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THE USE OF THE MILD HYBRID SYSTEM IN VEHICLES WITH REGARD TO EXHAUST EMISSIONS AND THEIR ENVIRONMENTAL IMPACT

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Abstract:

Pollution of the environment is a global phenomenon. The lack of specific actions to reduce environmental pollution can lead to an increase in the average temperature of the Earth's air and to global consequences. One of the important sectors affecting environmental pollution is transport, including road transport. Currently, intensive legislative and construction works are underway to reduce the emission of harmful substances from road transport. Meeting the requirements imposed by the European Union makes it necessary not only to make structural changes to combustion units or exhaust aftertreatment systems, but also to use additional systems supporting the operation of the main engine. This group includes, among others, Mild Hybrid propulsion systems and classic hybrid systems. Their application is to affect not only the possibility of reducing the swept volume of a combustion unit, while maintaining its operational parameters, but also to reduce the emission of harmful substances of exhaust gases. The conducted research and its analysis indicate the legitimacy of using a newer vehicle equipped with a modern propulsion system, i.e. Mild Hybrid, in real conditions. In the case of toxic emissions of exhaust gases, a difference in emissions of individual components is noticeable, depending on the chosen driving mode. However, it is worth mentioning the difference in the emission of nitrogen oxides and the number of particulate matters. Their emission is reduced in relation to a vehicle using a classic powertrain. The use of a modern propulsion system also improves reliability. The tested Mild Hybrid vehicle does not use a conventional alternator and starter. This eliminates the elements that are prone to damage in prolonged operation. This is an unquestionable advantage when taking into account the operation of the vehicle.

Keywords: *transport, exhaust emissions, environmental protection*

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1. Introduction

Excessive emissions of harmful exhaust gases from vehicles mainly affect cities. The phenomenon of California smog occurs mostly in city centers and its surroundings in lowland areas. Thus, it can be said that road transport has the largest share in setting this phenomenon. There are many ways to solve this problem. In (ETP, 2017) it is written that decarbonisation of transport is difficult.

Well-to-wheels (WTW) greenhouse gas (GHG) emissions from transport are 83% lower in 2060 than in 2015 (Fig. 1.). Between 2015 and 2060, the share of passenger transport energy use decreases from 60% to 48%, while the share of freight transport increases from 40% to 52%, reflecting the relative difficulty of decarbonizing freight modes. Light-duty vehicles (LDV) and trucks, which accounted for the majority (68%) of energy use in transport in 2015, are responsible for the largest share of GHG emissions reductions. In the RTS, total transportation final energy consumption grows from 113 exajoules (EJ) in 2015 to 165 EJ in 2060. In 2060, most of the demand (36%) comes from road freight vehicles (LCVs and trucks), followed by passenger light-duty vehicles (PLDV) (28%) (ETP, 2017).

Nonetheless, as in the case of Poland, the problem is that public transport is still being developed. However, according to The United Nations Organization, about 55% of the world population lives in urban areas. This proportion is expected to increase to 68% by 2050. Large migration to cities involves a number of challenges, e.g. the growing issue of increasing numbers of vehicles bought in Poland (Gis et al, 2016; Gis, 2018b; Gis, 2019; Nowak and Pielecha, 2017; Merkisz and Pielecha, 2016).

Another problem that concerns Poland is the increasing number of vehicles, that aren't necessarily in good technical condition. According to (JD, 2019) the number of vehicles in Poland in 2017 was equal to 29 149 178. Compared to 2007 this is an increase of 49.7%. It is also worth noting that in 2019 over 1.6 million vehicles were registered in Poland. The average age of vehicles in Poland is 12 years. In addition, over a million of used vehicles were imported to Poland in 2019. This is the cause of the deteriorating quality of air in the urban areas (Gis and Wisniowski, 2019).

According to the National Emission Ceilings (NEC) directive imposed on Poland, it is necessary to reduce emissions, including Particle Number (PN) and nitrogen oxides (NOX). The directive envisages inter alia that within 10 years (2020–2029) emission levels will be reduced in the country by 30% for PN and NOX. An analysis within the period up to 2015 shows that as regards the reference year – 2005 – total emission of those substances was limited in cases by 18% (Gis, 2019; Jasinski et al, 2017; Markowski et al, 2017; Pielecha et al, 2019).

