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THE LEGITIMACY OF USING HYBRID VEHICLES IN URBAN CONDITIONS IN RELATION TO EMPIRICAL STUDIES IN THE WLTC CYCLE

Key words: ecology, environment, hybrid, petrol engine, WLTP.

Abstract: Air pollution in cities is an increasing problem. The increased concentration of toxic harmful substances, including PM10 and PM2.5, is noticeable in the autumn and spring period. This is when the heating period begins. However, the industrial sector is not always responsible for air pollution. Transport also has its share. The share of transport depends on the terrain and buildings. The lack of proper air flow causes emitted suspended dust and other particulates to remain above the city creating smog. In Poland, there are up to 40,000 deaths per year because of PM10 and PM2.5 emissions. The same problem applies to other European cities. Therefore, it is necessary to take specific measures to limit as much as possible the emission of toxic substances. In the case of activities in the transport sector, several solutions are possible. One of them is the use of vehicles with alternative power systems. In the short-term, it is reasonable to use hybrid alternative drives. In order to verify the advantages of using vehicles with hybrid systems, the authors of the article performed comparative tests on a chassis dynamometer. The objects of the study were two vehicles – one with a classic propulsion system and the other with a hybrid system in the current WLTC homologation cycle (WLTP procedure).

Zasadność wykorzystania pojazdów hybrydowych w warunkach miejskich w odniesieniu do badań empirycznych w cyklu WLTC

Słowa kluczowe: ekologia, środowisko, pojazd hybrydowy, silnik spalinowy, WLTP.

Streszczenie: Zanieczyszczenie powietrza w miastach stanowi coraz większy problem. Zwiększone stężenia toksycznych szkodliwych substancji, w tym PM10 i PM2.5, jest zauważalne jesienią i wiosną. Jest to początek okresu grzewczego. Jednak sektor przemysłowy nie zawsze jest odpowiedzialny za zanieczyszczenie powietrza. Transport ma również swój udział. Udział transportu zależy od terenu i budynków. Brak odpowiedniego przepływu powietrza powoduje emisję między innymi zawieszonego pyłu, który pozostaje nad miastem, tworząc smog. W Polsce umiera do 40 000 osób rocznie z powodu PM10 i PM2,5. Ten sam problem dotyczy innych miast europejskich. Dlatego konieczne jest podjęcie szczególnych środków w celu ograniczenia w jak największym stopniu emisji toksycznych substancji. W przypadku działań w sektorze transportu możliwe są różne rozwiązania. Jednym z nich jest wykorzystanie pojazdów z alternatywnymi systemami energetycznymi. W perspektywie krótkoterminowej rozsądne jest stosowanie hybrydowych alternatywnych napędów. Aby zweryfikować zalety stosowania pojazdów z układami hybrydowymi, autorzy artykułu przeprowadzili testy porównawcze na hamowni podwoziowej. Przedmiotem badań były dwa pojazdy – jeden z klasycznym układem napędowym, a drugi z układem hybrydowym, w aktualnym cyklu homologacji WLTC (procedura WLTP).

Introduction

The problem of air pollution is an increasing challenge. Reducing pollution is a difficult task because the number of vehicles on the road increases year by year. In 2015, there were about 1.1 billion vehicles around the world. It resulted from the fact that there were roughly 6.5 people per vehicle. According to estimates, by 2025, the number of vehicles will increase to over 1.5 billion vehicles, and, in 2040, it will be almost 2 billion [1–3].

In the future, the largest increase in the number of vehicles is expected in developing countries, such as China or India. According to the World Energy Council, there were 4 vehicles per 1,000 people in China in 2000, 40 in 2010, and 310 vehicles per 1,000 inhabitants estimated in 2035. In 2013, 250 million vehicles were registered in China [4].

