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Investigation in fuel consumption of a hybrid and conventional vehicle

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Abstract. During the last decade the introduction of more environmentally friendly technologies were raised more rapidly by the decline in the global fossil energy resources and the increased negative environmental impact of conventional vehicles. One of such technology is the hybrid, which is currently making the transition from conventional vehicle with internal combustion engine to an electric vehicle. At this time there exist a lot of offers of such vehicles from different manufacturers, but there do not exist many researches connected with real hybrid performance in different road cycles and conditions allowing evaluate its real economical performance.
This research was realized with the aim to evaluate performance and fuel consumption of hybrid electric vehicle and its conventional internal combustion engine analogue in laboratory conditions. Tests were realized with two new Toyota Yaris vehicles in Alternative Fuels and Research Laboratory on chassis dynamometer MD-1750 using AVL KMA Mobile system. The results showed better adaptation of Toyota Yaris Hybrid to urban operation, demonstrating 21.3% lower fuel consumption than Toyota Yaris conventional gasoline vehicle, accordingly 7.29 and 8.84 L $(100\ km)^{-1}$.

Key words: hybrid, testing, driving cycle, operating time.

INTRODUCTION

During the last decade ecological aspect of conventional vehicles (CV) with internal combustion engines become more actual based on ecological changes worldwide. Carbon dioxide (CO_2) emissions, which are considered as the main reason for the development of these processes, in transportation accounts 24% of direct CO_2 emissions from fuel combustion (Tracking transport, 2019). In that case many different solutions have been analyzed during the last decade for the improvement of exhaust emissions from existing vehicles, including use of different alternative fuels (advanced biofuels, biomethane, etc.) and mixes with conventional fuels, as also putting attention on electrification. Despite to this, global transport emissions still increasing, for example by 0.6% in 2018, highlighting the main reasons for such an increase – car buyer demand for larger and heavier vehicles, as also raising road freight demand with the raise of global gross domestic product (Tracking transport, 2019). This was also a stimulus for EU, moving towards low and zero-emissions vehicles, in 2019 adopt CO_2 emission standards for heavy-duty vehicles setting targets for reduction the average emissions from new lorries for 2025 and 2030 (Regulation 2019/1242, 2019).

Electrification or use of battery electric vehicle (BEV) has been considered as a solution by car manufacturers in emission reduction, which could be observed in increase of the range of electric vehicles from almost all largest brands. Basically it is done by the fact that BEV does not produce harmful emissions from the point of driving (Krumbholc & Kotek, 2019). At the moment most aggressive adaptation of battery-electric transportation could be observed in places, where air pollution and traffic congestion problems are critical, for example, in China, where market share of BEV reached 3.39% in 2018 (Statista, 2020) confirming China as the biggest market for electric vehicles in the world. Despite to positive examples, globally switching to this type of vehicles is not as rapid as it would be desirable due to many unresolved problems concerning vehicle price, distance traveled, lack of infrastructure, etc.

Therefore, hybridisation of the vehicles could be transitional pathway allowing to reduce emissions and fuel consumption better than other technologies and/or fuels at the moment. The most important advantage of hybrid electric vehicle (HEV) is existence of more than two energy sources (Taymaz & Benli, 2014) and at least one of them can deliver electrical energy. Based on that different hybrid constructions are applied in automotive industry, which could be divided based on the complexity of the powertrain and the connection between the internal combustion engine and the vehicle wheels: mild, full and plug-in hybrid electric vehicle (Piechottka et al., 2018). If the mild hybrid electric technology incorporates small changes in conventional vehicle, and usually it do not have high power energy storage, then full hybrid technology incorporates higher electric motor capacity and battery package, as also more complex control system (Benajes et al., 2019). Depending on the connection between the internal combustion engine and the wheels full hybrid could be divided in such architectures: series, parallel and series-parallel (Liu et al., 2019). One of the most common type is parallel hybrid technology, where the electric motor is used, when it is more efficient, for example, for vehicle starting, but internal combustion engine is used in conditions, when it is more efficient, for example, at higher speed. Additionally battery is generated during operation of internal combustion engine. Therefore it is possible to reach higher overall efficiency, improve total emissions, and reduce fuel consumption, as also reduce total costs of the vehicle compared to other hybrid technologies. Besides of that electricity there is not a primary alternative fuel – there could be used also natural gas or bioethanol for internal combustion engine operation in such way making it more environmentally friendly.

