EFFECT OF IGNITION TIMING, EQUIVALENCE RATIO, AND COMPRESSION RATIO ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF A VARIABLE COMPRESSION RATIO SI ENGINE USING ETHANOL-UNLEADED GASOLINE BLENDS

Syed Yousufuddin*

Department of Mechanical Engineering, Vasavi College of Engineering
Hyderabad-500031, A. P, India
yousufuddin2k3@yahoo.co.in

Syed Nawazish Mehdi

Department of Mechanical Engineering, Muffakham Jah College of Engineering and Technology
Hyderabad-34, A. P, India
nawazishmehdi@yahoo.co.in

*Corresponding Author

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Abstract This paper investigates the effect of ethanol-unleaded gasoline blends (E0,E10,E25,E35,and E65) computer interfaced, four-stroke single cylinder compression ignition engine. The said engine was converted to spark ignition and carburetion to suit ethanol fuel. A suitable provision was provided on the engine to vary the compression ratio thereby making the engine adaptable to operate at lower compression ratios. The tests were performed by varying the ignition timing, equivalence ratio, and compression ratio at a constant speed of 1500 rpm and at wide open throttle (WOT). Effect of ethanol-unleaded gasoline blends and tests variables on engine torque and specific fuel consumption were examined experimentally. The results of this investigation, is believed, to contribute substantially to the knowledge, aimed to ensure a secure future energy.

Keywords Ethanol, Gasoline, Ignition Timing, Equivalence Ratio, Compression Ratio, Variable Compression Ratio, Performance, and Emissions

چکیده این مقاله، تاثیر ترکیبات آتانول - بنزین بدون سرب (E0, E10, E25, E35, E65) را در یک موتور احتراق تراکمی تک سیلندر چهار زمانه وصل به رایانه بررسی می‌کند. موتور مذکور به یک موتور احتراق جرقه ای با کاربراتور مناسب سوخت اتانول تبدیل شده بود. تدارک لازم برای تغییر نسبت تراکم موتور پیش پینی شده بود به طوری که امکان کارکرد موتور در نسبت های تراکم پائین فراهم شده بود. آزمایشها با تغییر مدت زمان احتراق، نسبت هم ارزی (اکی والانس) و نسبت تراکم در یک سرعت ثابت موتور (۱۵۰۰ دور در دقیقه) و در دریچه کاملا″ باز (WOT) انجام شدند. تاثیر مخلوط های اتانول - بنزین بدون سرب و متغییر های آزمایشی، یعنی گشتاور موتور مصرف سوخت موتور، بطور تجربی انجام شدند. تصور می‌شود که نتایج این تحقیق بتواند به دانش لازم برای تهیه انرژی مطمئن در آینده به طور قابل توجهی کمک کند.

1. INTRODUCTION

Fuel additives are very important, since many of these additives can be added to fuel in order to improve its efficiency and performance. One of the most important additives to improve fuel performance is oxygenates (oxygen containing organic compounds). Several oxygenates have been used as fuel additives, such as methanol, ethanol, tertiary butyl alcohol and methyl tertiary butyl ether.

Ethanol was the first fuel among the alcohols to be used to power vehicles in the 1880s and 1890s. Henry Ford presented it as the fuel of choice for his automobiles during their earliest stage of development [1].

Presently, ethanol is prospective material for use in automobiles as an alternative to petroleum based fuels. The main reason for advocating ethanol is that it can be manufactured from natural products or waste materials, compared with gasoline, which is produced from non-renewable natural resources. In addition, ethanol shows good anti-knock characteristics. However, economic reasons still limit its usage on a large scale. At the present time and instead of pure ethanol, a blend of ethanol and gasoline is a more attractive fuel with good anti-knock characteristics.

Palmer [2] reported that all oxygenated blends gave a better anti-knock performance during low speed acceleration than hydrocarbon fuels of the same octane range. Goodger [3] reported the comparisons with hydrocarbon fuels made by Ricardo at a fixed compression ratio, in which there was a 5 % improvement in efficiency, using ethanol. Winnington, et al [4] studied the effect of using ethanol-gasoline blends: A (15 % ethanol, 41 % premium and 44 % regular) and B (20 % ethanol, 54 % premium and 26 % regular), as a fuel on the performance of spark ignition engines, such as the Ricardo and Peugeot 504 GR engines. The Ricardo engine, over the test range of 8:1 to 10:1 compression ratio, showed an average drop in power compared to premium gasoline of 2.5 % on blend A and 7.5 % on blend B. The specific fuel consumption of the ethanol–gasoline blend showed an increase compared to premium gasoline of around 0.5 % and 4 % on blends A and B, respectively. The Peugeot engine tests showed that the power was down, overall, by around 1 % and 2.5 % on blends A and B, respectively, and the specific fuel consumption was increased by about 0.5 % for blend A and 1 % for blend B.

