Initial assessment of the legitimacy of limiting the maximum permissible speed on highways and motorways based on tests in real traffic conditions

Wojciech Gis1, Maciej Gis1,*, Piotr Wiśniowski1, Sławomir Taubert1

1 Motor Transport Institute, 80 Jagiellonska Street, Warsaw

*Corresponding author: maciej.gis@its.waw.pl

Abstract. The reduction of emissions of harmful exhaust gases is one of the main aspects in broadly understood automotive sector. Representatives of the European Union are encouraging vehicle manufacturers to comply with increasingly stringent standards related to the emission of harmful substances in passenger cars. From 2020, the new standard for CO, HC and NOx road emissions from these vehicles will come into force. It also assumes average CO2 emissions from fleets producer car at the level of 95 g/km. It is a big challenge.

The emission of harmful emissions is also a problem during the operation of vehicles. In real traffic conditions, a big challenge is the need to reduce average driving speeds due to emissions of harmful exhaust substances. With increasing driving speed, it increases. Therefore, the authors of the article decided to investigate the problem on the initial road and highway.

In our research, mobile PEMS type testing equipment was used for tests of vehicles with emission standards: EURO 5 and EURO 6. The tests were carried out in real traffic conditions on a fast-moving and motorway road with speeds up to 110, 120, 140 and 160 km/h. The research was aimed at showing differences in the level of exhaust emissions of emitted vehicles resulting from the speed of travel. In the article, on the basis of the tests carried out, speed was determined and recommended, which from the point of view of emission will be optimal for efficient and ecological movement on this discussed type of roads.

1. Introduction

According to the United Nations, approximately 55% of humanity in the world lives in urban areas. This percentage is to increase and reach approximately 80% by 2050 [2]. Such a large inflow to cities means a number of challenges [1, 8–10], which include the growing problem of the growing number of vehicles purchased in Poland. According to [2], the number of vehicles in Poland in 2017 was 29 149 178 units. In comparison to 2007 it is by 49.7% more. The average age of vehicles in Poland is 12 years [3]. In addition, in 2018 over one million used vehicles were imported to Poland [4-7]. This is the reason for the worsening air quality in cities.

Therefore, representatives of the European Union are trying to introduce the most stringent emission standards to minimize the impact of transport on environmental pollution. For this reason, it is necessary to look at the subject of road emissions in a broader sense.
NEDC (New European Driving Cycle) and WLTC (Worldwide harmonized Light vehicles Test Cycles) driving cycles are adopted by the European Union as approval cycles, on the basis of which road emissions of individual vehicles are determined. They do not take into account the specificities of individual markets and driving styles of drivers. For this reason, extensive testing in real traffic conditions is necessary to determine the real road emissions from vehicles [11–13].

The authors of the article decided to check on the example of two selected cars that meet the emission standard Euro 5 and Euro 6, what are the differences between their road emissions and check the impact of the maximum speed limit on express roads and motorways.

2. Course of research

2.1. Technical characteristic of tested vehicles

The aim of the study was to compare exhaust emissions of two passenger cars in real-world traffic conditions on a highway test route. The vehicles used had similar technical parameters. The difference between them was mainly based on the emission standard. The first - further vehicle 1 - of them was equipped with a spark ignition combustion unit with indirect fuel injection, meeting the Euro 5 emission standard. The second - further vehicle 2 - in turn was equipped with a spark ignition combustion unit with direct fuel injection into the combustion chamber and meets the Euro 6 emissions standard. Both cars were equipped with similar exhaust after-treatment systems. Vehicle 2 did not have a particulate filter, thus it was a popular design among vehicles registered in the country.

| Technical data                        | Vehicle 1                                      | Vehicle 2                                      |
|---------------------------------------|------------------------------------------------|------------------------------------------------|
| Engine                                | t.gas, R4, 16 valve                             | t.gas, R4, 16 valve                            |
| Fuel supply type                      | indirect injection                              | direct injection                               |
| Displacement volume                   | 1998 cm³                                       | 1618 cm³                                      |
| Maximum power                         | 151 kW at 5000 rpm                              | 147 kW at 6000 rpm                             |
| Torque                                | 300 Nm at 3000 rpm                              | 260 Nm at 2000 rpm                             |
| Transmission                          | manual, 6 speed                                 | automatic, 7 speed                             |
| Drive                                 | Front                                          |                                                |
| Fuel tank                             | 66 dm³                                         | 52 dm³                                        |
| Curb weight / payload                 | 1428/495 kg                                    | 1505/485 kg                                   |
| Trailer / brake weight                | –                                              | 710/1850 kg                                   |
| Average CO₂ emissions (according to manufacturer) | 194 g/km (NEDC) | 127 g/km (NEDC) |

2.2. Research route

Vehicle tests in real road conditions on the test route, which were mapped and gave the possibility of testing at highway speeds. In Poland, currently allowed speed on fast routes is 120 km/h. On motorways, the maximum speed allowed is 140 km/h. In order to conduct the planned tests, it was necessary to select a road section so that the developed speeds did not constitute a significant violation of traffic regulations. For this reason, a 24-kilometer section of the road near Warsaw was selected for testing. It should also be mentioned that the vehicles were driven by one driver and the vehicle load (driver and measuring apparatus) was the same.
2.3. Measuring devices

For testing in real road conditions, a mobile analyzer was used to measure harmful exhaust components in real operating conditions SEMTECH DS (Fig. 3) of the American company Sensors Inc. The device was located in the vehicle, and a flow meter was connected to the exhaust system for measuring the exhaust gas flow rate (selected depending on the engine displacement).

