ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Effect of Alumina coating on Performance and Emission characteristics of a Single Cylinder Spark Ignition engine with Ethanol-Gasoline blends.

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ABSTRACT

The contribution of automotive pollution towards environmental hazards has been increasing to a greater extent and necessary steps are being investigated to develop a greener environment. This experimental investigationfocuses on the effect of alumina ceramic coating on the piston of a single cylinder spark ignition engine, with Ethanol-Gasoline blend as fuel. 0.1 mm of alumina was deposited by thermal detonation spraying on the piston crown to enhance the engine efficiency. The performance and emission characteristics of the uncoated standard piston and alumina-coated piston were compared with variation in Ethanol-Gasoline blend. It was noticed that BSEC gradually reduced with the addition of Ethanol and furthermore decreased with LHR coating. The BTE and Mechanical efficiency exhibited positive increase with LHR coating and Ethanol-Gasoline blends. The UBHC and CO emission was found to decrease significantly with a marginal increase in NO_x emission.

Keywords: LHR, Performance, Emission, Ethanol, Alumina.

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INTRODUCTION

Complete utilization of fuel energy and reduction of harmful emissions are the prime concern for the researchers and engineers working on internal combustion engines. A number of methods are being employed to utilize fuel energy efficiently, out of which some of the most common are supercharging and turbocharging. Even though, supercharging, turbocharging and other methods improve the efficiency of the internal combustion engine, most of the energy losses incurred in an internal combustion engine are due to the heat losses to coolant and other parts. Only one third of energy from combustion will be available as useful work and the remaining energyis rejected to coolant and exhaust gases [3]. Thus, reducing the heat lost to coolant and exhaust system can lead to improved thermal efficiency, which in turn contributes to improved power and reduced emissions from the engine. Application of low heat rejection (LHR) or thermal barrier coating (TBC) to combustion surfaces imparts thermal insulation characteristics to the engine. Low heat rejection coating simulates adiabatic combustion in the engine, reducing heat lost to coolant. Added to this, coating the surface with a LHR material improves the life of the engine components by protecting it from thermal stresses and fluctuating temperatures that is prone to occur during combustion process.The rapid depletion of crude oil from earth's crust forces the human race to search for a suitable alternate fuel for the near future. Some of the best alternatives identified are biofuels, alcohols, hydrogen etc. Since the properties of alcohols being similar to Gasoline, it can be easily blended with petrol and can be used in the engine without any modification [10]. Due to higher octane number and flame speed, Ethanol is known to be most suited fuel for spark ignition engine. It can be produced from agricultural productslike sugarcane, grains agricultural wastes etc. which is a renewable source of energy, by fermentation using yeast.

Nitesh Mittal et al. [12] has discussed the use of n-Butanol and Gasoline blend in a partially coated LHR spark ignition engine to study combustion, performance and emission characteristics. Study included the coating of cylinder head surface and valves with a ceramic material consisting of Zirconium dioxide with 8% by weight of Yttrium oxide to a thickness of 0.3 mm by plasma spray process. Two different fuel blends, 10% and 15% by volume Butanol in Gasoline was tested in both coated and uncoated engines. The test was conducted on a single cylinder Briggs and Stratton engine and the results showed advanced combustion process and higher peak cylinder pressure in the coated engine, when compared to that of baseline engine. HC and CO emissions were seen to reduce in the coated engine, but an increase in NO_x emission was noted, which is due to higher gas temperatures in the coated engine.Rajasekaran et al. [15] reviewed the influence of thermal barrier coating on spark ignition engine for the improvement of performance and emission characteristics. The analysis was set on a single cylinder, four stroke, Honda GK 200 engine having a displacement of 1977 cc. Coating material used was yttrium stabilized zirconia, which was applied on top surface of piston, cylinder head and valve surface. The experiment results showcased an improvement in brake thermal efficiency and mechanical efficiency by 9% and 25%. Also 23% reduction in UBHC and 48% reduction in CO emissions were observed with the coated engine.

