INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 1, Issue 4, 2010 pp.715-726
Journal homepage: www.IJEE.IEEFoundation.org

Emission reduction in SI engine using ethanol – gasoline blends on thermal barrier coated pistons

C.Ananda Srinivasan, C.G.Saravanan

Faculty of Engineering and Technology, Department of Mechanical Engineering,
Annamalai University, Annamalai Nagar -608 002.Tamil Nadu, India.

Abstract
In this study, the effects of ethanol and unleaded gasoline with Isoheptanol blends on multi- cylinder SI engine were investigated. The test fuels were prepared using 99.9% pure ethanol and unleaded gasoline with Isoheptanol blend, in the ratio of E 60 + 2.0 Isoheptanol, E 50 + 1.0 Isoheptanol. In this work the performance, emission and combustion tests were conducted in multi-cylinder petrol engine. The experimental results reveal an increase in brake thermal efficiency on the use of test fuel. In the emission test, CO is found slightly decreased, while HC increased moderately and CO_2 and NOx are appreciably reduced, when compared to the sole fuel. The second part of the investigation is carried out in the same engine with Alumina Titania coated crown of the pistons, to gain more inside improvement of engine performance and in-cylinder pressure for coated pistons. The experiment is repeated along with fuel additives and ethanol blends in the same blended ratio to analyse the performance and combustion characteristics of the engine. The results show marginal increase in brake thermal efficiency and reduction in CO, NOx, HC and CO_2 emissions. In this study, combustion analyses are made with the help of AVL combustion analyzer, in which cylinder pressure, heat release rate and cumulative heat release are performed.

Keywords: CO – Carbon monoxide, HC – Unburnt Hydrocarbon, CO_2 – Carbon dioxide, O_2 – Oxygen, NOx – Oxides of Nitrogen, Isoheptanol, Alumina Titania coated pistons.

1. Introduction
Thermal barrier coatings (TBCs) have been applied to the internal combustion engine, in particular the combustion chamber and cylinder liner to act as low heat rejection engine. The application of TBC reduces the heat loss to the engine cooling water jacket through the surfaces exposed to the heat transfer such as cylinder head, liner, pistons crown and piston rings. The insulation of the combustion chamber with ceramic coatings affects the combustion process and hence there are changes in the performance and exhaust emissions of the engine. [1]
The increased use of fossil fuels for energy production is rapidly depleting the reserves of petroleum based fuels. It is well known that the fast decrease in the future availability of energy resources as well as the need for reducing the emissions from the fuels used has increased the need for the utilization of regenerative fuels. [2]
Alcohol such as ethanol, a colorless liquid with mild characteristic odor can be produced by fermentation of biomass crops, such as sugarcane, wheat and wood. The usage of alcohol as fuel for SI engine has

some advantages than gasoline. Ethanol has better anti – knock characteristics than gasoline. The thermal efficiency of the engine can be improved with the increase in compression ratio. [3] Alcohol burns with lower flame temperature and luminosity owing to the decrease in peak temperature inside the cylinder as a result of heat loss and NOx emission also found decreased. Ethanol has high latent heat of vaporization. The latent heat cools the intake air and hence there is an increase in density and volumetric efficiency. However, the oxygen content of ethanol reduces the heating value compared to gasoline. It is evident that Ethanol can be used as fuel in SI engines. [4]

Hsieh et al, [5] investigated the engine performance and emission of a spark ignition engine, experimentally using ethanol–gasoline blended fuels in the ratio of 5%, 10%, 20% and 30% respectively. The results showed that when the ethanol rate was increased the heating value of the blended fuel was found decreased but at the same time it increased torque of the engine.

Ethanol has high affinity for water. But this is not a problem for pure ethanol because it fully mixes with water, any how some serious problem may arise when gasoline – ethanol blends are used. Phase separation can also occur in gasoline – ethanol blends as gasoline and ethanol are immiscible. This problem can be overcome by using semi – polar co-solvents (solubility improvers) such as isopropanol. [6]

Guerrieri et al. [7] tested gasoline and gasoline–ethanol blends on six in-use vehicles to determine the effects of ethanol content on emissions and fuel economy. HC and CO emissions as well as fuel consumption found decreased in most vehicles, when the ethanol content was increased in the fuel. At the highest ethanol concentration of 40%, HC emission, CO emission and fuel consumption was found decreased by about 30%, 50% and 15%, respectively. Wu et al. [8] investigated the effect of air–fuel ratio on SI engine performance and pollutant emissions using ethanol–gasoline blends. The engine performance tests showed that torque output improved when ethanol– gasoline blends were used. However, there was no appreciable difference in the brake specific heat consumption. Hence CO and HC emissions were reduced when there is an increase in ethanol content in the blended fuel. It is proved in their study that by using 10% ethanol fuel, pollutant emissions can be reduced efficiently. He et al. [9] investigated the effects of ethanol–gasoline blends on emissions and catalyst conversion efficiencies in a spark ignition engine. It is proved that the blended fuels reduced CO, HC and NOx emissions.

General conclusions arrived from the above literature review are that ethanol can be produced abundantly and economically and it will be an attractive alternative fuel for S.I. engines. It can be used either as a pure fuel or as a gasoline additive. Gasoline – ethanol blends including ethanol at low proportions can be used without any modifications in the engine but pure ethanol usage requires major modifications to the engine design and fuel system. Fuel modification technique is employed in the form of fuel additives blended with gasoline or ethanol – gasoline blends that enhance the fuel properties. One of the promising techniques using fuel additives to improve the performance of the engine by oxygenates (oxygen containing organic compounds). Palmer [10] reported that all oxygenated blends gave a better anti – knock performance during low speed acceleration than hydrocarbon fuels of the same octane range. Consequently, the use of gasoline – ethanol blends with fuel additives in the S.I. engines is more practical than using ethanol alone. Based on this, the present experimental studies have been focused on fuel modification technique using gasoline – ethanol blends with fuel additives on S.I. engine to analyse the performance, combustion analyses and exhaust emissions.

This paper aims at running the engine with different percentage of blending of gasoline and ethanol with the oxygenated additive Isoheptanol to reduce the exhaust emissions and also to increase the brake thermal efficiency of the engine with and without Alumina Titania coated pistons.