The problem related to excessive emissions, including NOX and PN, are significant especially in urban areas. It is declared that it is in the case of these harmful ingredients that the reduction should be as large as possible. For this reason, specific measures are needed to minimize the share of their emissions from vehicles (Busch and Zellbeck, 2019; Giechaskiel et al, 2019; Merkisz-Guranowska and Pielecha, 2014; Merkisz and Pielecha, 2015.

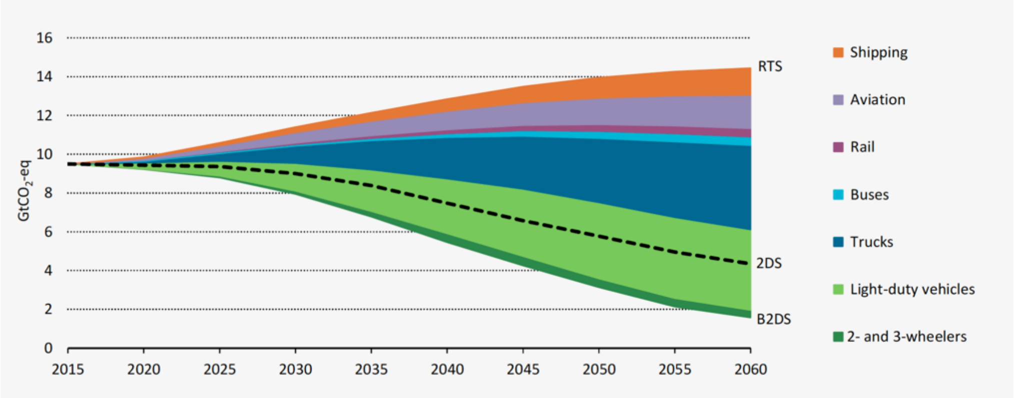


Fig. 1. WTW GHG emissions reductions by transport mode and scenario, 2015-2060 (IEA, 2017)

The problem relates not only to the emission of harmful substances but also the emission of substances contributing to the greenhouse effect. The main challenge for the world is to prevent a situation where the average temperature on Earth increases by 1.5 degrees Celsius. This is one of the reasons for which the European Commission presented a motion on 8 November 2017 specifying new standards of Carbon dioxide (CO_2) emissions from 2020 for passenger cars and trucks up to 3.5 tons. The motion also introduces proposals of incentives for producing emission-free and low-emission vehicles (Gis, 2018a; JD, 2019).

The EU's attempt to reduce CO_2 emissions is justified. It is estimated that 1/7 of global CO_2 emissions are associated with human activities. Transport, in general, is responsible for 14% of global CO_2 emissions. It is also worth noting that in 2017 the transport sector was responsible for 27% of total greenhouse gas emissions in EU countries. However, considering the origin of emissions by type of transport, road transport was responsible for 73.1% of CO_2 emissions. Of these, 44.3% were generated by passenger cars and 19.2% by heavy trucks. Therefore, reducing CO_2 emissions from passenger vehicles is significant to be able to reduce these emissions from the road transport sector.

According to the provisions laid down in the motion within the period 2020-2021 the average road emission of CO_2 should be equal to 95 g CO_2/km for all new passenger cars of a particular producer and for heavy vehicles with gross vehicle weight (GVW) up to 3.5 tonnes, this limit was set at 147 g CO_2/km (Gis and Wisniowski 2019; Pielecha et al, 2018).

A critical problem relating directly to the emission of harmful substances is the way how such emission is determined during a type-approval procedure. Tests performed in conditions specified – earlier in New European Driving Cycle (NEDC) tests – now according to the Worldwide harmonized Light vehicles Test Cycles (WLTC) – do not reflect actual levels of harmful exhaust emissions and fuel consumption (Kurtyka and Pielecha, 2019; Merkisz et al, 2009).

This is why the EU has made changes. Starting from 2017, a new and improved lab test WLTC – the successor to the NEDC test came into force (EC, 2008). Another change is the introduction of an emissions test carried out in real traffic conditions. Thanks to this solution, the discrepancy between the results obtained in laboratory tests and the results obtained in road tests will be reduced. The Real Driving Emissions (RDE) procedure consists of four legislative acts (three of them are already in force) (EU 2016/427) (EC, 2016).