Regarding the use of HEV a number of research works have been done in last few years more attention putting on emissions and fuel consumption in road tests in real driving conditions or cycles, which are more valid in exact country's traffic conditions, as also there are some researches on simulation of hybrids in different testing conditions.

Huang (Huang et al., 2019) has tested two pairs of hybrid and conventional gasoline vehicles (Lexus NX and Toyota Alphard) with the same dimensions, weight, suspension system and exhaust after-treatment technology in real-driving conditions. He has found that HEVs could save 23%–49% fuel than conventional internal combustion engine vehicles, reporting main advantage of HEVs under urban driving conditions with low speeds and stop-and-go traffic. According to emissions he concluded that hybridisation of the vehicle powertrain may not bring the expected benefits to urban air quality as testing of HEVs demonstrated no reduction in hydrocarbon (HC) emissions and higher carbon monoxide (CO) emissions compared to conventional internal combustion engine vehicles.

Researchers from Thailand (Pitanuwat & Sripakagorn, 2015) confirmed previously mentioned benefit of HEVs in relation to conventional vehicles. Road tests with four experienced drivers concerning driving styles and additional vehicles (HEV and CV) showed that HEVs are capable of reduction of fuel consumption by 46% in suburban and – 26% in highway traffic, but increase of fuel consumption even 2 times compared to CV, if aggressive driving style is practised. This was also confirmed in other review (Thomas et al., 2017) concerning HEV, where aggressiveness associated with higher levels of acceleration and braking, and higher speeds as well.

Research (Orecchini et al., 2018) on comparison of two different versions of Toyota Yaris vehicles – hybrid and 1.5 gasoline – showed that rapid reduction in fuel consumption for hybrid is realized for low and medium speeds, while such advantage is reduced with increase of speed reaching almost the same fuel consumption for both vehicles at 90 km h^{-1}. Experimental campaign was realized on road in urban, mixed, extra-urban and highway test path with participation of 30 drivers.

Not all results are ambiguous, but it seems that hybridisation has a potential in reduction of CO_2 emissions and fuel consumption, but confidence should be gained in case of cycles corresponding to Latvian road and traffic conditions. Therefore, the objective of this study was to evaluate the potential of commercially produced hybrid version of a light duty vehicle with an analogue gasoline version of the same model in order to find the benefits of a hybrid.

MATERIALS AND METHODS

For the comparable tests were selected two Toyota Yaris vehicles representing hybrid and gasoline versions of the same model. The main difference between models could be observed in capacity of fuel tank and total mass, which usually is characteristic for HEVs as they are equipped with batteries. Main characteristics of both vehicles are shown in Table 1.

Table 1. Specifications of the test vehicles

Parameter	Yaris Gasoline	Yaris Hybrid
Engine	1.5P Dual VVT-iE	1.5 HSD
Capacity, cm^3	1,496	1497
Max power, kW at rpm	82 at 6,000	54 at 4,800
Max torque, Nm at rpm	136 at 4,400	111 at 3,600
Motor Generator power, kW	-	45
Motor Generator torque Nm	-	169
Transmission	Automatic, CVT	Automatic, CVT
Mass		
Empty, kg	1,040–1,145	1,075–1,165
Total, kg	1,545	1,565
Fuel tank, L	42	36
Fuel consumption (WLTP), L (l00 km)$^{-1}$		
Combined cycle	4.8	3.6
Urban cycle	6.0	3.3
Extra urban cycle	4.1	3.6
Max. speed, km h^{-1}	175	165
Acceleration, 0–100 km h^{-1}, s	11.2	11.8

HEV engine uses a high-expansion ratio Atkinson cycle, variable valve timing-intelligent system, electric throttle control system, intelligent and exhaust gas recirculation system employing a highly efficient EGR cooler.