The percentages of blending are given in Table 1.

Table 1. Sample volumetric composition

Sample Name	Gasoline	Ethanol	Isoheptanol
Sample 1	49	50	1
Sample 2	38	60	2
Sole Fuel	100	-----	-----

Table 2. Properties of different fuels

	Sole fuel	Sample 1	Sample 2
Calorific value in MJ/kg	44	47.645	47.582
Specific gravity	0.7	0.751	0.757
Density@15^0C in gr/cm^3	0.72	0.7675	0.7735
Kinematic viscosity @ 40^0C in m^2/sec.	0.88E-4	0.76E-4	0.84E-4
Flash Point by Abel Method	-43^0C	-41^0C	-39^0C

Table 3. Error analysis

Parameters	% of Errors
O_2	1.05
NOx	0.94
HC	1.03
CO	0.09
λ	0.5

2. Experimental setup

Two sets of experiments namely, base-line test and thermal barrier pistons coated test were conducted. An inclined, water cooled, three cylinders, four stroke, 86.5 mm bore, 72mm stroke, and 796 cc displacement, 8.7:1compression ratio, 12.56 kW power with rated speed of 3000 rpm, engine was used for the experimental work. The engine was coupled to an eddy current dynamometer for load measurement. Hydrocarbon, carbon monoxide and Carbon dioxide emissions were measured by using AVL 5 – gas analyzer. NOx emissions were measured by using exhaust gas analyzer.

Combustion parameters were analyzed by using AVL combustion analyzer. The cylinder pressure, heat release rate and maximum pressure were analyzed. The cylinder pressure was measured with the help of a piezoelectric air – cooled transducer. An AVL make transducer with a sensitivity of 16.11 pC/bar was used for the purpose.

The experiments were performed at variable speeds of 2000, 2200, 2400, 2600 and 2800 rpm respectively with constant output of 7.53 KW. The volumetric percentages of ethanol – gasoline blends with additives were E60 + 2.0, E50 + 1.0. These represent the ratios of ethanol and Isoheptanol amount in the total blended. Ethanol with a purity of 99.9% was used in the blends. The schematic view of the test equipments is shown in Figure 1. The test engine was standard spark timing with 10^o bTDC. The engine was operated in Stoichiometric air fuel ratio for sole fuel only.

After completing the experiment with gasoline, the experiment was further conducted with blend fuel sample 1 and sample 2; Fresh gasoline procurements were made for experiments with each sample blend to reduce the effect of storing. Hence to compare the results of the sample blend runs, base line values with gasoline were obtained separately for each sample blend. After completing the experiments with the first sample blend, the engine was allowed to run for about half an hour with gasoline to eliminate the interference of the first sample blend. Then for each sample blend, after completion the gasoline run was repeated. The entire sample blends were tested by similar procedure. In the second stage the experiment was repeated with the Alumina Titania coated pistons. Thermal Conductivity of Alumina Titania is 33 W/m-K. and hence it is used it as a coating material.

3. Results and discussion

The effects of ethanol addition to gasoline with additives on SI engine performance and exhaust emissions at variable engine speeds were investigated.

3.1 Brake thermal efficiency

The effect of the gasoline – ethanol with Isoheptanol blends on the brake thermal efficiency is shown in Figure 2. The brake thermal efficiency is found higher for all the samples when compared to the use of sole fuel. The brake thermal efficiency is 32 % for sample 1 with coated pistons at 2600 rpm is higher when compared to the other samples and sole fuel. A marginal increase of brake thermal efficiency is observed for all samples at all speeds as shown in Figure 2. Among the samples, sample 1 with coated pistons shows the maximum brake thermal efficiency. This is due to the increase in cylinder pressure and heat rejection for coated pistons that increases the brake thermal efficiency of the engine. This is also due to the higher octane number of the samples. Hence it is evident that the blended fuel has relatively higher calorific value of 47.645 MJ/kg than gasoline. This is due to the addition of fuel additives that enhance the Calorific value of the fuel. The combined effect of coated pistons with fuel additive significantly increased the brake thermal efficiency of the engine.

3.2 CO emissions

The effect of the gasoline – ethanol with Isoheptanol blends, on CO emissions is shown in Figure 3. It can be seen that ethanol with oxygenated additive concentration increases as well as reduces the CO emission. It is noted that in sample 1 and sample 2 with coated pistons at 2000 rpm, the concentration of CO emission decreases by about 0.07 % by volume. The reduction rate of CO emissions at 2000 rpm is slightly less. The variation of CO emission for sample 1 and sample 2 coated pistons is less when compared to other samples and sole fuel. The reason is that the increase in the percentage of ethanol and additive concentrations as a result of leaner combustion due to the presence of oxygen in ethanol. Owing to the leaning, CO emissions decrease tremendously. In general, for all concentration blends CO emissions are reduced when concentration increases. The CO emission without coated pistons follows the same trend for all samples and sole fuel. Coated pistons contribute lower CO concentration than other samples.