Hamdan, et al [5] using the ATD 34 engine conducted performance tests using different ethanol-gasoline blends. The maximum percentage of ethanol used was 15 %. The best performance was achieved when the 5 % ethanol-gasoline blend was used, with thermal efficiency increasing by 4 % under low speed conditions and 20 % at the high speed condition.

El-Kassaby [6] studied the effect of ethanol-gasoline blends on SI engine performance. The performance tests were conducted using different percentages of ethanol-gasoline up to 40 % under variable compression ratio conditions. The results showed that the engine indicated power improvement with ethanol addition, the maximum improvement occurring at the 10 % ethanol and 90 % gasoline fuel blend. The effect of using ethanol with unleaded gasoline on exhaust emissions (carbon monoxide, CO; carbon dioxide, CO2 and unburned hydrocarbons, HC) have been experimentally investigated by Bata, et al [7]. The concentration of CO was reduced by about 40-50 % at an equivalence ratio on the lean side near stoichiometry. In addition, the concentration of CO decreases as the percent of ethanol increases in the blend. Gulder [8] performed a series of engine tests using ethanol-gasoline blends. The results of this study were summarized as follows. It is possible to obtain a lead-free, high octane fuel by adding 20-30 % ethanol to unleaded gasoline. Pure ethanol yields a higher engine thermal efficiency than gasoline. Taljaard, et al. [9] studied the effect of oxygenate in gasoline on exhaust emission and performance in a single cylinder, four stroke SI engine.

They concluded that oxygenates significantly decreased the CO, NOx and HC emissions at the stoichiometric air-fuel ratio. Unzelman [10] studied the influence of gasoline composition on air quality. The results indicated that oxygenates can improve air quality by reducing the amount of exhaust emission. Wu, et al. [11] investigated the effect of air-fuel ratio on SI engine performance and pollutant emissions using ethanol-gasoline blends. The result of engine performance tests showed that torque output improves when using ethanol-gasoline blends. However, there is no appreciable difference on the brake specific heat consumption. CO and HC emissions reduced with the increase of ethanol content in the blended fuel. The maximum CO_2 emission was obtained at relative air-fuel ratio equal to 1.01, but the smallest amount of CO_2 emission obtained with E30. In their study they found, that by using 10 % ethanol fuel, the pollutant emission can be reduced efficiently.

In this work, the effects of ignition timing, equivalence ratio, and compression ratios on engine performance and exhaust emissions were investigated with the said ethanol-gasoline fuel blends. Experiments were performed at a constant engine speed corresponding to 1500 rpm and wide open throttle.

2. EXPERIMENTAL WORK

The experimental set-up was designed and the scheme of experimentation planned, keeping in mind the objectives of the research problem. The essential components for the experimental setup were chosen and the instrumentation systems were selected judiciously with a clear understanding of their working, range, and limitations. The engine used in the present study was a Kirloskar AV-1, single cylinder direct injection diesel engine with the specifications given in Appendix-I. The said engine was modified to run at low compression ratios thus making it compatible and adaptable to run with spark ignition (SI) mode. The engine was modified and a provision was provided to vary the compression ratio from 4 to 11. The engine was coupled to a DC dynamometer and all the experiments were carried out a constant speed of 1500 rpm. The intake temperature and pressure were chosen to give stable and knock free engine operation. The experimental test rig is shown below in Figure 1. The technical details of the engine test rig with necessary measurement and instrumentation systems used are given in Appendix-1.

2.1. Modifications Made on the Engine to Suit Ethanol as an Alternate Fuel

The following modifications were made to the engine for operation on ethanol with carburetion and spark ignition.

- The diesel fuel system was replaced by a carburetor, which was connected to the air-intake manifold of the engine inlet system, and a spark plug was located in place of the diesel injector. For the engine to run on ethanol, the spark plug was activated and this was done by a special arrangement (i.e. a coil ignition system with a power supply to provide 12V Direct Current primary voltage was used), which produces sufficient spark required for combustion initiation. Also the spark plug gap was increased to 1 mm to help lean burning.
- To increase the flow, the carburetor jet size was increased to 1.5 times than its original size.
- The float was weighted down, to correct level due to higher specific gravity value of ethanol i.e. 0.79 as compared to a value of 0.72 for petrol.
- The floats on the carburetor float-bowl are

