Final Report

Studies on Performance and Emission Characteristics of different Straight Vegetable Oils (SVO) as fuels in a Diesel Engine for Urban Transportation

Submitted
To:

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Bangalore 560 012

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March, 2011

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Indian Institute of Science, Bangalore – 560 012

FORMAT FOR THE INTERIM REPORT ON CiSTUP FUNDED PROJECTS.

1. **Title of the Project**: Studies on Performance and Emission Characteristics of Different Straight Vegetable Oils (SVO) as Fuels in a Diesel Engine for Urban Transportation.

2. **Scheme Code No**.: CIST/MME/RTN/020

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4. **Date of Commencement**: 01-01-2010

Project Duration: one year

Ending Date of the Project. 31-12-2010

5. Discussion/Summary of work carried out (Explaining Deliverables, Implementation etc. with List and future direction.) ---2 to 5 Pages---

5.1 Summary of the Work

Petro diesel fuels are depleting at faster rate and causing lot of environmental pollutions from vehicle engine exhaust [1]. Hence, Biodiesel is considered as one of the most promising alternate fuels for diesel engines [3]. Biodiesel is an oxygenated diesel-like fuel made from vegetable oils and animal fats by conversion of the triglyceride fats into mono-alkyl esters of long chain fatty acids by transesterification [5]. We have examined biodiesel produced from seeds of Honge feedstock and emission and performance tests in a compression ignition engine were studies. Although the use of biodiesel offered many environmental advantages over petrodiesel, including reduction in CO, CO_2, hydrocarbon and particulate matter emissions, NO_x emissions were increased [7]. One of very effective way to reduce Nox is introducing additives into the fuel [9]. Four additives were identified to test the fuels. The effect of Ascorbic Acid, 3-Hydroxy Toluene, Phenyl ethyl ether and Methyl propyl ether as additive in biodiesel was observed. Concentrations of additives were varied in different percentages and corresponding changes particularly NO_x emissions along with other emissions were recorded. Break power also observed and compared with base fuel. All four additives helped to reduce NO_x emissions though the most significant decrease was observed for Methyl propyl ether and Phenyl ethyl ether. This was due to antioxidant nature and high latent heat of vaporization of the above mentioned additives.

5.2 Mechanism of NO_x emissions

Formation of NO_x in biodiesel can be explained by two mechanisms – Zeldovich and Fenimore. Zeldovich mechanism attributes the formation of NO to the oxidation of atmospheric nitrogen by oxygen in air. NO are produced as shown in equations (1), (2) and (3) respectively.

$$O^{\cdot} + N_2 \rightarrow NO + N^{\cdot} \quad (1)$$

$$N^{\cdot} + O_2 \rightarrow NO + O^{\cdot} \quad (2)$$

$$N^{\cdot} + {}^{\cdot}OH \rightarrow NO + H^{\cdot} \quad (3)$$

Zeldovich mechanism is dependent on flame temperature. This is due to the fact that formation of oxygen radical ($O^{\cdot}$) depends on presence of high temperature. Moreover activation energy required is maximum for (1). Hence it is the rate determining step in this mechanism. Greater temperature results in increase in rate of (2), hence increasing production of NO.

Fenimore mechanism or "Prompt mechanism" is more complex. It involves reaction of radicals present in fuel with nitrogen in air to form compounds which eventually form NO_x (4). This takes place very early in the combustion process and is dependent on radical concentration in fuel (5).

The formation of NO_x in biodiesel reactions have been suggested equations (4) to (6) as follows.

$$HCN + O^{\cdot} \rightarrow NCO + H^{\cdot} \quad (4)$$

$$NCO + H^{\cdot} \rightarrow NH + CO \quad (5)$$

$$NH + H^{\cdot} \rightarrow N^{\cdot} + H_2 \quad (6)$$

$$N^{\cdot} + OH \rightarrow NO + H^{\cdot} \quad (7)$$

The other component of NO_x emissions, NO_2, which accounts for around 10-30% of NO_x emissions, is produced by reaction of NO with peroxy radicals in the high temperature flame(8). NO_2 can be converted back to NO by reaction with oxygen radicals (9).

$$NO + HO_2^{\cdot} \rightarrow NO_2 + {}^{\cdot}OH \quad (8)$$

$$NO_2 + O^{\cdot} \rightarrow NO + O_2 \quad (9)$$

5.3 Developing additives to reduce NO_x emissions

Taking into consideration the Fenimore mechanism of NO_x emission in biodiesel as discussed in section 5.2, increase in NO_x emissions is plausible due to increase in free radical generation. The species responsible for production of NO and NO_2 are various free radicals produced in the combustion process like hydrogen ($H^{\cdot}$), oxygen ($O^{\cdot}$), nitrogen ($N^{\cdot}$) and peroxide ($HO_2^{\cdot}$) free radicals. These species oxidize the fuel to produce NO. But, NO_2 on the other hand, is produced by reaction between peroxy radical and NO molecules.

Another very important benefit of using an antioxidant as an additive for biodiesel is its role in increasing stability of biodiesel [10]. It has been observed that biodiesel is more prone to oxidation as compared to conventional diesel [11]. Hence its storage stability is a concern. Being an oxidation inhibitor antioxidant helps in storing biodiesel for a prolonged time.

Antioxidants have proven to be very effective additive as free radical quenching agents [12]. Therefore to control the production of both NO and NO_2, using a substance which can quench or consume free radicals seems to be a good strategy.

Taking into view all the above mentioned factors, Ascorbic acid (more commonly known as vitamin C) and 3-hydroxy toluene were used as additive in biodiesel. Both additives molecular structures and compounds were shown in figures 1 and 2, respectively:

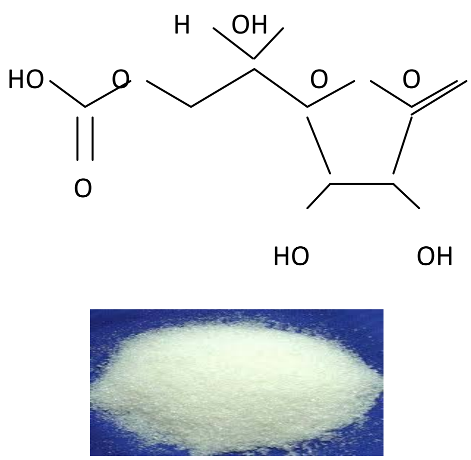


Figure. 1 .Ascorbic Acid structure

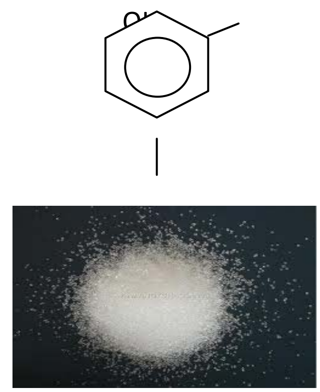


Figure.2. 3-hydroxy toluene structure

Methyl propyl ether and Phenyl ethyl ether were also used as additives since ethers act as very good antioxidants and some of them have very high latent heat of vaporization. Moreover, both the ethers selected were low volatile, very low auto ignition temperature and can be blended with biodiesel in any proportions. Both additives structure and compounds were shown in figure 3 and 4, respectively.

