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Maciej SIEDLECKI
Jerzy MERKISZ
Kamil KUBIAK
Łukasz RYMANIAK
Michał DOBRZYŃSKI
Dawid GALLAS

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Impact of the use of comfort devices on the exhaust emission from a hybrid vehicle

Vehicles are equipped with more and more devices to improve the comfort of traveling. They are usually powered by electricity generated by the engine, which translates into an increase in its loads and, as a consequence, fuel consumption and emission. However, there is no information about the possible increase in the amount of other harmful components contained in the exhaust gases. Often this result is inadequate to that obtained during the operation of the vehicle, where the obtained fuel consumption is higher. As part of this article, tests were carried out in real hybrid vehicle traffic conditions on the same test route using an analyzer from the PEMS (Portable Emission Measurement System) ¬ SEMTECH DS Sensors Inc. The analysis of gaseous components of exhaust gases together with the exhaust mass flow probe and the GPS system made it possible to calculate the pollutant emission.. On this basis, the actual mileage fuel consumption of the tested vehicle was calculated using the road emission of carbon-containing compounds (carbon balance method).

Key words: *emission, hybrid, fuel consumption*

1. Introduction

The vehicle engine, apart from generating the driving force, must also power the vehicle auxiliary systems. Today, the number of comfort devices, usually electrically operated, continues to increase in vehicles [5]. Many have become standard equipment in most of the produced cars, such as electric windows, and mirrors. Examples of luxury car comfort equipment include, for example: ventilated seats, multi-zone automatic climate control, pneumatic suspension or automatic driving systems. The additional power must be generated by the alternator by charging the engine crankshaft and thus affecting fuel consumption. This, in turn, directly affects the vehicle CO_2 emissions [6, 7]. However, their impact on emissions of other components has not yet been investigated, especially in a hybrid vehicle, where the computer determines the operating point of the internal combustion engine in terms of speed and load.

Increasing the engine load is expected to lead to a deterioration of ecological indicators, and in the case of engines with direct fuel injection, also an increase in the emission of particulate matter [1–3]. Research carried out as part of the article is an investigation on the actual exhaust emissions. In the case of hybrid vehicles in which the engine operates only periodically during vehicle movement, it may be more difficult to heat up the exhaust aftertreatment systems. Temperature is a factor required for their efficient operation, i.e. achieving the light-off temperature and performing oxidation reactions and reducing toxic compounds [8].

In the article, a hybrid vehicle belonging to the F segment, i.e. luxury vehicles equipped with a hybrid drive systems, has been used for research. The research problem is the impact of the increase in energy consumption caused by the vehicle comfort systems on the exhaust emissions. The authors expect increased fuel consumption, but the impact on other compounds is unclear. This problem is caused by the non-continuous nature of operation of the internal combustion engine, which works only periodically in this case which leads to difficulty in keeping the exhaust aftertreatment systems at their functional temperature and thus enable them to operate efficiently [4]. The tests were carried out by connecting mobile exhaust gas analyzers to the vehicle exhaust system and performing a test drive cycle on the same route in real operating conditions twice, once with comfort systems switched on and once with them being off.

2. Research methodology

2.1. Research objects

The tested vehicle was equipped with a petrol engine with a displacement of 4.0 dm^3, power of 404 kW and a direct fuel injection, as well as a 100 kW electric motor [9]. The total maximum power of the drive system is 504 kW and the maximum torque is 850 Nm.

Table 1. Data of the tested vehicles engines [9]

Parameter	Value
Combustion engine type, number and arrangement of cylinders and valves	8-cylinder, 4 valves per cylinder, SI V-engine
Fuel injection system	Direct injection
Displacement	3.998 dm^3
Maximum power	404 kW at 5750–6000 rpm
Maximum torque	700 Nm at 1960–4500 rpm
Compression ratio	10:1
Aftertreatment systems	Three Way Catalyst
Turbocharging	VGT turbocharger with intercooler
Electric motor power	100 kW at 2800 rpm
Electric motor torque	400 Nm at 100–2300 rpm

Due to the hybrid system, the vehicle was characterized by its considerable unladen mass, which amounted to 2310 kg. During the tests, due to the test apparatus, the total weight was approximately 2700 kg. The mileage of the vehicle is 1000 km. Before the tests, the technical condition of the vehicle was checked and the electrochemical batteries were fully charged.

