

Research Article

Analysis of the Relationship between Exhaust Gas Temperature (EGT in °C) and Nitrogen oxides (NO_x in ppm) during Performance and Emission tests on various Biodiesels derived from edible and non-edible oils and their blends

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Abstract

Present study is concerned about analyzing and establishing the relationship between EGT and NO_x. The results for EGT and NO_x were obtained by conducting performance and emission tests on a 4-Stroke CI DI engine using Waste Cooking Oil Methyl Ester (WCOME), Methyl Ester of Jatropha (JME), Methyl Ester of Pongamia (PME), Methyl Ester of Composite Oil (COME), Second Grade Coconut Oil Methyl Ester (SGCOME) and petrodiesel. For comparison and validation, extracted values of results of these parameters from other researchers have also been considered. Performance and emission results of COME have already been analyzed. Physico-chemical properties of COME, WCOME and SGCOME have been found to be within the limits prescribed by BIS and ASTM standards. Analysis of the results have emphatically shown that EGT has a linear relationship with NO_x irrespective of Mix, Blend, Injection pressure (IP) and oils used as feed stocks. The nature of the graphs showing variations of NO_x with EGT in the range of EGT considered, conformed to an 'S' curve. It has been concluded that measurement of EGT is more than sufficient for estimating NO_x in the ranges of power output of the engines considered.

Keywords: EGT, NO_x, COME, WCOME, SGCOME, 'S' curve

1. Introduction

Diesel engines have been used as prime movers for applications such as power generation, transportation, agriculture etc. Main reasons being, higher fuel efficiency and lower cost per liter in comparison with petrol. Higher fuel efficiency is due to higher compression ratio of diesel engines and higher oxygen content in petrodiesel.

NO_x formation is a complex phenomenon dependent on various parameters such as Peak Combustion Pressure, Injection Timing (IT), Injection Duration (ID), Injection Quantity (IQ), Rate of Heat Release (RoHR), Cetane Number (CN), Combustion Temperature and EGT.

Researchers have found that NO_x emission from engines run on petrodiesel is undesirable owing to environmental hazards causing health problems. Consequently, several researchers, in order to counteract emissions like NO_x and Particulate Matter (PM) have considered the use of biodiesel derived from both edible and non-edible individual oils, but have met with little success. They have used methods like Exhaust Gas Recirculation (EGR), High Voltage Plasma Treatment (HVPT) of exhaust gases, Retrofit arrangement, use of Water Emulsion and Intake Water Injection etc., as NO_x reduction techniques. In most of these works, NO_x and PM

emission reduced slightly at the cost of Brake Thermal Efficiency (BTE). It is found that the reduction in NO_x emission by the application of these techniques is not economically viable and financially feasible to be applicable in sectors mentioned. Also, Measurement of NO_x emission, at the end of application of these techniques, calls for sophisticated and costly measurement and control systems (Venkata Hanumantha Rao Yarrapathruni et al, 2009; S.Ghosh et al, 2012; ArunBalasubramanian K et al, 2013; S.Ghosh et al, 2012).

Two non-edible oils (Jatropha and Pongamia) were mixed in various proportions and biodiesel was derived from this composite oil using transesterification process. Owing to the synergetic effect of the two oils it was found that the physico-chemical properties were significantly similar to that of petrodiesel. Further, there was considerable overall increase and decrease in performance and emission characteristics by 53.9% and 54.83% respectively (H.Yogish et al, 2012; H.Yogish et al, 2013; H.Yogish et al).

Engine cooling did not allow engine temperature to increase since outlet temperature and flow rate of the coolant were maintained at the required levels. Due to positive synergetic effect of two oils, RoHRs were the minimum for the blends identified which signify that the heat release took place quickly so as not to increase the temperature. In the range of IPs considered (160bar and 200bar including 180bar), NO_x emissions were found to be

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in the range of 350 ppm to 450 ppm. These observations were also true for biodiesel derived from waste cooking oils. These values are significantly less than the values got by other researchers. This has emphatically proved that rather than considering costly methods and techniques, it would suffice to consider mixing of suitable edible or non-edible oils and use them as feed stock for biodiesel production (H.Yogish et al, 2012; H.Yogish et al, 2013; H.Yogish et al). Owing to the complexities involved in reducing NO_x emission and measurement of it, in the present study, an empirical correlation is established between EGT in 0C and NO_x in ppm.

2. Methods

NO_x emission (in terms of EGT 0C) from the engine with different biodiesel blends of COME, JME, PME, WCOME, SGCOME and petrodiesel are shown in Figures 1 through 8.

