

Investigation of NO_x emissions for mitigating public health risk with Mercedes E Coupe

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Abstract. Investigation of NO_x emissions is a worldwide concern in order to mitigate or to reduce the health risks that the pollutant poses for the public. It is known that the NO_x are a combination of highly reactive odourless gases containing nitrogen and oxygen in different proportions. The main objective of the present paper is to show the applied investigation and its following results regarding NO_x values and trendlines for the warm-up phase of a Mercedes E 350 CDI Cabrio-Coupe A/C/W207. The secondary objective of the investigation consists in dividing and comparing the results obtained before and after the threshold limit of 40°C in coolant temperature. The warm-up sequence is not the highest temperature stress regarding pollution and NO_x formation. It is although very important due to at least two reasons. In the first place, many of the usual road traffic trips are not exceeding the warm-up duration, meaning that the travel is below 40 minutes long. Secondly, the operation below 60°C is the most stressful both physically and chemically for the engine (its systems) and the environment being defined by high wear and pollution levels. Temperature is a key factor.

1. Introduction

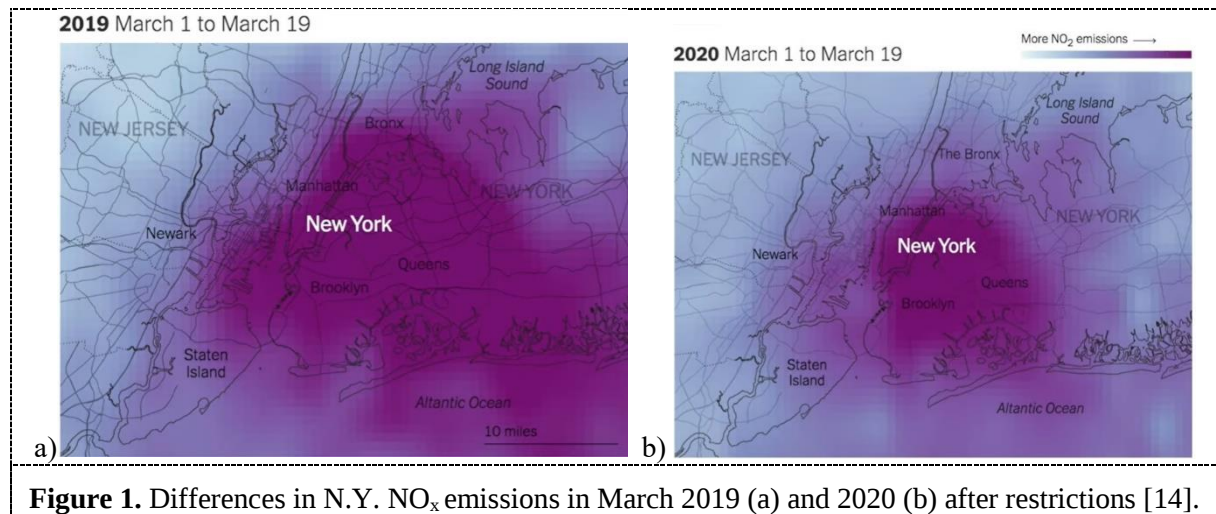
In the early 2020 the Corona virus pandemic brought both significant restrictions and research opportunities. Due to the risk of transmitting the deadly virus authorities worldwide have drastically limited the road traffic and other forms of transportation impacting the air quality and pollution levels. Some researchers took this opportunity to further the science and to gain valuable result by looking into the given problem as it was a great chance to understand the phenomena and to size the benefits [1, 15].

NO_x is produced during the compression, combustion and evacuation strokes when air is compressed at high temperatures and fuel is injected in order to generate mechanical work. NO_x leads to smog formation, acid rain, deterioration of water quality, greenhouse effect, and reduced visibility in urban areas [2, 3, 4]. Controlling the temperature is the key factor to impact engine performance [5]. Smart systems and comprehensive approaches allow the researchers to tackle both the operation and emission problems [6, 7, 8, 9, 10]. Climate emergency mandates the researchers to investigate furthermore the NO_x control technologies and emission model implementation for different vehicles [11, 12, 13, 14, 15].

Because there are two ways of determining the NO_x emissions in relation with the operating regime, the most common one is by taking into consideration the performance, as the power output – which coincides with the high engine speed and high temperatures. At high power output the hourly consumption is significantly high. In this first case the formation of NO_x compounds is sustained by the high temperatures and fuel consumption. Increasing the demand upon the accelerator leads to higher fuel injected quantity, thus increasing the temperature inside the cylinder, increasing the engine speed, thus increasing the power output and NO_x. In this stage, high engine loads lead to high NO_x emissions.