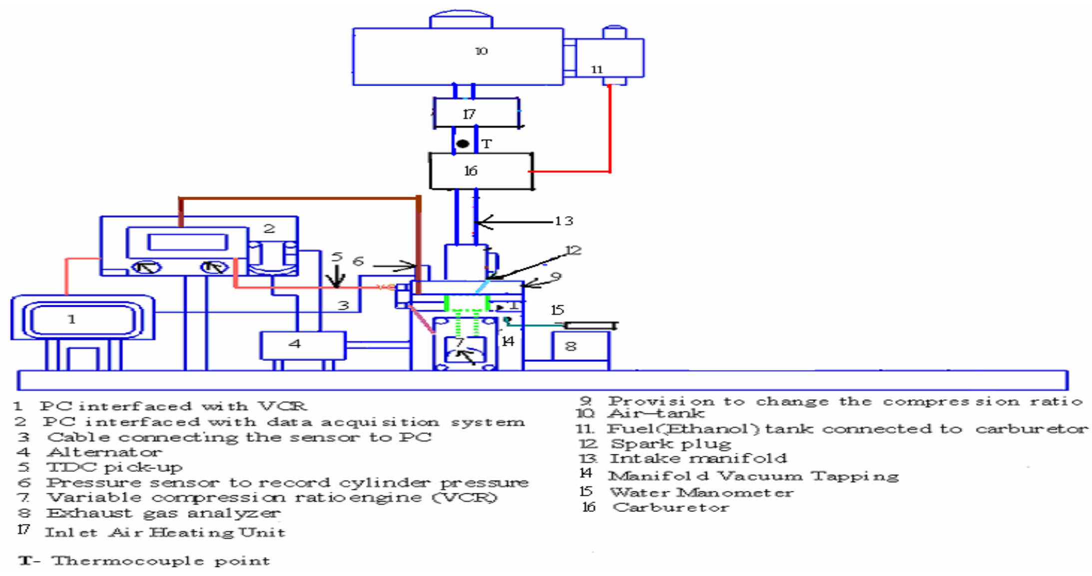

Figure 1. Experimental test rig with necessary instrumentation.

generally made of porous plastics, which are damaged by the ethanol, and the result is swelling and cracking. It is found that nylon floats are more durable. A float was made with thin sheet of Brass (0.005 inches or 0.125 mm thickness), molded, and welded with pure Tin (Sn).

- The air inlet i.e. orifice of the air-tank was also modified i.e. changed from 20 mm to 15 mm to get less air as ethanol being an oxygenated fuel requires less air for complete combustion.
- Specially designed heating element was placed between the air tank and the carburetor to heat the incoming air to a temperature of about 100 ˚C to ensure easy starting of the engine since lower vapor pressure of ethanol makes starting difficult below 70˚C.
- The materials for fuel tank strainer were compatible with ethanol. The materials for fuel hoses were not compatible and therefore were replaced with Teflon hoses. In addition, the fuel tank was coated with Teflon. Steel fuel lines were replaced with nylon tube (NYLON 11). Fuel filters used for gasoline are not usually recommended for any kind of alcohol. The internal element collapses after the glue that bonds it together, is softened by the alcohol. Also due to the higher flows, filters have to be bigger. Therefore, the filter body was also coated with Teflon.
- All the parts of the carburetor are compatible with ethanol fuel except carburetor body. Carburetors are normally made of Zamac (Al+Zn) alloy. Ethanol always contains acetic acid and is particularly corrosive to aluminum alloys. In addition, certain alloys containing lead are attacked with general result of the lead being leached out, leaving a porous surface. The Same phenomenon exists with alloys of zinc, such as Zamac. The zinc is leached out as a white zinc oxide, which clogs the small orifices and jets. In order to overcome the corrosion problem on the carburetor body, electrolysis Nickel plating was done. In this process, the carburetor parts were immersed in a bath of hot Nickel, which due to its very low viscosity, covers evenly all the surfaces without clogging the orifices.
- The insulation was done on the inlet manifold so that the maximum heat from the engine will be supplied to charge for better vaporization of ethanol fuel.
- Provision for thermocouple was made for the measurement of the temperature of air, mixture, and exhaust gases.
- Provision for pressure transducer and intake manifold vacuum tapping were made in the cylinder head.
- Cooler running spark plugs were used in place of hot plugs to avoid pre-ignition.