Fig. 1. The tested vehicle with PEMS apparatus

2.2. Used apparatus

The equipment from the PEMS group was used for the measurements. It is a set of analyzers that analyze the exhaust gas sample taken from the exhaust system for the presence of harmful components in the form of: carbon dioxide and monoxide, nitrogen oxides, hydrocarbons and mass and number of emitted particles.

Fig. 2. View of the SEMTECH DS analyzer [10]

Particulate emission measurements from modern vehicles with spark-ignition engines and direct fuel injection are particularly important because of their negative impact on the human respiratory system. Research on the impact particles have on human health lead to the introduction of emission limits. Initially those limits considered only the particle mass, but later also their number, for compression-ignition engines. The limit of the number of particles also applies to vehicles with SI DI engines since September 2017. For this reason, it is required to use two analyzers – one used to determine particle mass, and the other to obtain their number (Fig. 3). The measurement of particulate mass was made possible by the AVL MSS (Micro Soot Sensor) analyzer, based on the PAAS (Photo Acoustic Soot Sensor) method. In this method, solid particles are subjected to radiation of modulated light, resulting in their periodic heating and cooling. This leads to changes in the volume of the carrier gas being tested, acting like a sound wave. In the measurement, vibration-sensitive microphones are used only in a certain range of frequencies and amplitudes. When the air is clean, no signal is detected, while the increase in the number of solid particles in the gas (increase in concentration) increases the sound signal. In order to avoid the formation of a soot condensate, the exhaust gases are diluted (Fig. 3a). The Engine Exhaust Particle Sizer (EEPS™) 3090 spectrometer measures the emitted particle size distribution from 5.6 to 560 nm at the highest available resolution (10 Hz). This allows visualization and testing of dynamic changes of particulate emissions (Fig. 3a).

a) b)

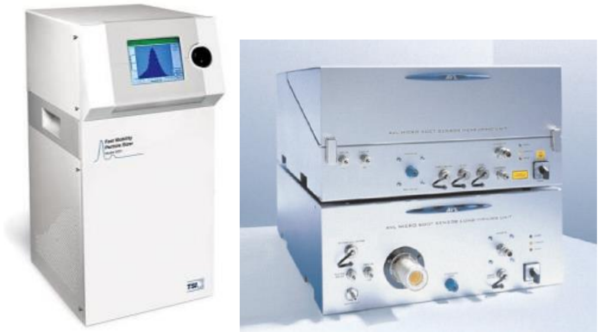

Fig. 3. Equipment used for measuring particulate matter in the scope of: a) number and dimensional distribution - EEPS TSI 3090, b) concentrations - AVL MSS [10]

2.3. Test route

The route used for the study was located in the center of the city of Poznań (Fig. 4). It is characterized by different speed limits and well reflects the conditions of vehicles driving in the urban agglomeration. There are numerous infrastructure elements on it, such as several lanes and intersections with traffic lights. The route was covered twice on the same day, which resulted in similar conditions of vehicle movement and the possible impact of environmental change on the measurement results was minimalized.

Fig. 4. View of the route used for testing [Source: Google maps]

3. Results

As part of the research, two trips were made on the same route with the tested vehicle. The first trip was carried out in a mode where comfort systems were not used, i.e. air conditioning, audio devices, seat ventilation and driving assistants. During the drive, the combustion engine worked in a limited range (Fig. 5).