This observation is valid only when we consider the warming up phase and acceleration process, with the precise consequence of increasing the power, the hourly fuel consumption, the engine speed and mixture temperature. Another way of looking into the problem is more practical and considers the fact of deceleration and engine brake when the temperature is already high. Depending on the environmental temperature level, the usual warm-up phase takes between 10 and 30 minutes. In the present case the first 5 to 7 minutes from engine start allowed the coolant to reach the 40°C level and the following 5 minutes led to another increase in temperature from 40 to almost 63°C.

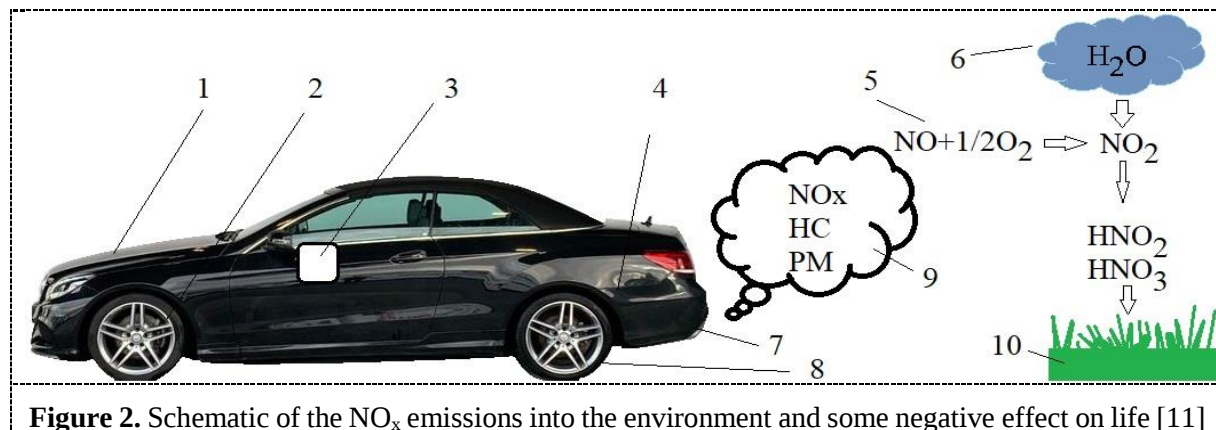
Figure 1 shows the map with the recorded differences between the NO₂ emissions before and after the road traffic restrictions in New York. It highlights the fact that the lower road traffic is the higher air quality will get. On global scale, after animal farming industry, the transportation is an important pollutant [14].



2. Applied research

Applied research is based on advanced computer aided investigation with models and methods used for taking measurements, calculating, predicting or estimating NO_x levels in exhaust gas, as it is allowed by the Law 104/2011 [14], and upon a vehicle which has diesel engine with technical data given in table 1.

Figure 2 presents the vehicle 1, a Mercedes E Cabrio-Coupe A207, having a common platform with C207 and W207 models, used in the current research for NO_x assessment. It has engine, clutch, gearbox and steering system placed on the front axle 2. The on-board data management system 3 records the vehicle performance in operation. Fuel tank 4 and traction 8 are disposed on the rear axle. Tail pipes 7 on the rear end allow the exhaust compounds 9 to affect the atmosphere and develop specific reaction 5 with oxygen. Rain 6 and NO₂ gas negatively impacts the environment 10 and public health [2, 3, 12].



In figures 3 to 12 are presented the results for NO_x levels determined when operating the vehicle in the warm-up phase, by taking the reference the point of 40°C which is also indicated on board.

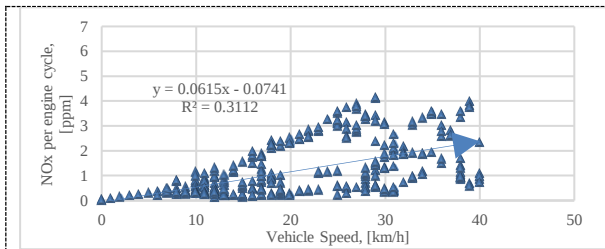


Figure 3. NO_x per stroke vs. speed below 40°C.