Al Hasan [1] has conducted an investigation on the effect of Ethanol–unleaded Gasoline blends on engine performance and emissions. The survey was done to analyze performance parameters like equivalence air-fuel ratio, fuel consumption, volumetric efficiency, brake thermal efficiency, brake power, engine torque and brake specific fuel consumption. Emission parameters like carbon dioxide and unburned hydrocarbon were considered for study. The results obtained indicate that blending unleaded Gasoline with Ethanol increases the brake power, torque, volumetric efficiency and brake thermal efficiency, whereas a decreasing trend was witnessed for brake specific fuel consumption and equivalence air-fuel ratio. Further 20% Ethanol by volume fuel blend gave the best results for all the measured parameters at all engine speeds.A review in thermal barrier coating was done by Piramanandhan et al. [14] to outcast the effects of thermal barrier coating on both SI and CI engines. An in-depth view of adiabatic engine was provided with different coating materials, with and without engine modifications, for performance, life and exhaust emissions of the engine. Review included the use of both conventional and alternate fuels before concluding that each type of ceramic coating materials, coating method and experimental technology offers its own merits and demerits. It is prescribed to have a thermal network study to obtain the combustion heat transfer of the coated pistons and engine components. It is also proposed to run the coated engine in practical conditions continuously to predict the actual life cycle of the engine.Dinesh Kumar J et al. [5] did a research on influence of thermal barrier coating on SI engine. The study was done using pistons coated with Titanium Dioxide and Zirconium Dioxide. A detailed comparison was done between the baseline piston and two of the coated pistons. Test results indicated the optimum performance with Zirconium dioxide coated piston. An average of 2% increase in brake thermal efficiency, indicated thermal efficiency, mechanical efficiency and volumetric efficiency was obtained when compared with TiO_2 coated piston and the improvement was seen to be about 4% when compared with that of aluminum alloy piston. Also the total fuel consumption was seen to reduce with coated piston. With the emission analysis, it was found that ZrO_2coated piston emitted less CO and HC when compared with all the other alternatives but a slight increase with NO_x and CO_2 emissions were observed with the same variants.

This research work aims at analyzing the performance and emission analysis of a spark ignition engine using a low heat rejection material coated piston. The piston was coated with 0.1 mm thickness of alumina and the evaluation was done on a single cylinder, four stroke TVS make OHC engine with a cubic capacity of 109.3 cc. The test was carried out using Gasoline and Gasoline-Ethanol blend at 10% and 20% Ethanol blend by volume in both coated and uncoated engine. The engine was loaded using a DC generator dynamometer and the performance and emission parameters were analyzed.

Nomenclature and Abbreviations	
BMEP	Brake Mean Effective Pressure
BSEC	Brake Specific Energy Consumption
BTE	Brake Thermal Efficiency
CO	Carbon Monoxide
CO_2	Carbon Dioxide
GE10	90% Gasoline with 10% Ethanol
GE20	80% Gasoline with 20% Ethanol
GE10-LHR	90% Gasoline with 10% Ethanol in Alumina coated engine
GE20-LHR	80% Gasoline with 20% Ethanol in Alumina coated engine
HC	Hydrocarbon
LHR	Low Heat Rejection
MON	Motor Octane Number
NO_x	Oxides of Nitrogen
OHC	Over Head Cam
RON	Research Octane Number
TBC	Thermal Barrier Coating
TiO_2	Titanium Dioxide
UBHC	Unburned Hydrocarbon
ZrO_2	Zirconium Dioxide

LHR engine development

Table 1: Comparison of properties of Zirconium dioxide and alumina coating

Properties	Zirconium Dioxide Coating	Alumina Coating
Formula	ZrO_2	Al_2O_3
Density (gm/cc)	6	3.89
Porosity (%)	0	0
Elastic modulus (GPa)	200	375
Hardness (kg/mm^2)	1300	1440
Maximum use temperature (^{o}C)	1500	1750
Thermal conductivity (W/m^{o}K)	2	35

