels of CO2. This is because the CO2 which is released during the burning of the fuel is counter-balanced by that which is removed from the environment by photosynthesis when growing crops and trees for ethanol production. There is considerable controversy as to whether corn-based ethanol is a net positive with respect to GHG emission. Production of ethanol fuel from sugar cane is however generally accepted to produce a reduction in GHG emission. On a life cycle basis, ethanol produced today roughly reduces 20% GHG emissions [1], and in terms of fossil energy, it delivers one third or more energy than is used to produce it when accounting for the energy contained in the co-products [1]. This GHG emission reduction could increase with improved efficiency and use of renewable energy, and producing ethanol from more abundant cellulosic biomass sources rather than corn or sugar cane. If ethanol has the potential to significantly reduce global GHG emissions associated with transportation, controls are definitely needed to protect ecologically important lands and the production efficiency and environmentally friendliness has to be incontestably improved as well. Adapting the fuel to the engine is to increase the compression ratio and fuel Injection system was modified, such that it is sufficient for all operating conditions. For smooth operation of an engine, combustion must spread smoothly throughout the combustion chamber. This was accomplished in high compression spark Ignition with high pressure manifold Injection having a homogeneous mixture in the cylinder ignited by means of a spark. On the other hand, the heterogeneous mixture in a diesel engine, when using Ethanol fuel High Compression Direct Injection. The thermal efficiency of the diesel engines can be increased by reducing the heat loss to the surroundings by means of coolant and exhaust gases. The heat can be transfer from the combustion chamber to the piston, to the combustion chamber walls and finally to the cooling water circulated in the cooling water jacket around the cylinder. The heat transfer can be minimized by reducing the heat that is transferred from combustion chamber to the pistons. This leads to the idea of insulating the piston and cylinder walls. These types of engines are known as Low Heat Rejection (LHR) engines. This can be realized by coating the pistons, cylinder walls with ceramics which can withstand high thermal stresses. They have low thermal conductivity thus reducing the heat flux into the piston and thus reduction of heat transfer to the coolant is reduced. Stringent emission legislation all over the world has led to the search for alternative fuels for I.C. Engines. The major pollutants from a diesel engine are oxides of nitrogen (NO_x), smoke and particulate matter. Concentration is very much focused on compression ignition engines.

1.1COATING MATERIALS

Two major obstacles of the LHR engine are component strength and tribology at high temperatures. Where conventional metals and lubricants fail to perform at elevated temperatures, advanced ceramic materials provide an alternative. These materials have provided the major impetus to LHR research and development in recent decades. Principal substances of interest include nitrides and carbides of silicon (Si_2N_4 and SiC); oxides of chromium, aluminum, and iron (Cr_2O_3, Al_2O_3, and FeO_2); and partially stabilized oxide of zirconium, (ZrO_2, or PSZ). Low ductility, low tensile strength, and low bending strength have impeded the direct replacement of metals with ceramics in conventional engine designs. Conventional piston and cylinder stresses make the application of ceramics extremely challenging. Large piston ring loading forces produce large stresses and large friction forces. To reduce these forces, modifications to piston and connecting rod mechanics would decrease the demands which are currently placed upon tribological research. Both monolithic ceramic component ceramic coatings have been used by various LHR engine researchers. It is another kind of high temperature resistant coating which has recently been developed. The main objective of this coating is to provide thermal insulation to metallic components at elevated temperature especially for diesel, gas turbine and aero-engine applications. Improvement of thermal efficiency and reduction of the NOx level in TBC coated piston heads of diesel engine have been studied and the thermal gradient between the substrate and the surface coating observed.

1.2COLD STARTING IN A SINGLE-CYLINDER ENGINE WITH ETHANOL

The ongoing research includes work with single- cylinder engines that simulate closely the characteristics of the multi-cylinder engine. The single-cylinder results presented below were for a PFI SI configuration with 16.5:1 compression ratio and identical cam timings, displacement, bore/stroke ratio, and intake manifold geometry as the multi-cylinder engine described earlier in this work. It was run naturally aspirated and lean, to simulate early stages of the open-loop startup strategy used in the multi-cylinder engine. Cold starting with the single cylinder was examined at ambient temperatures from [13].