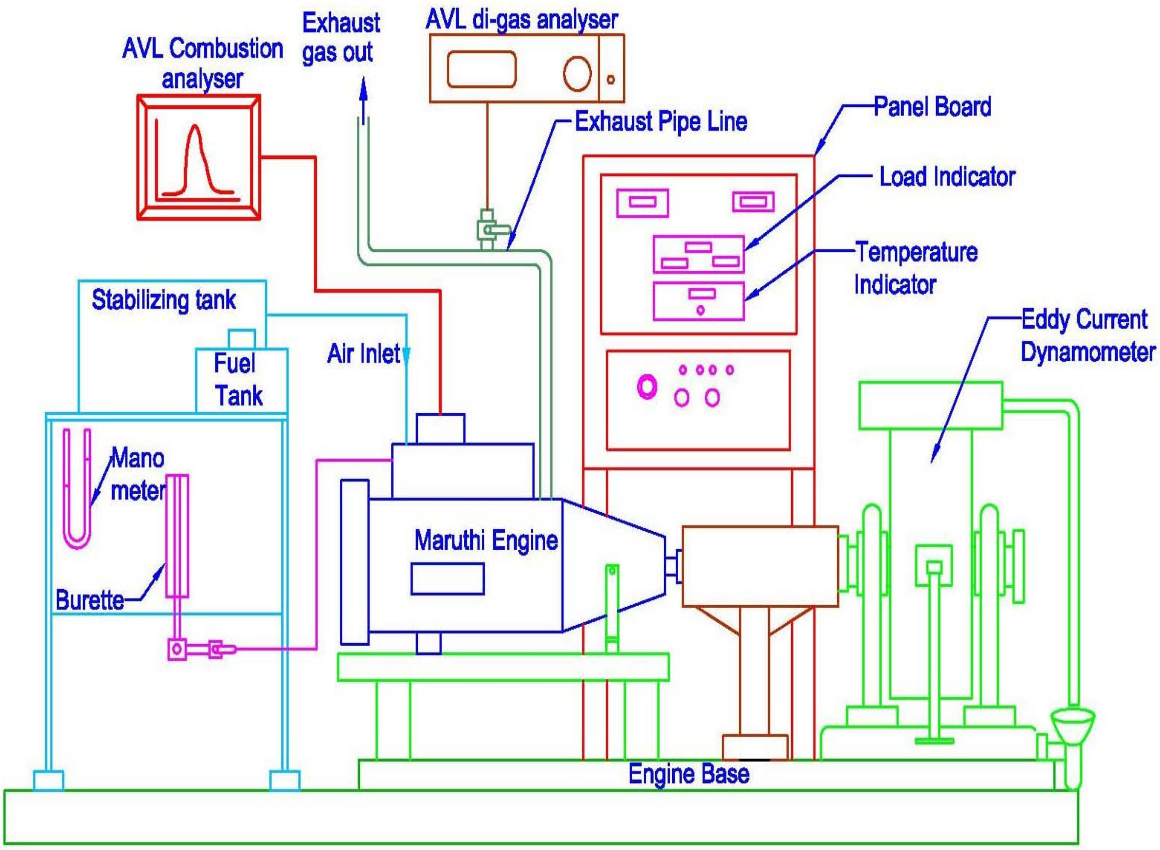

Figure 1. Experimental setup

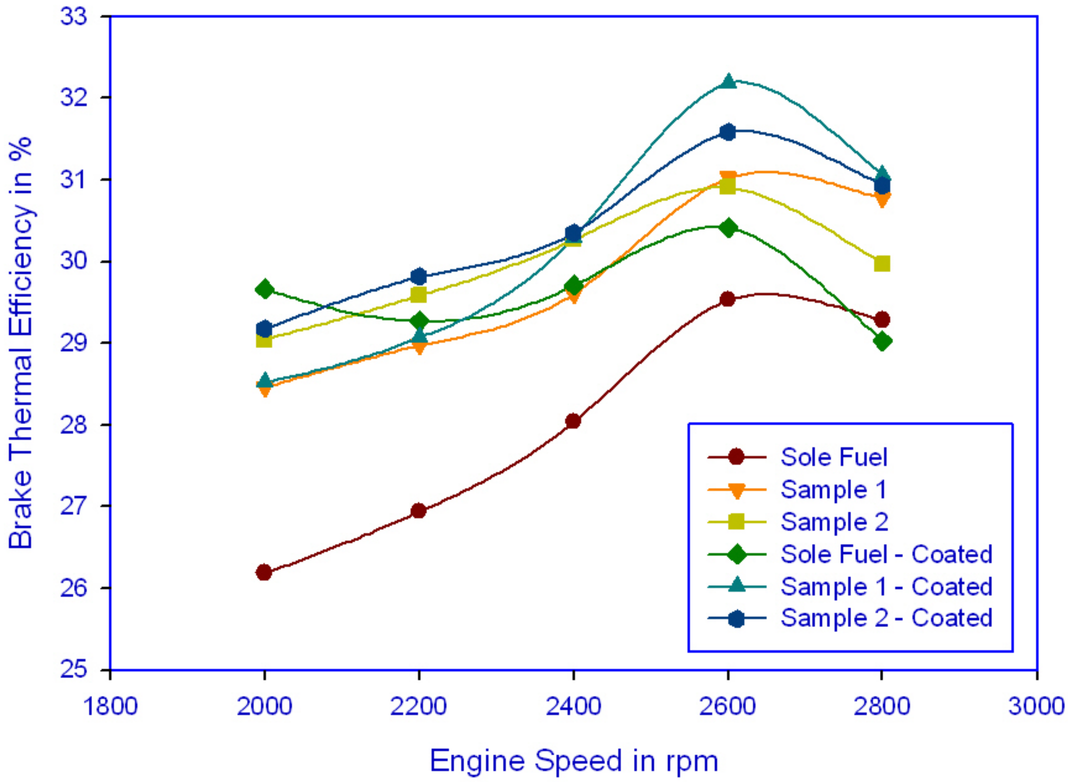

Figure 2. Brake thermal efficiency Vs engine speed

3.3 CO_2 emissions

The effect of the gasoline – ethanol with Isoheptanol blends, on the CO_2 is shown in Figure 4. It is found that the increase in speed, the CO_2 emissions gradually decreased. It indicates the complete combustion of the fuel in the combustion chamber. In sample 2 the CO_2 value is 7.7 % by volume at 2800 rpm is maximum when compared to other samples. It is obvious that there is significant reduction in CO_2 emissions when ethanol blends samples are used with Alumina Titania coated pistons. There was appreciable reduction in sample 2 when compared to other samples. This is due to the maximum blend of Isoheptanol in the ethanol – gasoline blends.

3.4 HC emissions

Figure 5 shows the effect of alcohol percentage in the blend additives on the HC emissions. The samples without coating were found to increase the HC emissions at all speeds. At this point it is to be noted that, ethanol has lower flame speed compared to sole fuel operation. As a result, less mass fraction of fuel is burnt in the case of ethanol blended gasoline. These factors along with increasing quench volume, because of cooling effect of ethanol in combustion chamber enhances the HC emissions. The ethanol cooling effect increases engine volumetric efficiency. But with coated pistons the HC emission it found decreased when compared to the other samples without coating.