Tests were realized in Alternative Fuels and Research Laboratory on chassis dynamometer MD-1750. The key parameters of dynamometer allows measure power in range till 1,700 HP and maximum speed of vehicle can reach 300 km h^{-1}; the brake mechanism is powered by electromagnetic eddy currents. Dynamometer allows to simulate road and air resistance, as well as experiments in different driving cycles.

Fuel consumption measurements were realized with AVL KMA Mobile system, which is a high precision measurement system for vehicle fuel consumption measurements on the road and on chassis dynamometers.

Before tests each car was placed on a chassis dynamometer MD-1750 and fastened with straps and anchors. Each car used in tests has a single fuel line fuelling system. The fuel pump is located in the fuel tank, so it is not necessary to use the fuel meter pump module and the meter switched in line, in the fuel supply line. Before connecting to the AVL KMA Mobile fuel meter, the equipment was rinsed from the previous fuel using 0.8–1.0 l of the fuel used for experiments (E95). Both vehicles were warmed up before the tests, therefore cold tests were not realized. Testing was carried out based on method showed in Fig. 1. Firstly, experiments were performed at a steady speed, then – at cycles: IM-240 and Jelgava cycle. The IM-240 belongs to the combined cycle type (Giakoumis, 2016), where the first part of the cycle simulates urban driving conditions, but the second part – relatively simulates driving in non-urban area. This 240 second test cycle represent a 3.1 km route with an average speed of 47.3 km h^{-1} and a maximum speed of 91.2 km h^{-1}. The IM240 cycle is used for emission testing of in-use light duty vehicles in inspection and maintenance programs.

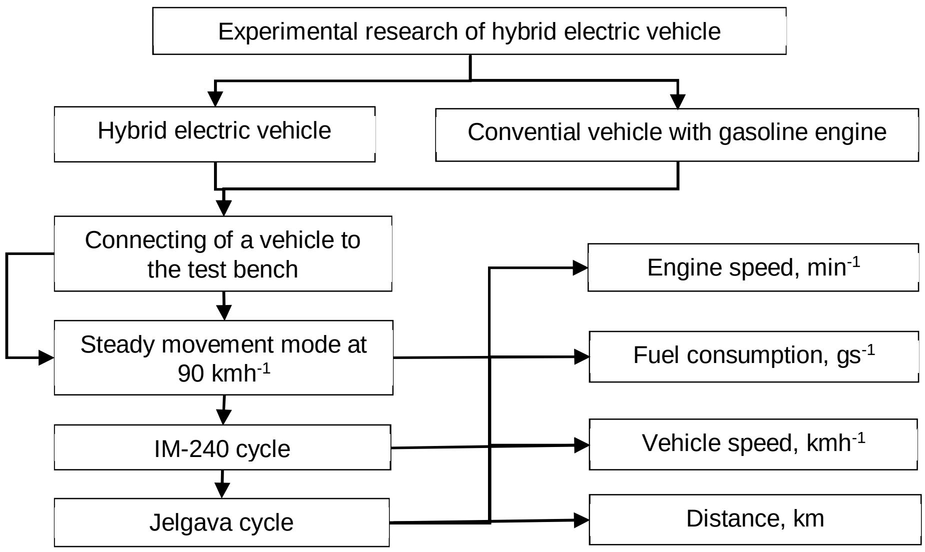

Figure 1. Sequential scheme of the experiment.

The Jelgava cycle is a driving schedule that represents the real driving conditions in the city Jelgava. This 360 second test representing 2.3 km route with an average speed – 23.3 km h^{-1} and maximum speed – 50.0 km h^{-1}. This cycle is developed at the Alternative Fuels and Research Laboratory and describes the car's movement in urban conditions, where are a lot of crossings, traffic lights, pedestrian crossings and other road and traffic elements. Cycle development methodology is already developed and approved at the Faculty of Engineering of Latvia University of Life Sciences and Technolgies in previous studies investigating the use of biofuels (Dukulis & Pirs, 2009).