2.2. Experimental Procedure The engine is modified to work on low compression ratios ranging from 4:1 to 11:1 on spark ignition mode. By adding the shims and spacer plates made of various thicknesses the clearance volume was increased, thereby the compression ratio was reduced. For performance characteristics study purpose two compression ratios have been considered, they are 9 and 11. For these selected compression ratios the information about clearance volumes (i.e. distance between the piston top and cylinder head at the end of compression stroke) is given below in Table 1. After the compression ratio is set, the total setup is checked for safe operation. The engine was started and allowed to warm up for a period of 10-15 min. The air-fuel ratio was adjusted to yield maximum power on unleaded gasoline. Engine tests were performed at 1500 rpm engine speed at wide-open throttle opening position. The required engine load was obtained through the dynamometer control. Before running the engine to a new fuel blend, it was allowed to run for sufficient time to consume the remaining fuel from the previous experiment. The effects of using unleaded gasoline E0 i.e.100 % gasoline and unleaded gasoline-ethanol blends E10 10 % ethanol and 90 % gasoline, E25 25% ethanol and 75 % gasoline, E35 35 % ethanol and 65 % gasoline and E65 65 % ethanol and 35 % gasoline on engine performance and exhaust emissions have been investigated experimentally. The experiments were performed under variable compression ratio conditions (9:1 and 11:1) by varying the ignition timing at a constant speed of 1500 rpm at wide open throttle (WOT). The percentages of ethanol blended with unleaded gasoline were 10 %, 25 %, 35 % and 65 %. Ethanol with a purity of 99.5 % was used in the blends. The mixtures were prepared just before the experiments to prevent the reaction of ethanol with water vapor. For each experiment, two runs were performed to obtain an average value of the experimental data. The other

TABLE 1. Various Compression Ratios with Different Combinations of Spacers.

SN0	Shims and Spacers	Total Clearance Length	Compression Ratio
1	(1.38 * 3) + (1.1 * 2)	6.34	18.35
2	(1.38 + 5.1 Metal Spacer)	6.48	17.97
3	1.38 + (1.1 * 5)	6.88	16.98
4	(1.38 *2) + (1.1 * 4)	7.16	16.36
5	(1.38 * 3) + (1.1* 3)	7.44	15.78
6	(1.38 + 1.1+ 5.1 Metal Spacer)	7.58	15.51
7	(1.38 +6.3 Metal Spacer)	7.68	15.3
8	(1.38 + (1.1 * 2) + 5.1 Metal Spacer)	8.68	13.67
9	(1.38 + 1.1 + 6.3 Metal Spacer)	8.78	13.52
10	(1.38 +7.5 Metal Spacer)	8.88	13.38
11	1.38 + 7.5 Metal Spacer	8.88	13.38
12	(1.38 + (1.1 * 3)+ 5.1 Metal Spacer)	9.78	12.2
13	(1.38 + (1.1*2) + 6.3 Metal Spacer)	9.88	12.13
14	2 * 1.38 + (1.1 * 2) + 5.1 Metal Spacer	10.06	11.93
15	1.38 + (1.1 * 3) + 6.3 Metal Spacer	10.98	11.01
16	1.38 + (1.1 * 3) + 7.5 Metal Spacer	12.18	10.03
17	1.38 * 3 + (1.1 * 4) + 5.1 Metal Spacer	13.64	9.06
18	1.38 * 2 + (1.1 * 6) + 6.3 Metal Spacer	15.66	8.02
19	1.38 * 3 + (1.1 * 6) + 7.5 Metal Spacer	18.24	7.03
20	1.38 * 6 + (1.1 * 6) + 7.5 Metal Spacer	22.38	5.91
21	1.38 * 6 + (1.1 * 8) + 7.5 + 6.3 + 5.1	35.98	4.05

variables that were continuously measured include engine rotational speed (rpm), torque, time required to consume 10 cc of fuel blends and air-fuel ratio. The parameters, such as fuel consumption rate, equivalence air-fuel ratio, volumetric efficiency, air consumption, brake power, brake specific fuel consumption, brake thermal efficiency, density, stoichiometric air-fuel ratio, and lower heating value (LHV) of the fuel blends, were calculated. Engine exhaust emissions like CO and HC were also measured using an advanced AVL five-gas analyzer. By varying the percentage substitution of ethanol along with the varying load, the performance characteristics, combustion details and the exhaust emissions are noted for analysis.

3. RESULTS AND DISCUSSIONS

The ignition timing has a significant effect on the performance of spark ignition engines. The variation brake specific fuel consumption (BSFC) and brake torque with ignition timing at the compression ratio of 9:1 is shown in Figures 2 and 3. It is seen from Figure 2, that the average increment in BSFC compared with E0 was about

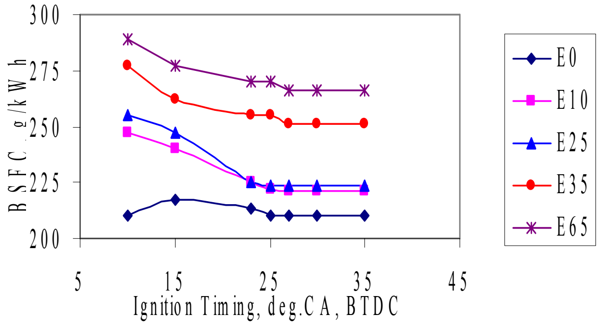

Figure 2. Variation of BSFC with ignition timing at the compression ratio of 9:1.