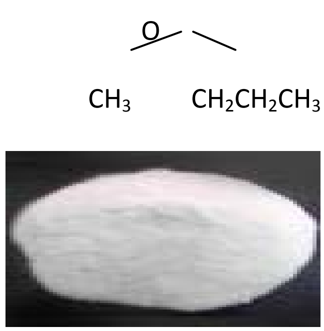


Figure.3 Methyl propyl ether structure

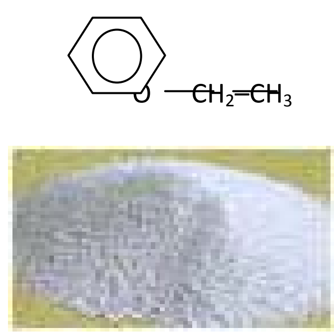


Figure.4 Phenyl ethyl ether structure

6. Experimental Methodology

Biodiesel used in this work was obtained from oil extracted from Honge feedstock. The oil was made to undergo transesterification reaction with methanol as shown in figure no.5. The catalyst used was NaOH. Free fatty acid content of oil was determined by titration with NaOH and it was neutralized by obtaining Glycerin as by-product as shown in the figure no.6.

Figure no. 5 Biodiesel Plant

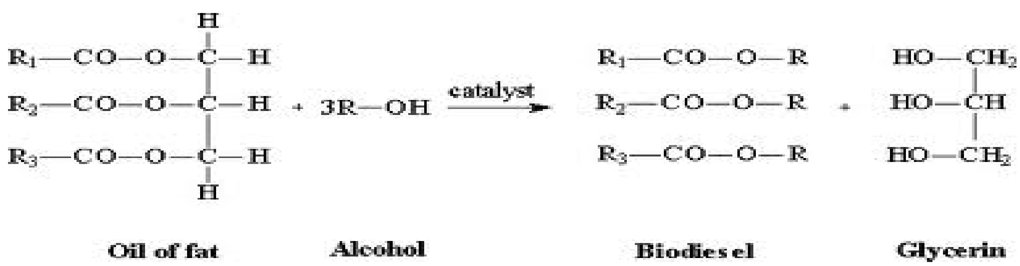


Figure no 6: Long Chain Fatty Acid with Biodiesel oil

Extracted biodiesel oil extracted through transesterification process and shown the samples in figure no.7. Various physical and chemical important properties of the biodiesel namely calorific value, flash point, fire point, pour point, aniline point and diesel index were tested as per ASTM standards and reported in table no.2.Similarly, density and kinematic viscosity were also measured as reported in the table no.3 and compared with diesel fuel and biodiesel fuel blends.

Figure no: 7 Biodiesel samples with blends

The entire experimental set has been developed as shown in figure no.8 and specification of the engine reported in the table no.1.After establishing emission levels and fuel consumption rates of diesel and neat biodiesel samples, the four additives were added one by one to B30 sample and emissions and performance were recorded. The concentration of additives in biodiesel-diesel blends as follows along with neat fuels.

- Diesel as base fuel and neat biodiesel with fuel blends
- For ascorbic acid: B30 + (0.25-0.75)% Ascorbic acid
- For 3-hydroxy toluene: B30 + (0.25%-0.75) 3-hydroxy toluene
- For phenyl ethyl ether: B30 + (1-3)% phenyl ethyl ether
- For methyl propyl ether: B30 + (1.5-4.5)% methyl propyl ether

Figure.8 Experimental Test rig

The engine was operated at maximum load of 3000 W at speed of 1500 rpm. The engine was run for an optimum time so that combustion chamber temperature can be rise up to a certain limit so that emissions and performances data were measured. Tachometer used to measure engine speed.

A Delta 1600-L of MRU makes as shown in figure no.9 Exhaust gas analyzer was used to measure the amount of NO_x, NO, CO, CO_2 and Hydrocarbon in the exhaust gases. Mass rate of the fuel was also measured by using burette and a stop watch. Engine output was connected to a computer using RS-232 port and all the data was directly stored in the computer.

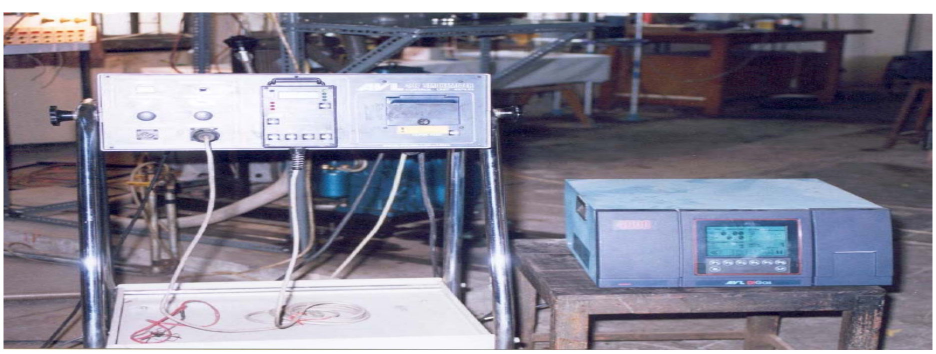


Figure.9 Five Gas Emission Analyzer

Table no: 1 Specifications of the Kirloskar Diesel Engine

Engine make	Specifications
Engine Type	4S / Air Cooled
Injection Type	Direct Injection
Power Rating	7.5 kVA
Engine Speed	1500 rpm
Number of Cylinders	one
Bore / Stroke	63 / 78 mm