Real road testing seems to be the best reflection of vehicle road emissions. For this reason, the authors of the article examined two vehicles of the same manufacturer and the same class, but with different propulsion systems - one is a classic solution used for many years and the other, a modern combination of two technologies.

2. Methodology

The comparison of both vehicles was aimed at determining the differences in terms of emissions and fuel consumption in real road traffic conditions (RDE – Real Driving Emissions). The vehicles were equipped with two different power units. The first vehicle was equipped with a classic solution comprising a spark-ignition combustion engine (Fig. 2). The second vehicle was equipped with a Mild Hybrid system.

The vehicle equipped with Mild Hybrid system (Fig. 3) used a 48 V electrical installation and EQ Boost system. This unit allows for better management of electrical power supplying various systems of the vehicle and also helps reduce fuel consumption. When accelerating the EQ Boost may also support for a short time the 184 horsepower (HP) internal combustion piston engine with spark ignition with extra 14 HP. When decelerating, the integrated electrical starter and alternation unit allows for regaining kinetic energy and battery recharging. The coolant pump is provided with an electric drive and triggered according to the requirements of the power unit. In result the cooling effectiveness is adjusted optimally to the current operating state of the piston engine. A material difference between the vehicles is the fact that the Mild Hybrid car was additionally equipped by the producer with a Gasoline Particle Filter. Table 1 presents chosen technical data of the tested vehicles.

3. Test route

The test subjects have been tested in real traffic conditions. The research route was in Poznan and its vicinities. It was determined according to the EU-wide directive, which contains all the guidelines (EC, 2008; EC 2016). Thus, the road was planned in such way that it could include a cold start procedure, as well as urban, non-urban and highway sections (Fig. 4). What is worth emphasizing is that the tests were performed on the same day (in respective driving modes). One driver drove the vehicles, with the same load (driver, passenger and measurement equipment).

4. Measurement equipment

The exhaust emission levels from the tested vehicles were analysed with the use of SEMTECH DS portable system by Sensors Inc. The device was placed in the vehicle and a flowmeter was connected to the exhaust unit to measure the exhaust flow levels (selected depending on the engine displacement).

With the use of analysers which SEMTECH DS was equipped with it was possible to measure – among others – the concentration levels of carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and nitrogen oxides (NOX). Data from the vehicle's diagnostic system, Global Positioning System (GPS), ambient temperature and pressure measurement system were also recorded. Those values are recorded with 1 Hz frequency; thus, it is possible to observe dynamic changes in the concentration of harmful substances in exhaust gases.

Fig. 2. Test vehicle equipped with a spark-ignition engine

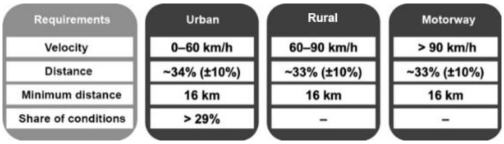
Fig. 3. Test vehicle – Mercedes-Benz W205 equipped with a spark-ignition engine with EQ Boost

Table 1. Technical parameters of tested vehicles

Technical parameters	Vehicle 1	Vehicle 2
Engine	Gasoline, Turbo, R4, 16 V	Gasoline, Turbo, R4, 16 V
Fuel system	direct injection	direct injection
Engine displacement	1991 cm^3	1497 cm^3
Max. power	135 kW at 5500 rpm	135 kW at 5800 rpm
Max. torque	300 Nm at 1200–4000 rpm	280 Nm at 1200–4000 rpm
Gearbox	automatic, 7 gears	automatic, 9 gears
Power unit	4MATIC (fixed with distribution of 60:40)	
Front tyres	225/40 R18	
Rear tyres	245/40 R18	
Fuel tank	66 dm^3	60 dm^3
Size (length/width/height)	4686/1810/1442 mm	
Wheelbase	2840 mm	
Kerb weight/capacity	1465/565 kg	1430/580 kg
Weight of trailer/with brakes	725/1600 kg	710/1800 kg
Average CO_2 emissions	131 g/km (NEDC)	136–144 g/km (WLTC)
Euro Standard	Euro 5	Euro 6d-Temp