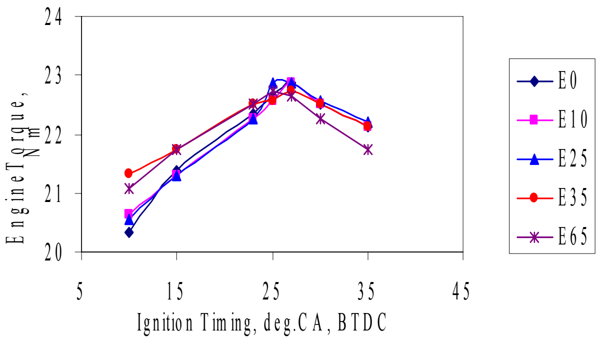

Figure 3. Variation of engine torque with ignition timing at the compression ratio of 9:1.

6.43 %, 8.37 %, 17.79 %, and 25.31 % with E10, E25, E35, and E65 respectively at 9:1 compression ratio. It is revealed from Figure. 3 that maximum brake torque was obtained at 27˚ CA (crank angle) advanced ignition timing with E0 fuel, however it was obtained at 25˚ CA advanced ignition timing with E65 fuel at the compression ratio of 9: 1. As seen in Figure 3, MBT timing of the engine showed no significant variation with unleaded gasoline and unleaded gasoline–ethanol blends. However, experimental results showed that usage of ethanol blends yields higher brake torque of the engine than the unleaded gasoline at retarded ignition timings. The increment of the brake torque depends on the ethanol ratio in the blend. The results showed that the addition of 65 % ethanol to the unleaded gasoline yield a 3.56 % increase in the brake torque compared with unleaded gasoline when the ignition timing was advanced to 10˚ CA. On the other hand, advancing the ignition timing to 35˚ CA leads to a 1.69 % increase in the brake.

Figures 4 and 5 shows the effects of ignition timing on BSFC and brake torque at the compression ratio of 11:1. The average increment in BSFC compared with E0 as seen in Figure. 4 was about 2.07 %, 3.35 %, 14.44 % and 30.9 % with E10, E25, E35 and E65 respectively at 11:1 compression ratio. The Figure 5 shows that the maximum brake torque was obtained at 23˚ CA (crank angle) advanced ignition timing with all fuels. The knock occurrence was not observed up to 35˚ CA advanced ignition timing with unleaded gasoline-ethanol blends (E35,E65). On the other hand, when the ignition timing was advanced to 29˚ CA, knock occurrence was observed with E0 fuel. Ethanol has been considered as blending agents to rise up the octane number of gasoline and has been used as anti-knock additives to unleaded gasoline. Blending with ethanol allows increasing the compression ratio without knock occurrence in spark ignition engines for better

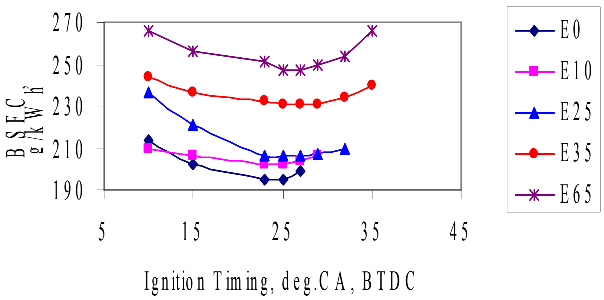

Figure 4. Variation of BSFC with ignition timing at the compression ratio of 11:1.

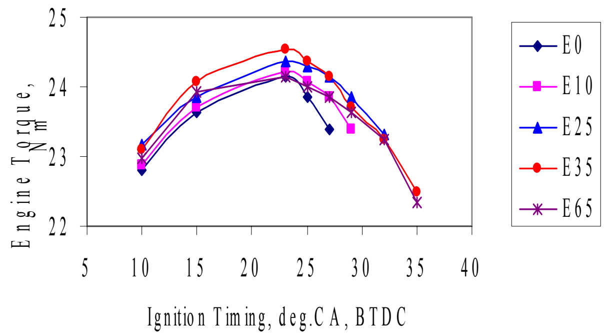

Figure 5. Variation of engine torque with ignition timing at the compression ratio of 11:1.

thermal efficiency.