According to a report by Euler Hermes, an insurance company dealing in transaction insurance and debt collection in 2017, global vehicle production is expected to exceed 100 million cars a year. Industry forecasts indicate an average increase of 4% [5–7]. According to OICA data, forecasts for vehicle production in China are very optimistic. In 2017, about 20 million vehicles will leave factories, and China will strengthen its global position as the world's leading vehicle manufacturer [5].

1. Main problem

In road transport, especially in cities, the largest problem is the older type of vehicles, which do not meet the stringent emission requirements of exhaust gases [8–9]. This causes excessive emission of toxic substances from harmful exhaust gases; therefore, it significantly affects air pollution, especially in cities.

In the world, vehicles with alternative power systems are increasingly involved in transportation [10–11]. One of these options is hybrid vehicles. They are to be particularly used in the short and medium term. Their main advantage is noticed primarily in cities. By using a hybrid system in which the electric motor is the main drive unit and the combustion engine is a generator or support system, it is possible to significantly reduce fuel consumption and harmful emissions.

Therefore, it is necessary to increase the share in the transport sector, alternatively powered vehicles including those equipped with hybrid systems. With more vehicles of this type, it will be possible to reduce harmful emissions and meet the European guidelines for reducing carbon dioxide emissions (Figure 1).

2. Methodology

The comparative tests were carried out under a set of conditions in order to make the results reproducible as much as possible. For this reason, the authors of the article decided to carry out a series of measurements on the chassis dynamometer at the Motor Transport Institute. In order to make the results as close as possible to the actual ones, the authors decided to use the WLTC driving cycle for testing. The test stand (chassis dynamometer) and the driving cycle (WLTC) used in the tests are described below.

Dynamometer

One-roll chassis dynamometer by Zoellner, type RPL 1220/12 C 221 113 / GPM 200 with the roll of 48” diameter and electric simulation of resistance to the motion and inertia of the vehicle, allowing particularly testing vehicles with the following characteristics:

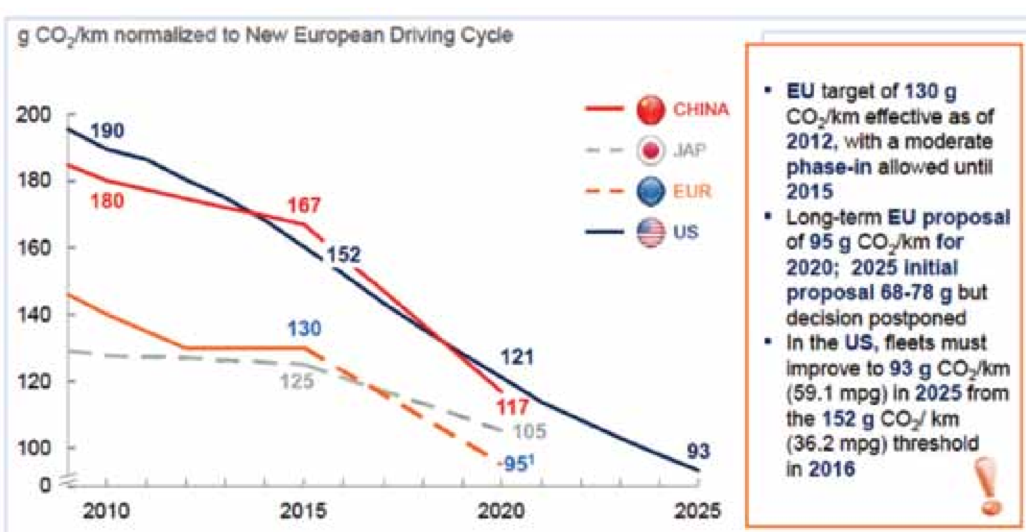

Fig. 1. Assumptions of reducing carbon dioxide emissions for light vehicle fleet manufacturers in the world in the perspective of 2025 [2]

- Maximum net power on a wheel: up to 200 kW,
- Maximum speed: up to 200 km/h,
- Driving axle load: up to 3500 kg,
- Drive on one or more than one axle with the possibility of disconnecting the drive,
- Maximum wheel track of driving axle: 2150 mm,
- Maximum height of the vehicle: 3400 mm.