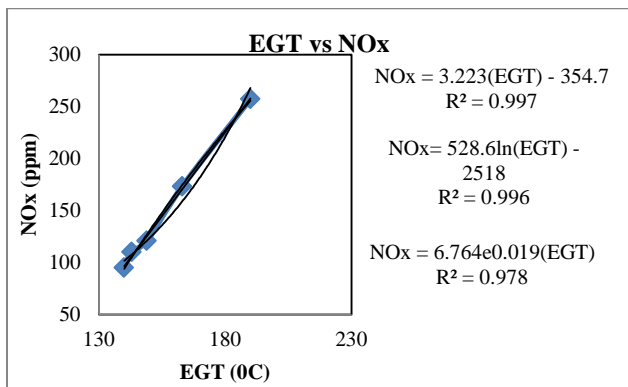


Fig.1 Variation of EGT with NO_x for WCOME at 180 bar IP

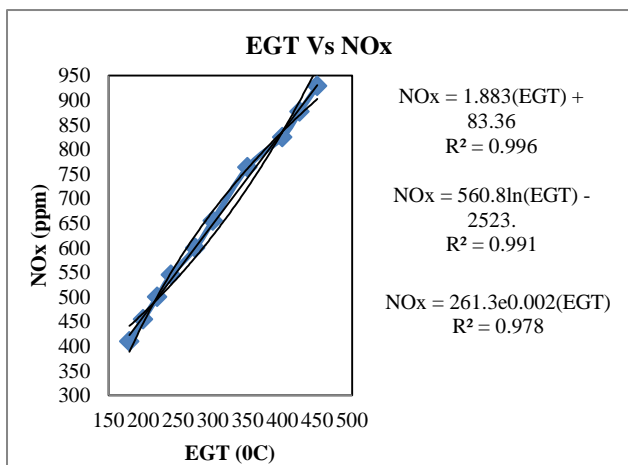


Fig.2 Variation of EGT with NO_x for JME and PME at 180 bar IP

All the plots are for 180 bar IP and engine rated capacity in the range of 3.75 kW to 5.20 kW. For COME and WCOME NO_x was measured in terms of both ppm and EGT. NO_x and EGT values for JME, PME were extracted from other research works (P.V. Rao, 2011; M.

Loganathan et al, 2012; S. Ghosh et al, 2012; T.T. AL Shemmeri et al, 2011; P. Suresh Kumar et al, 2012; Bhupendra Sing Chauhan et al, 2010; R.D.Gorle et al, 2012). For SGCOME it was made in terms of EGT in 0C. Interpolation and extrapolation techniques were used to get other missing data points considering EGT in 0C and NO_x in ppm from other research works. It is observed from the figures that, for lower range of EGT, between 130 0C to 180 0C, its relationship with NO_x is significantly linear for lower portion of the 'S' curve.

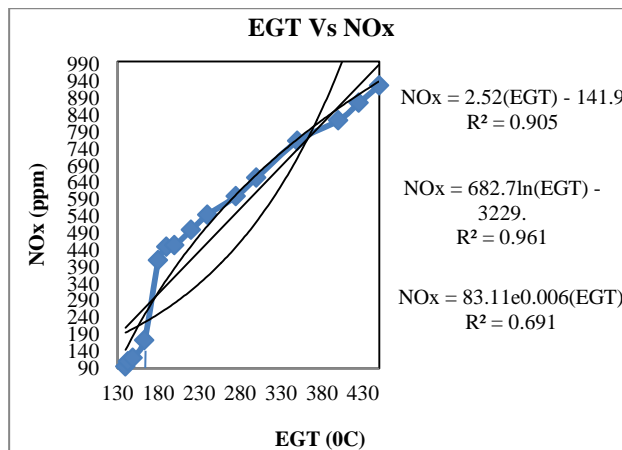


Fig.3 Variation of EGT with NO_x for WCOME, JME and PME at 180 bar IP

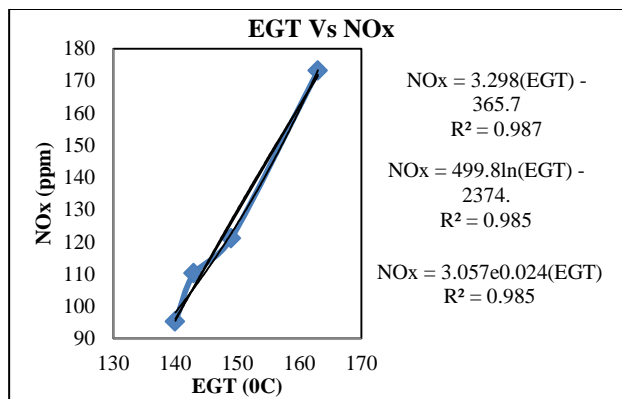


Fig.4 Variation of EGT with NO_x for WCOME, JME and PME in the range 130 0C to 170 0C at 180 bar IP