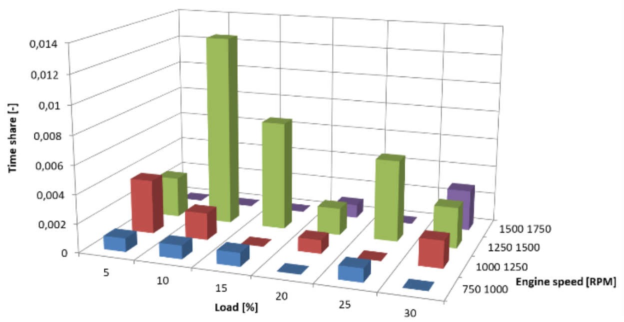

Fig. 5. Engine operating time share according to load and engine speed

The limited use of the internal combustion engine in the range of low rotational speeds and loads results from its considerable power, mostly unused for urban driving and instead the increased use of the electrochemical battery. During testing with PEMS, it is impossible to determine the power output of electric motors. The distribution of emissions of individual exhaust components is shown in Figs 6–10.

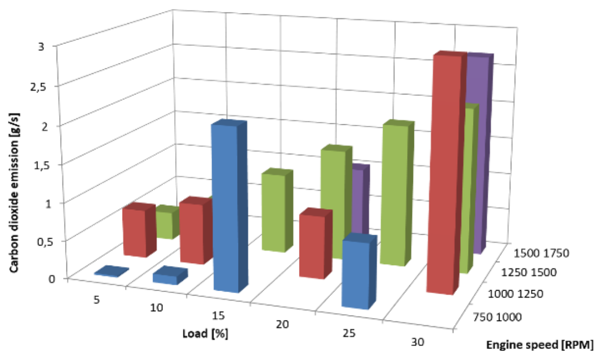

Fig. 6. Carbon dioxide emission according to load and engine speed

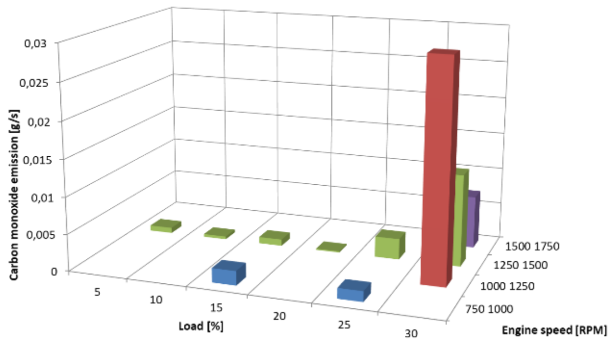

Fig. 7. Carbon monoxide emission according to load and engine speed

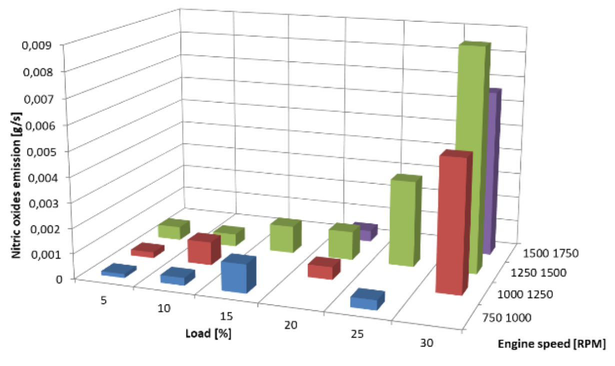

Fig. 8. Nitrogen oxides emission according to load and engine speed

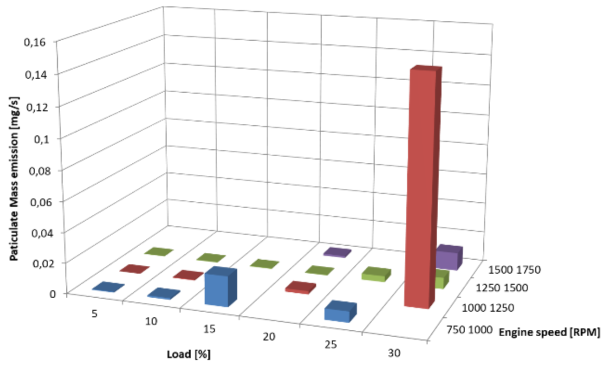

Fig. 9. Particulate mass emission according to load and engine speed

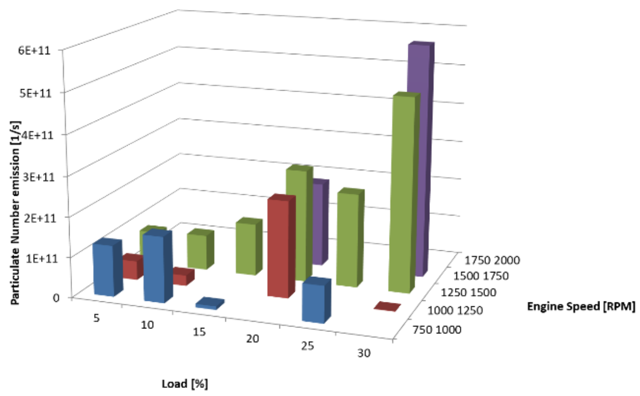

Fig. 10. Particle number emission according to load and engine speed