After realization of both cycle trips, repeats were started again with a steady speed mode. At least 5 repeats were performed for each vehicle. If some significant deviations from the movement speed during the cycle were observed, the experiment was scrapped and repeated. The first series of experiments were conducted with a Toyota HEV and the second one with a conventional gasoline powered car. The basic connection scheme of experimental vehicles to the equipment is shown in Fig. 2.

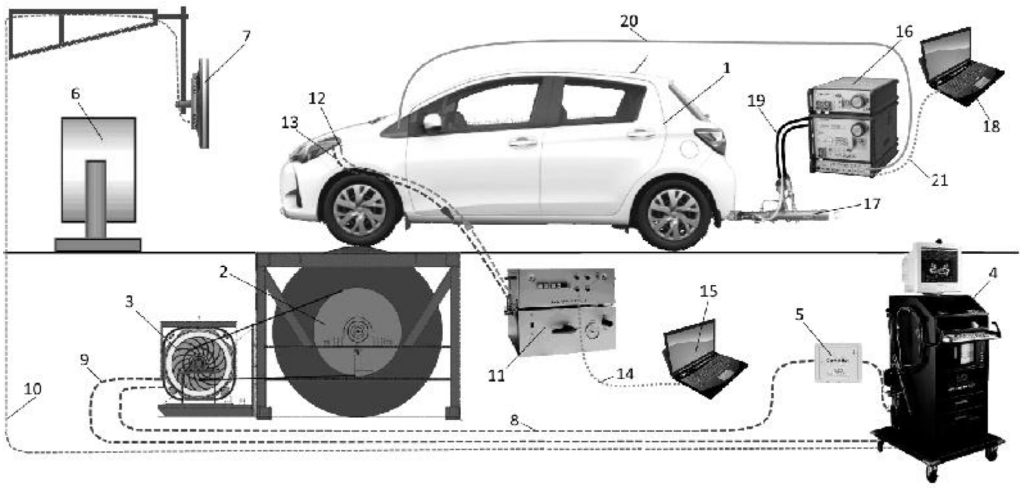

Figure 2. Connection scheme of equipment sensors to experimental vehicles.
1 – experimental car; 2 – chassis dynamometer Mustang MD-1750; 3 – power absorber unit (PAU); 4 – Mustang chassis dyno control module & PC with special software; 5 – dynamometer control box; 6 – air blower; 7 – test cycle simulation screen; 8 – dyno control circuit; 9 – Mustang dyno date communication cable; 10 – screen communication cable; 11 – fuel measuring device AVL KMA Mobile; 12, 13 – fuel lines; 14 – fuel measuring device date communication cable; 15 – fuel measuring system PC with special software & data recording; 16 – HORIBA portable emissions measurement system (PEMS); 17 – exhaust flow meter unit; 18 – PEMS PC with special software & data recording; 19 – heated gas sample lines; 20 – OBD data communication cable; 21 – PEMS date communication cable.

Necessary information was taken from the OBD socket of the vehicle (for the exhaust emission measurement system), chassis dynamometer and the fuel consumption meter. The results were stored on three computers, and all data was processed and synchronized after the experiment.

The experiments have also been carried out in a complex research getting many additional data, as also variation of exhaust components. This article summarises and analyses information only on fuel consumption in different modes and the operating time of the internal combustion engine of HEV.

RESULTS AND DISCUSSION

Fig. 3 summarizes fuel consumption results of HEV and CV with gasoline engine. Results could be interpreted as highly precise, as variation coefficient for HEV was obtained between 1.52% and 3.10%, while in case of CV this value varied between 0.64% and 0.81%. HEV has a slightly higher coefficient of variation due to the specific action of the hybrid drive in the run-in and braking processes, which may vary between repeats of one group of experiments.

The lowest fuel consumption, 5.34 L $(100\ km)^{-1}$ for HEV was obtained in IM-240 cycle, while the highest, 7.29 L $(100\ km)^{-1}$, was obtained during Jelgava cycle. Driving at a steady speed, HEV at 90 km h^{-1} consumed 5.39 L $(100\ km)^{-1}$. The highest fuel consumption in Jelgava's driving cycle is explained by its rapid acceleration and frequent breaking. IM-240 cycle is a combined driving cycle with a relatively small running speeds, allowing to achieve best economic indicators.