Tab. 2. Technical parameters of the SEMTECH DS measuring instrument [5]

| Parameter     | Measuring method | Measuring range       | Accuracy of the measuring range |
|---------------|------------------|-----------------------|---------------------------------|
| CO            | NDIR             | 0–10%                 | ±3%                             |
| THC           | FID              | 0–10000 ppm           | ±2,5%                           |
| NOx (NO + NO2)| NDUV             | NO: 0–2500 ppm        | ±3%                             |
| CO2           | NDIR             | NO2: 0–500 ppm        | ±3%                             |
| O2 frequency  | electrochemical analyzer | 0–20%            | ±1%                             |
| exhaust flow  | mass flow rate   | 0–500 kg/h            | ±1%                             |

The exhaust sample is taken by a mass exhaust gas probe and supplied to the device by a heated route that maintains a temperature of 191°C. Exhaust gases are filtered from solid particles (in the case of compression ignition engines) and the hydrocarbon concentration is measured in the FID (Flame Ionization Detector). Then the sample is cooled to 4°C and the NDUV (Non-Dispersive Detector Ultra Violet) analyzer measures the concentration of nitrogen oxides and nitrogen dioxide, and the NDIR (Non-Dispersive Detector Infra-Red) analyzer measures the concentration of carbon monoxide and carbon dioxide. Oxygen measurement is carried out using an electrochemical sensor. The device enables registration of parameters read from the vehicle diagnostic system and geographical location using the GPS module [5].
3. Obtained test results
The tests allowed to determine the average emission of two vehicles representing the average class of cars in the country. The tests were carried out at different speeds. The goal was to drive the measuring
section at a speed close to the determined maximum speed. The assumptions of the study were to obtain results at maximum speeds of 110 km/h, 120 km/h, 140 km/h and 160 km/h.

As can be seen from the graphs above, the average speeds were similar to each other so that it was possible to compare the results of emissions of harmful substances. Using the SEMTECH DS measuring device, it was possible to determine the road emissions of such components as carbon dioxide, carbon monoxide, hydrocarbons or nitrogen oxides depending on the speed of travel.

Tests carried out assuming a maximum speed of 110 km/h on the two vehicles tested showed two important issues. First of all, it is worth paying attention to the fact that vehicle 1, which has a Euro 5 exhaust emission standard and a larger displacement engine, was characterized by higher road emissions of nitrogen oxides (by 29.9%), hydrocarbons (by 11.2%) and carbon dioxide (25.5%) compared to vehicle 2 with a downsized engine. However, it turned out that carbon monoxide emissions were reduced by (7.28%).

![Graphs showing driving speed during vehicle 1 and vehicle 2 at maximum speeds of 110 km/h, 120 km/h, 140 km/h, and 160 km/h.](image)

Fig. 4–7. Driving speed during the vehicle 1 and vehicle 2 at a maximum speed of: a) 110 km/h, b) 120 km/h, c) 140 km/h, d) 160 km/h

![Graphs showing road emissions of tested vehicles at maximum speeds not exceeding 110 km/h and 120 km/h.](image)

Fig. 8–9. Road emission of tested vehicles at maximum speed not exceeding: a) 110 km/h, b) 120 km/h
Also in the case of tests at a maximum speed of up to 120 km/h, significant differences can be seen in the case of emissions of harmful substances of the two vehicles tested. Vehicle 1 with a larger displacement engine was characterized by higher road emissions of hydrocarbons (by 13.5%) and carbon dioxide (by 26.9%) compared to vehicle 2 with a downsized engine. In this case, however, it came out that the emission of nitrogen oxides is lower by 2.5% and carbon monoxide by 21.1%.

At higher speeds - 140 km/h, it can be seen that emissions are constantly increasing. This applies to every ingredient. Compared to cars, the vehicle 1 with a larger engine volume and older structure has a higher road emission of nitrogen oxides by 22.1% and carbon dioxide by 33.9%. In turn, as the speed increases, the trend changes in relation to hydrocarbons and carbon monoxide. In this case, vehicle 2 had higher road emissions of these components by 24.2% and 147.0% respectively.

4. The legitimacy of limiting the maximum speed on expressways and highways
The tests also allowed to demonstrate the legitimacy of reducing the maximum permissible speed on expressways and highways. In the case of tested vehicles, significant differences in road emissions can be seen with a 10 km/h reduction of the maximum permissible speed.

The analysis of test results in most cases confirms the legitimacy of reducing the speed of travel on fast roads from 120 km/h to 110 km/h. Comparing the road emissions of the same car at two different
maximum speeds, it was found that the reduction in road emissions occurred for CO₂ (-10%), CO (-7.2%) and HC (-1.2%). Only in relation to NOₓ there was an increase in average emissions (+23.2%).

