Calculations of exhaust emissions produced by vehicle with petrol engine in urban area

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Abstract. The paper deals with the method of calculating exhaust emissions of a passenger vehicle during drive in urban area. For this calculation, a running test was conducted in which exhaust gas volume data and engine control data were recorded. The evaluated exhaust gas components are nitrogen oxide, hydrocarbon, carbon monoxide, carbon dioxide. The engine speed, intake air quantity, vehicle speed and intake air temperature were recorded from the engine control unit. The exhaust components are calculated in gram per kilometre of vehicle drive.

1. Introduction

Air pollution contributes significantly to global environmental problems such as climate change. The transport sector presents the major factors in energy issues and environmental problems, because it is one of the biggest consumers of fossil energy sources [1-3].

Greenhouse gases are classified as gases that cause global warming. It is one of the most serious environmental problems of modern times. These greenhouse gases include carbon dioxide CO₂, methane CH₄, nitrous oxide N₂O and fluorine compounds [4-6].

Over the past few decades, the European Union has introduced regulations and standards with clearly defined limits for individual exhaust gas components to eliminate emissions from road vehicles (CO, CO₂, HC, NOₓ and PM) [7]. This was due to the reduction in the volume of greenhouse gases produced by the transport sector. The European Union is committed to reducing the fuel consumption of road vehicles in order to reduce greenhouse gas emissions. It is in line with long-term requirements to prevent temperatures increase caused by climate change. The European Union’s aim is to reduce emissions by 80% by 2050 comparing to 1990 values. CO₂ emissions which are related to transport should be reduced by 60% by 2050 comparing to 1990 [8].

Some components of emissions from transport in Slovakia are being gradually eliminated. It is mainly CO, NOₓ, VOC and SO₂. On the other hand, components of emissions such as CO₂, PM10 and PM2.5 are constantly increasing year by year. This applies to urban areas with increased traffic due to missing or inconvenient road infrastructure [9-10].

The European Commission set up the Real Driving Emissions legislation (RDE) to ensure that cars produce low pollutant emissions values in real driving. This legislation came into force in March 2016. RDE test is carried out by vehicle manufacturers as part of type-approval tests. Under RDE, a vehicle is driven on public roads and exposed to a wide range of different conditions. Specific equipment installed
on the vehicle collects data to verify that legislative caps for pollutants such as NO\textsubscript{x} are not exceeded [11-12].

During measurement, the vehicle is equipped with a Portable Emission Measuring System (PEMS). It is a combination of complex measuring devices that integrate advanced exhaust gas analysers, exhaust mass flowmeters, weather stations, GPS (Global Positioning System) and vehicle network connections. These measuring devices are very expensive, and they are mostly operated by type-approval authorities, vehicle manufacturers, or major research and development centres.

2. Measurement methodology

The Department of Road and Urban Transport has its own measurement technology, with which it is possible to determine the amount of exhaust gas emissions produced while driving a vehicle in grams per kilometre using known calculation procedures [13].

The main measuring device is the Maha MGT 5 exhaust gas analyser. This gas analyser is capable to measure HC, CO, CO\textsubscript{2}, O\textsubscript{2} and NO\textsubscript{x} emissions. The analyser operates on the principle of selective absorption which means that each component of the exhaust is assessed in the infrared range. The tested exhaust gases are conducted from a vehicle exhaust pipe to an exhaust probe that is connected to the analyser by a hose. The whole scheme of data acquisition and processing is presented in Figure 1 [14] [15].

At first, H\textsubscript{2}O water vapor is separated from exhaust gases, which then are led to the measuring chamber. The infrared light beam in the direction of the measuring element is weakened by the gas. The amount of attenuation of this light beam is manifested by a different wavelength depending on the type of gas. Such a method is the measured amount of HC, CO, CO\textsubscript{2}. On the other hand, O\textsubscript{2} and NO\textsubscript{x} are measured by electrochemical detection. The measured data is from the emission analyser evaluated on a portable computer with Maha Emission Viewer software, which allows emissions to be recorded during whole driving of the vehicle [16].

A simple Bluetooth OBD ELM327 paired with a mobile phone was used to record data from the engine control unit. The mobile phone was processing and storing data through application Torque Pro. During the measurements data about the intake air mass MAF (g/s), vehicle speed (km/h), and RPM engine speed and intake air temperature IAT (°C) were recorded and stored [17-18].

The used application allows also recording the GPS position of the vehicle from which the vehicle route data can be evaluated. All measured and stored data are transferred to an evaluation computer, where vehicle emissions in g/km are evaluated according to known methodologies [19].

The data from emission analyser is delayed by 8 seconds because of transmission of emissions from the exhaust pipe to the analyser. The data recording frequency is 1 Hz [20-21].
Emissions measurements while driving were carried out on a Toyota RAV 4 which was made in 2015. This vehicle is powered by a 1987 cc petrol engine with a maximum power of 112 kW and torque of 195 Nm. It is subject to the EURO 6 emission standard with the following emission values: CO = 0.384 g/km, NO\textsubscript{x} = 0.012 g/km, HC = 0.032 g/km, CO\textsubscript{2} = 159 g/km. The vehicle was operated at the urban ring road in Žilina as it is shown in figure 2. The route was 9.3 km long and the measurement was repeated three times.

![Figure 2. The route of urban ring road in Žilina (Source: authors).](image)

3. Results
The measured exhaust emission values in volume expression had to be converted into mass expression. For this purpose, the methodology published by the author was used [19].

![Figure 3. The course of the individual components of the emissions while driving the vehicle (Source: authors).](image)

The cumulative values of the individual emission components are processed by this methodology for all three measurements. The course of the individual components of the emissions while driving the vehicle is shown in figure 3.

The parameters of each driving were affected by the traffic situation. During three measurements were achieved maximum speeds of 66, 70 and 69 km/h and average vehicle speeds of 36.11 km/h, 33.96 km/h and 37.89 km/h. The whole speed course of the vehicle during measurement No.1 is shown in figure 4.
Figure 4. The speed course of the vehicle during measurement No.1. (Source: authors).

In the following Table 1, the exhaust gas components are calculated for all three measurements in grams per kilometre and these values are compared to the vehicle type approval values. As can be seen, especially the HC values are significantly different from those measured on dynamometer in a laboratory.

Table 1. The comparison components of emissions values (Source: authors).

| Emissions components | Values from the measurements | Type approval values |
|----------------------|-------------------------------|----------------------|
|                      | No. 1                         | No. 2               | No. 3               |                  |
| CO₂ [g/km]           | 169.26                        | 156.40              | 170.35              | 159.00            |
| O₂ [g/km]            | 0.0164                        | 0.012               | 0.0150              | -                 |
| CO [g/km]            | 0.165                         | 0.1253              | 0.1039              | 0.384             |
| HC [g/km]            | 0.0167                        | 0.0178              | 0.0240              | 0.032             |
| NOₓ [g/km]           | 0.0066                        | 0.0073              | 0.0101              | 0.012             |
| Average speed        | 36.11                         | 33.96               | 37.89               |                   |

The next part of the results is aimed at comparing different driving modes of the vehicle within the first emission measurement. The measurement No. 1 took a total of 902 seconds and this time period was divided into four different driving modes. Then, exhaust gas components were calculated for each driving mode separately. Four modes were selected: standing of the vehicle (idle mode), steady drive mode, acceleration mode and finally – vehicle deceleration mode.

Table 2. Emission values during different vehicle travel modes during measurement No.1 (Source: authors)

| Emissions components | Idle   | Steady drive | Steady drive | Acceleration | Deceleration |
|----------------------|--------|--------------|--------------|--------------|--------------|
| Whole Drive 902 s    | 114 sec| 396 sec      | 396 sec      | 210 sec      | 182 sec      |
| CO₂ [g]              | 69.491 | 671.27       | 671.27       | 704.115      | 129.278      |
| O₂ [g]               | 0.957  | 68.25        | 68.25        | 13.303       | 70.083       |
| CO [g]               | 0.1505 | 0.3401       | 0.3401       | 0.8993       | 0.1471       |
| HC [g]               | 0.0087 | 0.0612       | 0.0612       | 0.0722       | 0.0139       |
| NOₓ [g]              | 0.00199| 0.00998      | 0.00998      | 0.03402      | 0.01601      |
Up to 13% of the total measurement time, the vehicle was in idle mode, which was mainly due to the traffic situation on a given measurement route. This was also due to the presence of light-signalling devices on the measuring route. During the first measurement, the vehicle was stopped three times with a total duration of 114 seconds. Almost half of the total measurement time, the vehicle was moving at steady speed (steady drive) and the rest of the time the vehicle was accelerated and decelerated. To compare the components of the exhaust, the individual components had to be calculated in grams (not in grams per kilometre). This is in order to make it possible to compare the production of emissions while the vehicle is stationary (in idle mode).

In order to be able to compare the driving modes with each other, not only the total emissions production has been quantified in the driving modes, but also the individual components of emissions were recalculated per one second. These values are shown for each components of emissions at following figures 5, 6, 7 and 8.

Figure 5. The amount of CO₂ (g/s) (Source: authors).

![CO₂](image)

Figure 6. The amount of CO (g/s) (Source: authors).

![CO](image)
4. Conclusion
The method of measuring the emissions of passenger cars during their urban and extra-urban operation is nowadays an obligation in the vehicle type-approval process. The method of calculating emissions through a simple exhaust gas analyser is an alternative to the PEMS method, especially in scientific researches. It proposes a relatively fast and cheap measurement method. Results from this kind of measurement can be used to determine the impact of road transport on selected areas of cities.

The results show that the way the vehicle is driven has a significant impact on the amount of produced emissions. If a vehicle in one area of the city has to constantly accelerate, this will affect the amount of emissions produced in that area. For the purpose of quantifying the impact of road transport on the environment, it is necessary to have the most accurate data about traffic flow structure. There are differences in emissions in the case of trucks and in the case of passenger cars. However, differences can be observed in vehicles with petrol engines and diesel engines, too.

Data from such types of emission measurements should in future serve, for example, to decision of cities where to introduce emission zones and the prohibition of entry of vehicles of particular category or emission system.
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