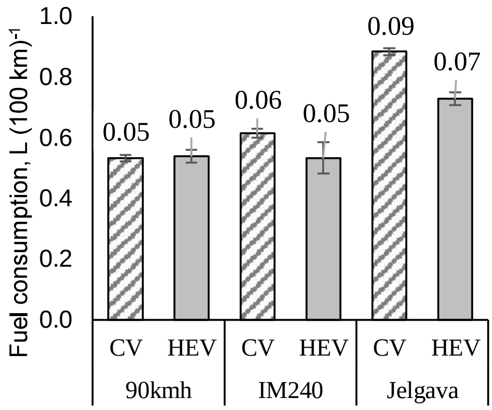

Figure 3. Fuel consumption of Toyota Yaris HEV and CV in different cycles.

For a CV with an Otto engine, the lowest fuel consumption of 5.33 L $(100\ km)^{-1}$ was achieved at a steady speed of 90 km h^{-1}, when the electric drive of HEV is not used. During the driving cycles there could be observed benefits of hybrid technologies, when HEV in IM-240 cycle achieves 14.7% lower fuel consumption than CV. An even more important effect has been achieved during Jelgava cycle, when HEV consumed 17.5% less fuel than CV.

Comparing the experimental data with those given in technical characteristics from the manufacturer, such low fuel consumption rates was not achieved in any mode, and the average fuel consumption in combined driving cycle for HEV is about 32.6% higher. In case of CV this number is 21.8% higher.

A separate study has been carried out to find out running time of internal combustion engine from the total cycle time. Fig. 4 summarises the average speed of the HEV Toyota Yaris during IM-240 cycle and the average engine rotation frequency during this cycle.

For a CV, the engine speed during driving is proportional to the speed of movement depending on the gear engaged. As shown in Fig. 4, during the analysis of the first 50 seconds of the cycle in the area of low speed in the run-in mode the internal combustion engine has reached 1,860 rpm and then switched off. Further movement of the vehicle was carried out by an electric motor until the moment, when acceleration begins in the 42th second. At this stage of acceleration the internal combustion engine is switching on again, but reaching a steady speed, it switching off again. A detailed analysis of these regularities during IM-240 and Jelgava cycle is shown in Table 2.

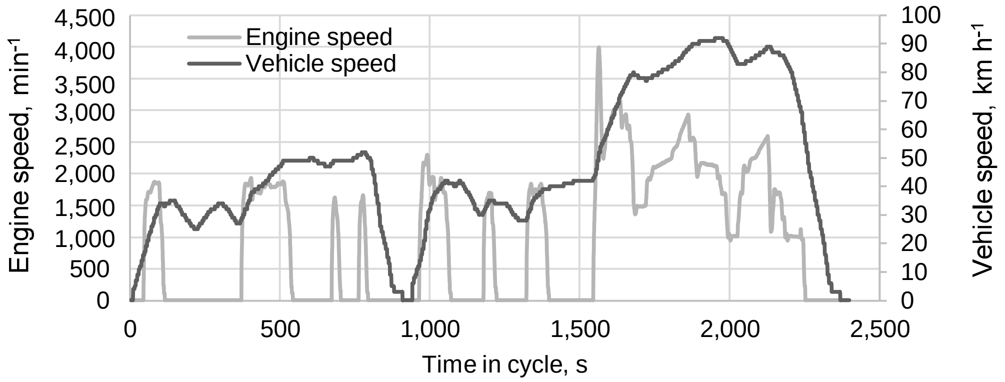

Figure 4. Toyota Yaris HEV speed and engine rotation frequency in cycle IM240.

Table 2. Movement time (s) of HEV in test cycles

Total time	Time in movement	Time with operating engine	Time in movement, % from total	Time with operating engine, % from total	Time with operating engine, % from time in movement
IM-240 cycle					
240	233.36	135.31	97.23	56.38	57.98
Jelgava cycle					
360	290.18	140.26	80.60	38.96	48.33

The total cycle time of IM-240 is 240 seconds, while for Jelgava cycle this is 360 seconds. From the total cycle time in IM-240 about 233.36 seconds have been spent in motion, while in Jelgava cycle it was about 290.18 seconds.