Table 2. Technical parameters of measurement equipment SEMTECH DS

Description	**Measurement method**	**Range**	**Accuracy of the measurement range**
CO	NDIR	0–10%	±3%
THC	FID	0–10,000 ppm	±2.5%
NO_x ($NO + NO_2$)	NDUV	NO: 0–2500 ppm NO_2: 0–500 ppm	±3%
CO_2	NDIR	0–20%	±3%
O_2	electrical & chemical analyser	0–22%	±1%
Frequency	–	1–4 Hz	–
Exhaust flow	mass flow intensity	0–500 kg/h	±1%



Requirements	Urban	Rural	Motorway
Velocity	0–60 km/h	60–90 km/h	> 90 km/h
Distance	~34% (±10%)	~33% (±10%)	~33% (±10%)
Minimum distance	16 km	16 km	16 km
Share of conditions	> 29%	–	–

Fig. 4. Requirements regarding the test route and the example of velocity profile (vehicle 1, comfort mode)

Fig. 5. Measurement equipment used for tests in real traffic conditions

5. Test results

In the first place, the authors of the article carried out a comparative analysis of the similarity of road conditions of the tested vehicles. For this purpose, speeds and accelerations were compared. To better illustrate this comparison, acceleration–speed graphs were created (Fig. 6), which show a comparison in terms of similarity of traffic conditions, where for the same coordinates (V–a) during two journeys the share of operating parameters in the test were assessed (Fig. 7).

Based on the comparative analysis of the above-mentioned vehicle driving parameters, a high correlation can be seen between velocity and acceleration. The shares of the operating conditions described with the same velocities and accelerations are consistent in 93%, which allows for deciding about the possibility of comparing harmful emissions for the two tested vehicles. In the next steps the concentration of harmful substances was compared, based on which it was possible to determine levels of respective substances and their road emissions.

Studies have shown a high correlation in the case of carbon dioxide. This ingredient reached maximum values of approx. 14%, which was consistent for both vehicles (the engines operated with the use of a stoichiometric mixture). The correlation was worse for other exhaust gas components (Fig. 8). The concentration of carbon monoxide for the vehicle 2 after downsizing was significantly lower – maximum values during acceleration were roughly 5 times smaller than for the initial engine. The concentration of hydrocarbons was the highest only in the cold start procedure and did not exceed several ppm throughout the test. On the other hand, the level of nitrogen oxides for vehicle 1 with conventional propulsion system was c.a. 200 times greater in the acceleration phase (short periods of time in the motorway phase of RDE test) than in vehicle 2 with hybrid propulsion system. Such large differences were caused primarily by smaller gear ratio and greater engine load of vehicle 1. The RDE tests, performed in real road traffic conditions, allowed to determine the differences in the emission of individual harmful exhaust gases of the tested vehicles. The test objects were equipped with various propulsion system solutions, which, according to the conducted research, directly influenced the average emission of individual tested components. That allowed to examine the differences in this matter. In addition, it should be mentioned that the tests have been made several times and the results presented are the average of the results obtained. Therefore, the calculations specified spreads for individual components, which for CO_2 amounted 10%, for CO it was 8%, for HC – 8%, and for NOX – 5%.

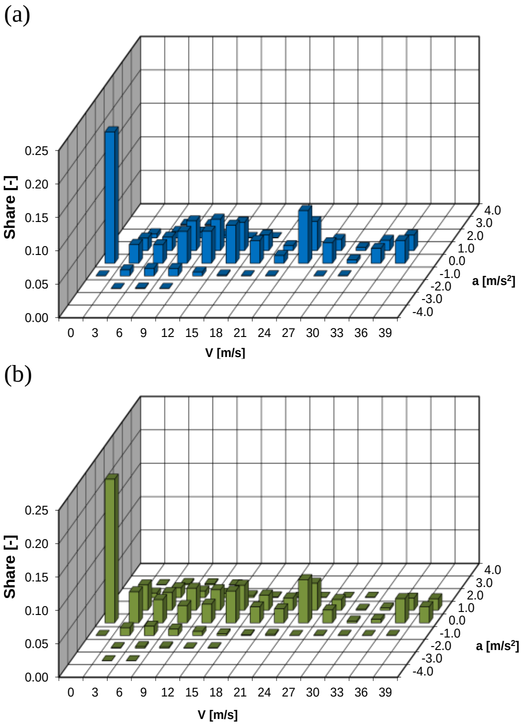


Fig. 6. Comparison of the share of the vehicle's operation in the velocity – acceleration coordinates in the tested vehicles 1 (a) and vehicles 2 (b) in the Comfort mode (example)