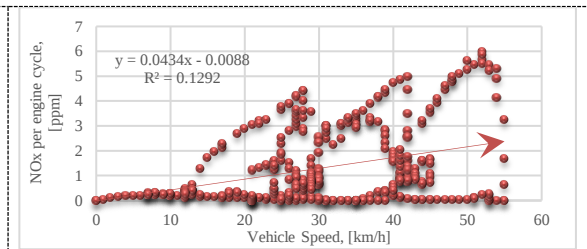


Figure 4. NO_x per stroke vs. speed above 40°C.

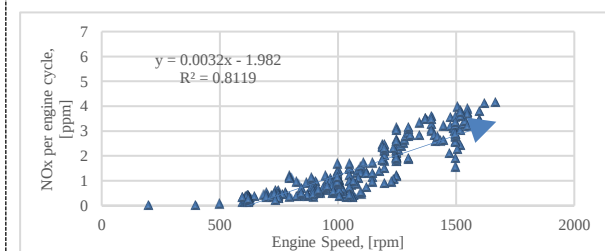


Figure 5. NO_x vs. engine speed, when below 40°C.

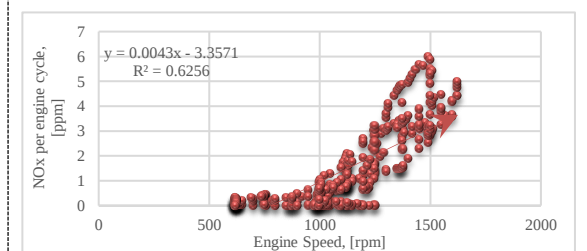


Figure 6. NO_x vs. engine speed above 40°C.

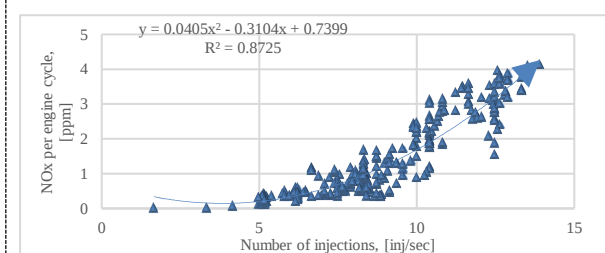


Figure 7. NO_x vs. no. of inj., when below 40°C.

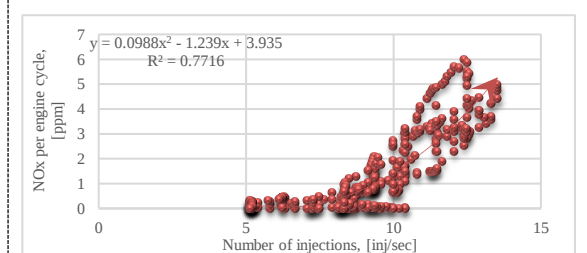


Figure 8. NO_x vs. no. of inj., when above 40°C.

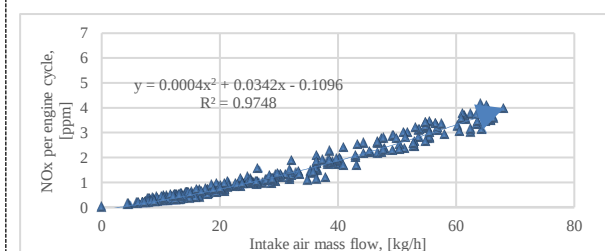


Figure 9. NO_x vs. air mass flow when below 40°C.

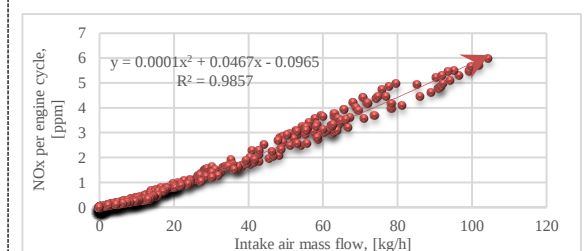


Figure 10. NO_x vs. air mass flow above 40°C.

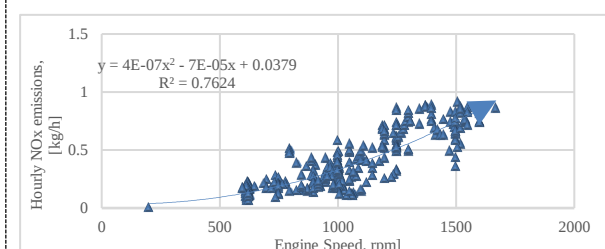


Figure 11. Hourly NO_x vs. rpm, when below 40°C.