The main intention behind LHR coating is to reduce the amount of heat losses to the cooling system and to outside through exhaust gases. The aid to improve the thermal efficiency of the engine which in sequence contribute to upgrade the performance and emission parameters. Various materials are available for surface coating with distinct properties and some of them are Alumina (Al_2O_3), Zirconium dioxide (ZrO_2), Titanium dioxide etc. Coating materials are chosen with respect to applications, considering their properties. Property comparison of Alumina and Zirconium dioxide is done in Table (1). It can be seen that Zirconium dioxide is about 35% denser compared to alumina, howeverhardness and maximum use temperature for

ISSN: 0975-8585

alumina is observed to be higher than that of Zirconium dioxide. Both materials share distinctive properties; consequently casting a suitable material for LHR coating is a challenging measure. In view of properties, alumina was chosen as coating material for this investigation, favoring the higher maximum use temperature, which is 15% more than that of Zirconium dioxide [2-5].

Figure 1: Uncoated Piston (A) and Piston coated with Alumina (B)

Alumina was coated on the piston surface by thermal spraying. Surface preparation was done before coating the ceramic on the top surface of piston. Initially the surface was wiped with acetone, which is basically a degreaser followed by hand abrading the surface to improve the adhesiveness of the coating material on the surface. Later, powered alumina was fed in powder form to barrel of thermal spray attachment, from where it was melted by an electric arc and was accelerated towards substrate in the form of micro particles. The major advantage of using thermal spraying process is that it will not heat up the surface significantly, thus retaining the structure of the base material. Increasing the particle velocities can increase coating quality.

Figure(1) shows the pictorial view of coated and uncoated pistons. Excluding the primary edge of retaining the energy in combustion chamber, Alumina coating offers additional benefits like wear resistance, thermal stress resistance etc. which enhance the overall lifespan of the piston [13,17-19].

MATERIALS AND METHODS

Distinct properties of Ethanol and Gasoline are given in Table (2). Since the crucial properties of Ethanol lies in the range satisfying the working of spark ignition engine, it can be blended with Gasoline up to certain limits and can be used in engines without any modifications. Due to the presence of oxygen atom in Ethanol, it is considered as partially oxidized fuel. This oxygen atom reduces stoichiometric ratio of Ethanol, which is observed to be 9.0 over 14.6 of that of Gasoline. Density, RON, MON and Heat of vaporization of Ethanol is seen to be elevated over the values exhibited by Gasoline. The higher octane number of Ethanol makes it feasible to operate at higher compression ratios, which benefit improvement in power output, efficiency and fuel consumption.

Table 2: Comparison of properties of Gasoline and Ethanol

Property	Gasoline	Ethanol
Chemical formula	–	C_2H_5OH
Molar C/H ratio	0.44 - 0.50	0.33
Density (g/cm^3 @20^{o}C)	0.72 – 0.76	0.790
Latent heating value (kJ/kg)	44300	26900
Stoichiometric air/fuel ratio	14.6	9.0
Oxygen % (weight)	–	34.73
RON/MON	95/85	108.6/89.7
Auto ignition temperature (^{o}C)	228 – 470	363
Boiling point (^{o}C)	27 – 225	78.3
Heat of vaporization (kJ/kg)	349	923
Flammable limits (% Volume)	1.4 – 7.6	3.5 – 15
Stoichiometric flame speed (m/s)	0.34	0.41
Adiabatic flame temperature (^{o}C)	2002	1920

Table 3: Comparison of properties of fuel blends

Parameters	Unit	GE10	GE20
Density @ 15°C	gm/cm^3	0.7582	0.7649
Kinematic viscosity @ 40°C	cst	1.23	1.25
Gross calorific value	Kcals/kg	8426	8327
Flash point	°C	48.6	49.3
Fire point	°C	53.3	53.8
Ash content	%	0.01	0.01
Conradson carbon residue	%	0.01	0.01

Heat of vaporization of Ethanol is observed to be around 63% more than that of Gasoline, which shows that Ethanol in the liquid state can be transformed into a gas at given pressure, quickly than that of Gasoline. The density, auto ignition temperature and adiabatic flame temperature were noticed to be in similar range for both Gasoline and Ethanol, but latent heating value for Gasoline is higher compared to that of Ethanol. Hence, in case of Ethanol or Ethanol blends, more amount of fuel is to be burned to obtain the same performance as that of Gasoline. The property comparison of GE10 and GE20 is given in Table (3). Density, kinematic viscosity, flash point and fire point is higher for higher blend of Ethanol, but gross calorific value is recognized to be lower for higher blends. This research work targets on using Gasoline, GE10 and GE20 fuels in both uncoated and coated engines for performance and emission comparisons [9-11].