A comparative analysis has been performed for Toyota Yaris, with a hybrid drive and automatic transmission, experimenting in Jelgava and IM-240 driving cycles. Engine operating time in IM-240 cycle is shown in Fig. 5.

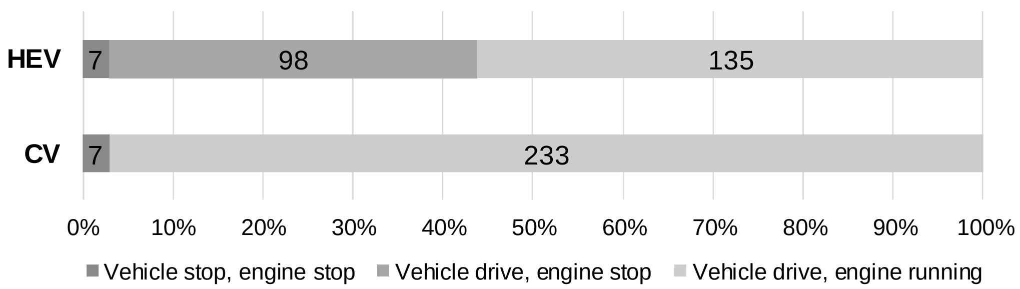

Figure 5. Internal combustion engine operating time for test vehicles in cycle IM240.

During IM-240 cycle, CVs as also HEVs internal combustion engine has been operated all time, except 7% of the time in the initial and final part of the cycle. HEV has not been operated for 98 seconds in this cycle and its movement was provided by an electric motor at this time. Remaining operation of 135 seconds of internal combustion engine was also observed. Engine operating time in Jelgava cycle is shown in Fig. 6.

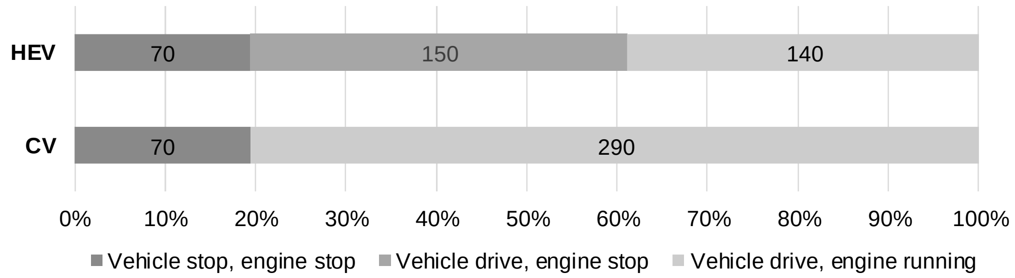

Figure 6. Internal combustion engine operating time for test vehicles in Jelgava cycle.

During development of Jelgava cycle, movement took place in the area of intensive traffic with several traffic lights therefore standing of the car is 70 seconds from the cycle total time for both the HEV and CV. The HEV has not operated for 150 seconds from the total time, which can provide a significant fuel economy. In comparison to IM-240 cycle, Jelgava cycle has provided a higher (percentage) non-operating time for the internal combustion engine.

The following steps of the study are intended to set the inductive loop of the power meter on the battery lines for the HEV, which will ensure instantaneous measurement recording for charging or discharging of the battery. This will allow to record the electricity generated during the braking – recovery process.

CONCLUSIONS

1. HEV consumes 1.1% more fuel than a similar design car with a conventional Otto engine without a hybrid at a steady speed of 90 $km \cdot h^{-1}$.

2. Fuel consumption for the Toyota Yaris Hybrid is 5.34 L $(100\ km)^{-1}$, which is 15% less than for the conventional CVT vehicle, which shows 6.14 L $(100\ km)^{-1}$, in IM-240 combined cycle.

3. The fuel consumption in Jelgava cycle is higher due to the typical urban traffic. During these tests, Toyota Yaris Hybrid demonstrated 21.3% lower fuel consumption than Toyota Yaris CVT, accordingly 7.29 and 8.84 L $(100\ km)^{-1}$.