The initial fueling and ignition timing sequences were varied to determine optimal combinations to ignite the charge and sustain combustion during the first ten firing cycles. The engine was ramped quickly up to speeds ranging between 1000 rpm to 1500 rpm, This higher cranking speed results in a higher compression temperature, and therefore improved low-temperature ignition [20]. Fueling with neat methanol was initiated such that the end of the injection event occurred just prior to intake valve closure.

Fig 1.0 Photographic view of Zirconia coated piston

Fig 1.1 Photographic view of zirconia coated cylinder head and valves

2. EXPERIMENTAL SETUP

The experimental setup used in this studied schematically in fig. The experimental work is conducted on four strokes, single cylinder, water cooled, manifold injection ethanol engine and direct injection Ethanol engine coupled on an eddy current dynamometer. For measuring of exhaust temperature, NO_X, CO , CO_2 and Unburned HC level are made in the exhaust pipe. The exhaust temperature of the engine measured using digital chromel -alumel thermocouple.

The NO_X level is measured using NO_X analyzer. The carbon monoxide and unburned hydrocarbon is measured by using infrared analyzer. Fuel consumption is measured with the help of burette and digital stop watch. The experiments are conducted at various loads from no load to full load with uncoated piston and coated piston with different fuel (wet ethanol, diesel).

3. 0 ENGINE MODIFICATION

The selected engine is field marshal diesel engine. The specifications and technical details of the engine are given below. The engine is water cooled and single cylinder vertical engine. The engine is mounted on a sturdy concrete bed to withstand the dynamic forces and vibrations produced. The required compression ratio and manifold Injection setups are provided with modifications as shown in fig.(2)

Fig1.2 Engine Modification with modified Combustion Chamber

3.1 ENGINE AND TEST DESCRIPTION

The engine designed for this work is derived from the single cylinder diesel engine, modified suitably to accommodated fuel injectors and spark plugs. The stock inlet ports give a swirl ratio of about 2.0, a factor that has been demonstrated to reduce the tendency for knock [18].

Knock was further reduced by modifying the stock combustion chamber to eliminate potential resignation sites. A range of compression ratios from 17:1 to 44.4 :1 were tested in this engine with Ethanol fuel, although the results reported below were conducted at a nominal compression ratio of 16.5:1.Intake manifold pressure was maintained, also varied the exhaust backpressure on the engine. At least four different types of port fuel injectors were evaluated for measured engine brake thermal efficiency as well as spray characteristics with methanol, verified with high-speed planar laser imaging. The best- atomizing injectors among the group were 210 kg/cm^2 pressure port fuel Injectors used . For best startup and transient performance, the injector tip was targeted at the back of the intake valve, from a distance of approximately 80 mm. The ignition system consisted of a production Toyota coil with a Champion dual electrode, recessed gap spark plug. High load operation, with a combination of high cylinder pressures and smaller spark advance, placed great demand on both the plugs and coils.

Table : 1

Make	FIELD MARSHAL
No of cylinder	One
Type of cooling	Water
Ignition	Compression Ignition
Bore	95 mm
Stroke	110 mm
Compression ratio	16.5: 1
Speed	1500 rpm
Brake power	5.9 kW

Fig – 2.0 Experimental setup high compression spark Ignition Engine and Direct Injection (with Modification)

Fig- 2.1 Experimental setup modified piston assembling

Fig – 2.2 Modified combustion chamber In piston

Fig -2.3 Experimental setup high compression Direct Injection Engine

5.0 RESULTS AND DISCUSSION

5.1 BRAKE-SPECIFIC EMISSIONS FOR ETHANOL

The figures below show HC ,CO NO_x and TFC emissions for the engine operating with Ethanol Similar results are expected for ethanol [18], but are not included. Brake-specific NOx emissions as a function of BMEP and RPM are shown in Figure 3.3.The high pressure manifold Injection and Direct Injection Experimental Comparison for performance and Emissions with Coating and with out coating results are compared are shown in the graph . In the context of the objective of reducing greenhouse gas emissions, it is worth closely evaluating the use of fuels in internal combustion engines.

First, ethanol characteristics when used pure as fuel in a dedicated engine were reviewed, to determine the balance between its main advantages and disadvantages. Later, after having summarized the main combustion processes and their relative efficiencies, the main physical properties of ethanol have been analyzed in regard to their positive or negative impact on engine running. Finally, the results obtained on a dedicated engine are presented.