A set of two-span analysers by AVL, type AMA i60, allowed measuring the concentrations of the following pollutants:

- Carbon monoxide (low concentrations) CO_{low},
- Carbon dioxide CO_2,
- Total hydrocarbons THC,
- Methane CH_4,
- Nitrogen oxides NO_X, nitric oxide NO and nitrogen dioxide NO_2.

WLTC cycle

The Worldwide Harmonized Light Vehicles Test Cycles (WLTC) are chassis dynamometer tests for the determination of emissions and fuel consumption from light-duty vehicles. The tests have been developed by the UN ECE GRPE (Working Party on Pollution and Energy) group. The WLTC cycles are part of the Worldwide Harmonised Light Vehicles Test Procedures (WLTP) published as UNECE Global technical regulation No. 15 (GTR 15). While the acronyms WLTP and WLTC are sometimes used interchangeably, the WLTP procedures define a number of other procedures-in addition to the WLTC test cycles that are needed to type approve a vehicle [3, 12–16].

The WLTP replaces the European NEDC based procedure for type approval testing of light-duty vehicles, with the transition from NEDC to WLTP occurring over 2017–2019 [3, 12–15].

The WLTP procedures include several WLTC test cycles applicable to vehicle categories of different power-to-mass (PMR) ratios (Tab. 1). The PMR parameter is defined as the ratio of rated power (W) / curb mass (kg). The curb mass (or kerb mass) means the "unladed mass" as defined in ECE R83. The cycle definitions may also depend on the maximum speed (v_max), which is the maximum speed of the vehicle as declared by the manufacturer (ECE R68) and without use restrictions or safety-based limitations. Cycle modifications allowed the accommodation of drivability problems for vehicles with a power to mass ratios close to the borderlines or with maximum speeds limited to values below the maximum speed required by the cycle [3, 12–15, 17].

Class 3 Cycle

With the highest power-to-mass ratio, Class 3 is representative of vehicles driven in Europe and Japan. Class 3 vehicles are divided into 2 subclasses according to their maximum speed: Class 3a with v_max < 120 km/h and Class 3b with v_max ≥ 120 km/h. Selected parameters of the Class 3 cycles are given in Tab. 2, and the vehicle speed for Class 3b is shown in Fig. 3 (in this representation, Class 3a trace would look very similar) [3, 12–15].

Table 1. WLTC test cycles [3, 12–15]

Category	PMR, W/kg	v_max, km/h	Speed Phase Sequence
Class 3b	PMR > 34	v_max ≥ 120	Low 3 + Medium 3-2 + High 3-2 + Extra High 3
Class 3a		v_max < 120	Low 3 + Medium 3-1 + High 3-1 + Extra High 3
Class 2	34 ≥ PMR > 22	-	Low 2 + Medium 2 + High 2 + Extra High 2
Class 1	PMR ≤ 22	-	Low 1 + Medium 1 + Low 1

Table 2. WLTC Class 3 cycle: selected parameters [3, 12–15]

Phase	Duration	Stop Duration	Distance	p_stop	v_max	v_ave w/o stops	v_ave w/ stops	a_min	a_max
	s	s	m	-	km/h	km/h	km/h	m/s²	m/s²
Class 3b (v_max ≥ 120 km/h)									
Low 3	589	156	3095	26.5%	56.5	25.7	18.9	-1.47	1.47
Medium 3-2	433	48	4756	11.1%	76.6	44.5	39.5	-1.49	1.57
High 3-2	455	31	7162	6.8%	97.4	60.8	56.7	-1.49	1.58
Extra-High 3	323	7	8254	2.2%	131.3	94.0	92.0	-1.21	1.03
Total	**1800**	**242**	**23266**	-	-	-	-	-	-