EXPERIMENTATION

A single cylinder four stroke TVS make victor OHC engine was chosen for experimentation. The engine offered a maximum power of 8.1 bhp @ 7250 rpm and a maximum torque of 8.1 Nm @ 5500 rpm. The specifications of the engine is given in Table(4). A DC generator type dynamometer was coupled to the engine for loading purpose. Speed of the engine was measured using a proximity sensor. Engine was loaded from 0% to 100% at an interval of 25% using the rheostat coupled to the DC dynamometer for performance and emission analysis of the engine.

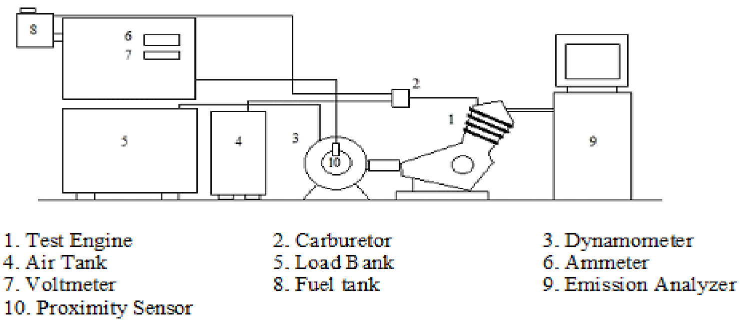

Figure 2: Schematic view of test setup

Figure 3: Pictorial view of test setup

Table 4: Engine Specifications

Engine model	TVS Victor
Type	4 Stroke air cooled OHC
Cubic capacity	109.3cc
Bore	51mm
Stroke	53.5mm
Compression Ratio	9.3:1
RPM	1000-5000
Max Power	8.1 bhp@7250rpm
Max Torque	8.1Nm@5500

Schematic and pictorial view of test setup is shown in Figure (2) and Figure(3) respectively. Emission analysis was done by Crypton five-gas analyzer setup. Unburned hydrocarbon, carbon monoxide and oxides of nitrogen emission were noted for different fuels in both coated and uncoated engine.

RESULTS AND DISCUSSIONS

Application of LHR coating on piston and its adoption in the engine modifies the temperature in the combustion chamber. Only limited amount of heat will be rejected to coolant in the coated engine unlike that of baseline engine. Due to high melting point and corrosion resistance, the LHR coating is believed to improve the life of parts exposed to extreme temperature conditions. Considering the fuel, blending of Ethanol with Gasoline changes the properties of fuel, which in turn changes the combustion behavior of the fuel inside the combustion chamber. Hence, comparison of engine performance and emission parameters was made for GE10 and GE20 in both coated and uncoated engine.

Variation in Performance parameters

Figure (4) shows the comparison of brake specific energy consumption for both coated and uncoated engines with Gasoline, GE10 and GE20. At low load conditions, highest BSEC is observed for Gasoline when used in uncoated engine at 12.01 MJ/kWh. But the trend was found to reduce with increase in blend concentration and fueled in coated engine. BSEC varies from 7.23 MJ/kWh to 5.06 MJ/kWh at part load operations.For full condition, BSEC was further reduced to the least value among all the loads, observed at 4.67 MJ/kWh, 3.95 MJ/kWh, 3.71 MJ/kWh, 3.22 MJ/kWh, 2.97 MJ/kWh and 2.82 MJ/kWh for Gasoline, GE10, GE20, Gasoline-LHR, GE10-LHR and GE20-LHR respectively. The reduction in BSEC may be due to improved combustion of fuel with increase in blend concentration and the use of LHR coating [6-8].