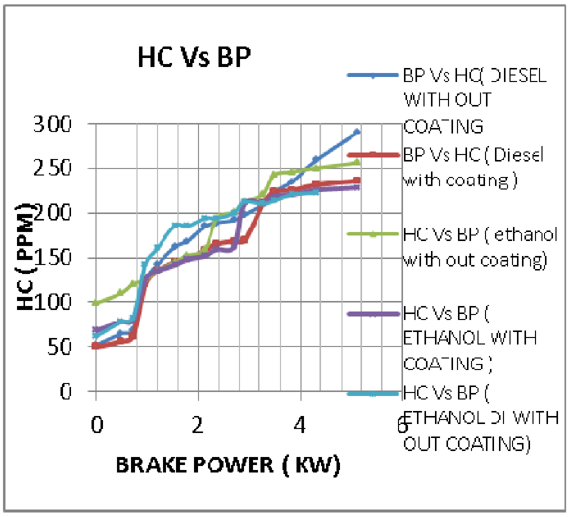

Fig 3.0 – HC Vs BP COMPARISTION AT CONSTANT SPEED MODE (1500RPM)

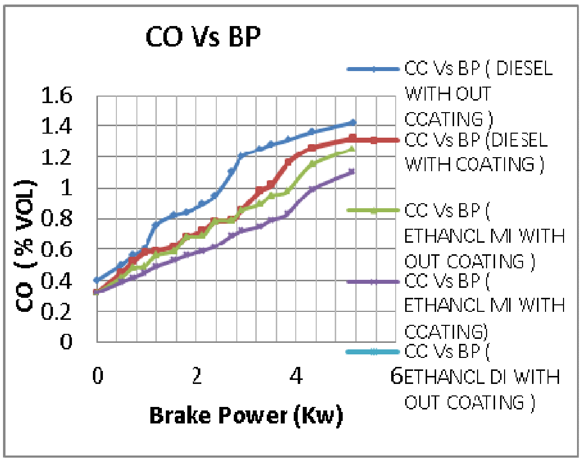

FIG 3.1 CO Vs BP COMPARITION AT CONSTANT SPEED MODE (1500 RPM)

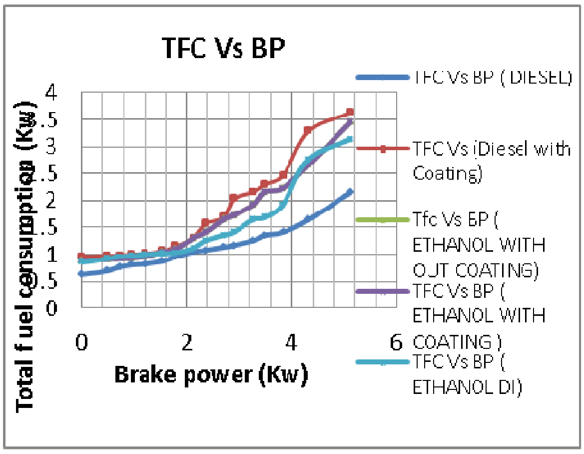

FIG 3.2 - TFC Vs BP COMPARITION AT CONSTANT SPEED MODE (1500 RPM

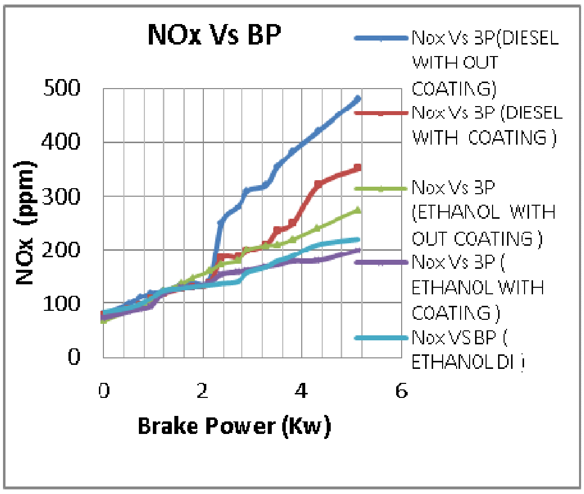

FIG 3.3 - NOx Vs BP COMPARITION AT CONSTANT SPEED MODE (1500 RPM)