Effects of equivalence ratio on BSFC and engine torque at compression ratio of 9:1 are shown in Figure 6 and 7. The influence of equivalence ratio on BSFC and engine torque at compression ratio of 11:1 is discussed in Figures 8 and 9. The minimum BSFC was obtained at 0.95 equivalence ratio for all test fuels and increased depending on ethanol percentages as depicted from Figures 6 and 8. Minimum BSFC was obtained at 11:1 compression ratio with E0 fuel. Comparison with 9:1 compression ratio, the BSFC decreased 9.25 %. The maximum decreasing of BSFC was obtained with E25 at 11:1 compression ratio. It is seen from Figures 7 and 9 that maximum torque was obtained at an equivalence ratio of 1.11 for all test fuels for both compression ratios 9:1 and 11:1. It was found that engine torque of ethanol-blended fuels was higher than that of E0 obtained at purer and richer working region than stoichiometric air-

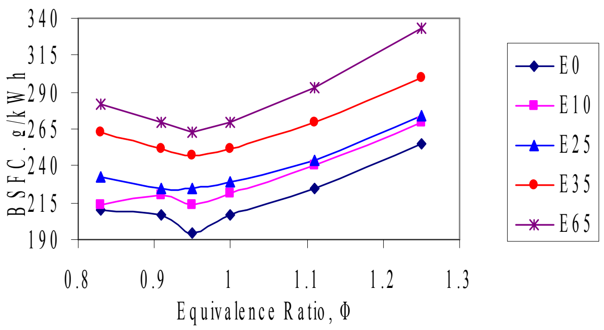

Figure 6. Variation of BSFC with equivalence ratio at the compression ratio of 9:1.

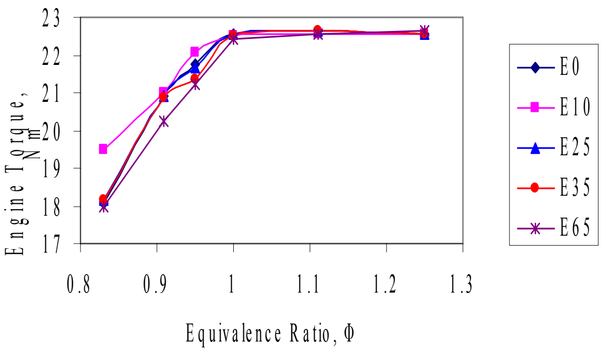

Figure 7. Variation of engine torque with equivalence ratio at the compression ratio of 9:1.

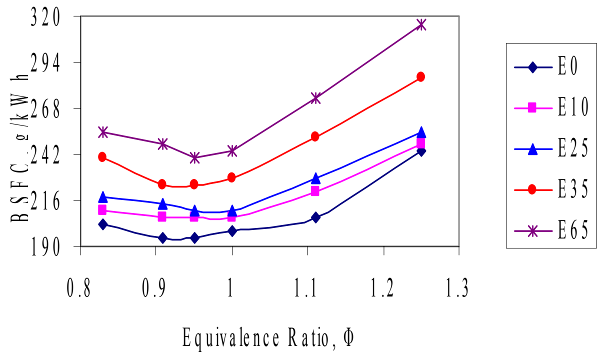

Figure 8. Variation of BSFC with equivalence ratio at the compression ratio of 11:1.

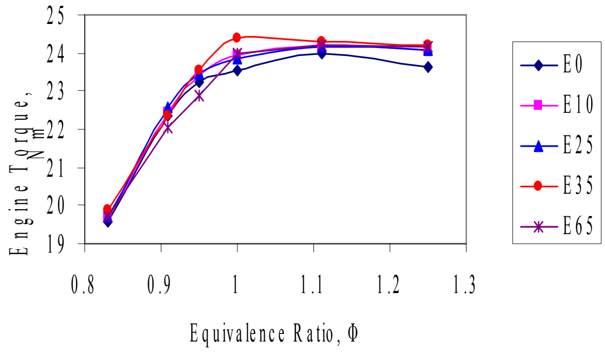

Figure 9. Variation of engine torque with equivalence ratio at the compression ratio of 11:1.

fuel ratio at both compression ratios of 9:1 and 11:1 as shown in Figures 7 and 9. As seen from Figure.7 there is an increase of 0.33 % for E0 in the brake torque when compared with E10 and E65 at an equivalence ratio of 1.11 at 9:1 compression ratio. Further, it was found that E0 showed no increase in brake torque when compared with E25 and E35. As seen from Figure 9 there is an increase of 0.93 % for E65 and E10 in the brake torque when compared with E0 at an equivalence ratio of 1.11 at 11:1 compression ratio. It is also revealed from Figure.9 that there is an increase of 0.62 % for E25 and 1.23 % for E35 in brake torque when compared with E0. Using E0, the engine torque increased with increasing compression ratio to 11:1, the increment is about 5.72 % when compared with 9:1 compression ratio.