7. Results and Discussions

Table no: 2 physical and chemical properties of biodiesel and diesel

Property	Diesel	Biodiesel
Calorific value (KJ/kg)	42000	36378
Flash point (˚C)	73	142
Fire point (˚C)	78	143
Pour point (˚C)	-23	4
Aniline point (˚C)	70	37
Diesel index	55	42.21

Table no: 3 Kinematic viscosity and density of various diesel-biodiesel blends

Fuel sample	Density (kg/m^3)	Kinematic viscosity at 25 ˚C
Diesel	836	3.45
Biodiesel (Honge methyl ester)	878	4.67
Honge oil	9918	52.7
B75	867	4.21
B50	857	3.94
B25	847	4.02

7.1 Performance Characteristics of Various blends

Various fuel sample bends compared with fuel consumption as shown in figure no.10. Increase in fuel consumption with increasing biodiesel was attributed with lower combustion capacity of biodiesel due to lower calorific value of biodiesel at various load conditions.B30 case fuel consumption was even lower compared diesel and other fuel blends under no load case.

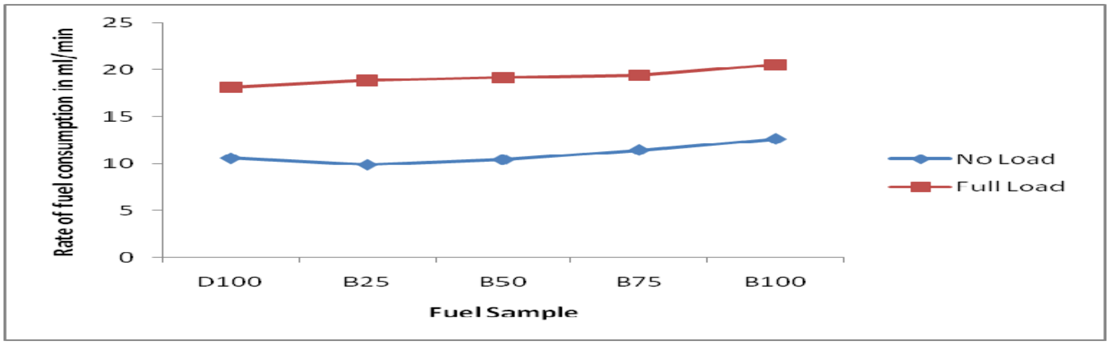


Figure 10.Comparision of fuel consumption with various blends

Brake power output decreases as the content of biodiesel and its diesel blend increases as shown in figure 11. This can be attributed to lesser calorific value of biodiesel as compared to diesel. Hence total heat released reduces when the amount of diesel in the blend reduces.

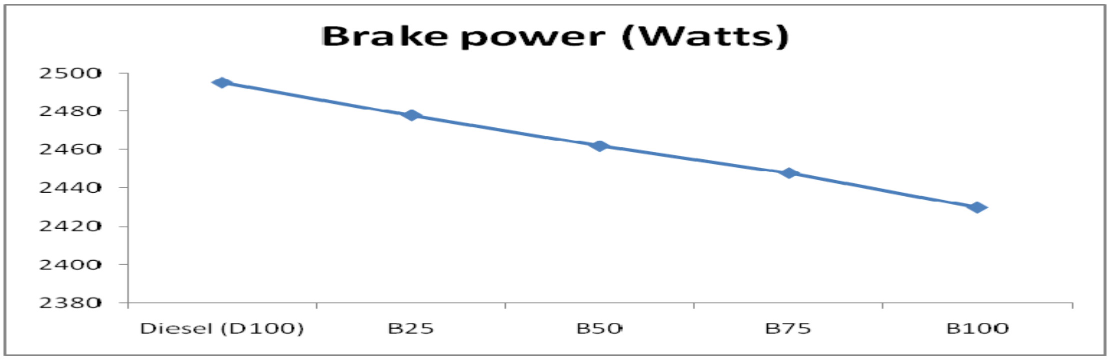
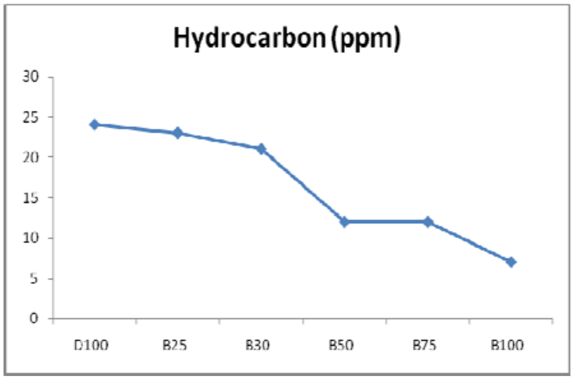


Figure 11. Comparison of Break Power output with various fuel blends

7.2 Emission Characteristics of Various blends

The comparison of emissions namely HC, CO, CO_2 and NOx showed in figures 12, 13, 14 and 15 respectively. The decrease in CO, CO_2 and HC with increasing biodiesel content in diesel-biodiesel blend due to the presence of greater number of oxygen molecules in biodiesel compared to diesel fuel. On the contrary increase in NO_x emissions was due to increase in cylinder temperature and formation of more free radicals within the combustion chamber.



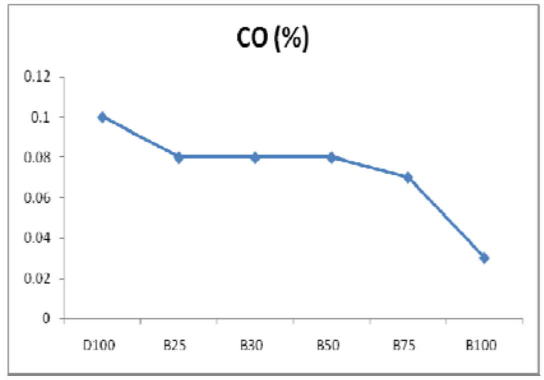
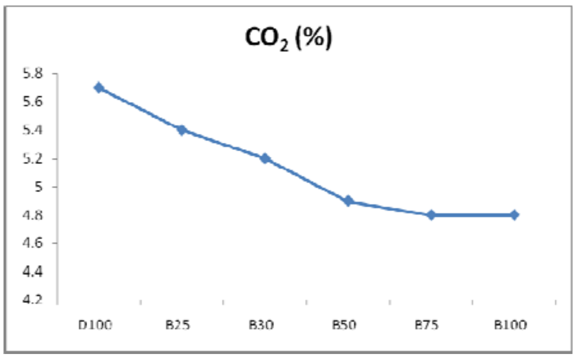