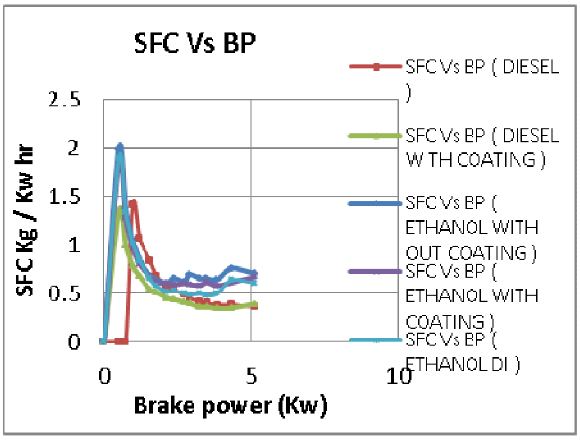

FIG 3.4 - NOx Vs BP COMPARITION AT CONSTANT SPEED MODE (1500 RP

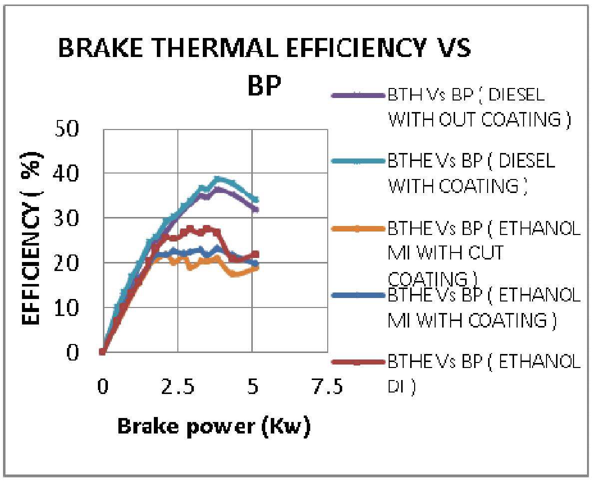

FIG 3.5 - BTHE Vs BP COMPARITION AT CONSTANT SPEED MODE (1500 RPM

FIG 3.5 – EDDY CURRENT DYNAMOMETRE

TABLE : 2 FUEL PROPERTIES

Property	**Ethanol**	**Gasoline**	**Diesel**
Chemical Formula	C2H5OH	C4 to C12	C3 to C25
Molecular Weight	46.07	100–105	≈200
Carbon	52.2	85–88	84–87
Hydrogen	13.1	12–15	33–16
Oxygen	34.7	0	0
Specific gravity, 60° F/60° F	0.796	0.72–0.78	0.81–0.89
Density, lb/gal @ 60° F	6.61	6.0–6.5	6.7–7.4
Boiling temperature, °F	172	80–437	370–650
Reid vapor pressure, psi	2.3	8–15	0.2
Research octane no.	108	90–100	--
Motor octane no.	92	81–90	--
(R + M)/2	100	86–94	N/A
Cetane no.(1)	--	5–20	40–55
Fuel in water, volume %	100	Negligible	Negligible
Water in fuel, volume %	100	Negligible	Negligible
Freezing point, °F	-173.2	-40	-40–30[a]
Centipoise @ 60° F	1.19	0.37–0.44[b]	2.6–4.1
Flash point, closed cup, °F	55	-45	165
Autoignition temperature, °F	793	495	≈600
Lower	4.3	1.4	1
Higher	19	7.6	6
Btu/gal @ 60° F	2,378	≈900	≈700

6.0 CONCLUSION

The present work describes a PFI,(manifold)SI high compression ratio engine operating with coating and with out coating ,operating on neat alcohol fuels. From the steady state results presented above, it is concluded that:

- The present engine, optimized for alcohol fuels, exceeds the performance of current conventional- fueled engines, and has potential as a lower-cost alternative to the diesel.

- Brake thermal efficiency levels better than a comparable manifold Injection and diesel are demonstrated. The engine operating with Ethanol fuel showed peak BTE of nearly 29%, and nearaly operating range than the baseline diesel.

- Emissions of NOx, CO and HC using a conventional engine were shown to be extremely low with ethanol mode

- Brake thermal efficiency with ethanol fuel is also favorable compared to that of the baseline diesel engine.

- The present engine offers the potential for a lower- cost renewable fuel alternative to the diesel, by virtue of its less-complex PFI fuel system and Di in CI Engine .

7.0 ACKNOWLEDGMENTS

The authors express their deep gratitude to the management of Coimbatore Institute of Technology for providing the necessary facilities for carrying out the experiments.