The variation of the exhaust temperature with ignition timing at the compression ratio of 9:1 and

11:1 are shown in Figures 10 and 11. The ignition timing affects the in-cylinder gas temperature and the exhaust temperature. As shown in Figures. 10 and 11, increasing the ignition timing decreases the exhaust gas temperature. The results showed that blending unleaded gasoline with ethanol increases the brake torque due to the more efficient conversion process of heat to work. This also decreases the exhaust gas temperature. Depending on the amount of ethanol in the blend, the exhaust gas temperature was decreased. Increasing the ignition timing causes the combustion process to occur earlier in the cycle thus it decreases the exhaust gas temperature.

The variation of CO and HC emissions reduction with compression ratio, using different ethanol–unleaded gasoline blends E10, E25, E35, and E65 compared to E0 fuel, are depicted in Figures 12 and 13. As shown in Figure 12, CO emissions was decreased using different ethanol-unleaded gasoline blends over the test range of 9:1 to 11:1 compression ratio. The decrease in CO emissions with pure petrol E0 when the compression ratio was varied from 9 to 11 was found to be 13.2 %. Whereas, with E10, E25, E35, E65 the reduction under identical conditions was 16.11 %, 20.63 %, 23.33 % and 25 % respectively. Especially, considerable decrease was observed when the fuels contained higher amount of ethanol like E35 and E65. The most significant decrease in CO emission was observed with the use of E35 and E65 fuels at 1500 rpm engine speed at a compression ratio of 11. Average decrease in percentages of CO emissions was 43.42 % and 47.2 % for E35 and E65, respectively in comparison to E0 over the test range of 9:1 to 11:1 compression ratio. On the other hand, it was found that there is an increase in HC emissions for E0, E10, E25, E35, and E65 with increase in compression ratio from 9 to 11 as shown in Figure 13. As the compression ratio was increased, it was found that there is an increase in HC emissions. The increase in HC emissions with E0, E10, E25, E35, E65 when the compression ratio was varied from 9 to 11 was found to be 5.45 %, 3.72 %, 3.79 %, 3.2% and 2.68 %

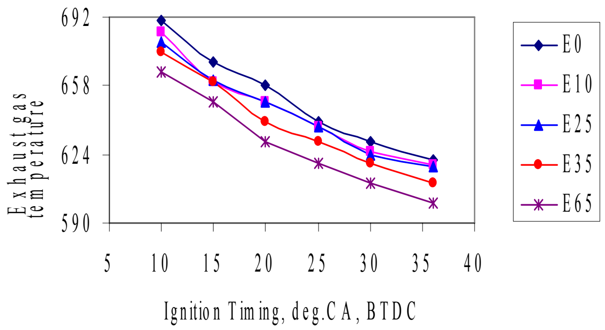

Figure 10. Variation of exhaust gas temperature with ignition timing at the compression ratio of 9:1.

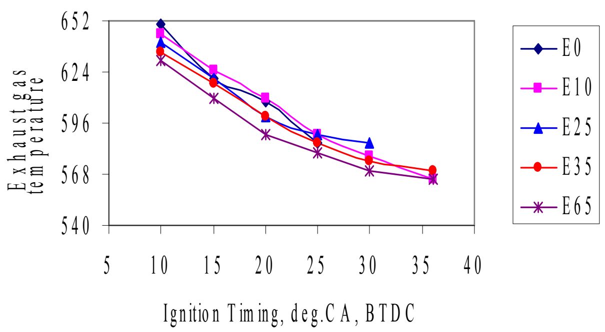

Figure 11. Variation of exhaust gas temperature with ignition timing at the compression ratio of 11:1.

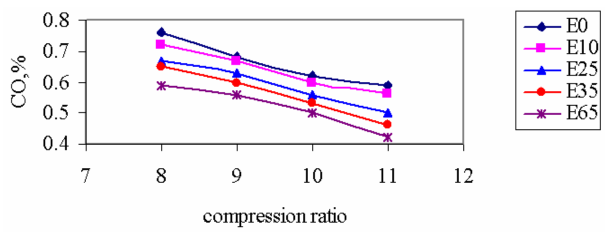

Figure 12. Variation percentages of carbon monoxide with compression ratio.