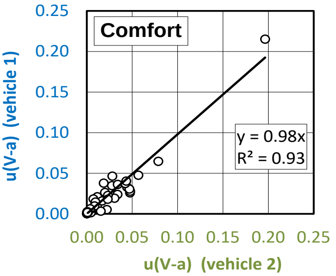


Fig. 7. Comparison of the similarity of journeys made by vehicles 1 and vehicles 2 in Comfort driving mode

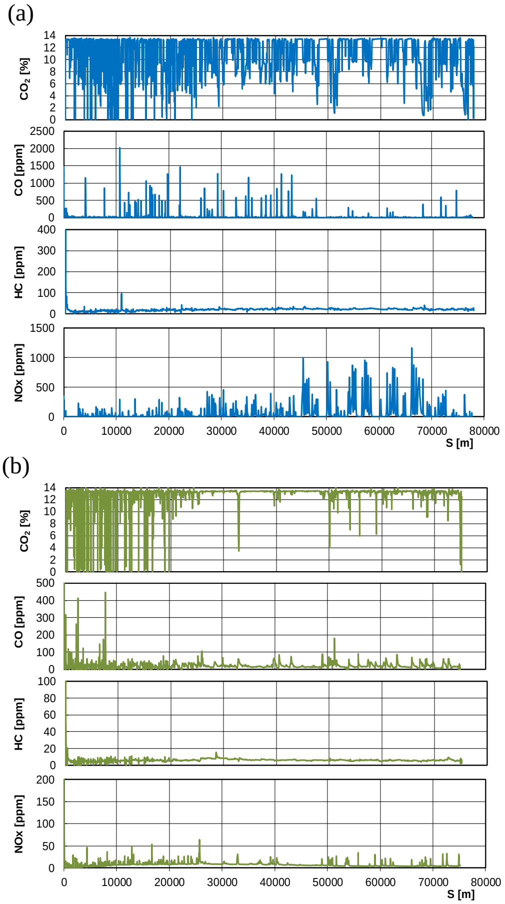


Fig. 8. Comparison of the real driving emissions of harmful exhaust gases in vehicle 1 (a) and vehicle 2 (b) in Comfort driving modes (example)

Vehicle tests were additionally carried out using different driving modes to better illustrate the differences in emissions of individual harmful substances using the available driving modes. For the entire route of the RDE test in Comfort driving mode the changes in road emissions for the vehicle with engine displacement of 1497 cm3 compared to the vehicle with engine displacement of 1991 cm3 are as follows: carbon dioxide emission increased by 13% (Fig. 9a), carbon monoxide emission dropped by 37% (Fig. 9b), hydrocarbons emission decreased by 31% (Fig. 9c) and nitrogen oxides emission dropped by 81% (Fig. 9d).

For the entire route of the RDE test in Eco driving mode the changes in road emissions for the vehicle with engine displacement of 1497 cm3 compared to the vehicle with engine displacement of 1991 cm3 are as follows: carbon dioxide emission decreased by 4% (Fig. 9a), carbon monoxide emission dropped by 40% (Fig. 9b), hydrocarbons emission decreased by 23% (Fig. 9c) and nitrogen oxides emission dropped by 87% (Fig. 9d).

For the entire route of the RDE test in Sport driving mode the changes in road emissions for the vehicle with engine displacement of 1497 cm3 compared to the vehicle with engine displacement of 1991 cm3 are as follows: carbon dioxide emission decreased by 5% (Fig. 9a), carbon monoxide emission dropped by 47% (Fig. 9b), hydrocarbons emission decreased by 40% (Fig. 9c) and nitrogen oxides emission dropped by 95% (Fig. 9d). In the graphs, a vehicle equipped with a modern Mild Hybrid system has practically every case with lower CO_2, CO, HC and NOX emissions. Only in one case increased CO_2 emission were noted (in a Comfort driving mode).