Carbon dioxide emissions are associated with increasing engine load. The increase is proportional to the increasing load. In the case of carbon monoxide and particulate mass, visible emission peaks can be seen in the range of the maximum engine load reached in the speed range of 1000–1250 rpm. The emission of these components is related to each other and caused by the enrichment of the fuel and air mixture. The results of nitrogen oxide emissions are distributed in a way that is more proportional to the engine load. The second drive took place under the same conditions and with the same battery charge. Already in the case of analysis of engine operating points, differences can be observed (Fig. 11).

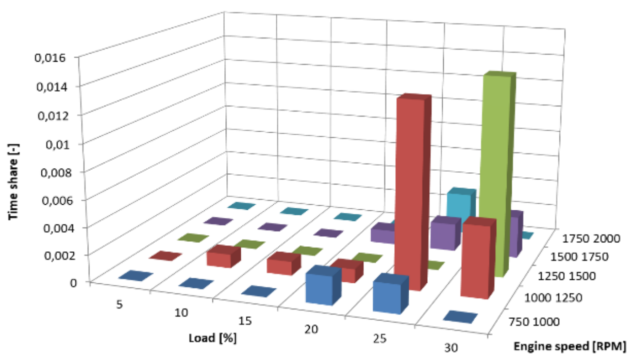

Fig. 11. Engine operating time share according to load and engine speed

The largest shares moved towards higher loads, which is clearly illustrated by the increased demand for energy caused by the active use of vehicle comfort systems. The emission of harmful components is again presented in the graphical form in Figs 12–16.