Figure 12.Variation of hydrocarbon emissions with various blends

Figure13.Variation of CO with various blends



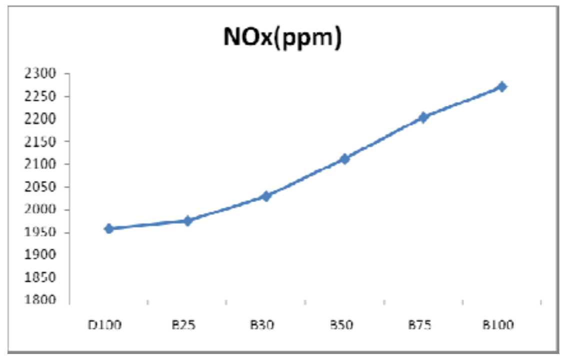
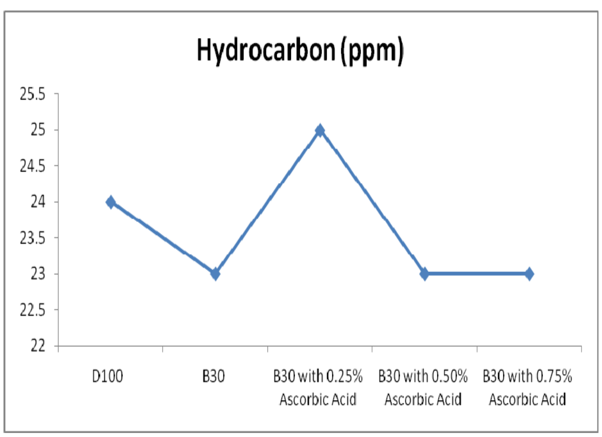


Figure 14.Variation of CO_2 with various blends

Figure 15.Variation of NO_x emissions with various blends

7.3 Effect of Ascorbic acid on emissions

The comparison of emissions of HC, CO, CO_2 and NO_X showed in figures 16, 17, 18 and 19 respectively**.** The trend shows most of the emissions were decreasing with various fuel blends.



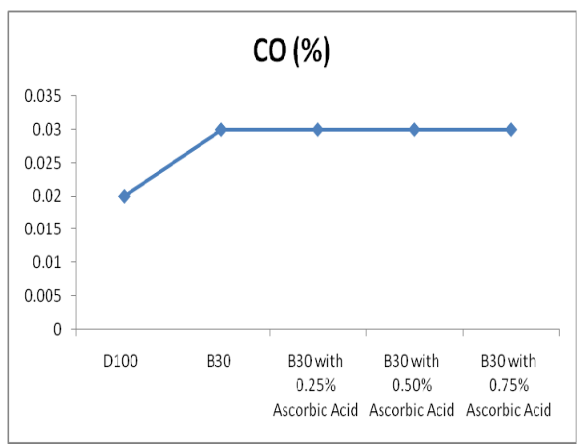
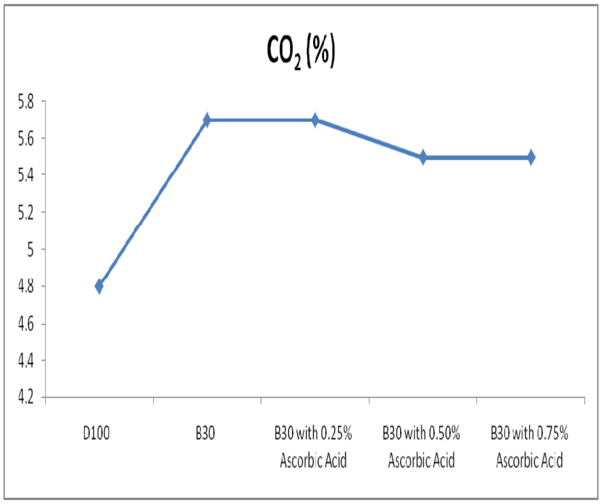


Figure 16.Variation of HC emissions with Ascorbic acid blends

Figure 17.Variation of CO emissions with Ascorbic acid with blends

The slight increase in NO_x emissions due to addition of small amount of ascorbic acid in the biodiesel could be due to low solubility of ascorbic acid in biodiesel. Hence antioxidant effect of Ascorbic acid could able to reduce the NO_x emissions by consuming free radicals of blends.



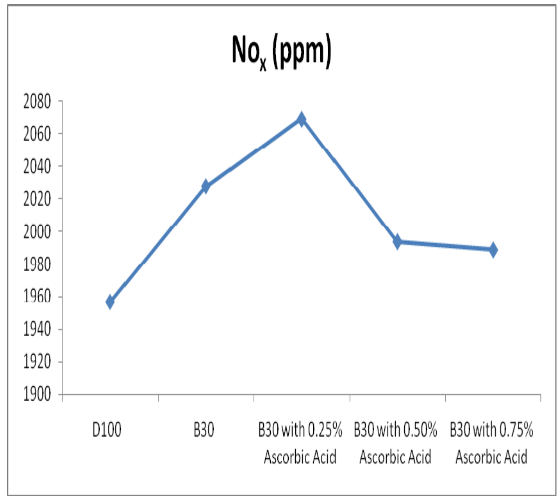


Figure 18.Variation of CO_2 emissions with Ascorbic acid blends   Figure 19.Variation of NO_x emissions with Ascorbic acid blends

Similarly emissions of CO, CO_2 and HC emissions were decreasing due to efficient combustion as compared to biodiesel by various ascorbic acid blends along with the presence of more number of oxygen molecules.

7.4 Effect of addition of Ascorbic acid on power output of biodiesel:

Power output has shown some variation with increasing Ascorbic acid content as shown in figure 20.At smaller concentrations it reduces the power output of biodiesel. At very high concentration also the power output drops below that of biodiesel was due to interference in combustion as ascorbic acid was due to non soluble at higher concentrations in biodiesel.