3.5 NO_X emissions

The effect of the gasoline – ethanol with Isoheptanol blends on the engine speed is shown in Figure 6. It can be seen that ethanol gasoline blend decreases NOx emission. This is the main reason attributed to the properties of ethanol blends. For sample 2 it is found that NOx level is significantly reduced for all speeds. The reduction in NOx level ranges from 1000 to 800 ppm for sample 2. It is noted that the other samples also follow the same trend. But, NOx emission for sample 2 is slightly less than that of the other samples. Ethanol decreases the combustion heat energy and lowers the combustion temperature in the cylinder. The major factors contributing to NOx emissions include high flame temperature and presence of excessive oxygen during combustion. Because of the lower flame temperature of ethanol combustion, NOx emissions are lower than gasoline. The NOx emission results are significantly higher in the coated pistons which are evident for higher cylinder pressure in p – θ diagram (Figure 8).

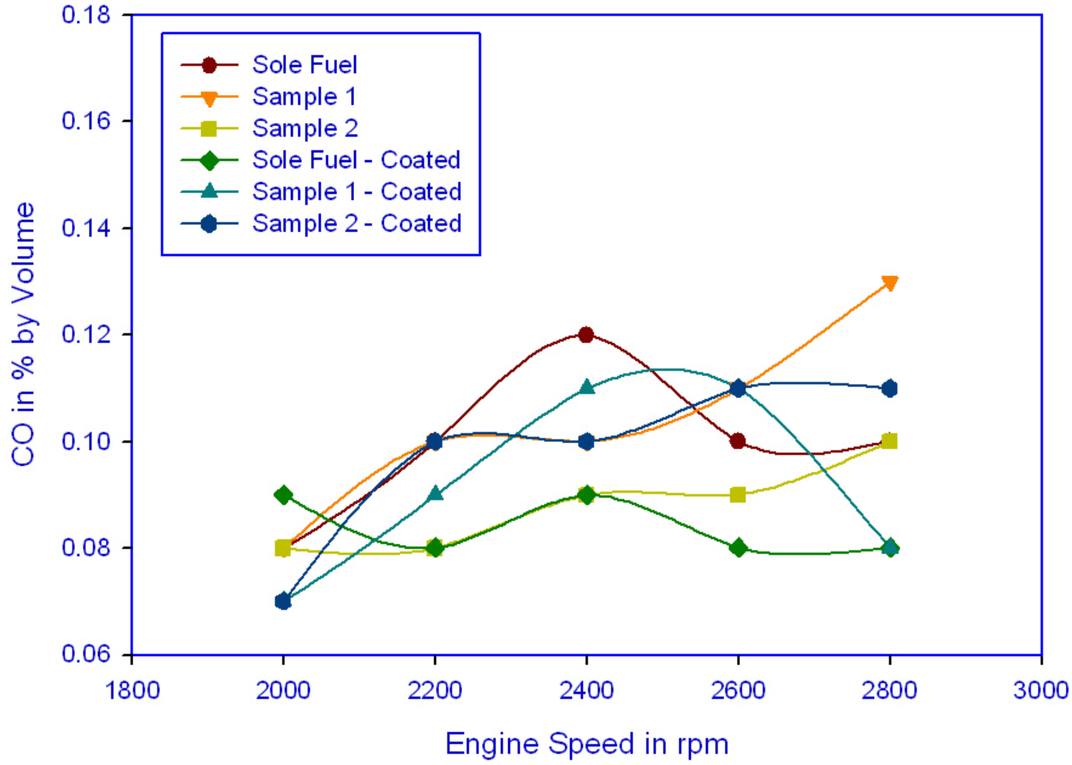

Figure 3. CO Vs engine speed

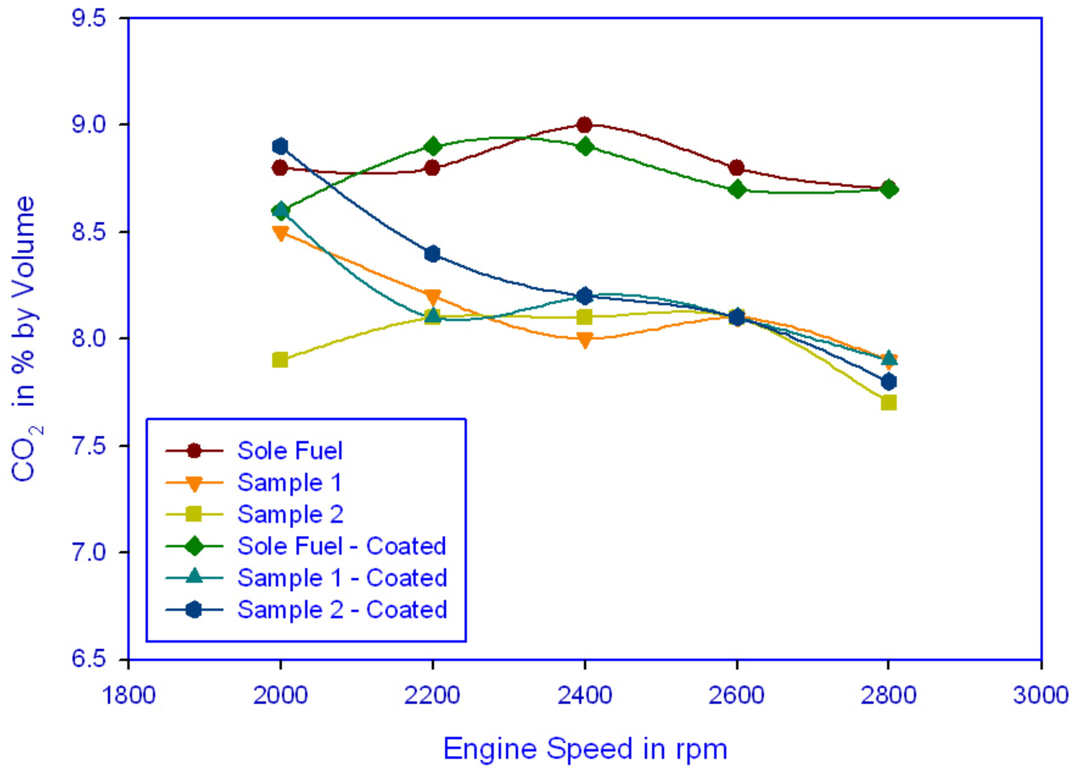

Figure 4. CO_2 Vs engine speed

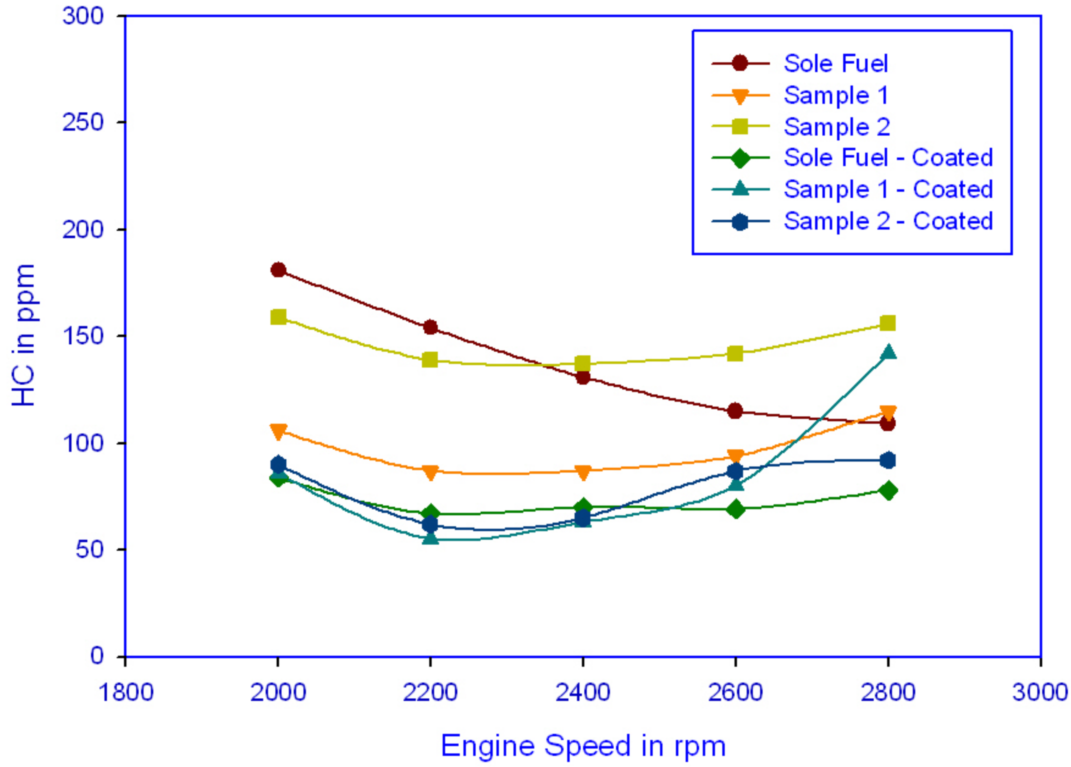

Figure 5. HC Vs engine speed

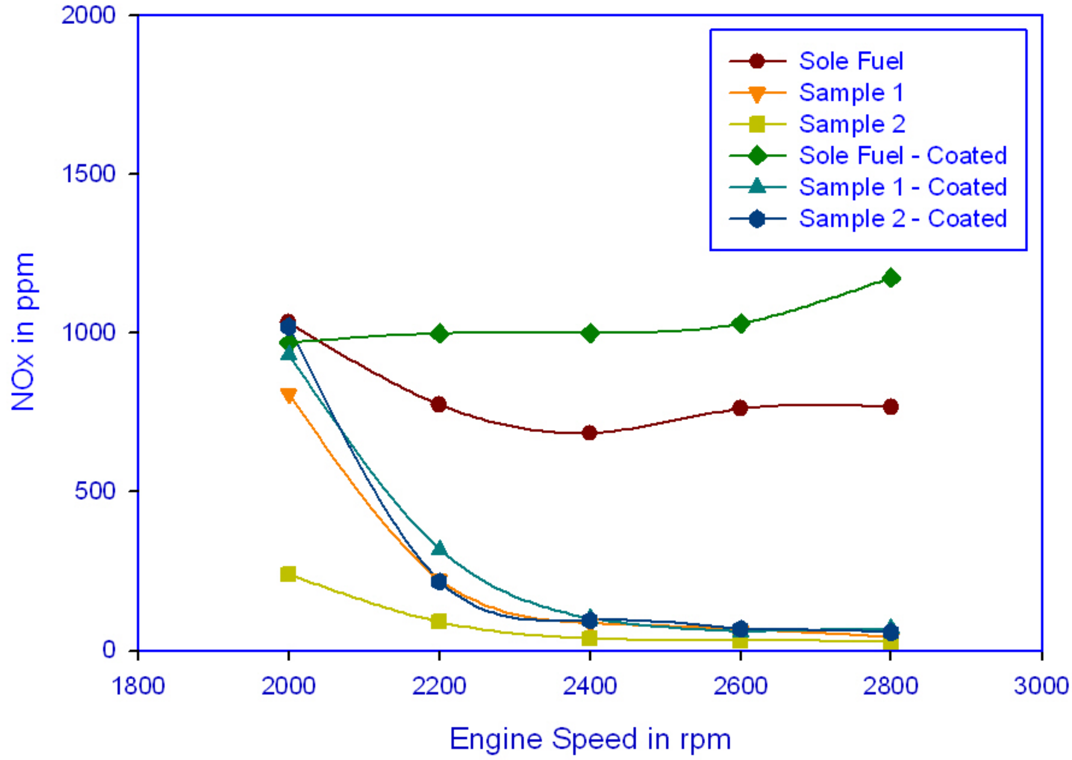

Figure 6. NOx Vs engine speed

3.6 O_2 emissions

The effect of the gasoline – ethanol with Isoheptanol blends, on the Engine Speed is shown in Figure 7. All the samples where found to increase the O_2 emissions at all speeds. In sample 2 it is found, the maximum oxygen content in the exhaust gas is 9.85 % by volume at 2800 rpm. The reason for the increase in oxygen content in the exhaust gas is due to the increase in ethanol and additive percentage.