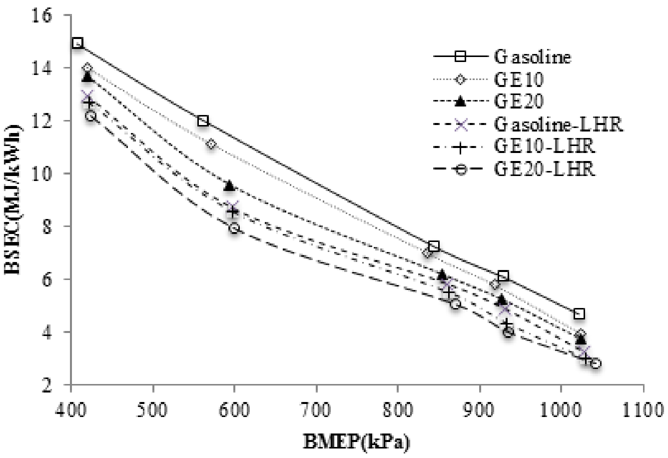

Figure 4: Variation of BSEC with BMEP

Brake thermal efficiency evaluates how efficiently an engine converts the heat from fuel into mechanical energy. The variation of BTE with respect to BMEP is shown in Figure (5).

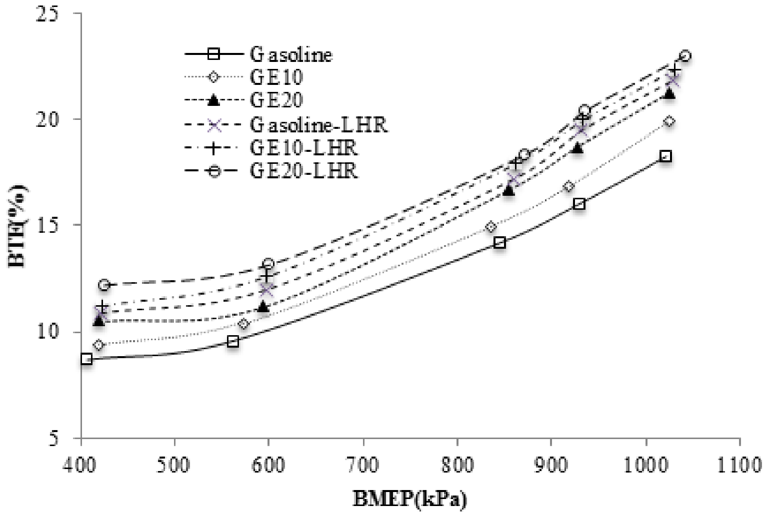

Figure 5: Variation of BTE with BMEP

BTE tends to increase with load for all the fuels on both coated and uncoated engines. A maximum brake thermal efficiency of 23.01% was witnessed for the alumina-coated engine when fuelled with GE20 at full load condition. Gasoline showed a variation from 9.57% to 18.27% in BTE when used in uncoated engine, whereas the same fuel showed a variation from 11.98% to 21.87% in alumina-coated engine. A variation of 1-2 % in BTE was observed for different fuel blends in coated and uncoated engine at half load conditions.At full load, a variation of about 5% was noted between the blends. The higher BTE observed for the coated engine may be due to retaining more heat energy in the combustion chamber by the ceramic material, which otherwise go wasted to cooling and exhaust system [11].

The variation of mechanical efficiency with BMEP for low, part ant and full load is shown in Figure (6). Mechanical efficiency is an indication of how much power is developed by the expansion of gases in cylinder is actually delivered as useful power. Friction is a major factor concerned with mechanical efficiency. From the Figure (6) for low load conditions, mechanical efficiency is seen to vary from 24.01% to 37.27%. But when the load is increased, during part load conditions, mechanical efficiency was observed to be 38.01%, 39.17%, 43.21%, 45.87%, 48.29% and 79.76% for Gasoline, GE10, GE20, Gasoline-LHR, GE10-LHR and GE20-LHR respectively.