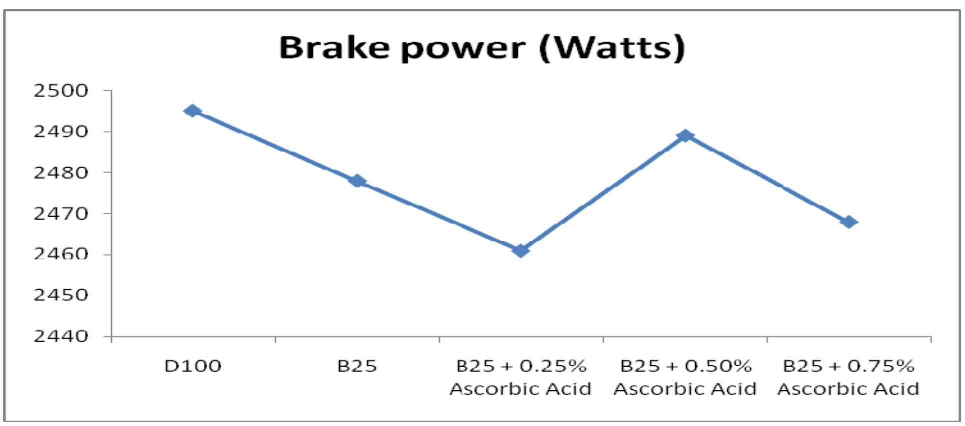
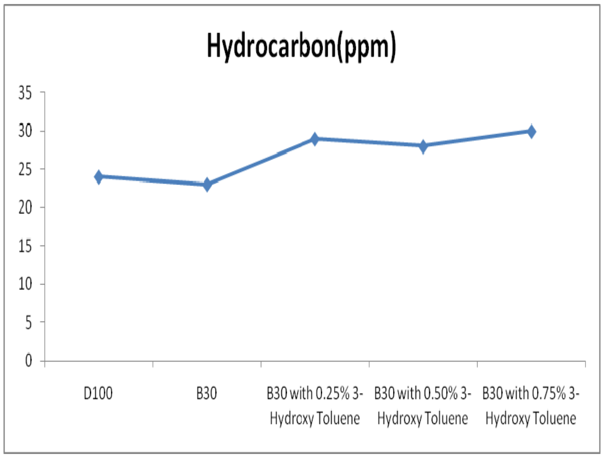


Figure 20. Comparison of Break Power output with Ascorbic Acid blends

7.5 Effect of 3-hydroxy toluene on emissions

Decrease in NO_x emissions was observed when 3-hydroxy toluene is used as an additive for biodiesel shown in figure 24. The antioxidant nature of 3-hydroxy toluene has helped immensely in reducing NO_x emissions by quenching proxy free radicals.



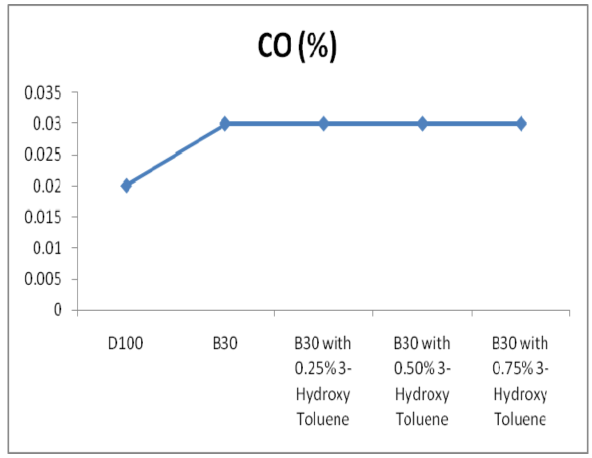
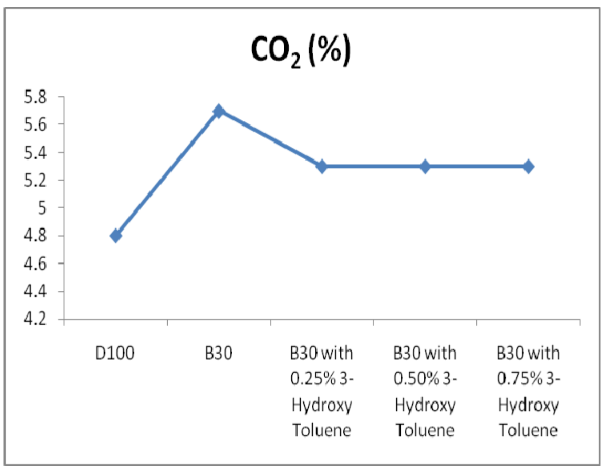


Figure 21.Variation of HC emissions with 3-hydroxy toluene blends Figure22.Variation of CO emissions with 3-hydroxy toluene blends

After increasing the concentration of 3-hydroxy toluene up to fifty percentages, no more reduction in NO_x emission is observed. This could be due to limited solubility of 3-hydroxy toluene in biodiesel.



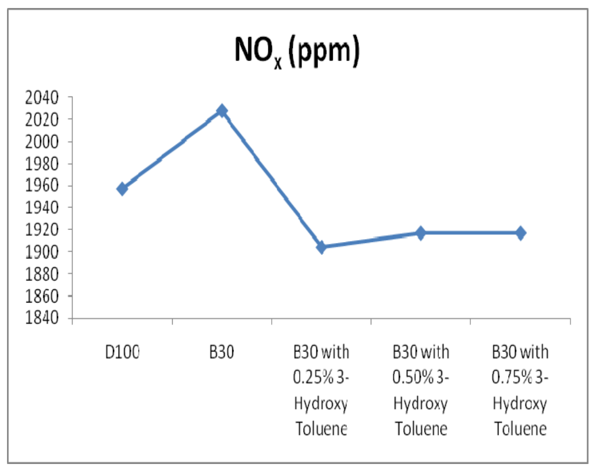


Figure 23.Variation of CO_2 emissions with 3-hydroxy toluene blends Figure 24.Variation of NOx emissions with 3-hydroxy toluene blends

As shown in figures 21, 22 and 23 represents the emissions of HC, CO and CO_2 respectively. Emissions were decreasing due to efficient combustion as compared to biodiesel with their 3-hydroxy toluene blends due to the presence of more number of oxygen molecules which causes efficient combustion.

7.6 Effect of 3-hydroxy toluene on performance

Power output increases with addition of 3-Hydroxy Toluene as shown in figure no.25. At fifty percentage concentration of additive it is slightly greater than diesel itself. This can be attributed to proper solubility of additive in biodiesel and high calorific value along with the presence of more number of oxygen molecules in the biodiesel.