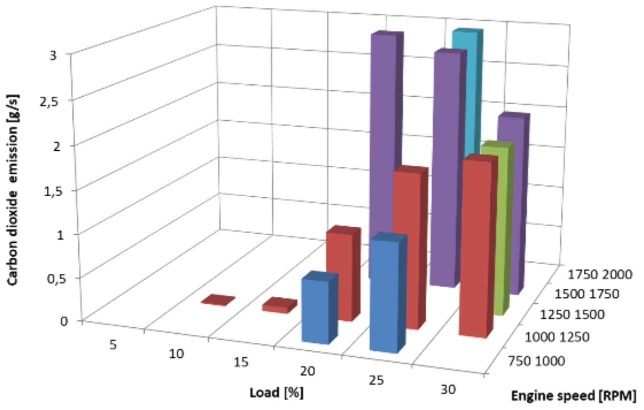

Fig. 12. Carbon dioxide emission according to load and engine speed

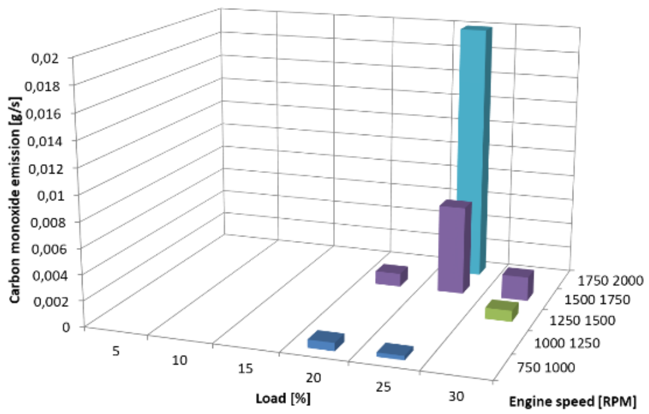

Fig. 13. Carbon monoxide emission according to load and engine speed

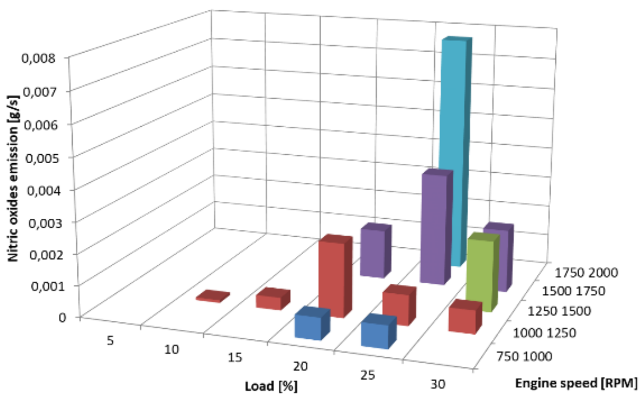

Fig. 14. Nitrogen oxides emission according to load and engine speed

In all the graphs one can notice practically no emission results in the range of up to 15% of the load. Emission of carbon dioxide (Fig. 12) moves according to engine operating points, but during the second test drive the peaks are at a similar level. The carbon monoxide emission is similar (Fig. 13) and obtains similar values as in the case of the first test drive (Fig. 7). The emission of nitrogen oxides for the second drive shows a different character than in the first drive, but the obtained maximum value of per second emission is closer in value. The biggest differences can be seen in the case of particulate emissions, both in the mass range (Fig. 15) and in their number (Fig. 16). The mass was distributed more evenly, and the number was accumulated in three areas of engine operation. The harmful compounds mass emission results were converted into road emissions (Table 2).

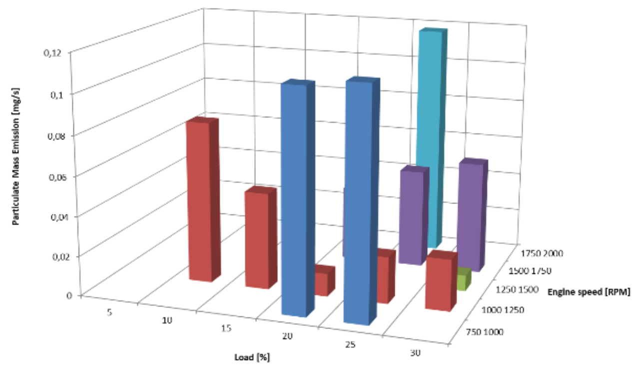

Fig. 15. Particulate mass emission according to load and engine speed

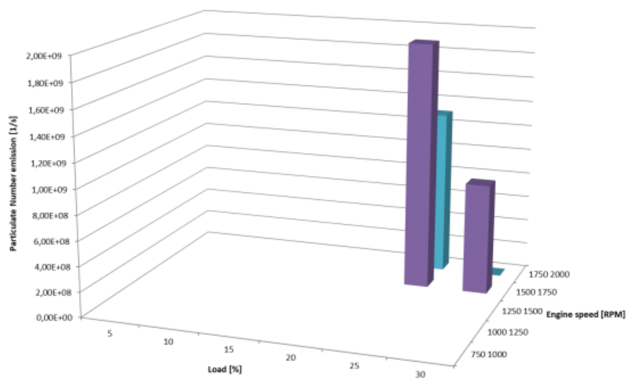

Fig. 16. Particle number emission according to load and engine speed

Table 2. Road emission values for the two drive tests [2]