6. Analysis of particle number emission

During testing vehicles in real traffic conditions, particulate matter emissions were also measured. Particulate matter is a significant problem, especially in cities, where high density of vehicles causes their excessive concentration. This is a significant problem, because they penetrate the human body to, among others, lungs and the circulatory system, thus posing a threat to human life.

Therefore, during the study attention was paid to particle number emissions both, in the entire RDE test and its individual parts. In addition, particle emissions, as with the other components, were tested using different driving modes for both vehicles.

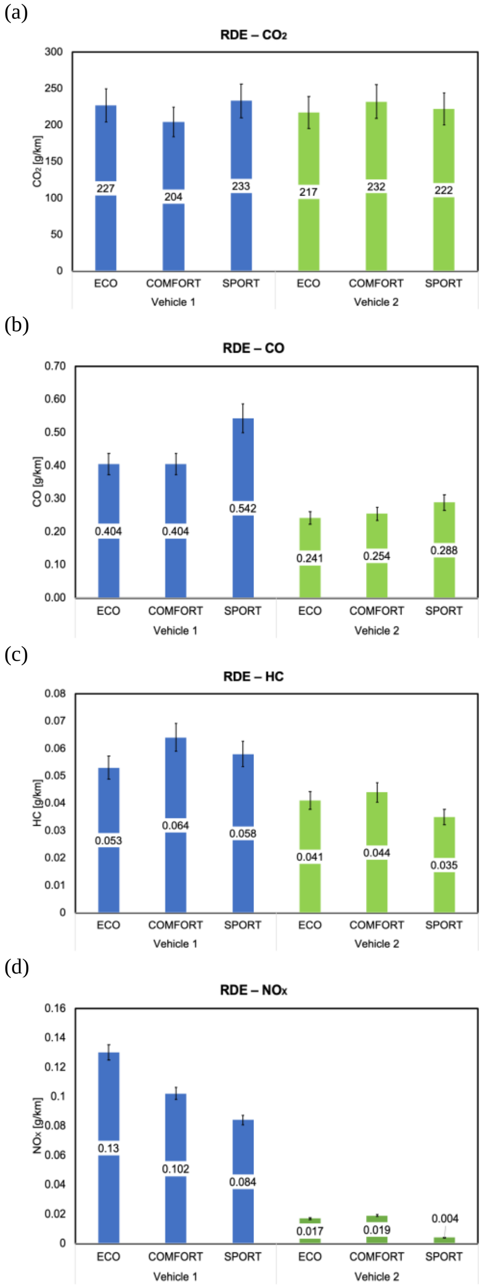


Fig. 9. Comparison of exhaust road emissions of vehicle 1 and 1vehicle 2 in different drive mode for: (a) carbon dioxide, (b) carbon monoxide, (c) hydrocarbons, (d) nitrogen oxide

Fig. 10 presents detailed test results for the entire RDE test (Fig. 10a), as well as its individual parts (urban – Fig. 10b, rural – Fig. 10c, highway – Fig. 10d). An interesting correlation can be noticed. For a vehicle 1 (Euro 5) compliant with a conventional powertrain, the Comfort mode has the lowest particle emissions. However, in Eco and Sport driving modes they were comparable with each other. On the contrary, in the case of a vehicle 2 (Euro 6d-Temp emission standard), equipped with a modern propulsion system – Mild Hybrid, this trend was the opposite. The highest particle emissions were recorded during Comfort mode test. It is also worth emphasizing that in the case of a vehicle 2, the particle number was significantly lower than for a vehicle.

7. Conclusions

The tests of two passenger cars, equipped with spark-ignition engines with a displacement of 2.0 L (conventional spark-ignition engine) – vehicle 1 and 1.5 L (Mild Hybrid) – vehicle 2, in real traffic conditions provided the basis for determining the impact of downsizing on-road emissions. In the tests the impact of the driver and weather conditions (the vehicles were driven by one driver and the tests in respective driving modes were performed one after another) can be omitted. The analysis of the test results led to the following conclusions:

- use of a downsized engine with Mild Hybrid system (vehicle 2) to power a modern tested passenger car brings a decrease of the average road exhaust emissions,
- tests in respective driving modes confirm the reasonableness of using a downsized engine with Mild Hybrid system (vehicle 2) in terms of reduced carbon monoxide emissions, where such reduction is equal to 41% in COMFORT mode, 58% in ECO mode and 44% in SPORT mode
- tests in respective driving modes confirm the reasonableness of using a downsized engine with Mild Hybrid system (vehicle 2) in terms of reduced emissions of nitrogen oxides, where reduction is equal to 51% in COMFORT mode, 85% in ECO mode and 89% in SPORT mode,
- as regards carbon dioxide emissions in COMFORT and ECO driving modes noticeable is an increased emission of CO_2 by respectively 24% and 1%. The average CO_2 emission in the SPORT mode was decreased by 5%,

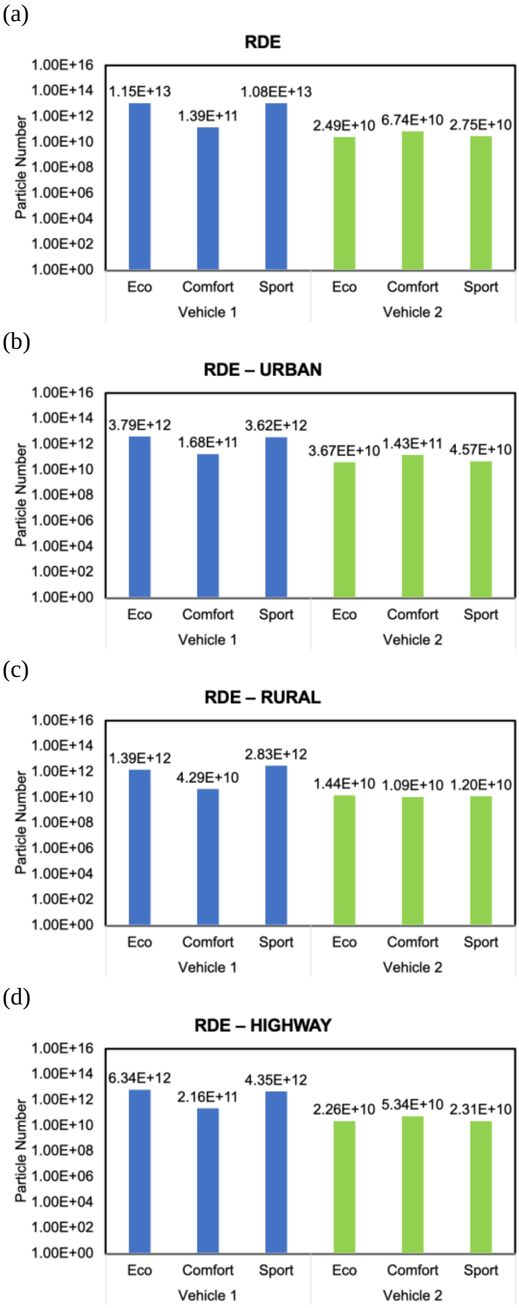


Fig. 10. Particle number emission in (a) RDE test, (b) urban part, (c) rural part, (d) motorway part

References

[1] BUSCH, S., ZELLBECK, H., 2019. *Particle emission of the direct-injection gasoline engine under real driving emissions conditions*. MTZ Worldwide, 1, 66-71

[2] EC, 2008. EUROPEAN COMMISSION (EC), 2008. *Commission Regulation, 2008, 692/2008 of 18 July 2008 implementing and amending Regulation (EC) 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information*. Official J. European Union, L 199. http://data.europa.eu/eli/reg/2008/692/oj

[3] EU 2016. EUROPEAN COMMISSION (EC). *Commission Regulation, 2016, 2016/427 of 10 March 2016 amending Regulation (EC) No. 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6), Verifying Real Driving Emissions,* Official J. European Union, L 82. http://data.europa.eu/eli/reg/2016/427/oj

[4] ETP, 2017. *Energy Technology Perspective*, 2017. International Energy Agency

[5] GIECHASKIEL, B., SUAREZ-BERTOA, R., LAHDE, T., CLAIROTTE, M., CARRIERO, M., BONNEL, P., MAGGIORE, M., 2019. *Evaluation of NOx emissions of a retrofitted Euro 5 passenger car for the Horizon prize "Engine retrofit"*. Environmental Research, 166, pp. 298-309. DOI: 10.1016/j.envres.2018.06.006

[6] GIS, M., 2018a. *Unia Europejska przycina emisję CO2. Pociągnie to za sobą niższe zużycie paliwa*. Online access: http://moto.pl/MotoPL/7,88389,23277145,unia-europejska-przycina-emisje-co2-pociagnie-to-za-soba-nizsze.html.