The authors would like to thank in particular, beloved Correspondent Dr. S. R. K. Prasad, Revered Seceratary Dr. R. Prabhakar, Seceratary, CIT, and our Principal Dr. V.Selladurai who have been constantly encouraging and supporting us in this research. The authors also would like to thank and appreciate the support of the members of IC Engine Research Laboratory Mr G. Sureshkanan Assistant Professor and Scientific Assistants Mr. D. Ravi and Mr. K. Balasubaramanian for their enthusiastic assistance and maintenance of the test engine

REFERENCES

[1] .M. N. Nabi, et al., “Ultra Low Emission and High Performance Diesel Combustion with Highly Oxygenated Fuel”, SAE Paper 2000-01-0231, 2000.

[2.] N. Miyamoto, et al., “Smokeless, Low NOx, High
Thermal Efficiency, and Low Noise Diesel Combustion with Oxygenated Agents as Main Fuel, SAE Paper 980506, 1998.

[3]. R. Baranescu, et al., “Prototype Development of a Methanol Engine for Heavy-Duty Application- Performance and Emissions”, SAE Paper 891653, 1989.

[4] .B. Dhaliwal, et al., “Emissions Effects of Alternative Fuels in Light-Duty and Heavy-Duty Vehicles”, SAE Paper 2000-01-0692, 2000.

[5]. N. D. Brinkman, “Effect of Compression Ratio on Exhaust Emissions and Performance of a Methanol- Fueled Single-Cylinder Engine”, SAE Pape 770791, 1977.

[6]. P. Mohanan, M. K. Gajendra Babu, “A Simulation Model for a Methanol-Fueled Turbocharged Multi-Cylinder Automotive Spark Ignition Engine”, SAE Paper 912417, 1991.

[7]. T. Ryan, S. Lestz, "The Laminar Burning Velocity of Isooctane, N-Heptane, Methanol, Methane and Propane at Elevated Temperatures and Pressures in the Presence of a Diluent", SAE Paper 800103, 1980.

[8].V. Battista, et al., “Review of the Cold Starting Performance of Methanol and High Methanol Blends in Spark Ignition Engines: Neat Methanol”, SAE Paper 902154, 1990.

[9].K. Hikino, T. Suzuki, “Development of Methanol Engine with Autoignition for Low NOx Emission and Better Fuel Economy”, SAE Paper 891842, 1989.

[10].L. G. Dodge, et al., “Development of an Ethanol- Fueled Ultra-Low Emissions Vehicle”, SAE 981358, 1998.

[11]. K. Iwachidou, M. Kawagoe, “Transient Unburned Methanol and Formaldehyde Emission Characteristics in Cold Operation of a SI Engine Powered by High-Methanol-Content Fuels”, VIII Int. Symp. On Alcohol Fuels, pp. 443-448, Nov. 13-16, 1988.

[12].N. Iwai, et al., “A Study on Cold Startability and Mixture Formation of High-Percentage Methanol Blends”, SAE Paper 880044, 1988.

[13]. D. M. Swain, D. Yerace, Cold-Start Hydrocarbon Reduction Strategy for Hybrid Vehicles, M. S. Thesis, University of Michigan, 2002.

[14]. W. Clemmens, “Performance of Sequential Port Fuel Injection on a High Compression Ratio Neat Methanol Engine”, SAE Paper 872070, 1987.

[15]. C. D. de Boer, et al., “The Optimum Methanol Engine with Electronic Control for Fuel Efficiency and Low Emissions”, VIII Int. Symp. On Alcohol Fuels, pp. 425-430, Nov. 13-16, 1988.

[16]. R. I. Bruetsch, K. H. Hellman, “Evaluation of a Passenger Car Equipped with a Direct Injection Neat Methanol Engine”, SAE Paper 920196, 1992.

[17]. R. M. Siewert, E. G. Groff, “Unassisted Cold Starts to –29 oC and Steady-State Tests of a Direct-Injection Stratified-Charge (DISC) Engine Operated on Neat Alcohols, SAE Paper 872066 1987.

[18]. W. H. Haight III, P. C. Malte, “Methanol Preignition Temperature Behavior”, SAE Paper 912414, 1991.

[19]. R. L. Bechtold, Alternative Fuels Guidebook, SAE International, 1997.