4. A higher percentage reduction in fuel consumption in Jelgava cycle shows better adaptation of HEV to urban operation. During steady motion in extra urban traffic, HEV does not demonstrate its economical benefits over conventional CVT transmission vehicle.

5. Depending on the mode of movement simulated in two different cycles, Toyota Yaris Hybrid's internal combustion engine may not operate up to 52% of the total travel time, sparing the environment and saving energy resources. In driving conditions with a

smaller proportion of urban traffic, internal combustion engine of HEV has been running for longer time than in urban traffic.

6. During analysis of the HEVs engine speed and movement speed curves, it is possible to determine operating time of the internal combustion engine, however, it is appropriate to use in the next tests the current and direction meter for the battery of HEV to find out the amount of energy produced during the regeneration phase.

REFERENCES

Benajes, J., Garcia, A., Monsalve-Serrano, J. & Martinez-Boggio, S. 2019. Optimization of the parallel and mild hybrid vehicle platforms operating under conventional and advanced combustion modes. *Energy Conversion and Management* **190**, 73–90. doi: 10.1016/j.enconman.2019.04.010

Dukulis, I. & Pirs, V. 2009. Development of driving cycles for dynamometer control software corresponding to peculiarities of Latvia. In: *15th international scientific conference Research for rural development*. Latvia University of Agriculture, Jelgava, pp. 95–102.

Giakoumis, E.G. 2016. *Driving and Engine Cycles*. Springer, 408 pp.

Huang, Y., Surawski, N.C., Organ, B., Zhou, J.L., Tang, O.H.H. & Chan, E.F.C. 2019. Fuel consumption and emissions performance under real driving: Comparison between hybrid and conventional vehicles. *Science of The Total Environment* **659**, 275–282. doi: 10.1016/j.scitotenv.2018.12.349

Krumbholc, M. & Kotek, M. 2019. Analysis of operation parameters of electric and gasoline vehicle in real driving. *Agronomy Research* **17**(S1), 1089–1096. doi: 10.15159/ar.19.035

Liu, Z., Ivanco, A. & Onori, S. 2019. Aging characterization and modeling of nickel-manganesecobalt lithium-ion batteries for 48V mild hybrid electric vehicle applications. *Energy Storage* **21**, 519–527. https://doi.org/10.1016/j.est.2018.11.016

Orecchini, F., Santiangeli, A., Zuccari, F., Ortenzi, F., Genovese, A., Spazzafumo, G. & Nardone, L. 2018. Energy consumption of a last generation full hybrid vehicle compared with a conventional vehicle in real drive conditions. *Energy Procedia* **148**, 289–296. doi: 10.1016/j.egypro.2018.08.080

Piechottka, H., Küçükay, F., Kercher, F. & Bargende, M. 2018. Optimal powertrain design through a virtual development process. *World Electric Vehicles* **9**, 11. doi: 10.3390/wevj9010011

Pitanuwat, S. & Sripakagorn, A. 2015. An Investigation of Fuel Economy Potential of Hybrid Vehicles under Real-World Driving Conditions in Bangkok. *Energy Procedia* **79**, 1046–1053. doi: 10.1016/j.egypro.2015.11.607

Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019. 2019. *Official Journal of the European Union* L198/202, 1–39.

Statista, Inc. 2020. *https://www.statista.com/statistics/1050120/china-battery-electric-car-market-share/.* Accessed 22.1.2020.

Taymaz, I. & Benli, M. 2014. Emissions and fuel economy for a hybrid vehicle. *Fuel* **115**, 812–817. doi: 10.1016/j.fuel.2013.04.045

Thomas, J., Huff, S., West, B. & Chambon, P. 2017. Fuel consumption sensitivity of conventional and hybrid electric light-duty gasoline vehicles to driving style. *SAE Int. J. Fuels Lubr.* **10**(3). doi:10.4271/2017-01-9379

Tracking Transport 2019. IEA, Paris *https://www.iea.org/reports/tracking-transport-2019.* Accessed 22.1.2020.