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Impact of Oxidation Inhibitors on Performance and Emission Characteristics of a Low Heat Rejection Engine

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ABSTRACT:

In this study, for the first time analysis of a low heat rejection engine was carried out along with the addition of oxidation inhibitors. If the combustion chamber components of the engine such as piston, cylinder head, and inlet and outlet valves are insulated with a thermal barrier material, then the engine will be referred as low heat rejection engine. In this study yttria stabilized zirconia was coated on the combustion chamber components for a thickness of about 150 microns. Then the analysis of performance parameters such as brake thermal efficiency and specific fuel consumption and emission characteristics such as emission of carbon monoxide, hydrocarbon and nitrogen oxide was carried out in single cylinder four stroke diesel engine with electrical loading using diesel and pongamia methyl ester as the fuels. The major problem associated with the usage of biodiesels and low heat rejection engine is the increased NOX emission than the normal engine operated with the diesel. This problem has been overcome by the usage of oxidation inhibitors such as ethyl hexyl nitrate (EHN), tert-butyl hydroquinone (TBHQ). The results showed that addition of oxidation inhibitors leads to increase in brake thermal efficiency, reduced specific fuel consumption and reduced NOX emission.

KEYWORDS:

Low heat rejection engine; Yttria stabilized zirconia; Pongamia Methyl Este; Oxidation inhibitor

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1. Introduction

The internal combustion engine is a device which is used to convert the chemical energy of the fuel into heat energy by the process of combustion which in turn is converted into mechanical work. Since the invention of the engines we are heavily relying on the petroleum as the fuel for the engines. The main problem associated with the fuels is their continuous depletion and increase in price [1-3]. Usage of petroleum products also leads to emission of harmful gases such as carbon monoxide, nitrogen oxide hydrocarbons etc. This leads to severe environmental problems such as global warming and air pollution. We the engineers should find a solution to the above mentioned problems. Instead of using fossil fuels which is a non-renewable source of energy, we should focus on renewable form of energy. One such fuel is biodiesel. Since the beginning of 19th century the usage of these fuels has gained attention. But there was no lot of researches available at that time. But when the fossil fuels were started to deplete, the people started to realize the importance of usage of biodiesels.

These fuels are environmental friendly energy which could be a better substitute for the fossil fuels. The emission of carbon monoxide and hydrocarbons will be reduced, when biodiesel is used as fuel in the internal combustion engine [4, 5]. This is due to the fact that there is large amount of oxygen content is available in the biodiesel which enables better oxidation and complete combustion. On the other hand usage of biodiesel lead to increase in the emission of nitrogen oxide which is not to be ignored because nitrogen oxide more harmful than any other gases that the internal combustion emits [6-8]. Another problem associated with the biodiesel is that no modifications are made in the engine design according to the properties of the biodiesel that is to be used [9, 10]. Therefore in order to overcome the above mentioned problem of increased nitrogen oxide emission due to the usage of biodiesel, oxidation inhibitors can be used which may reduce the emission of nitrogen oxide [11-13]. The oxidation inhibitors curtail the process of oxidation by donating hydrogen or by supplying an electron to radical derivatives.

This process can be achieved in any of the following four methods. They are reducing free radical concentrations, chelating transition metal catalyst, scavenging initiating radicals and chain breaking reactions [14-16]. Another problem that we have to concentrate is that about 67% of heat energy supplied to any diesel engine is rejected to the environment as waste.

In order to overcome this problem insulation of combustion chamber elements such as piston, cylinder head and inlet and outlet valves is recommended and this type of engine is usually called as low heat rejection engine. The insulation can be done with aid of thermal barrier coating materials such as PSZ, YSZ, fly ash, barium zirconate [17, 18]. The material should possess the following characteristics such as low thermal conductivity, good chemical inertness, high melting point and low porosity in order to use it as a thermal barrier coating material [19-22].

In this study, the analysis of performance characteristics such as brake thermal efficiency and specific fuel consumption and emission characteristics such as emissions of carbon monoxide, hydrocarbons and nitrogen oxide for the standard engine (uncoated engine) was carried out with diesel and pongamia methyl ester as fuels without any blends. Then the parameters were compared with the YSZ coated engine using the same fuels. Among these combinations the best one is selected and with that the oxidation inhibitors such as ethyl hexyl nitrate (EHN), tert-butyl hydroquinone (TBHQ) were added with either diesel or with pongamia methyl ester and the results were compared.

2. Materials and Methods

2.1. Preparation of biodiesel

The pongamia oil is extracted from the seeds of Millettia pinnata trees which are extensively found in Asia. Expeller pressing, solvent extraction or cold pressing are some of the processes that are used to extract Pongamia. The oil is yellowish-orange to brown in colour. It is antiseptic and resistant to pests. It has been used as a lubricant for many years and traditionally used as a medicine for treating skin diseases and liver diseases. The pongamia oil required for the experiment was purchased from Selva Kumaran oil stores, Madurai, Tamil Nadu, and India. The purchased oil was then filtered in order to get rid of the impurities. Then the oil was heated to the temperature of 1250°C [23-25]. Then the esterification process was carried out with the heated oil. Usually 17% of methanol solution by volume and 1% of potassium hydroxide solution by weight is required for the trans esterification process [26-28]. The methanol solution was heated and the magnetic stirrer was used continuous stirring.

After the completion of settling process it can be seen that two layers were formed. The pongamia methyl ester was seen in the upper layer and the glycerine was seen in the lower layer. Then it was found that the yield of the pongamia methyl ester obtained about 87%. The biodiesel produced was tested to examine the fuel properties and the properties of the pongamia methyl ester were compared with the corresponding properties of the conventional diesel. The standards adopted for the measurement was ASTM [29, 30]. Digital density meter was used to determine the density of the fuel and the density was measured at 150°C. The kinematic viscosity of the fuel was measured at 400°C. The calorific value of the biodiesel was measured using bomb calorimeter. Table 1 depicts the various properties of the pongamia methyl ester in comparison with diesel.

Table 1: Properties of Pongamia Methyl Ester & Diesel

Properties	Diesel	Pongamia Methyl Ester
Kinetic viscosity 40°C	4.5	5.24
Density at 15°C (kg/m^3)	834	880
Cetane number	45	57
Calorific value (MJ/kg)	44.5	36.09
Flash point °C	74	147
Fire point °C	64	159

2.2. Thermal barrier coating of engine components

Using YSZ as a thermal barrier coating material many investigations have been available in the field of low hear rejection engine. But analysis of this type of engine with the addition of oxidation inhibitors in the fuel has not been done yet. The properties of YSZ in comparison with the materials which are suitable to be used as thermal; barrier coating material has been presented in Table 2. The YSZ required for coating the engine components was purchased from Premnath Eshwar Scientific Company, Salem, India.

Table 2: Properties of YSZ material

Type	Four stroke, Single cylinder vertical air cooled Engine
Rated power	4.4 [KW]
Bore diameter (D)	87.5 [mm]
Stroke (L)	110[mm]
Compression ratio	17.5:1
Injection pressure	200 bars
Cubic capacity	661cm^3

The coating technique selected for converting the standard engine into the low heat rejection engine was plasma spraying process [31, 32]. The coating thickness employed was about 150 µm. The plasma spraying technique is used to coat the combustion chamber elements of the engine. The injecting pressure of nozzle is about 100-120 psi for argon and 50 psi for hydrogen. The flow rate of argon from the nozzle is about 80-90 ℓ/min and that of hydrogen is about 15-18 ℓ/min. The voltage developed is about 65-70 volts and current is about is about 500 A. The powder is feed at the rate of 40-45 g/min and the spray distance is about 2-3 inches. The ceramic material YSZ which is used for coating is white in colour and 500 g of powder were required for coating.

2.3 Experimental setup

The experiment was carried out in a single cylinder, vertical, air cooled four stroke engines. The injection pressure of the engine was 200 bars. The detailed specification of the engine is presented in the Table 3. The capacity of the engine was 661 cm^3. For applying variable loads the engine was coupled with eddy current dynamometer. The AVL 444 Di-gas analysers were used to measure the emissions of carbon monoxide, hydrocarbon and nitrogen oxide. The AVL combustion data acquisition system was used to determine the heat release rate and cylinder pressure. The experimental setup is shown in Fig. 1.

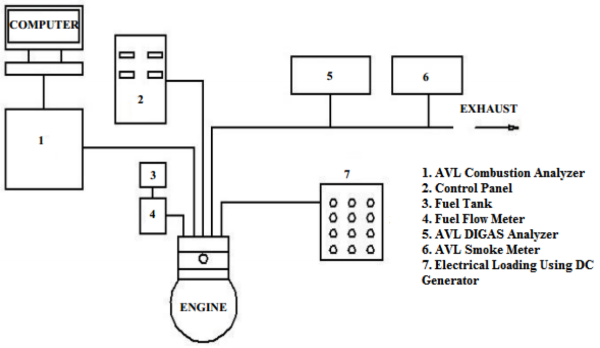

Fig. 1: Experimental setup

3. Results and discussions

3.1. Brake thermal efficiency

Brake thermal efficiency indicates how effectively the heat energy of the fuel is converted into useful work at the crankshaft. The brake thermal efficiency for the coated and uncoated engine has been presented in Fig. 2. It is clear that the brake thermal efficiency varies linearly with the load. The brake thermal efficiency is higher for the coated engine than the uncoated engine for both the fuels such as diesel and pure pongamia methyl ester. The efficiency of engine when operated with PME B100 is greater than that of operated with the diesel. It is observed that the brake thermal efficiency increased by 11.57% for the PME B100 and 7.7% for the diesel in the coated engine when compared with the uncoated engine at the full load condition. This is due to the decrease in in-cylinder heat transfer in the coated engine. The YSZ coated engine operated with the PME B100 has the highest brake thermal efficiency at all the load conditions.

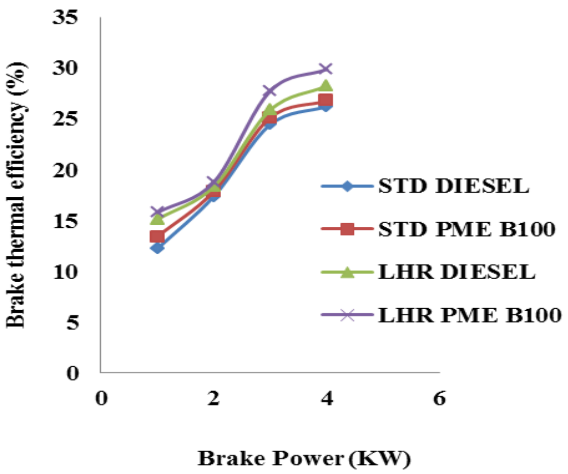

Fig. 2: Comparison of brake thermal efficiency

The brake thermal efficiency of the diesel engine operated at three varying conditions such as PME B100 without anti-oxidant, with anti-oxidant EHN and with TBHQ has been presented in Fig. 3. From the Fig. it is clear that there is no significant variation in the brake thermal efficiency while adding anti-oxidants. By adding the anti-oxidant EHN there was a slight increase in the brake thermal efficiency by 1.4%. Therefore it is clear that the anti-oxidants have not an influence over the brake thermal efficiency.

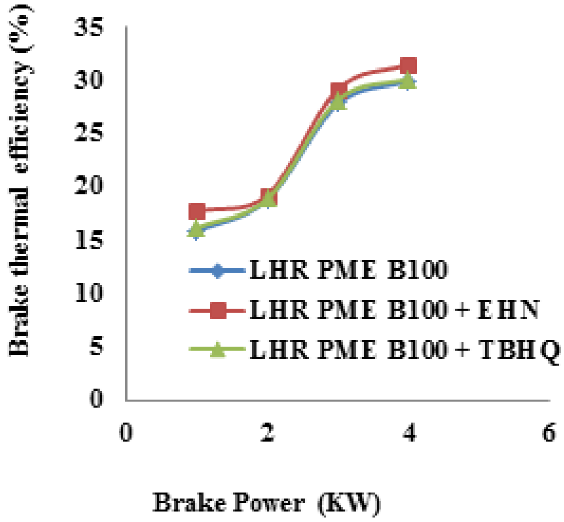

Fig. 3: Comparison of brake thermal efficiency

3.2. Brake specific fuel consumption

The brake specific fuel consumption indicates the amount of fuel consumed per unit time to develop unit power. It is an important parameter that indicates how well the performance of the engine is. It is inversely to the thermal efficiency of the engine. The comparison of brake specific fuel consumption for the coated and uncoated engine is shown in Fig. 4. The specific fuel consumption decreases with increase in the load. The fuel consumption for the YSZ coated engine is found to be lower than the uncoated engine. It was found that the fuel consumption of the coated engine is lower by 7.06% for PME B100 and 13.11% lower for the diesel than in the uncoated engine. The main reason for the decreased fuel consumption in the coated engine is increase in temperature of the cylinder wall leads to decrease in ignition delay period of the fuel which has the positive effect on physical and chemical properties of the fuel. The YSZ coated engine operated with the PME B100 has the lowest brake specific fuel consumption at all the load conditions.

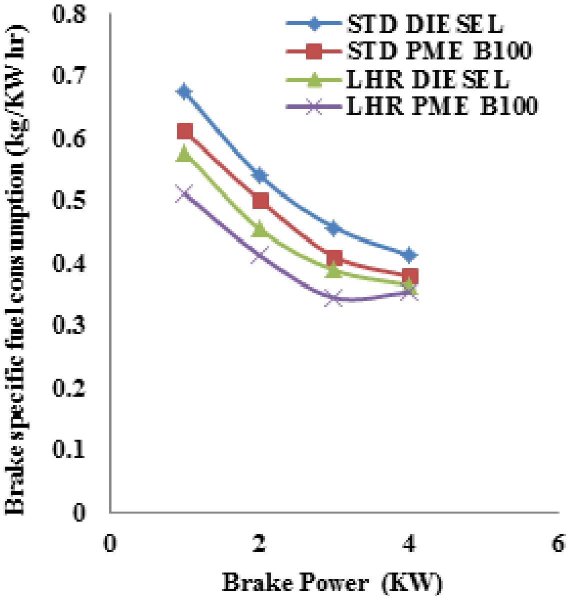

Fig. 4: Comparison of brake specific fuel consumption

The variation of brake specific fuel consumption for the PME B100 without anti-oxidant, with anti-oxidant EHN and with TBHQ is shown in Fig. 5. The brake specific fuel consumption was found to be lower when EHN was used as an anti-oxidant. The fuel consumption reduced by 24.42% for the EHN anti-oxidant and reduced by 15.56% when TBHQ was used.

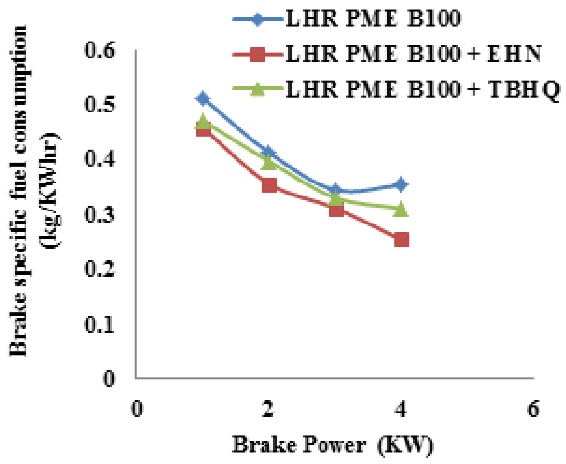

Fig. 5: Comparison of brake specific fuel consumption

3.3. Emission characteristics

The emission of hydrocarbon, carbon monoxide and nitrogen oxide has been compared between the uncoated and YSZ coated engine running with both diesel and pongamia methyl ester.

3.3.1. Emission of un-burnt hydrocarbon

Hydrocarbon is the organic compound which mainly consists of carbon and hydrogen. The un-burnt hydrocarbon emissions are the result of incomplete combustion. The parameters that have an influence over the emission of HC are the air fuel ratio, combustion chamber design and load applied on the engine. The variation in the emission of hydrocarbon with respect to the brake power is shown in Fig. 6. The coated engine has lower hydrocarbon emission than that of the uncoated engine. The emission of hydrocarbon was found to be lower in the coated engine by 30% for diesel and 26.67% for PME B100 at the full load condition. The main reason for the decrease in HC emission in the coated engine is that increased combustion duration which leads to complete combustion of the fuel. The YSZ coated engine operated with the PME B100 has the lowest HC emission at all the load conditions.

The emission of un-burnt hydrocarbon with the anti-oxidants has been shown in Fig. 7. As the name itself indicates that it inhibits the process of oxidation and therefore the emission of hydrocarbons will be increased when the oxidation inhibitors is added with the biodiesel. The HC emission was found to be increased by 11.24% for EHN and 13.42% for the TBHQ additive. But still it was found to be lower than the normal operating conditions (uncoated engine operated with diesel) which emits 65 ppm of hydrocarbon whereas the engine operated with EHN and TBHQ additives emits 50 ppm and 45 ppm of hydrocarbon respectively.

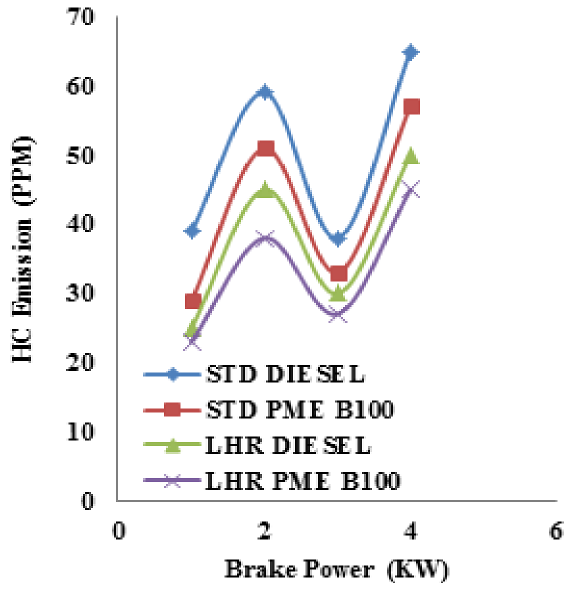

Fig. 6: Comparison of emission of un-burnt hydrocarbon

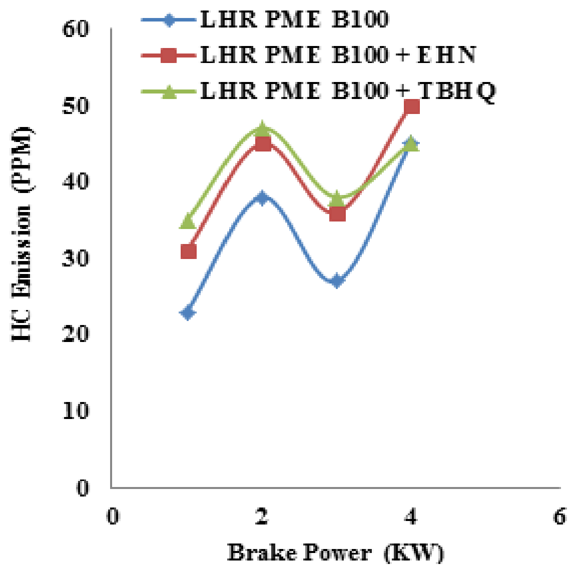

Fig. 7: Comparison of emission of un-burnt hydrocarbon

3.3.2. Emission of carbon monoxide

The emission of carbon monoxide is due to low oxygen content in the air fuel mixture. The carbon monoxide would be present in the air-fuel mixture below 16:1. But in actual practice it could not be neglected even in the lean mixtures. The emission of CO with respect to the brake power for both the coated and uncoated engines fuelled with diesel and PME B100 has been presented in Fig. 8. It is clear that the carbon monoxide emission is found to be lower in the coated engine than the uncoated engine. It is found that the carbon monoxide emission was lower in the coated engine by 33.33% when diesel was used as the test fuel and 28.57% when pongamia methyl ester was used as the test fuel when compared with the uncoated engine. The main reason for the decreased emission of carbon monoxide in the coated engine is that increased combustion duration of the fuel which enables the oxidation of carbon monoxide into carbon dioxide. The YSZ coated engine operated with the PME B100 has the lowest CO emission at all the load conditions.

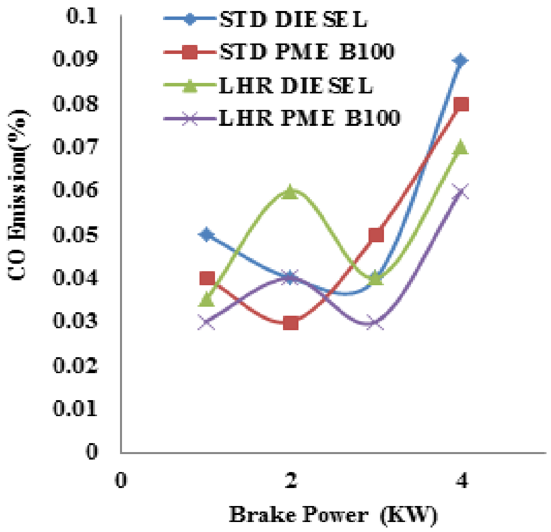

Fig. 8: Comparison of emission of carbon monoxide

Similar to the emission of un-burnt hydrocarbon, the carbon monoxide was also increased when the anti-oxidants were added with biodiesel. The variation of the carbon monoxide emission is shown in Fig. 9. It was found that the emission of carbon monoxide was increased by 12.48% when EHN was added with the biodiesel and increased by 10.12% when TBHQ anti-oxidant was used.

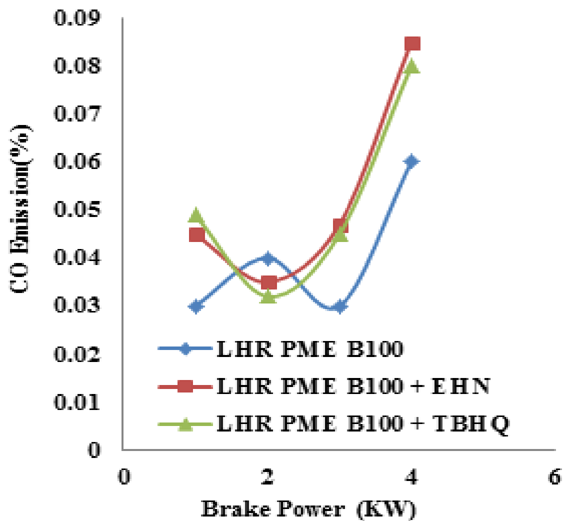

Fig. 9: Comparison of emission of carbon monoxide

3.3.3. Emission of nitrogen oxide

The nitrogen oxide is the most harmful emission form the engine exhaust. The causes for the emission of NOX are high oxygen availability and high cylinder temperature which is just opposite to that of the causes of emissions of CO and HC. The emission of NOX with respect to the brake power for the coated and uncoated engines is shown in Fig. 10. The nitrogen oxide emission was found to be varied linearly with the load. Also the pongamia methyl ester showed increased NOX emission than the diesel because of the high oxygen content than that of the diesel. It is clear that the NOX emission was found to be higher in the coated engine than that of the uncoated engine for both the test fuels. It was found that the NOX emission of the coated engine was 24.4% higher than that of the coated engine for diesel and 7.7% for PME B100. The main reason for this increased emission of NOX is increased combustion duration in the coated engine which enables the oxidation of nitrogen into nitrogen oxide. From the above results it is clear that the YSZ coated engine fuelled with pongamia methyl ester has best performance, lower emission of HC and CO except NOX emission. In order to reduce the emission of NOX, oxidation inhibitors such as EHN and TBHQ were separately added in the biodiesel for 2000 ppm and the analysis was again carried out for coated engine with pongamia methyl ester with EHN as the anti-oxidant and coated engine with pongamia methyl ester with TBHQ as the anti-oxidant and the results were compared.

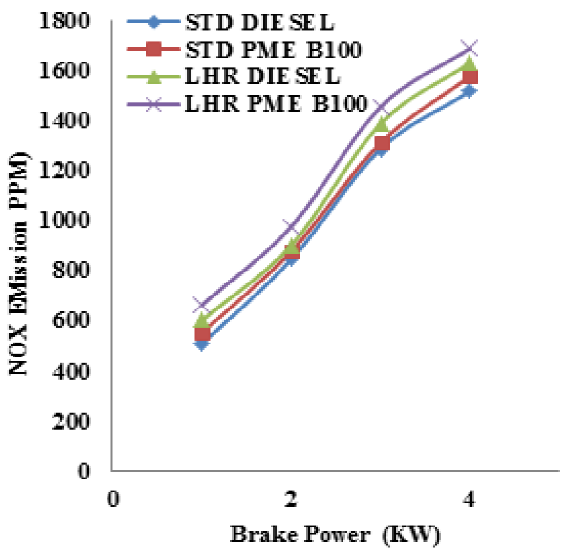

Fig. 10: Comparison of emission of nitrogen oxide

The main purpose of adding anti-oxidants with the biodiesel is to reduce the emission of nitrogen oxide which is more harmful than any other emissions. The variation of the nitrogen oxide emission is shown in Fig. 11. The NOX emission was found to be decreased by 24.81% when EHN was used as the additive and decreased by 15.72% when TBHQ was added with the biodiesel.

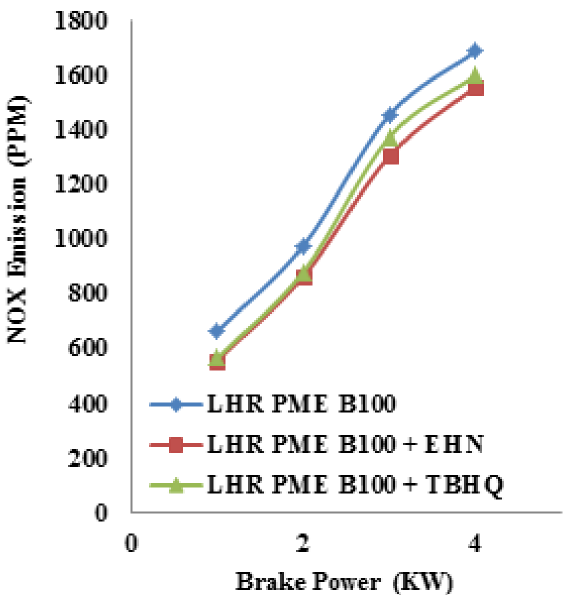

Fig. 11: Comparison of emission of nitrogen oxide

4. Conclusions

Based on the results obtained the following conclusions were drawn:

- The brake thermal efficiency of the coated engine is more than that of the uncoated engine.
- Specific fuel consumption is less for the coated engine than the uncoated engine.
- The emissions of CO and, HC in the coated engine are lesser than those of the uncoated engine.
- The emission of NO_X is found to be greater for coated engine.
- Therefore the engine coated with YSZ and operated with pongamia methyl ester found to be the best among the four combinations in which the analysis was carried out and the analysis was again carried out by adding two oxidation inhibitors
- The specific fuel consumption was decreased by 24.42% for the EHN anti-oxidant and reduced by 15.56% when TBHQ was used.
- There was a reduction in the emission of NOX by 24.81% when EHN was used as the additive and 15.72% when TBHQ was added with the biodiesel.
- The emission of HC and CO was not increased very much when the anti-oxidants were added.
- Therefore EHN was found to be a better anti-oxidant than TBHQ.

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