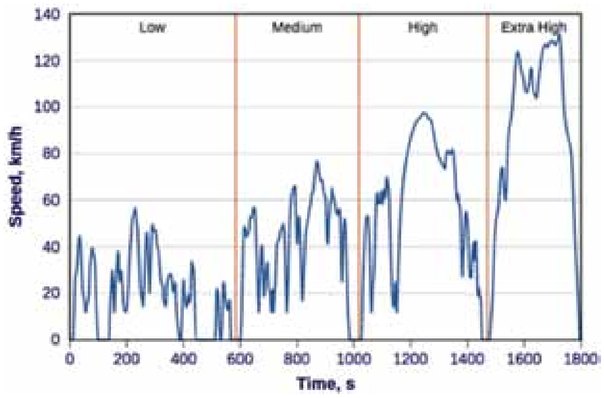

Fig. 2. WLTC cycle for Class 3b vehicles [3, 12–15]

3. Test objects

Two vehicles were used for the tests. The first one was equipped with a spark-ignition drive unit. The second one was equipped with a hybrid system. The hybrid vehicle was powered with a spark ignition engine -generator. The main shaft unit transferring power to the wheels via CVT was an electric motor. Table 3 presents the chosen technical parameters of both vehicles (Fig. 2). Attention should be given to the fact that the difference in the weight of both vehicles was taken into account by selecting relevant load parameters of the chassis dynamometer.

4. Results

Repeated tests carried out on a chassis dynamometer allowed the determination of the averaged emission results of harmful exhaust gas and the concentration of toxic exhaust gas emissions. In the following diagrams (Figs 4–5), the concentrations of carbon monoxide are shown. The vehicle with the SI engine was characterized by significant concentrations of carbon monoxide in the off-site WLTC cycle. Attention should also be paid to the urban parts of the WLTC cycle. Higher concentrations are noticeable when starting a cold engine and also for the subsequent phases of the cycle.

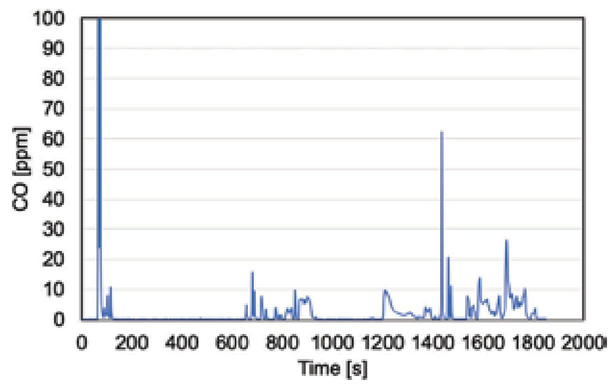

Fig. 4. The concentration of carbon monoxide emissions of a hybrid vehicle at cold start

Table 3. Chosen technical data of tested vehicles

	The vehicle with a spark-ignition engine	Hybrid vehicle
Engine displacement	1798 cm^3	1798 cm^3
Max. rating power	108 kW @ 6400 rpm	90 kW @ 5200 rpm
Max. torque	180 Nm @ 4000 rpm	142 Nm @ 3600 rpm
Compression ratio	11	13
Type of fuel injection	Multi-point (MPI)	Multi-point (MPI)
Gearbox	CVT	e-CVT

Fig. 3. Research facilities (on the left side a vehicle with an SI engine, on the right a vehicle with a hybrid system)

The same applies to nitrogen oxides (Figs 6–7). In this case, significant concentrations are also noted for a vehicle equipped with a spark-ignition drive unit. The hybrid vehicle was characterized by much smaller peak concentrations of this toxic exhaust component throughout the cycle.

The third types of toxic exhaust components studied are hydrocarbons (Figs 8–9). The vehicle with the SI engine was characterized by higher concentrations of hydrocarbons. This is noticeable especially in the fourth phase of the cycle. Moreover, significant concentrations were observed at the very beginning of the tests in the "cold start" phase.

