ASSESSMENT OF NOX EMISSION CHARACTERISTICS OF E85-FUELLED VEHICLE WITH IMPLICATIONS FOR RURAL TRANSPORT SYSTEMS

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Abstract. Nitrogen oxides (NO_x) are key air pollutants that affect environmental quality, particularly in agricultural regions, where they can contribute to the formation of tropospheric ozone and secondary aerosols, negatively impacting crops and ecosystems. At the same time, these areas offer significant potential for local biofuel production, including E85 bioethanol produced from crops or waste materials. In this context, it is worthwhile to investigate the potential for reducing NOx emissions through the use of E85 fuel in rural road transport. This work aims to develop a methodology for analysing the instantaneous NOx emissions of vehicles powered by E10 and E85 fuels, taking into account dynamic driving conditions. The tests were conducted under WLTP test conditions on a chassis dynamometer, and the analysis focused solely on vehicle driving phases. Machine learning was used to describe the relationship between NOx emissions and operational parameters, allowing for the mapping of the influence of vehicle speed and acceleration on emissions. The model fit was assessed using standard classical statistical tools, including the coefficient of determination and parameter significance tests. Additionally, a comparative analysis was conducted using a relative emission difference indicator, enabling the identification of engine operating areas where the use of E85 can reduce NOx emissions compared to conventional fuel. The proposed approach provides a tool to support the assessment of biofuel potential to reduce nitrogen oxide emissions in road transport in rural areas, without being limited to average emission indicators.

Keywords: nitrogen oxide, ethanol, renewable energy, fuel.

Introduction

Reducing road transport emissions requires not only the development of zero-emission technologies but also transitional solutions to reduce emissions in the existing fleet of spark-ignition engine vehicles. One such solution is to increase the share of renewable fuels in the mix of conventional fuels. In this context, E85 fuel, containing approximately 85% ethanol, is of particular interest. It can be used in flex-fuel vehicles with minimal changes to the drivetrain.

The impact of increased ethanol content on nitrogen oxide (NO_x) emissions is ambiguous. On the one hand, ethanol's high heat of vaporisation can lower combustion temperature and limit NO_x formation. On the other hand, faster combustion and increased oxygen availability can promote their formation under certain engine operating conditions [1-5]. To date, research on ethanol fuels has focused primarily on aggregate emissions over test cycles. However, it is increasingly being emphasised that exhaust emissions are strongly related to the vehicle instantaneous driving dynamics, particularly speed and acceleration [6-10].

This paper aims to analyse instantaneous NO_x emissions as a function of vehicle speed and acceleration for E10- and E85-fueled vehicles, based on repeated WLTP tests [7; 11]. The paper determines emission surfaces in the speed-acceleration space and identifies areas of driving dynamics where using E85 fuel alters NO_x emissions. Despite numerous studies on the effects of ethanol on exhaust emissions, the literature still lacks analyses that allow a direct comparison of the emission characteristics of E10 and E85 fuels as a function of vehicle driving dynamics. In particular, few studies analyse how changing the ethanol content in the fuel affects the structure of instantaneous emissions in the speed-acceleration space.

Methodology

The tests were conducted using a passenger car equipped with a spark-ignition engine adapted to run on high-ethanol fuels (flex-fuel). The vehicle met the Euro 6 emission standard. It was equipped with a three-way exhaust gas aftertreatment system and an electronic fuel injection system operating in

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a closed-loop λ air-fuel ratio control. The engine controller automatically adjusted the engine operating parameters to the fuel composition.

The experiments were conducted on a chassis dynamometer under controlled laboratory conditions using the WLTP cycle. Two fuels were analysed: E10 reference gasoline and E85 high-quality fuel. Each test was performed three times. The test chamber temperature was maintained at 23 ± 2 °C, and the dynamometer settings matched the vehicle resistance to motion. During the WLTP cycle, instantaneous NO_x emission values and vehicle motion parameters were recorded with a resolution of one second. Emissions were analysed on a g/km basis. Based on the vehicle speed over time, four WLTP cycle phases were identified: Low, Medium, High, and Extra High. Further analysis only considered moments corresponding to vehicle motion, so observations below 1 km/h were removed from the dataset.

The relationship between NO_x emissions and vehicle driving dynamics was described using an instantaneous emissions model that accounts for vehicle speed and acceleration. The general form of the model is presented in the following equation:

$$P_t = C V_t^{\theta_1 + \theta_2 a_t} e^{\theta_3 V_t + \theta_4 a_t + \theta_5 V_t a_t + \theta_6 V_t^2 + \theta_7 a_t^2 + \varepsilon_t} . \quad (1)$$

Taking the logarithm of both sides of equation (1) we convert it to the form:

$$\log(P_t) = \theta_0 + \theta_1 \log(V_t) + \theta_2 a_t \log(V_t) + \theta_3 V_t + \theta_4 a_t + \theta_5 V_t a_t + \theta_6 V_t^2 + \theta_7 a_t^2 + \varepsilon_t . \quad (2)$$

The parameters of model (2) were estimated using the least squares method. A stepwise regression procedure was used to limit the number of explanatory variables.