Emission	Drive 1	Drive 2
CO_2 [g/km]	11.157	18.671
CO [g/km]	0.039	0.039
NO_x [g/km]	0.02	0.024
PM [mg/km]	0.0114	0.0109
PN [-/km]	1.19E+8	1.75E+9

In the case of emissions of carbon monoxide, nitrogen oxides and particulate mass, the differences are minimal, and their occurrence cannot be demonstrated by activating the vehicle comfort systems. The values of carbon dioxide emissions are proportional to fuel consumption, and thus their increase by over 50% can be observed, however, in the case of the particle number, the value increased by a factor of 12. For this reason, the authors decided to perform an extended analysis of the dimensional distribution of particle size diameters (Figs 17 and 18).

The distributions clearly differ. Emission of large particles dominates in the first drive, and therefore their overall number is smaller. While the second drive (Fig. 18) shows the increased emission of the so-called Nanoparticles that are the most dangerous for humans. This is caused by increased engine load, which in the case of direct fuel injection systems leads to decrease in the combustion process quality.

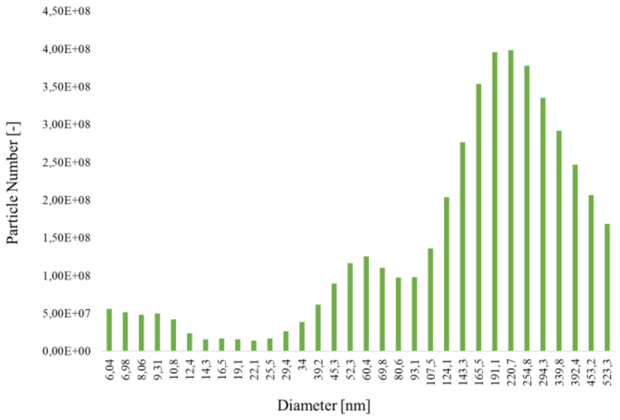

Fig. 17. Particle size distribution in the 1st test drive

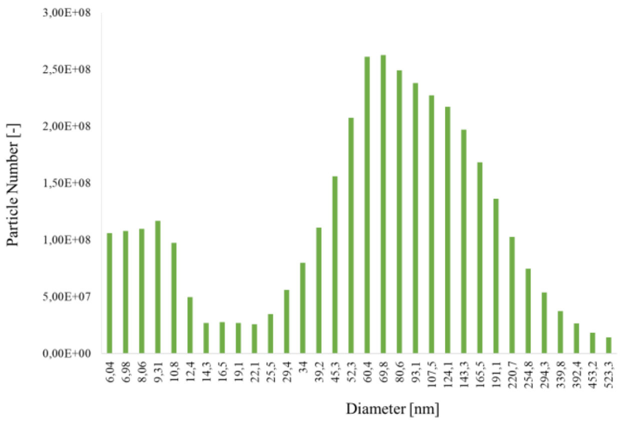

Fig. 18. Particle size distribution in the 2nd test drive

4. Conclusion

New motor vehicles are equipped with more and more technically advanced driver comfort systems, which increase the energy demand related to fuel consumption. As part of the research performed, a new F-segment hybrid vehicle was tested in two test drives: without and with active comfort systems. The obtained results confirmed increased fuel consumption, however, the exhaust emissions remained at a similar level.

However, it should be noted that there were significant differences in the impact of engine operating parameters variability on the characteristics of engine operating time share. The most significant differences in the obtained ecological indicators were recorded for the particle number.