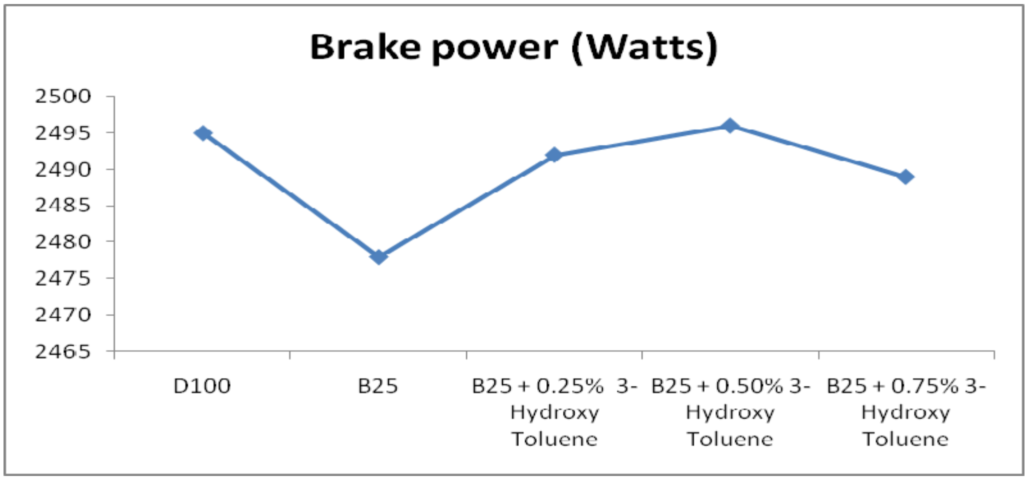
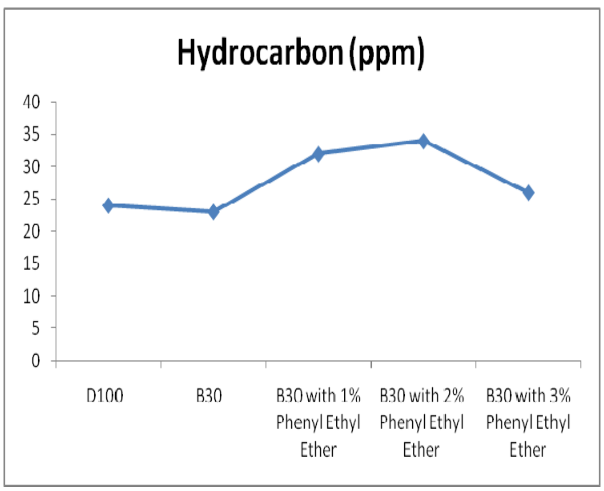


Figure 25. Power output with 3– Hydroxy Toluene

7.7 Effect of Phenyl ethyl ether on emissions

Phenyl ethyl ether increases hydrocarbon emissions due to increase in effective hydrocarbon content of the fuel as shown in figure 26. The decrease in NO_x emissions is due to high latent heat of vaporization of phenyl ethyl ether as shown in figure 29.



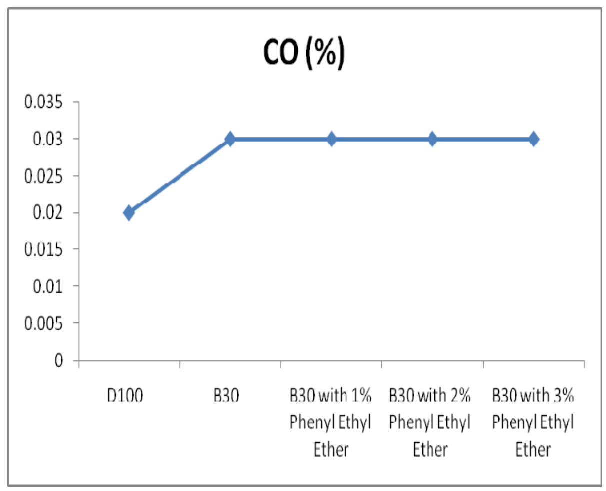
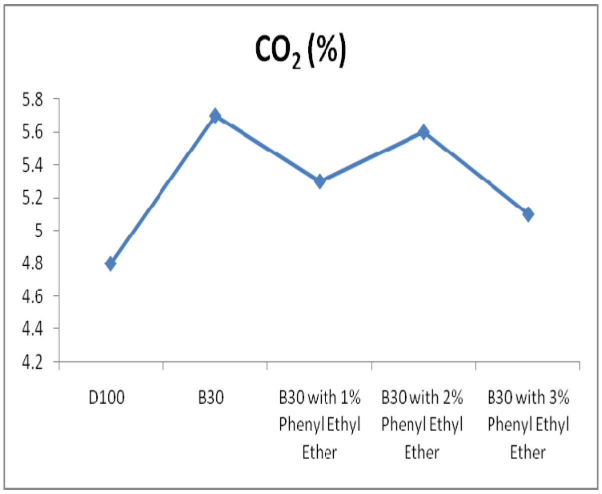


Figure 26.Variation of HC emissions with Phenyl ethyl ether blends Figure 27.Variation of CO emissions with Phenyl ethyl ether blends

The slight increase in NO_x emission when 2% phenyl ethyl ether is added may be due to increase in aromaticity of fuel which increases iodine number of fuel. Hence sites of unsaturation or sites of free radical formation increase leading to a greater amount of NO_x emissions.

As shown in figures 27 and 28 represents the emissions of CO and CO_2 respectively. Emissions were decreasing due to efficient combustion as compared to biodiesel with their phenyl ethyl ether blends with the presence of more number of oxygen molecules and causes increase of high calorific values of the additive fuels blends.



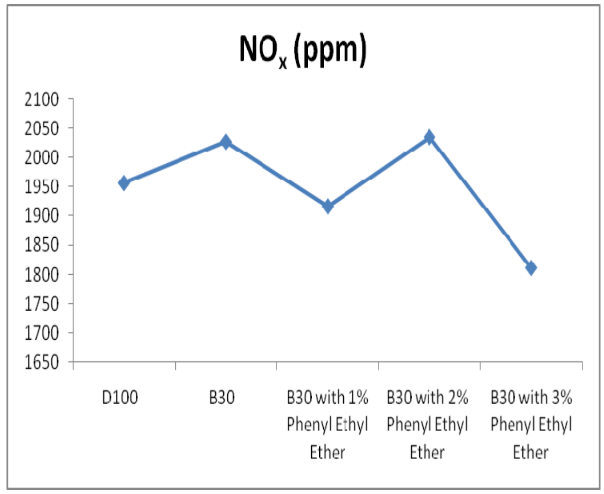


Figure 28.variation of CO_2 emissions with Phenyl ethyl ether blends Figure 29. Variation of NO_x emissions with Phenyl ethyl ether blends

7.8 Effect of Phenyl ethyl ether on performance

Addition of Ethyl Phenyl Ether in biodiesel increases power output of biodiesel due to its higher calorific value as shown in figure no.30. Since the miscibility is same even at higher concentrations no major change is seen on increasing concentration of Ethyl Phenyl Ether.