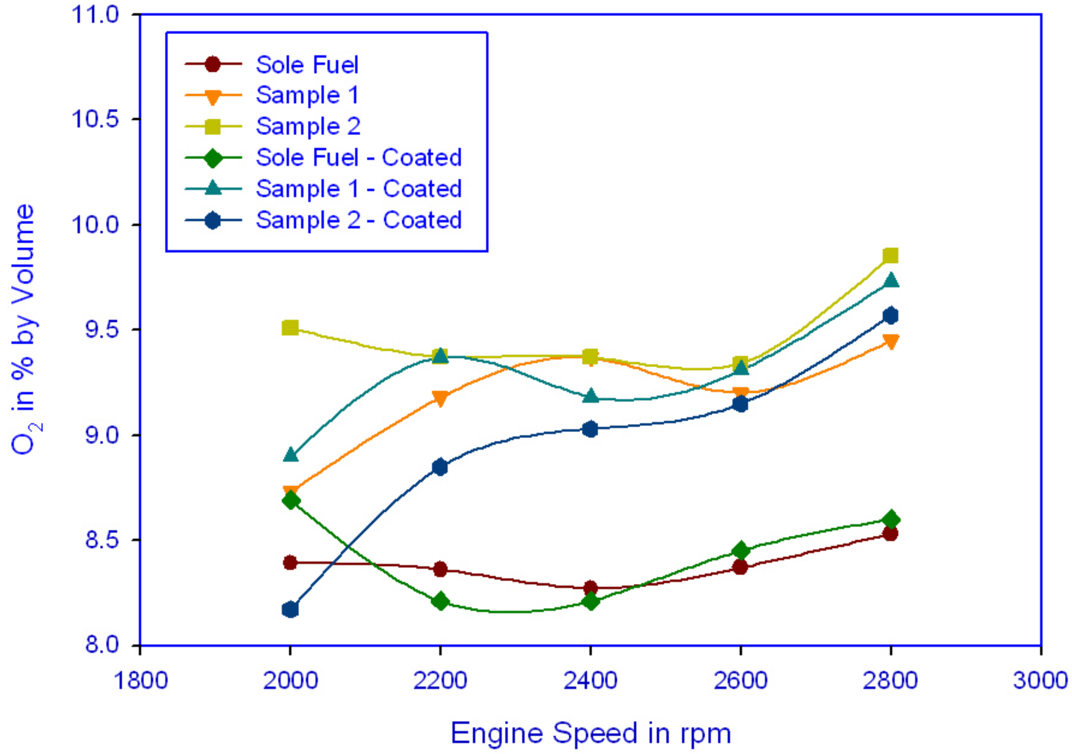

Figure 7. O_2 Vs engine speed

4. Combustion analysis

The S.I. engines do not maintain perfectly a stable operation under steady state conditions and the cyclic variations have inconsistency of the combustion process and appear to cause higher engine emissions. Hami et al [11] studied the incomplete mixing of fuel; air and residual contribute cycle variations during combustion. After reviewing the literature on S.I. engine and its influence on cyclic variations it is found that good spark ignition system reduces cycle variations. In this study combustion analyses are made with maximum load of 40 N at 3000 rpm.

4.1 Pressure and crank angle

Figure 8 shows the test results comparison of cylinder pressure between base-line, coated pistons and fuel additive. The cylinder pressure was found significantly higher for sole fuel with coated pistons. This is due to the low heat rejection to the cylinder walls. The increase in cylinder pressure is due to increase in trapped gas temperature in the combustion chamber. The maximum cylinder pressure for sample 1 with coated pistons is 53 bar pressure followed by the other samples. If the engine is fuelled with gasoline and blends, the peak pressure is obtained 10^0 after TDC as in Figure 9. This value is nearly equal to 26 % of pressure obtained when the engine is operated with gasoline. The effect of blending of additive has highest heating value than ethanol and consequently produces highest peak pressure on combustion.

4.2 Heat release rate

Figure 9 shows the heat release rate that varies with the crank angle. For the coated pistons the rate of heat release is faster and reaches a peak at 15^0 after TDC. It is observed that sample 1 with coated pistons slightly decreases the heat release rate which comes down sharply because of the amount of unburnt fuel available due to the quenching effect. This is the main reasons for the reduction in heat release rate for the ethanol – gasoline blended fuels. The other samples have more or less the same effect of heat release rate. This may be due to the lower heating values and more percentage of blends of ethanol in gasoline. The heat release is calculated by the inbuilt software provided by AVL combustion analyzer.