[7] GIS, M., 2019. *Assessment of exhaust emissions from vehicles in real traffic conditions*. IOP Conference Series: Earth and Environmental Science, 214, 012035. DOI: 10.1088/1755-1315/214/1/012035

[8] GIS M., WISNIOWSKI P., 2019. *Ekologiczne aspekty zasilania silników gazowym paliwem LPG*. Gospodarka Materiałowa i Logistyka, 5. DOI: 10.33226/1231-2037.2019.5.17

[9] GIS, W., 2018b. *Existing state and future opportunities to use selected fuels and alternative propulsion systems in Poland*. E3S Web of Conferences, 44, 00044. DOI: 10.1051/e3sconf/20184400044

[10] GIS, W., PIELECHA, J., WASKIEWICZ, J., GIS, M., MENES, M., 2016. *Use of certain alternative fuels in road transport in Poland*. IOP Conference Series: Materials Science and Engineering, 148, 012040. DOI: 10.1088/1757-899X/148/1/012040

[11] JASINSKI, R., MARKOWSKI, J., PIELECHA, J., 2017. *Probe Positioning for the Exhaust Emissions Measurements*. Procedia Engineering, 192, pp. 381-386. DOI: 10.1016/j.proeng.2017.06.066

[12] IEA, 2017. *Database and Simulation Model, Mobility Model*. Online access: www.iea.org/etp/etpmodel/transport/)

[13] JD, 2019. JATO DYNAMICS, 2019. *CO2 Emissions Rise To Highest Average Since 2014, As The Shift From Diesel To Gasoline Continues*. London

[14] KURTYKA, K., PIELECHA, J., 2019. *The evaluation of exhaust emission in RDE tests including dynamic driving conditions*. Transportation Research Procedia, 40, 338-345. DOI: 10.1016/j.trpro.2019.07.050

[15] MARKOWSKI, J., PIELECHA, J., JASINSKI, R., 2017. *Model to Assess the Exhaust Emissions from the Engine of a Small Aircraft During Flight*. Procedia Engineering, 192, 557-562. DOI: 10.1016/j.proeng.2017.06.096

[16] MERKISZ-GURANOWSKA, A., PIELECHA, J., 2014. *Passenger Cars and Heavy Duty Vehicles Exhaust Emissions under Real Driving Conditions*. Archives of Transport, 3, 47-59. DOI: 10.5604/0866954 6.1146986

[17] MERKISZ, J., PIELECHA, J., 2015. *Nanoparticle Emissions from Combustion Engines*. Springer Tracts on Transportation and Traffic, 8. DOI: 10.1007/978-3-319-15928-7

[18] MERKISZ, J., PIELECHA, J., 2016. *Conversion of the exhaust emission results obtained from combustion engines of heavy-duty vehicles*. IOP Conference Series: Materials Science and Engineering, 148, 012078. DOI: 10.1088/1757-899X/148/1/012078

[19] NIK, 2018. *Ochrona powietrza przez zanieczyszczeniami - Lata 2014-2017*. Warszawa

[20] NOWAK, M., PIELECHA, J., 2017. *Comparison of exhaust emission on the basis of Real Driving Emissions measurements and simulations*. MATEC Web of Conferences, 118, 00026. DOI: 10.1051/matecconf/201711800026
[21] PIELECHA, I., CIESLIK, W., SZALEK, A., 2018. *Operation of electric hybrid drive systems in varied driving conditions*. Eksploatacja i Niezawodnosc – Maintenance and Reliability, 20 (1), 16-23. DOI: 10.17531/ein.2018.1.3
[22] PIELECHA, J., MAGDZIAK, A., BRZEZINSKI, L., 2019. *Nitrogen oxides emission evaluation for Euro 6 category vehicles equipped with combustion engines of different displacement volume*. IOP Conference Series: Earth and Environmental Science, 214, 012010. DOI: 10.1088/1755-1315/214/1/012010.