It is also reasonable to reduce the maximum speed by 10 km/h regarding the maximum speed. Test analysis carried out on vehicle 1 confirms the reduction of CO₂, HC and NOₓ emissions by 7.9%, 13.9% and 42.2% respectively. Only in the case of CO there was an increase in emissions by 35.8%.

Road tests on vehicle 2 also made it possible to carry out a comparison of the road emissions of this vehicle at different maximum travel speeds. As in the case of vehicle 1, the average road emissions were also compared here assuming a reduction of the maximum speed by 10 km/h. The analysis of the data shows that in the case of components such as CO₂, CO and NOₓ there was a decrease in average road emissions by 8.2%, 17.4% and 15.8% respectively. Only in relation to HC, the average emission increased by 1.4%.

a) 

![Graph a](image1.png)

b) 

![Graph b](image2.png)

Fig. 14–15. Comparison of road emissions of the tested vehicle 2 assuming the reduction of the maximum speed: a) from 120 km/h to 110 km/h, b) from 140 km/h to 120 km/h

Similar conclusions result in the case of reduced speed from 140 km/h to 120 km/h. Vehicle 2 with a downsized spark ignition engine (without diesel particulate filter) with Euro 6 emissions, in this comparison, had a lower average CO, HC and NOₓ road emissions (33.5%, 40% and 24% respectively) but higher CO₂ emissions (by 1.9%) with a maximum speed reduction of 10 km/h.

The research also took into account the fact that traffic regulations are often violated in Poland, in particular on expressways and motorways. Therefore, tests were also carried out at a maximum speed of 160 km/h.
Fig. 16. Summary of average road emissions of vehicle 1 at speeds 110 km/h, 120 km/h, 140 km/h and 160 km/h and the percentage differences between them.

Fig. 16–17 presents a summary of all adopted maximum speeds and percentage differences in the average emission of individual components for individual vehicles tested. Figure 16 corresponds to vehicle 1 and figure 17 to the second vehicle. The individual colors represent the respective vehicle speeds: purple is for 110 km/h, orange 120 km/h, blue 140 km/h and green 160 km/h. Thanks to this, it is possible to illustrate what emission benefits can be brought by reducing the maximum speed on highways and motorways.

Fig. 17. List of average road emissions of vehicle 2 at speeds 110 km/h, 120 km/h, 140 km/h and 160 km/h and the percentage differences between them.

5. Conclusions
Tests carried out in real traffic conditions using PEMS measuring equipment on two vehicles with spark ignition engines that meet the Euro 5 and Euro 6 emission standards, made it possible to compare two vehicles with a classic unit with spark ignition and with a spark ignition engine after
downsizing, with the same power. In addition, it was possible to compile the justification for reducing the maximum permissible speed on highways and motorways in terms of average road emissions.

The tests carried out on the example of tested cars indicate the legitimacy of reducing the maximum speed by 10 km/h. As a result, the emission of individual components will be reduced. Both for older and newer vehicle designs, of course in the range of maximum constant speeds. Therefore, limiting the maximum speed seems to be a good and effective solution to reduce the emission of all discussed in this work toxic engine exhaust substances. For many drivers, such changes are also an incentive to change the way they travel.

It is also reasonable to replace the car fleet with those that meet the more stringent exhaust emission standards. As a result, it will be possible to reduce emissions of harmful substances from vehicles equipped with internal combustion piston engines to an even greater extent.

In further work, being a continuation of this research intention, tests will be carried out on cars meeting the Euro 6d-temp emission standard, equipped with a particulate filter, and tests on vehicle 1 and vehicle 2 in terms of PM and PN emissions. This will allow for even more accurate determination of the benefits of reducing the maximum speed on highways and motorways, as well as confirming the legitimacy of replacing the fleet of vehicles with newer ones.

References
[1] DataArt. Transport-sharing w Polsce. Raport. Styczeń 2019.
[2] stat.gov.pl
[3] www.samar.pl
[4] Gis M, Wymiary sprzedaży aut w roku 2018, Menadżer Floty, kwiecień 2019, Warszawa.
[5] SEMTECH®-DS On Board, In-Use Emissions Analyzer. Service Manual.
[6] Kurtyka K and Pielecha J 2019 Transportation Research Procedia 40, 338-345
[7] Jasinski R, Markowski J and Pielecha J 2017 Procedia Engineering 192 381-386
[8] Markowski J, Pielecha J and Jasinski R 2017 Procedia Engineering 192 557-562
[9] Nowak M and Pielecha J 2017 MATEC Web of Conf 118 00026
[10] Merkisz J and Pielecha J 2016 IOP Conf Ser Mat Sci and Eng 148 012078
[11] Gis M, Wiśniowski P 2019 Representativeness of emissions of toxic substances in bench tests reflecting the road traffic conditions of a vehicle Combustion Engines 177 88-90
[12] Gis W 2018 E3S Web of Conf 44 00044
[13] Gis M 2019 IOP Conf Ser Earth and Environ Sci 214 012035