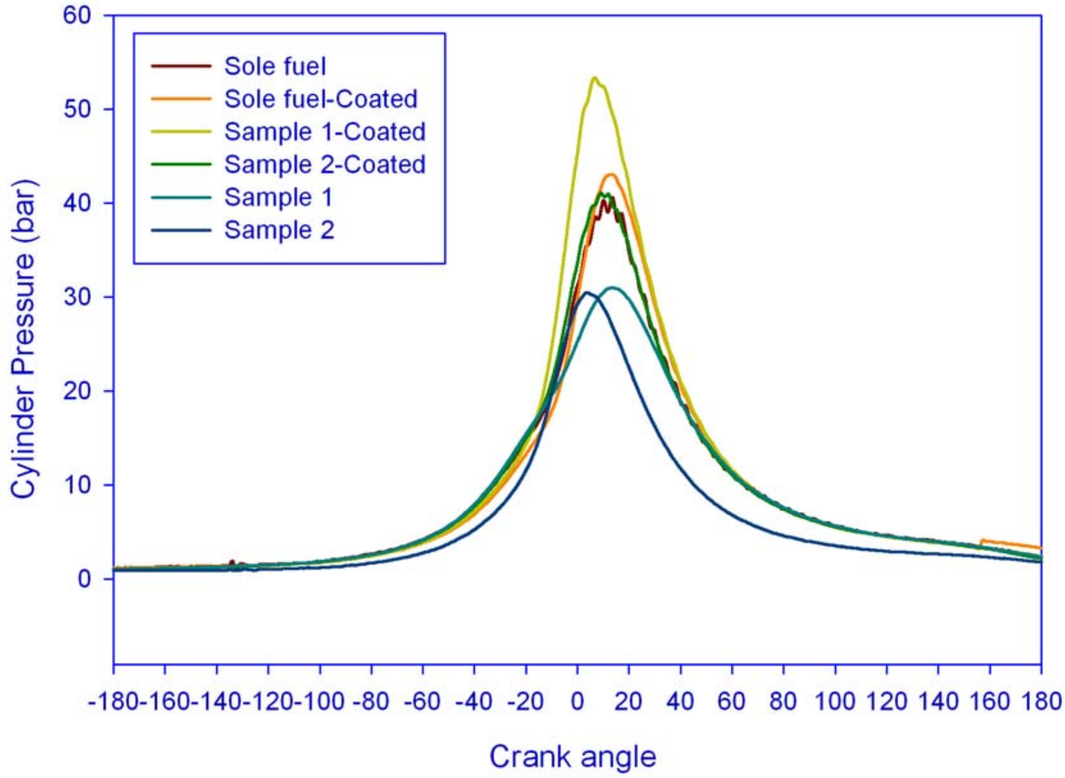

Figure 8. Cylinder pressure Vs crank angle

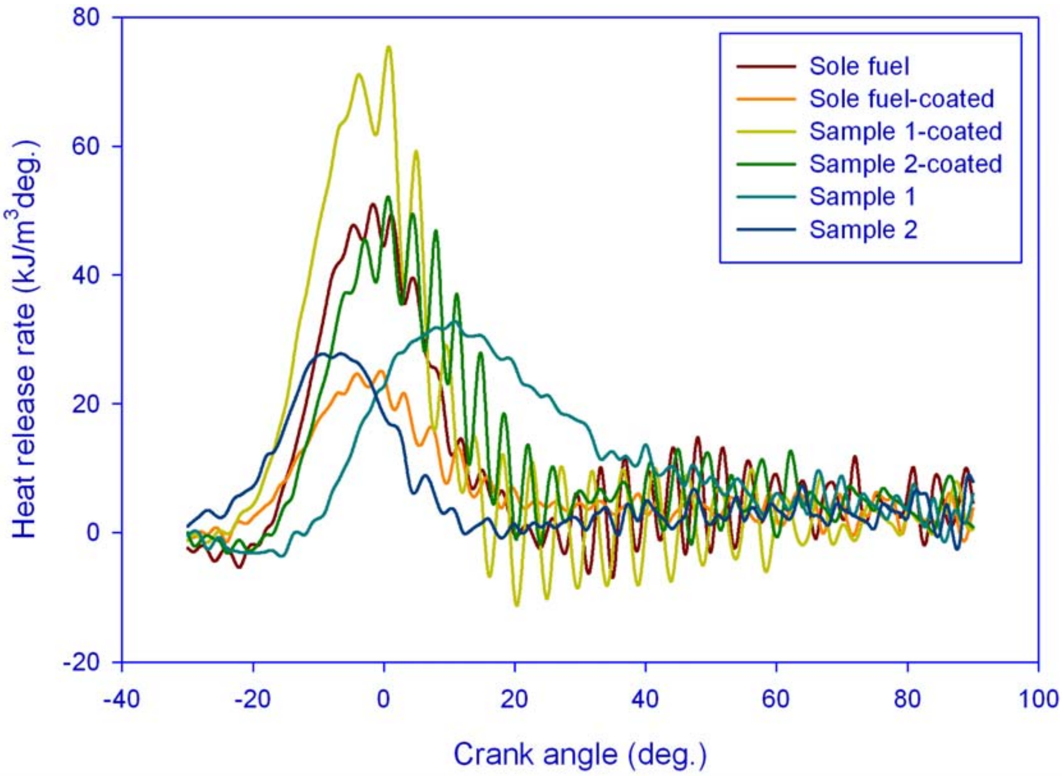

Figure 9. Heat release rate Vs crank angle

4.3 Cumulative heat release

Figure 10 shows the comparison of the cumulative heat release rate between the standard engine and coated engine. In general, the coated engine results show higher cumulative heat release rate than other samples. The maximum difference was 800 kJ/m^3 at 3000 rpm with 80^o crank angle. The increase in cumulative heat release rate reduces the exhaust gas temperature in the coated pistons engine correspondingly improving the thermal efficiency of the engine.