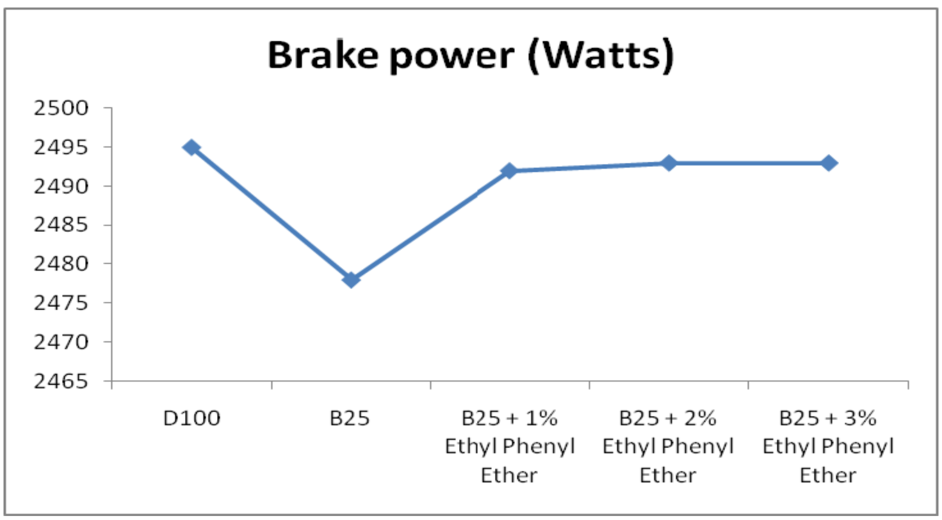
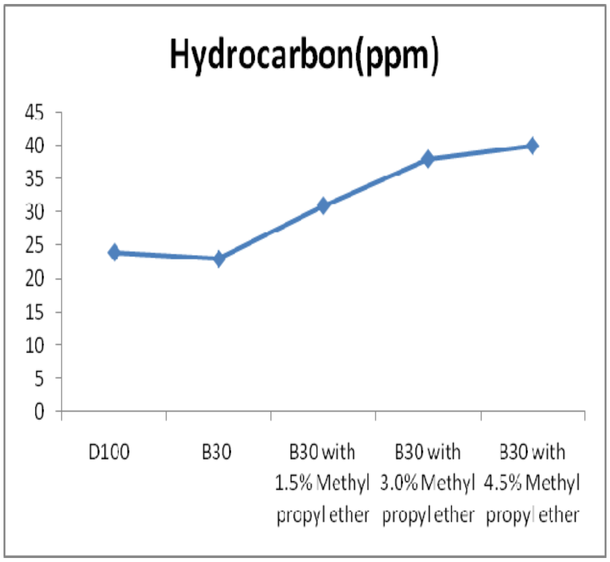


Figure 30. Comparison of break Power output with Phenyl ethyl ether blends

7.9 Effect of Methyl propyl ether on emissions

Effect of methyl propyl ether as an additive for biodiesel is very encouraging. It decreases CO and CO_2 emissions constantly with increasing content of biodiesel as shown in figures 32 and 33 respectively. This could be due to high volatility and ease of combustion of methyl propyl ether and hence complete combustion of biodiesel.



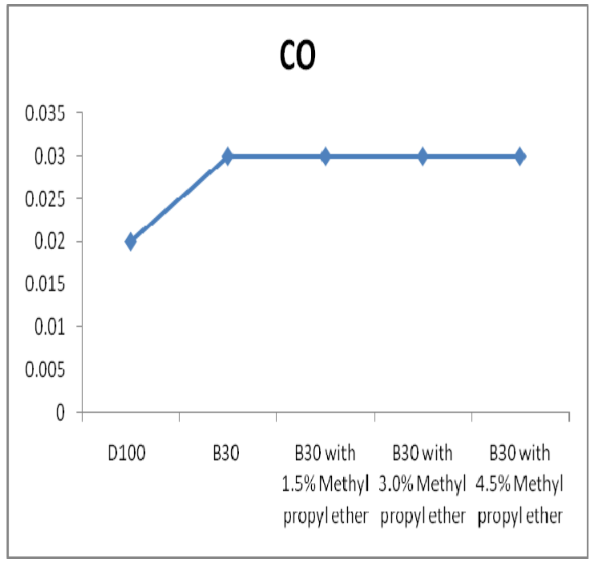
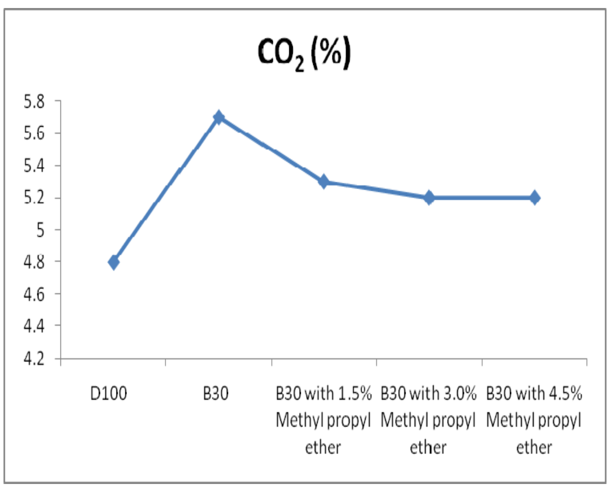


Figure 31.Variation of HC emissions with methyl propyl ether blends Figure 32.Variation of CO emissions with methyl propyl ether blends

Increase in hydrocarbon content in exhaust shown in figure no.31 could be explained by the increase in hydrocarbon content of fuel due to addition of methyl propyl ether and also due to almost inert chemical nature of methyl propyl ether.