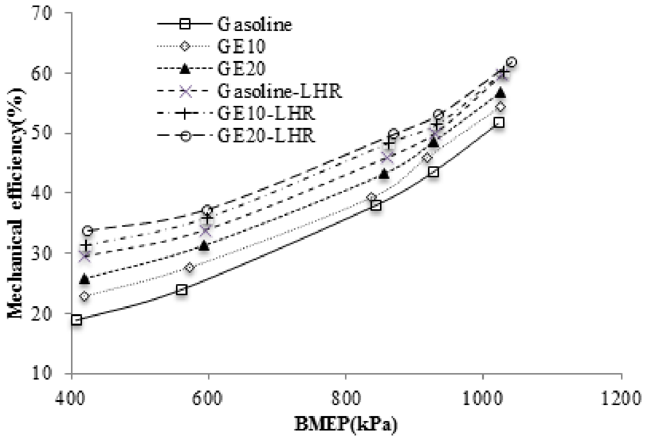

Figure 6: Variation of Mechanical Efficiency with BMEP

At full load conditions, mechanical efficiency was found to be further improved to 51.61%, 54.45%, 56.81%, 59.69%, 60.23% and 61.78% for the same fuel blends. The increasing trend of mechanical efficiency may be due to the use of Ethanol blend, which has higher octane number, thus reducing knocking. Also more heat energy will be available as work output due to LHR coating [12].

Variation in Emission parameters

A number of factors directly affect unburned hydrocarbon emission in the engine. Some of the major factors are combustion chamber geometry, engine-operating conditions, fuel properties etc. the comparison of UBHC emissions at different load conditions is shown in Figure (7). A decreasing trend in UBHC emission is observed for all the fuel blends with the increase in load. Least emission was observed for GE20 blend when used in the LHR coated engine.

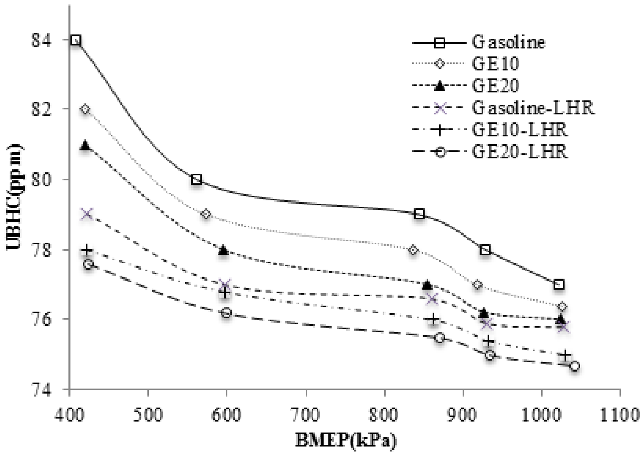

Figure 7: Variation of UBHC emission with BMEP

At low load conditions, UBHC is seen to vary from 80 ppm to 76 ppm for different blend of fuel in coated and uncoated engines. When load is increased, UBHC exhibited 79 ppm, 78ppm, 77 ppm, 76 ppm, 76 ppm and 75 ppm for fuel blends varying from Gasoline to GE20-LHR respectively. At full load GE20 blend when fuelled in LHR coatedengine showed the least emission of 74 ppm, which may be due to the higher temperature and pressure conditions in the coated engine, which improves the oxidation of fuel.

Carbon monoxide is a colorless and odorless gas, whichis formed as an intermediate product of engine combustion. The variation of CO emission with respect to BMEP is shown in Figure (8). The reducing trend of carbon monoxide emission is seen in the graph due to the use of rich mixture by the engine during starting.

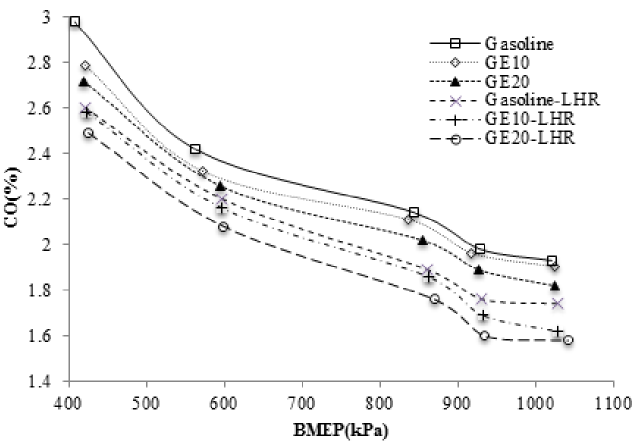

Figure 8: Variation of CO emissions with BMEP

At low load conditions CO emissions are seen to vary from 2.42% to 2.08%, whereas for full load condition, further reduction in CO emission was observed varying from 1.93% to 1.58%. For the half load condition, the engine exhibited 2.14%, 2.11%, 2.02%, 1.89%, 1.86% and 1.76% for Gasoline, GE10, GE20, Gasoline-LHR, GE10-LHR, and GE20-LHR respectively.

The variation of oxides of nitrogen emission is shown in Figure (9). Unlike UBHC and CO emission, NO_x emission shows an increasing trend when plotted with respect to BMEP. For low load conditions, NO_x emissions are observed to be 292 ppm, 321 ppm, 337 ppm, 349 ppm, 356 ppm and 378 ppm for Gasoline, GE10, GE20, Gasoline-LHR, GE10-LHR, and GE20-LHR respectively.

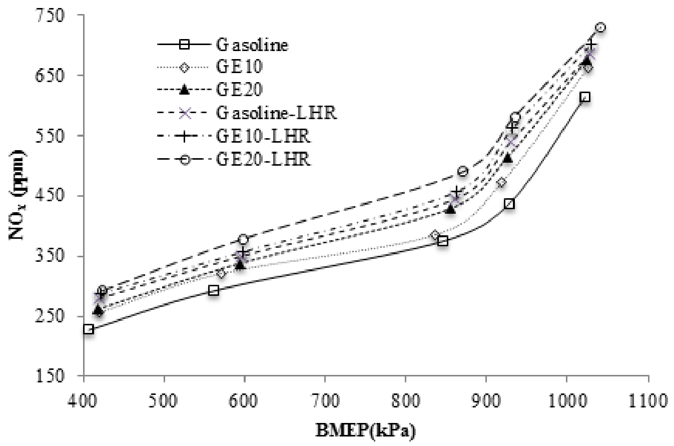

Figure 9: Variation of NO_xemissions with BMEP

For part load, NO_x emission further increased around 20% for all the fuel blends. At full load again the graph showed elevated NOx emissions. This may be due to higher temperatures being experienced inside the combustion chamber. A maximum NO_x emission of 729 ppm was witnessed for GE20-LHR engine [7].

CONCLUSION

From the experimental study, following conclusions were drawn,

- 0.1 mm of Alumina ceramic coating was successfully deposited on the piston crown through thermal detonation spraying technique and was effective with maximum usage temperature of 1750°C.
- Blending of Ethanol with Gasoline resulted in enhanced combustion performance. The density and kinematic viscosity were marginally increased with the addition of Ethanol in Gasoline. The higher latent heat of vaporization for Ethanol favors it's blending with Gasoline and contributes effectively towards engine performance.
- The BSEC of Gasoline for uncoated piston and Alumina coated piston was found to be 14.92 MJ/kWhr and 12.96 MJ/kWhr respectively, which was 11.46% and 10.85% higher than GE20 and GE20-LHR respectively.
- The Brake thermal efficiency and Mechanical efficiency of LHR coated piston with Ethanol-Gasoline blend also showed improved performance on comparison with uncoated piston.
- The UBHC emission was found to be decreasing significantly from 84 ppm to 78 ppm at load condition in the presence of LHR coating with Ethanol-Gasoline blends. The CO emission also exhibited a similar trend with reduction between 8% and 10%.
- The NOx emission was found to increase with the addition of Ethanol concentration in Gasoline and was furthermore increase with the employment of Alumina coated piston.

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