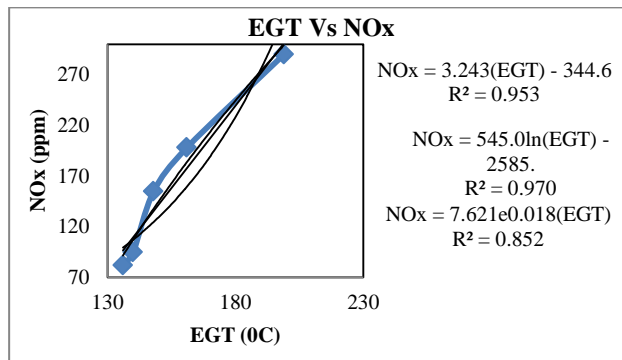


Fig.5 Variation of EGT with NO_x for petrodiesel at 180 bar IP

In the range of 180 °C to 450 °C, the relationship is also significantly linear for the upper portion of ‘S’ curve. One must observe that the slopes for these ranges are different.

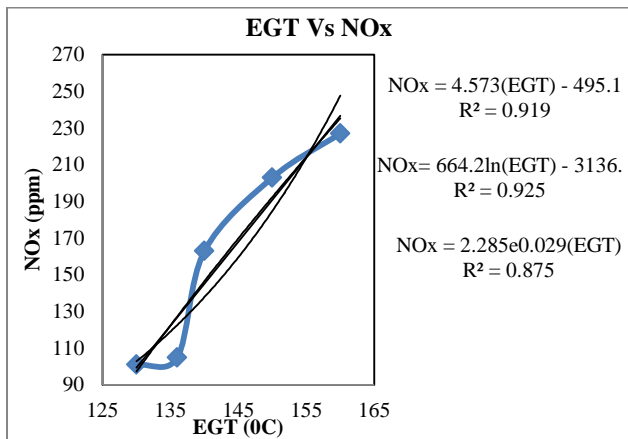


Fig.6 Variation of EGT with NO_x for COME at 180bar IP without Plasma Treatment

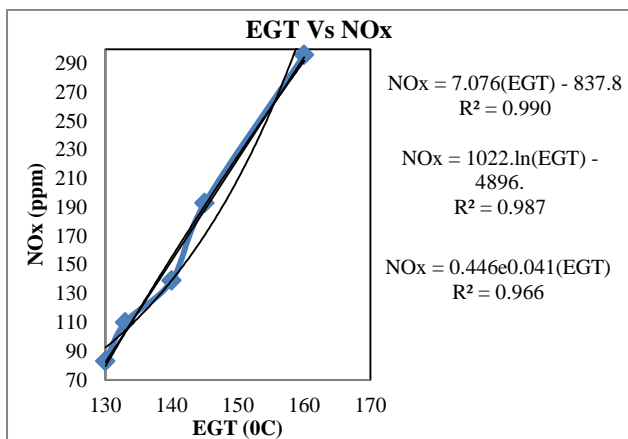


Fig.7 Variation of EGT with NO_x for COME at 180bar IP with Plasma Treatment

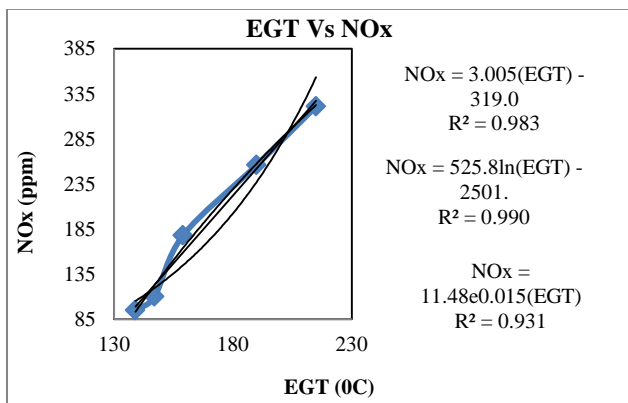


Fig.8 Variation of EGT with NO_x for SGCOME at 180bar IP

3 Results and Discussion

Figure 1 is showing variation of EGT in °C with NO_xin ppm for WCOME at 180 bar IP. It is the designed pressure