The Akaike information criterion was used to select the best-fitting model, which accounts for both the quality of the model's fit to the data and the number of model parameters.

$$AIC = n \ln\left(\frac{1}{n}\left(\log(P_t) - \log(\hat{P}_t)\right)^2\right) + 2k . \quad (3)$$

Based on the estimated model parameters, emission values in the velocity–acceleration space were determined for the analysed fuels, enabling further comparison of NOx emission characteristics.

Results and discussion

The WLTP cycle comprises four driving phases: Low, Medium, High, and Extra High, corresponding to different speed ranges and vehicle load levels. This allows the cycle to encompass both conditions, similar to city driving and high-speed driving. The distribution of measurement points in the speed-acceleration space for both fuels is shown in Fig. 1. The visible range of variability confirms that the analysed data covers a wide range of vehicle dynamic states relevant to instantaneous emissions.

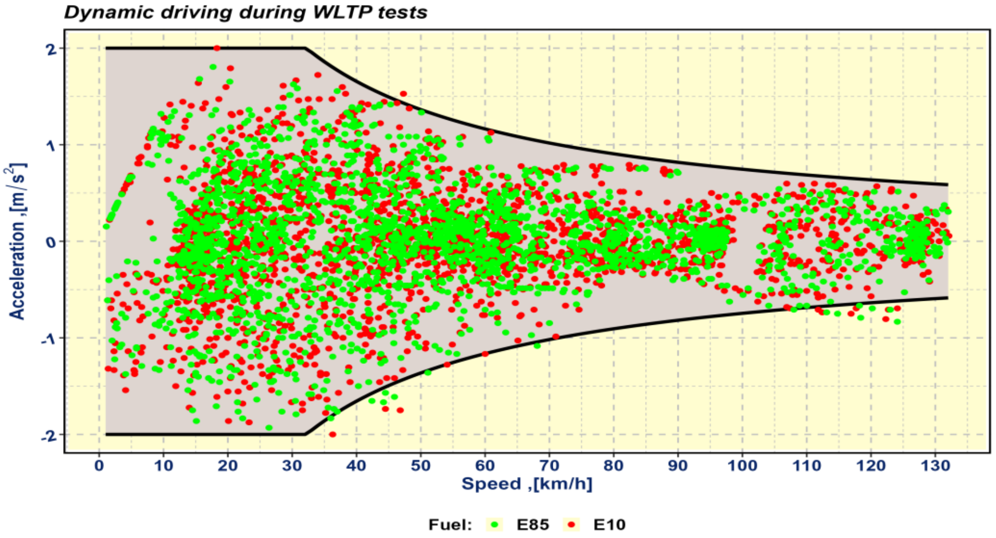

Fig. 1. **Vehicle dynamics during the WLTP test**

The boundaries of the analysed speed and acceleration region are based on the actual driving conditions observed during the test. Limiting the analysis to this range prevents extrapolation beyond the measured data. Based on the model presented in the methods section, the instantaneous NOx emission surfaces in the speed-acceleration space were determined for both analysed fuels. The emission surface for E10 fuel is shown in Fig. 2a, and for E85 fuel in Fig. 2b.