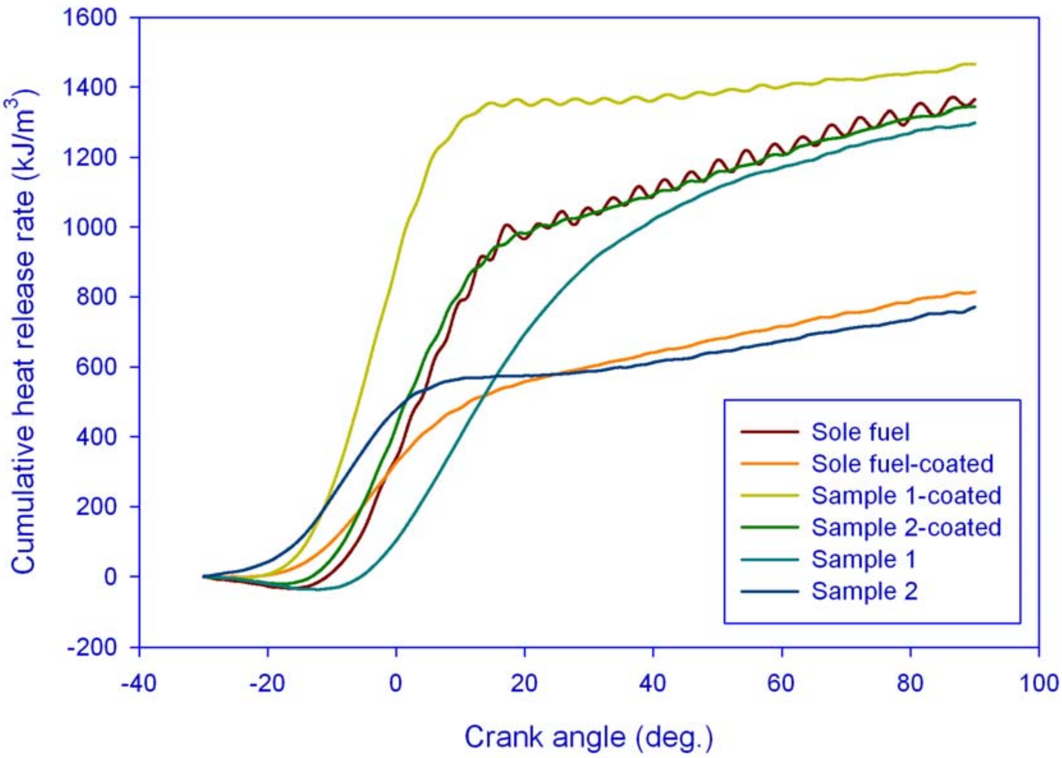

Figure 10. Cumulative heat release Vs crank angle

5. Conclusion

From the study, the following conclusions can be deduced:

1. Coated pistons with ethanol blend and oxygenated additive to gasoline causes improvement in engine performance and reduces exhaust emissions.
2. Coated pistons with ethanol blended gasoline leads to a significant reduction in exhaust emissions. For all engine speeds the values of CO, CO_2 and NOx are found reduced. On the other hand HC emissions have increased significantly.
3. Coated pistons with Ethanol addition and oxygenated additive results in the increase in brake thermal efficiency with 32 % at 2600 rpm for the sample 1 with coated pistons gives the best results for the engine performance.
4. The sample 2 with combined effect of coated pistons with ethanol blend and oxygenated additive gives the best results for the exhaust emissions.
    i. The CO emission is reduced to 0.07 % by Volume at 2000 rpm
    ii. The CO_2 emission is reduced to 7.8 % by Volume at 2800 rpm
5. For the NOx emission, sample 2 without coated pistons gives the best results with 28 ppm. And also O_2 , is increased to 9.85 % by Volume at 2800 rpm
6. The addition of 60% of ethanol blend gasoline with oxygenated additive is achieved in our experiments without any problem during engine operation. However, without additives the performance gave better result up to 40 % beyond that it is absorbed that abnormal combustion, vibration and starting problem is achieved in our experimental investigation.
7. The sample 1 with coated piston in combustion analyses occurs the maximum cylinder pressure with a value of 53 bar.
8. In the heat release rate, sample 1 with coated pistons is higher when compared to the other samples with 70 kJ/m^3 deg.

9. The cumulative heat release rate is achieved to the maximum value for sample 1 with coated pistons with 1466 kJ/m^3.

References

[1] siew Hwa chan. Performance and emission characteristics of a partially insulated gasoline engine, Journal of Thermal science 2001, 40, 255 – 261.
[2] Jian Gao, Deming Jiang, Zuohua Huang. Spray properties of alternative fuels: A comparative analysis of ethanol–gasoline blends and gasoline, Journal of Fuel 2007, 86, 1645–1650.
[3] Owen Keith, Coley Trevor, Automotive fuels reference book, 2nd Edition. New York: SAE. 1995
[4] Serdar, H. Yu¨cesu, Adnan Sozen, Tolga Topgu, Erol Arcakliog, Comparative study of mathematical and experimental analysis of spark ignition engine performance used ethanol–gasoline blend fuel,Journal of Applied Thermal Engineering 2007, 27, 358–368.
[5] Hsieh, W.D., Chen, R.H., Wu, T.L., Lin, T.H., Engine performance and pollutant emission of an SI engine using ethanol–gasoline blended fuels, journal of Atmospheric Environment, 2002, 36 (3), 403–410.
[6] Al-Hasan, M., Effect of ethanol–unleaded gasoline blends on engine performance and exhaust emission, Journal of Energy Conversion and Management, 2003, 44, 1547–1561.
[7] Guerrieri, D.A., Caffrey, P.J., Rao, V., Investigation into the vehicle exhaust emissions of high percentage ethanol blends, Journal of SAE 1995, Paper No: 950777, 85–95.
[8] Wu, C.W., Chen, R.H., Pu, J.Y., Lin, T.H., The influence of air–fuel ratio on engine performance and pollutant emission of an SI engine using ethanol–gasoline blended fuels, Journal of Atmospheric Environment, 2004, 38 (40),7093–7100.
[9] He BQ, Wang JX, Hao JM, Yan XG, Xiao JH., A study on emission characteristics of an EFI engine with ethanol blended gasoline fuels, Journal of Atmospheric Environment, 2003, 37(7), 949–57.
[10] Palmer FH, Vehicle performance of gasoline containing oxygenates, paper C319/86. In: International Conference on Petroleum Based Fuels and Automotive Applications. London: I. Mech. E Conf. Publication 1986-11, MEP; pp. 36–46.
[11] Hami, K., Kawajiri, H., Ishizuka T., Nakai, M., (1986), "Combustion Fluctuation Mechanism Involving cycle – to – cycle Spark Ignition Variation due to Gas Flow Motion in S.I. Engines", Twenty First Symposium (International) on combustion.

C.Ananda Srinivasan degree and master's degree from Annamalai University, Tamil Nadu, India. Ph.D. pursued from the same university. He has published 7 papers in Conferences and Journals. He got project worth of Rs. 53.9 Lakhs [INR]. Member in Combustion Institute (Indian Section) & Member in Indian Society of Technical Education, He is working as a Lecturer [Senior Scale] in the Department of Mechanical Engineering, Annamalai University.
E-mail address: anandsrinivasa@yahoo.com

C.G.Saravanan degree from University of Madras, master's degree from Annamalai University, Ph.D. from Anna University, Tamil Nadu, India. He has published More than 70 papers in Conferences and Journals. He guided 6 PhDs. and got project worth of Rs. 1.63 Crore [INR] Executive Member in Combustion Institute (Indian Section), Member in Indian Society of Technical Education, Member in SAE (Indian Section) & Member in Energy and Fuel User's Association of India. He is working as a Professor in the Department of Mechanical Engineering, Annamalai University.
E-mail address: rsdk66@yahoo.com

