

Research Article

# Analysis of the Relationship between Exhaust Gas Temperature (EGT in <sup>0</sup>C) and Nitrogen oxides (NO<sub>x</sub> 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 NOx. The results for EGT and NOx 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 NOx irrespective of Mix, Blend, Injection pressure (IP) and oils used as feed stocks. The nature of the graphs showing variations of NOx 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 NOx in the ranges of power output of the engines considered.

Keywords: EGT, NOx, 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> reduction techniques. In most of these works, NO<sub>x</sub> and PM emission reduced slightly at the cost of Brake Thermal Efficiency (BTE). It is found thatthe 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<sub>x</sub>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 empathically 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<sub>x</sub>emission and measurement of it, in the present study, an empirical correlation is established between EGT in  ${}^{0}C$  and NO<sub>x</sub> in ppm.

### 2. Methods

 $NO_x$  emission (in terms of EGT <sup>0</sup>C) 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<sub>x</sub> 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  $^{0}$ C. Interpolation and extrapolation techniques were used to get other missing data points considering EGT in  $^{0}$ C and NO<sub>x</sub> in ppm from other research works. It is observed from the figures that, for lower range of EGT, between 130  $^{0}$ C to 180  $^{0}$ C, its relationship with NO<sub>x</sub> is significantly linear for lower portion of the 'S' curve.







**Fig.4** Variation of EGT with NO<sub>x</sub> for WCOME, JME and PME in the range 130  $^{\circ}$ C to 170 $^{\circ}$ C at 180 bar IP





In the range of  $180 \,{}^{0}\text{C}$  to  $450 \,{}^{0}\text{C}$ , the relationship is also significantly linear for the upper portion of 'S' curve. One must observer 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.8 Variation of EGT with  $NO_x$  for SGCOME at 180bar IP

#### **3 Results and Discussion**

Figure 1 is showing variation of EGT in  ${}^{0}C$  with NO<sub>x</sub>in 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<sub>x</sub>in ppm and EGT in °C bear linear relationship, with R-squared value of 0.997 in the range between  $130^{\circ}$ C and  $210^{\circ}$ 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<sub>x</sub> 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<sub>x</sub> has very significant linear relationship with EGT in the range considered. Figure 3 is showing variations of EGT and NO<sub>x</sub> 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, vet 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  ${}^{0}C$  and NO<sub>x</sub> 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  ${}^{0}$ C and NO<sub>x</sub> 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<sub>x</sub> have linear relationship irrespective of the oil under consideration.

Figure 8 is showing the variation of EGT in  ${}^{0}$ C and NO<sub>x</sub>in 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<sub>x</sub>.

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  $NO_x$  and 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 <sup>0</sup>C and NO<sub>x</sub> 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; NOx = 3.243 (EGT) - 344.6, with R<sup>2</sup> = 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.

#### References

- H.Yogish, K.Chandrashekara, M.R. Pramod Kumar, (2012), Optimization of Experimental Conditions for Composite Biodiesel Production from Transesterification of mixed oils of Jatropha and Pongamia,*Heat and Mass Transfer, Springer*, 48 (11), pp 1955 – 1960.
- H.Yogish, K.Chandrashekara, M.R. Pramod Kumar, (2013), A Study of Performance and Emission Characteristics of Computerized CI Engine with Composite Biodiesel Blends as fuel at Various Injection Pressures, *Heat and Mass Transfer*, *Springer*, 49 (9), pp 1345 – 1355.

- H.Yogish, K.Chandrashekara, M.R. Pramod Kumar, Performance and Emission Study on a Computerized CI Engine with Composite Biodiesel at Various blends and Injection Pressures (Revised manuscript communicated), *Heat and Mass Transfer*, Springer.
- VenkataHanumanthaRao YARRAPATHRUNI, Ram Sudheer VOLETI, Nageswara Reddy PEREDDY, VenkataSitaramaRaju ALLURU (2009), Jatropha Oil Methyl Ester and Its Blends used as an Alternative Fuel in Diesel Engine, *Thermal Science*, 13 (3), pp 207-217.
- S. Ghosh, D. Dutta (2012), Performance and Exhaust Emission Analysis of Direct Injection Diesel Engine Using Pongamia Oil, *International Journal of Emerging Technology and Advanced Engineering*, 2 (12), pp 341-346.
- ArunBalasubramanian K, Guruprasath A, Vivar M, Skryabin I, Srithar K (2013), Performance and Emission Characteristics of Double Biodiesel Blends with Diesel, *Thermal Science*, 17 (1), pp 252-262.
- S. Ghosh and D. Dutta. (2012), A Comparative Study of the Performance & Emission Characteristics of a Diesel Engine Operated on Soybean Oil Methyl Ester (SOME), PongamiaPinata Methyl Ester (PME) and Diesel, *International Refereed Journal of Engineering and Science (IRJES)*, 1 (4), pp 22-27.
- P. V. Rao (2011), Experimental Investigations on the Influence of Properties of Jatropha Biodiesel on Performance, Combustion, and Emission Characteristics of a DI-CI Engine, *World Academy of Science, Engineering and Technology*, 51, pp 854-867.
- M. Loganathan, A. Anbarasu, A. Velmurugan (2012), Emission Characteristics of Jatropha - Dimethyl Ether Fuel Blends on A DI Diesel Engine, *International Journal of Scientific & Technology Research*, 1 (8), pp 28-32.
- S. Ghosh, D. Dutta (2012), A Comparative Study of the Performance & Emission Characteristics of a Diesel Engine Operated on Soybean Oil Methyl Ester (SOME), PongamiaPinata Methyl Ester (PME) and Diesel, *International Refereed Journal of Engineering and Science(IRJES)*, 1 (4), pp 22-27.
- T.T. AL Shemmeri, S. Oberweis (2011), Correlation of the NOx emission and exhaust gas temperature for biodiesel, *Applied Thermal Engineering*, 3, pp 1682 1688.
- P. Suresh Kumar, Ramesh Kumar Donga, P. K. Sahoo (2012), Experimental Comparative Study Between Performance and Emissions of Jatropha Biodiesel and Diesel under varying Injection Pressures, *International Journal of Engineering Sciences & Emerging Technologies (IJESET)*, 3 (1), pp 98-112.
- Bhupendra Singh Chauhan, Naveen Kumar, HaengMuk Cho (2010), Performance and emission studies on an agriculture engine on neat Jatropha oil, *Journal of Mechanical Science and Technology*, 24(2), pp 529-535.
- R.D.Gorle, A.V.Kolhe (2012), Performance Analysis of a CI Engine Using Biodiesel as an Alternative Fuel, *Golden Research Thoughts*, 3, pp 1-9.