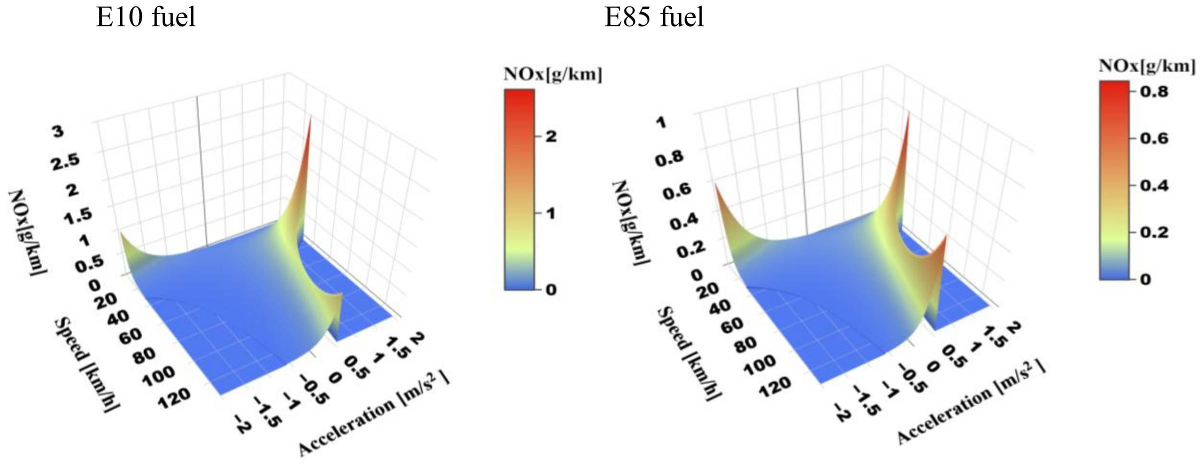

Fig. 2. **Surface of instantaneous NOx emission for E10 and E85 fuels in the velocity-acceleration space**

The highest emission values occur in areas of positive acceleration and at higher vehicle speeds, while under negative acceleration conditions, emissions remain relatively low. Compared to E10 fuel, the emission surface for E85 shows lower peak values, particularly in areas of high positive acceleration. Differences in NOx emissions between the fuels are shown in Fig. 3, which shows the areas of increase and decrease in emissions over the speed-acceleration timescale.

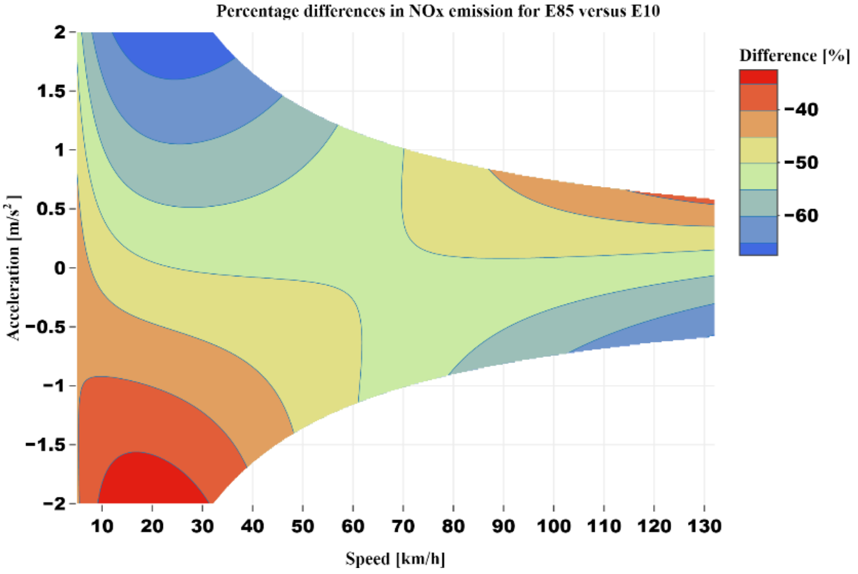

Fig. 3. **Comparison of instantaneous NOx emissions for E85 and E10 fuels**

In most of the analysed areas, using E85 fuel reduces NO_x emissions compared to E10. Areas of emission increase are limited and occur only under specific dynamic conditions.

The obtained results indicate that instantaneous NO_x emissions are strongly dependent on vehicle dynamic parameters, particularly speed and acceleration. The highest emission values are observed under positive acceleration and at higher vehicle speeds, which correspond to increased engine load.

A comparison of E10 and E85 fuels shows that using high-ethanol fuel reduces NO_x emissions in most of the analysed driving dynamics. Similar trends were observed in studies by other authors on ethanol-fuelled spark-ignition engines [1; 10; 12]. This observed effect may be related to charge cooling resulting from ethanol high heat of vaporisation, which favours lower combustion temperatures.

Conclusions

1. Instantaneous NO_x emissions show a strong dependence on vehicle speed and acceleration.
2. The use of E85 fuel leads to a reduction in NO_x emissions compared to E10 fuel in most of the analysed driving dynamics.
3. The largest emission differences are observed under conditions of positive acceleration and higher vehicle speeds.
4. Analysing emissions in the speed-acceleration timeframe allows for a more accurate assessment of the fuel impact than approaches based solely on average values.

Author contributions

Conceptualization, P.L., P.W. and A.S.; methodology, E.K. and M.Z.L.; software, E.K.; validation, P.W. and M.Z.L.; formal analysis, P.L and A.S.; investigation, P.L., E.K., M.Z.L., and P.W.; data curation, P.L. and P.W.; writing – original draft preparation, P.W., E.K. and M.Z.L.; writing – review and editing, E.K., M.Z.L. and A.S.; visualization, E.K. and M.Z.L.; project administration, A.S.; funding acquisition, P.L. All authors have read and agreed to the published version of the manuscript.

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