Increased engine load caused a higher emission of the so-called Nanoparticles, which are one of the main problems faced by SI engines today, as has been confirmed in other publications [1–3]. The total particle number emission in comparison to other vehicles was not significant, which was caused by the use of electric drive throughout the majority of the test drive. The latest emission norms introduce tests of vehicles in versions increasingly more supplementary and driver comfort systems, which will better illustrate the actual environmental impact these vehicles have. The direction of further work of the Authors will be the introduction of measurements for electric drive units in order to perform a full energy balance calculation.

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Nomenclature

CI	compression ignition
DI	direct injection
PEMS	Portable Emissions Measurement System
PM	Particle mass
PN	Particle number
SI	spark ignition

Bibliography

[1] FUĆ, P., LIJEWSKI, P., SIEDLECKI, M. et al. Analysis of particle mass and number emission from an SI engine with direct fuel injection and a particulate filter. *IOP Conference Series: Materials Science and Engineering*. 2018, **421**, 042019-1-042019-8.

[2] FUĆ, P., RYMANIAK, Ł., ZIOLKOWSKI, A. The correlation of distribution of PM number emitted under actual conditions of operation by PC and HDV vehicles. *WIT Transactions on Ecology and the Environment*. 2013, **174**, 207-218.

[3] FUĆ, P., RYMANIAK, Ł., ZIÓLKOWSKI, A. et al. Pollutant emissions analysis of a hybrid drive bus in a SORT 2 test. *IOP Conference Series: Materials Science and Engineering*. 2018, **421**, 042020-1-042020-10.

[4] MERKISZ, J., ANDRZEJEWSKI, M., PIELECHA, J. The impact of the selected gear ratio on carbon dioxide emissions by vehicle during its acceleration. *Combustion Engines*. 2013, **154**(3), 324-331.

[5] MERKISZ, J., DOBRZYSKI M., KUBIAK K. An impact assessment of functional systems in vehicles on CO_2 emissions and fuel consumption. *MATEC Web of Conferences*. 2017, **118**, 00030. DOI: 10.1051/matecconf/201711800030

[6] MERKISZ, J., FUĆ, P., LIJEWSKI, P., ZIÓŁKOWSKI, A. Analiza emisji spalin z pojazdów wyposażonych w system start-stop. *Logistyka*. 2015, **5**, 648-654.

[7] MERKISZ, J., PIELECHA, I., ANDRZEJEWSKI, M. Wpływ dynamiki rozpędzania samochodu na emisję zanieczyszczeń. *Logistyka*. 2012, **3**.

[8] NOWAK, M,. FUĆ, P., ANDRZEJEWSKI, M., RYMANIAK, Ł. Analysis of LDV operation manner in terms of its environmental and economical indexes. *Journal of KONES Powertrain and Transport*. 2018, 25(4), 317-323.

[9] Porsche materials.

[10] Sensors Inc., AVL and TSI manuals.

Maciej Siedlecki, MEng. – Faculty of Transport Engineering, Poznan University of Technology.
e-mail: *Maciej.Siedlecki@put.poznan.pl*

Łukasz Rymaniak, DEng. – Faculty of Transport Engineering, Poznan University of Technology.
e-mail: *Lukasz.Rymaniak@put.poznan.pl*

Michał Dobrzyński, DEng. – Faculty of Transport Engineering, Poznan University of Technology.
e-mail: *Michal.Dobrzynski @put.poznan.pl*

Prof. Jerzy Merkisz, DSc., DEng. – Faculty of Transport Engineering, Poznan University of Technology.
e-mail: *Jerzy.Merkisz@put.poznan.pl*

Kamil Kubiak, MEng. – Faculty of Transport Engineering, Poznan University of Technology.
e-mail: *Kamil.Da.Kubiak@doctorate.put.poznan.pl*

Dawid Gallas, MSc. – Faculty of Transport Engineering, Poznan University of Technology.
e-mail: *Dawid.P.Gallas@doctorate.put.poznan.pl*