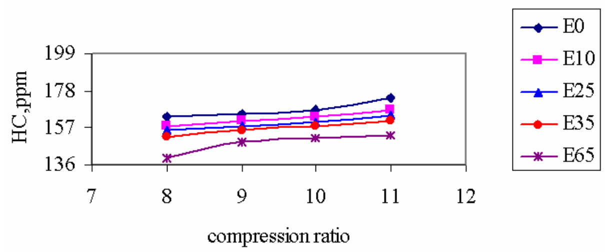

Figure 13. Variation of hydrocarbon emissions with compression ratio.

respectively. With respect to HC emissions, the highest decrease was found for E65 in comparison with E0. Decreasing ratio of HC emission was found to be higher than CO.

4. CONCLUSIONS

In this study, the effects of using unleaded gasoline and unleaded gasoline-ethanol blends on engine performance and exhaust emissions were investigated by varying the ignition timing and compression ratio. Based on the experimental study, the following results were obtained:

- Minimum BSFC was obtained at 11:1 compression ratio with E0 fuel. Comparison with 9:1 compression ratio, the BSFC decreased 9.25 %. The maximum decreasing of BSFC was obtained with E25 at 11:1 compression ratio.
- The minimum BSFC was obtained at 0.95 equivalence ratio for all test fuels and increased depending on ethanol percentages.
- Blending unleaded gasoline with ethanol increased the brake torque when the ignition timing was retarded.
- Ethanol addition did not increase the brake torque at all ignition timings at the compression ratio of 11:1. For ignition timing of 25˚ CA and over, the engine torque decreases. Advancing the ignition timing to 29˚ CA caused knock occurrence with E0 fuel. However, knock occurrence was not observed up to 35˚ CA advanced ignition timing with unleaded gasoline-ethanol blends (E35 and E65).
- Using E0, the engine torque increased with increasing compression ratio to 11:1, the increment is about 5.72 % when compared with 9:1 compression ratio.
- The variation of exhaust temperature with ignition timing at the compression ratio of 9:1 was very similar to the variation at the compression ratio of 11:1. Retarding the ignition timing caused the exhaust temperature to increase.
- The fuels containing high ratios of ethanol; E35 and E65 had significant effects on the reduction of exhaust emissions.
- The addition of 35 % ethanol and 65 % ethanol to the unleaded gasoline gave the best results for reduction of CO emissions by about 43.42 % and 47.2 %, respectively in comparison to E0 over the test range of 9:1 to 11:1 compression ratio.
- In respect of HC emissions, the highest decrease was found for E65. Decreasing ratio of HC emission was found to be higher than that of CO emissions.
- From the present findings, we can conclude that using ethanol as a fuel additive to unleaded gasoline causes an improvement in engine performance and exhaust emissions.
- By making the necessary modifications to the engine we could successfully add 65 % ethanol to the unleaded gasoline in our experiment without any problem during engine operation.

5. ACKNOWLEDGEMENTS

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6. APPENDIX-I

Specifications:

Make:	Kirloskar
Model:	AV1
Number of Cylinders:	One
Position:	Vertical
Arrangement of Valves:	Overhead
Cooling Medium:	Water
Cycle:	Four Strokes
Ignition:	Compression Ignition (before modification)

Combustion chamber form:	Cup in Piston
Rated Power:	3.7 kW
Rated Speed:	1500 rpm
Bore:	80 mm
Stroke:	110 mm
Cylinder Capacity:	552.64 cc
Compression Ratio:	18.35 (before modification)
Dynamometer:	Electrical-AC Alternator
Cylinder Pressure:	By Piezo Sensor
Starting:	Auto Start Facility
Exhaust Gas Calorimeter:	Ind. Labs Company Make
Orifice Diameter:	15 mm

This engine was converted for spark ignition and carburetion to suit ethanol fuel.

Parameters

Compression Ratio:	Made Variable (with modified engine head) from 4 to 11.
Fuels Used:	Ethanol and Petrol
Ignition (after modification):	Spark Ignition
Computer Interface:	For Indicated Power (I.P) Measurement
Exhaust Gas Recirculation:	For Admitting a Part of Exhaust Gas Back into the Engine Cylinder

Measurements

Ethanol Flow:	Measured Using Pipette Reading for a Known Time
Air Flow:	Measured by Manometer Connected to the Air Tank
Loading:	Different Electrical Loadings by Switching off Air Heaters (in steps of 20 %) in Steps Connected to Dynamometer.
Cylinder Pressure:	Measured Using Piezo Sensor, which is Fitted at Top of the Engine Head.
Water Flow:	By Water Meter
Speed:	Measured Using Proximity rpm Sensor Connected to Digital rpm Indicator

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