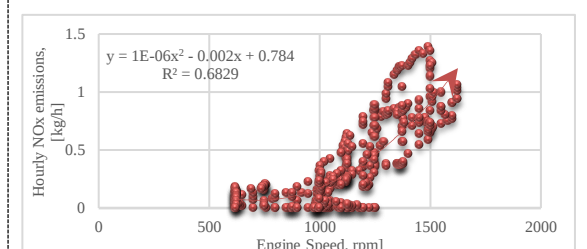


Figure 12. Hourly NO_x vs. rpm, above 40°C.

The NO_x emissions were determined just for a limited period of time to reach 60°C in worm up process. The hourly NO_x emissions versus the selected gear ratio are given in figures 13 and 14.

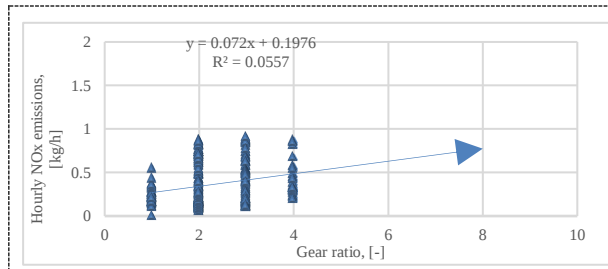


Figure 13. NO_x values vs. gear ratio in first 5 min.

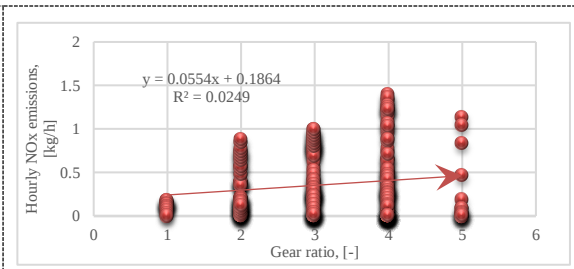


Figure 14. NO_x vs. gear ratio above 40°C

Most significant technical specifications regarding the vehicle's power-train are presented in table 1.

Table 1. Technical data for the vehicle under testing

Parameter	Mercedes-Benz E350 CDI/Bluetec (2013) Model W/A207
Engine	Diesel 350 CDI/Compression ignited/W207/2013 3.0 L OM642 V6 turbo
Fuel supply	Common-Rail/6 injectors
Clutch	Dual
Transmission	7G-TRONIC 7-speed
Axle	Rear axle drive, Front axle steering
Wheelbase	2874 mm

NO_x assessment based on air and fuel consumption makes use of the instant mixture as modeled below:

$$\text{NO}_x = 5 \cdot 10^{-2} I_{\text{AFM}} / 6 = 5 \cdot 10^{-2} [(F_c + A_c) \cdot N_c] / 6, [\text{kg/h}] \quad (1)$$

where I_{AFM} is the instant air-fuel mixture introduced each operational cycle into the engine; F_c – fuel consumption, in kg/h; A_c – air consumption, in kg/h; N_c – number of working cycles.

3. Observations and conclusions

Outside environment temperature during the experimental test was 13°C. The Mercedes E-Class Cabrio under testing in this research has a complex transmission with 7 gear ratios for forward drive and one for reverse, with three optional gear change strategies (M-manual; S-sporty; E- automatic eco-mode). There have been written more than 300 lines of data code and a total of 3920 digital cells were created for the current investigation. Steering excessively leads to higher fuel consumption and less autonomy. In approximately ten to twelve minutes, the engine has been warmed up above 60°C due to traction load and operation in road conditions. Changing in temperature led to a significant improvement in fuel economy due to the reduction of fuel consumption. There are at least 2-3 seconds delay between actuating the accelerator of the car, increasing consequently the fuel injected quantity, and the following process of engine speed increase. After increasing the engine speed there are at least 1-2 seconds delay till the recorded vehicle speed is following up the engine crankshaft.

The average NO_x value, during the first phase of the investigation, when the coolant temperatures increased from 13°C to 40°C, was 1.198 ppm. The same pollutant recorded an average of 1.326 ppm in the second part of investigation, when the engine coolant was between 40°C and 63°C. The NO_x increase trend on average with approximately 10% is also validation proof of the research, showing the effect of a higher temperature upon the formation of nitrogen and oxygen compounds. Estimation allows us to foresee a significant increase in NO_x levels when coolant temperatures are above 80°C and the vehicle operates in engine braking regime. These insights, to be proven and discussed, require further research.

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