for the considered engine and performance and emission parameters were maximum and minimum at this pressure (H.Yogish et al, 2012; H.Yogish et al, 2013; H.Yogish et al). It is evident from figure that NO_xin ppm and EGT in °C bear linear relationship, with R-squared value of 0.997 in the range between 130°C and 210°C. For the same curve, R-squared values for logarithmic and exponential fits are 0.996 and 0.978 respectively. Obviously, linear fit is the best fit. Figure 2 is depicting the same parameters but it is for JME and PME. R-squared value being 0.996 signifies the linear relationship between NO_x and EGT. It should be observed that, the range of EGT in figure 2 is between 150 °C to 500 °C. This emphatically illustrates that the NO_x has very significant linear relationship with EGT in the range considered. Figure 3 is showing variations of EGT and NO_x for all the three methyl esters considered. One can observe that, the range is between 130°C and 450°C. Linear relationship has the R-squared value 0.901, whereas it is 0.961 for logarithmic fit. This is quite expected since the values are from the works of different researchers and investigations conducted at different experimental conditions, yet linear relationship is observed. Figure 4 is showing the plot of variables for lower range of them. R-squared value for this is 0.987 and 0.985 for linear and logarithmic fits.

Figure 5 is showing the graph of EGT in °C and NO_x in ppm. This graph is plotted to ascertain whether the observations and analyses made for other oils is true with petrodiesel. These are significantly so for petrodiesel, as R-squared values are 0.953 and 0.970 for linear and logarithmic fits.

Figure 6 is showing the variation of EGT in °C and NO_x in ppm for COME at 180 bar IP without HVPT. Figure 7 is illustrating the values of the same parameters with HVPT. These curves have significant linear fit with R-squared values 0.919 and 0.990 respectively. An interesting observation is that, without HVPT, though the fit is linear, the significance is lesser in comparison with that of R- squared value of the fit of HVPT. The deviation is only 7.2%. This again has proved that EGT and NO_x have linear relationship irrespective of the oil under consideration.

Figure 8 is showing the variation of EGT in °C and NO_xin ppm for SGCOME at 180 bar IP. It is clear from the figure that, the relationship is linear with R-squared value being 0.983. For logarithmic relationship it is 0.990. The deviation is only 0.7%. Hence, one can say that for the considered oil, in comparison with other oils, linear relationship is the best suited one for EGT and NO_x.

One striking nature of the curves for all the considered oils is their shape conformance with letter ‘S’. The slopes for lower portions of the curves, for all the considered oils, are generally 2. For the upper portion it is 0.625. The same trends and shapes of the curves were observed during the investigations at other IPs, but are not reported here. Further, by the observation of these figures, it is found that NO_xand EGT have linear relationship irrespective of the type of feed stock, methyl esters, IPs, and rated power of the engine.

The steep nature of the curves in all the figures for lower ranges of EGT (lower portion of ‘S’ curve) is

expected because it is dependent on Peak Combustion Pressure, IT, ID, RoHR and CN, which signify that the heat release has taken place quickly so as not to increase the temperature thereby decreasing NO_x formation. Lower RoHR also facilitates combustion during ID period. Burning of this fuel occurs very quickly due to auto ignition. Shortening of ID period and lowering of amount of fuel that is involved with premixed portion of the blends during combustion is due to higher CN of Methyl Esters of different oils. This has given steep nature to the lower portion of the 'S' curve.

Conclusions

The present study has emphatically shown that EGT in °C and NO_x in ppm have linear or logarithmic relationship with each other. This relationship is true for Methyl Ester of any oil. This is quite evident from the following analyses. For WCOME the best fit equation is; $NO_x = 3.223(EGT) - 354.7$, with $R^2 = 0.997$. For JME and PME the best fit equation is; $NO_x = 1.883(EGT) + 83.36$, with $R^2 = 0.996$. For COME, without HVPT the best fit equation is; $NO_x = 4.573(EGT) - 495.1$, $R^2 = 0.919$, with HVPT the best fit equation is; $NO_x = 7.076(EGT) - 837.8$, with $R^2 = 0.990$. For SGCOME it is; $NO_x = 3.005(EGT) - 319.0$, with $R^2 = 0.983$. For the combined values of WCOME, JME and PME the equation is; $NO_x = 2.52(EGT) - 141.9$, with $R^2 = 0.905$. For petrodiesel the equation is; $NO_x = 3.243(EGT) - 344.6$, with $R^2 = 0.953$.

From Figures 3, 5, 6 and 8, it is seen that logarithmic fit is very slightly more significant than linear fit. However the overall deviation between these is only 2.23%. Hence, the conclusion is that, when EGT range is larger, consideration of logarithmic fit is slightly preferable than linear fit. For shorter ranges linear fit is the most significant.

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