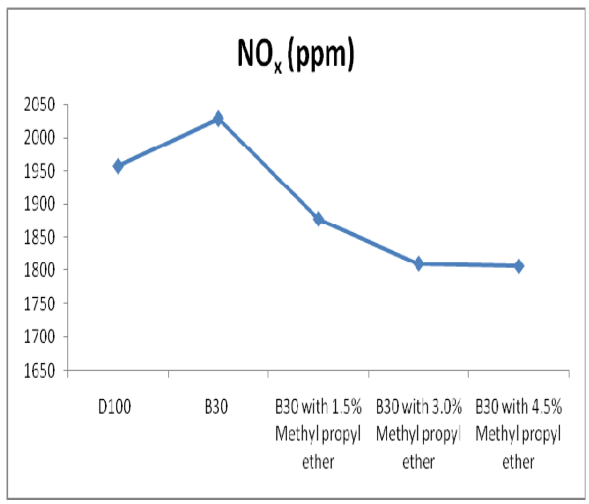


Figure 33.Variation of CO_2 emissions with methyl propyl ether blends Figure 34. Variation of NO_x emissions with methyl propyl ether blends

Decrease in NO_x emission due to addition of methyl propyl ether is highest compared to all other additives used shown in figure no.34. This is mainly due to high latent heat of vaporization of methyl propyl ether. When combustion starts in engine, methyl propyl ether absorbs high amount of energy and gets evaporated to gas. This reduces temperature of cylinder hence reducing NO_x.

7.10 Effect of addition of Methyl Propyl Ether on power output:

Power output increases with increasing content of Methyl Propyl Ether in biodiesel as shown in figure no.35. This can be due to high enthalpy of vaporization of Methyl Ethyl ether. Moreover the boiling point is also very low, 40˚C. Due to the more ether vaporizes as combustion takes place and was replaced by biodiesel-diesel blend in the combustion chamber. Hence more fuel is burnt leading to higher amount of energy released in the cylinder leading to more power output.

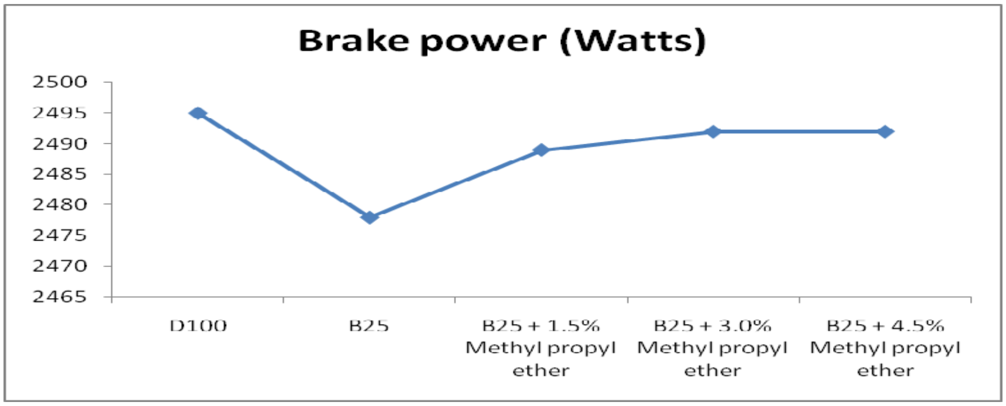


Figure 35. Power output with Methyl Propyl Ether with blends

8. Conclusions

1. The neat biodiesel and its bends emissions were lower compared to diesel fuel due to efficient combustion in the presence of more number of oxygen molecules. But, NOx emission was increasing in all fuel cases due to increase of cylinder temperature. Break power were decreasing due to lower calorific of the fuel blends.

2. The effect of Ascorbic acid as additive showing the HC, CO, CO_2 and NOx emissions are initially showing the trend of increasing compared to neat Diesel and biodiesel fuels due to addition of small amount of ascorbic acid in the biodiesel or could be due to low solubility of ascorbic acid in biodiesel. But, increased quantity of Ascorbic acid as shown makes it a little more soluble in biodiesel and hence it starts consuming free radicals produced and therefore reducing the all emissions compared to neat biodiesel emissions.

3. Break power was increased with the addition of ascorbic acid with various biodiesel blends compared to neat biodiesel fuel due to efficient combustion with additives.

4. Three-hydroxy toluene additive indicates the increase in HC, CO, CO_2 and NOx emissions initially due to insoluble of additives in the biodiesel. But, CO, CO_2 and NOx are decreasing due to antioxidant nature of additive helped in quenching peroxy free radicals compared to biodiesel.

5. Break power was increased with the addition of three-hydroxy toluene additive with various biodiesel blends compared to neat biodiesel fuel due to efficient combustion with additives.

6. Phenyl ethyl ether additive increases hydrocarbon emissions due to increase in effective hydrocarbon content of the fuel. The decrease in HC, CO_2 and NO_x emissions is due to high latent heat of vaporization of phenyl ethyl ether. The slight increase in NO_x emission with higher

amounts of phenyl ethyl ether is added may be due to increase in aromaticity of fuel which increases iodine number of fuel, which intern forms the free radicals to increase NO_x.

7. Break power was increased with the addition of Phenyl ethyl ether additive with various biodiesel blends compared to neat biodiesel fuel due to efficient combustion with additives.

8. The Methyl propyl ether as an additive for biodiesel is very encouraging. It decreases CO_2 and NOx emissions constantly with increasing of additive. This is mainly due to high latent heat of vaporization of methyl propyl ether, which is 346 kJ/kg. When combustion starts in engine, methyl propyl ether absorbs high amount of energy and gets evaporated to gas. This reduces temperature of cylinder hence reducing NO_x emissions. But, CO and HC are increasing due to more carbon contents in the fuel and could be inert chemical nature of additive.

9. Break power was increased with the addition of Methyl propyl ether additive with various biodiesel blends compared to neat biodiesel fuel due to efficient combustion with additives.

10. Most of the cases B30 showing an optimum fuel blends for lower emissions and higher break power output compared to other furl blends due to optimum calorific value of the fuel.

9. Scope of future work

Various other commonly available antioxidants can also be analyzed in reducing NO_x emissions. Other special additives also can be exploring the possibility of reducing Nox emissions.

10. Acknowledgement

We are thankful to the CiSTUP for funding this project.

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12. Signature of the Principal Investigator/Investigator: