An impact assessment of functional systems in vehicles on CO₂ emissions and fuel consumption

Jerzy Merkisz^{1,*}, Michal Dobrzynski¹, and Kamil Kubiak¹

¹Poznan University of Technology, Faculty of Machines and Transport, ul. Piotrowo 3, 60-965 Poznan, Poland

Abstract. The number of facilities for a driver increasing the travel comfort in a PC vehicle is constantly increasing. Most of them are powered by electricity generated at a cost of additional engine load. Power is received directly from the crankshaft by an alternator or air conditioning compressor, which negatively affects fuel consumption. This paper presents the results of CO₂ emission testing in actual traffic conditions for vehicles with on and off functional systems responsible for driving comfort. In addition, an assessment of fuel consumption calculated using the carbon balance method was performed. Measurements were made for cold start and preheated combustion unit the research used the latest PEMS mobile apparatus.

1 Introduction

Among the many factors that negatively affect the quality of human life is motorization. Striving for a higher standard of living forces automotive companies to introduce new technological solutions, whose task is to improve the safety of travel, lowering the cost of travel, and increasing the comfort of driving and adjusting the vehicle to the tastes of the driver. Modern functional systems in the vehicle are directly associated with improved driving characteristics, as well as the comfort of traveling. There are many expressions of travel comfort, which are not precisely defined, and that is used intuitively with variable and often overlapping meaning: comfort, passenger comfort, driving quality, driving comfort [1]. Improvements in operating conditions can be defined on the basis of the concept definition "Comfort" in the article [2] presented, and it should be understood as follows "a set of devices and conditions that ensure comfort and fully meet the aesthetics". It can be stated that travel comfort refers to the "state of physical, mental and aesthetic satisfaction associated with the movement of a passenger on a given route". There is also a whole range of external conditions that ensure a person's sense of safety, characterized by a state of physical and mental fulfillment, and the elimination of unforeseen situations [3, 4].

Improvements of the usefulness of relevant material from many points of view. One of the aspects is the continual increase in the number of vehicles on the roads, as a consequence it leads to an ever-increasing transit time on the same stretch of road [5, 6]. Another source is the growing supply of car manufacturers in the world markets, which forces increasing competitiveness of the offered products. This is especially evident in the regions of North America and Europe where saturation of the car market can be observed – an insignificant

increase in the number of vehicles. The only exceptions are developing countries, where the share of vehicles per capita is inconsiderable, and this increase is almost four times larger [8].

Undoubtedly the consequence of the development and the increasing number of systems improving the use of vehicles is to increase energy intensity, which translates into unit fuel consumption, and increased exhaust gas emissions. Current regulations concerning emissions testing from motor vehicles do not allow for the precise definition of the impact of using additional electric power receivers on the emissions in real operating conditions RDE. The progressing in recent years development and miniaturization of measuring apparatus in the PEMS group, makes it possible to perform more and more accurate vehicle environmental testing. Considering the current trends aimed at ever increasing dissemination and use of functional systems mounted in vehicles it is justified to undertake activities that influence the assessment of their ecological aspects [4, 8, 9].

2 Methodology of research

2.1 Apparatus used for measuring emissions of harmful substances in exhaust gases

Measurement of fuel consumption and emission of harmful exhaust gas components, carried out within the framework of the research, required the use of specialized exhaust gas toxicity measurement apparatus [7, 10]. The research performed (in the conditions of actual vehicles operation) used the mobile test apparatus type PEMS, namely SEMTECH DS of Sensors Inc. (Fig. 1), a unique combination of high measuring accuracy and the ability to record the following parameters:

* Corresponding author: jerzy.merkisz@put.poznan.pl

- concentrations of CO and CO₂ (analyzer NDIR), NO_x = NO + NO₂ (analyzer NDUV), HC (analyzer FID), O₂ (electrochemical sensor),
- thermodynamic exhaust parameters (mass flow, temperature, pressure) – a flow meter using Pitot tube,
- environmental conditions – atmospheric pressure, temperature, humidity,
- vehicle position and speed – GPS,
- data from vehicle diagnostic network – data transmission protocol CAN SAE J1939/J2284.

In the tests carried out the main unit, the SEMTECH DS device, was placed inside the vehicle (Fig. 2). On the roof of the vehicle was a GPS positioning system and weather sensor, which were connected to the main unit of the instrument. Connection to the diagnostic network was made by a special data module using a dedicated protocol for PC category vehicles. The sample of exhaust gas for analysis was taken from the flow meter and transported by a heated line to maintain the temperature of 190 °C. This is to protect against emission condensation on the walls of the cord. Then the sample, after passing through the filter, goes to the analyzer NDIR, which made it possible to register the CO₂ concentration. Controlling and monitoring the SEMTECH DS instrument was done using a laptop connected to the main unit via a wireless network.

Fig. 1. Mobile exhaust gas analyzer SEMTECH DS.

Fig. 2. SEMTECH DS measuring device during installation in a vehicle.

Measurement ranges of the apparatus allow for its application in a wide range. In addition to measuring the concentration of individual gaseous pollutants in the exhaust gases, it also allows measurement of mass flow rate (with the mentioned flowmeter). It is necessary to calculate the emission of these compounds (e.g. road, specific). It is important to note that due to the varying displacement of engines in vehicles, there is also a difference in the amount of exhaust gas. Therefore, it is necessary to select exhaust gas flow meters for testing that have an appropriate diameter (Fig 3). Equipment SEMTECH DS, when using the so-called carbon balance method, also allows to calculate the fuel consumption of the vehicle.

Currently this type of measurement is set to be integrated into the European legislative action (especially in the measurement of gas component emissions). For environmental assessment of vehicles the road tests are most desirable (in this case actual operating conditions), because only then it is possible to obtain information about real vehicle emissions. Tests are performed, for example, on stretches from several to dozens of kilometers in different road conditions. The biggest disadvantage, however, is the cost of measuring equipment and adaptation to the conditions in the vehicle. On the other hand, reliable measurement results are obtained, Impossible to obtain under simulation conditions or on a stationary dynamometer.

Fig. 3. Mass flow mass meter installed on exhaust system.

2.2 Research objects

The research used PC category vehicles equipped with a number of functional systems vehicle A (Fig. 4a) equipped with a spark-ignition engine powered by direct injection of gasoline. The vehicle was equipped with a three-way catalytic converter TWC, along with a lambda probe working in the feedback loop. The second vehicle marked B (Fig. 4b) powered by diesel fuel, which carries out a combustion cycle with compression ignition, equipped with an additional DPF in the engine exhaust system, and selective catalytic reduction in SCR. The Table 1 shown below contains the basic parameters in used propulsion units.

Table 1. Vehicle technical parameters.

Parameter	Tested vehicle	
	Vehicle A	Vehicle B
Engine type/fuel	4-stroke, SI/Gasoline	6-stroke, CI /Diesel
Displacement [dm ³]	2.0	3.0
Compression ratio	9.6	16.8
Max. power [kW]/[rpm]	185/6800	193/4000
Max. torque [N·m]/[rpm]	370/ 1600–4500	580/ 1750–2500
Aftertreatment system	TWC	DOC/DPF/SCR
Drive system	Start–stop	Start–stop
Vehicle curb weight [kg]	1845	2185

Presented objects as standard are equipped with automatic transmission gears, and their propulsion units meet the Euro 6 emission standard of exhaust gas [11]. Modern solutions used in this category of vehicles are activated directly by the user. Depending on the demand, these functions allow for making changes in the operating characteristics of the power unit, transmission ratios, suspension, thermal conditions inside the vehicle, and audio-visual elements. All implemented components require the proper functioning of the power supply generated by the internal combustion engine used to drive the vehicle, affecting its additional load during regular operation.

a)

b)

Fig. 4. Research objects used for research: a) vehicle A powered by gasoline, b) vehicle B powered diesel fuel.

2.3 Measurements carried out in real vehicle traffic conditions

As standard, type approval tests for passenger vehicles are carried out on chassis dynamometer, whose results are inadequate to the conditions that exist during actual operation. To make a real assessment of the pollutant emissions to determine the impact of the application non-essential vehicle assistance systems measurements were made based on a route representative of the category of vehicles tested [9, 12]. Road emission studies were carried out on the urban route in the Poznan agglomeration (Fig. 5). In some parts of the route there were a large number of vehicles causing road congestion, thanks to that, it was possible to reproduce conditions in the strict city center. In addition, on the selected route it was possible to obtain larger average speeds during the ride, which allowed to simulate driving through non-urban regions and on the main communication arteries. The total length of the measuring section was 12 km.

Fig. 5. Route used in RDE.

Passages were made to achieve the purpose of the research in the following configurations, and the adopted signs defined in the following way the work of the systems:

- “cold engine, no power receivers” – deactivated power receivers,
- “hot engine, no power receivers” – deactivated power receivers,
- “hot engine, active power receivers” – activated all circuits with energy consumption,
- “hot engine, active power receivers, sport mode” – change of operating characteristics of the drive unit, power transmission system, suspension system, activated all power systems.

The set of devices that are power receivers in the case in question are:

- interior air conditioning system,
- ventilated / heated seats,
- interior lighting,
- audio-visual system.

3 Research results

Scheduled route drive cycles have been repeated many times, each time making changes to the configuration implemented in the vehicle's functional systems. The first stage of the study refers to the registration of emissions from the vehicle without the use of additional power receivers, both in the conditions before reaching

the thermal equilibrium of the drive unit, as well as after reaching the state of thermal equilibrium. These measurements made it possible to set a reference point for the intended purpose in the resulting work.

The first test vehicle identified as A was powered with Gasoline. On the basis of the recorded data CO₂ concentration was determined (Fig. 6). The results of the measurements are shown in (Tab. 2).

Fig. 6. Carbon monoxide emission in vehicle A.

Table 2. Results of measurements from vehicle B.

Parameter	Cold engine, no power receivers	Hot engine, no power receivers	Hot engine, active power receivers	Hot engine, active power receivers, sport mode
CO ₂ [g/km]	347.2	299.3	398.6	437.8
Fuel consumption [dm ³ /100 km]	14.4	12.4	16.6	19.5
Distance traveled [km]	12.1	12.2	12.3	12.1

Obtained results of road emission during the conducted tests allowed to determine the fuel consumption (Fig. 7) the carbon balance method, which uses the formula:

$$FC_w = \frac{1155}{\rho_{\text{fuel}}} \cdot [(0,866 \cdot \text{HC}) + (0,429 \times \text{CO}) + (0,273 \times \text{CO}_2)] \quad (2)$$

where: FC – fuel consumption [dm³/100 km]; HC, CO, CO₂ – emission of ingredients harmful [g/km]; ρ_{fuel} – fuel density at temperature 15 °C [g/cm³].

During the first passage the propulsion unit was struggling to achieve thermal equilibrium, the power receivers were inactive. Concentration of carbon dioxide emission in the test reached 347 g/km, and the fuel consumption was 14.5 dm³/100 km. Another passage made after reaching the rated operating conditions has demonstrated a reduction in unit fuel consumption and emissions of CO₂. In the next stage of the study, “warm engine, active power receivers” the drive components worked in standard mode with all functional systems activated. Registered measurements showed the highest

concentration CO₂, and an increase in fuel consumption of over 52%, reaching the value of 19 dm³/100 km. Working conditions during the mobile test extended by the active work system suspension system, and the modified operating characteristics of the drive unit marked as “SPORT mode” showed the highest levels of measured parameters. The results obtained can be attributed to the unfavorable influence of drive control on the selected test section. During the vehicle speed test phase the gearbox mode controller has forced high speed values. Change gear ratio to the higher gear was in this case only after exceeding 60% of the range engine crankshaft rotational speed, thus increasing the share of working time during generated loads. Fuel consumption and carbon dioxide emissions have reached values, which significantly deviated from the previously performed tests.

Fig. 7. Fuel consumption while traveling from vehicle A.

The second of the objects tested powered by diesel fuel exhibits similar tendencies of obtained characteristics relative to the first of the tested vehicles. Considering, however, for a different type of drive unit used smaller differences in the designated fuel consumption were recorded (Fig. 8) as well as the concentration of emissions CO₂ (Fig.9). The results are shown in Table 3.

Notably, road tests were carried out under similar ambient conditions. The concentration of carbon dioxide in the first case reached 218 g/km, at the same time fuel consumption ratio was 8 dm³/100 km. Another attempt

Fig. 8. Carbon monoxide emission in vehicle B.

Fig. 9. Fuel consumption while traveling from vehicle B.

Table 3. Results of measurements from vehicle B.

Parameter	Cold engine, no power receivers	Hot engine, no power receivers	Hot engine, active power receivers	Hot engine, active power receivers, sport mode
CO ₂ [g/km]	347.2	299.3	398.6	437.8
Fuel consumption [dm ³ /100 km]	8.1	7.6	8.7	10.0
Distance traveled[km]	12.1	12.2	12.3	12.1

was made after stabilization of the engine operating conditions and an increase in CO₂ concentration by 13% was recorded. Under test conditions extended by the active suspension system, and the modified operating characteristics of the drive unit has occurred at the highest fuel consumption in the test. In the case of the vehicle B the differences referring to the adopted starting point in the performed analyzes have reached a maximum change of 30%, both for fuel consumption and for carbon dioxide emissions.

4 Summary

In this article a comparison of tests performed in actual operating conditions is drawn. The unified research route, and use for testing vehicles of one category It had a positive effect on the comparative analysis of the results obtained, because they have excluded any discrepancies associated with the route profile, physical characteristics of the tested vehicles, and drive components.

Based on the results obtained it can be seen that the use of additional solutions in the form of functional elements implemented in vehicles has a significant impact on the emissions, and also on the vehicle fuel consumption. The comparative analysis made recorded increases in value, which in the extreme cases have reached levels exceeding 50%, exposing the adverse effects on the ecological aspects, as well as on the economic considerations during operation.

In the context of the research done it is worth noting that the current research of exhaust emissions for previous Euro categories do not take into account the impact of high-involvement of additional components installed in vehicles on their ecological indicators. Use of the research methodology based on the application of PEMS type apparatus, as used in the realized research work, allows for more precise estimation of the exhaust emissions in real operating conditions from vehicles equipped with a series of increasingly accessible facilities. It is therefore reasonable to conduct further research based on the methodology presented in this article.

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