The research also determined the average emission of harmful substances, as well as the average fuel consumption of the tested vehicles (Fig. 10). With respect to each of the tested exhaust gas constituents (carbon monoxide, nitrogen oxides, hydrocarbons, carbon dioxide), a significant reduction in emissions of these components is noticeable. Moreover, in terms of fuel consumption, the vehicle equipped with a hybrid system was characterized by better results in the WLTC

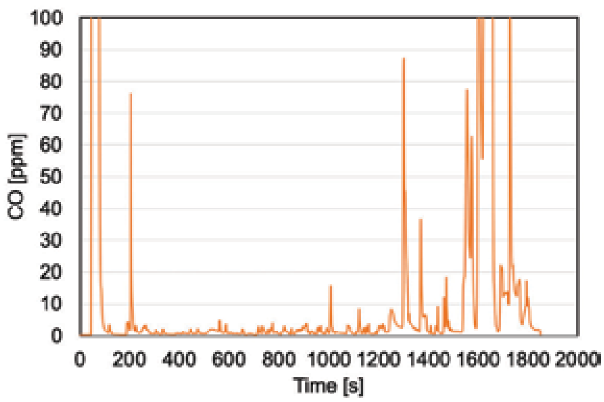

Fig. 5. The concentration of the carbon monoxide emission of a vehicle with a spark-ignition engine at the start of a cold engine

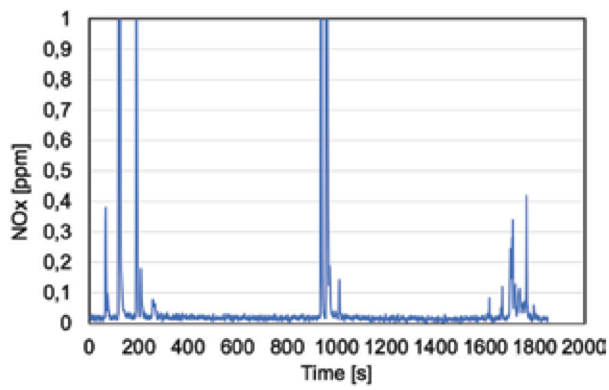

Fig. 6. The concentration of nitrogen oxides emissions of a hybrid vehicle at cold start

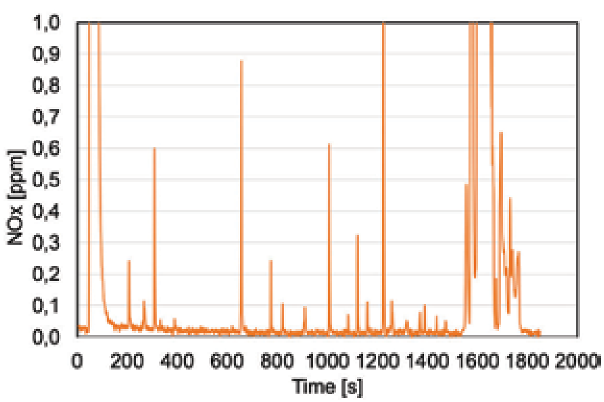

Fig. 7. The concentration of the nitrogen oxides emission of a vehicle with a spark-ignition engine at the start of a cold engine

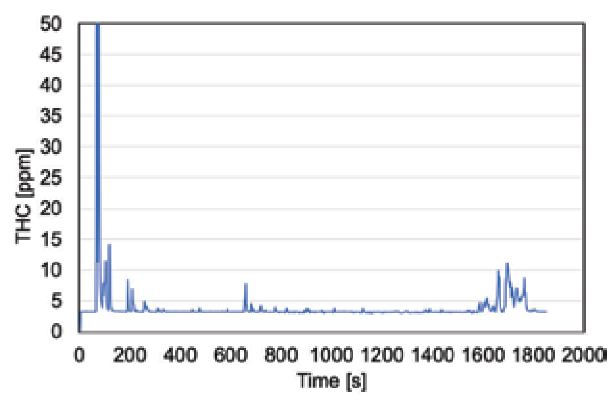

Fig. 8. The concentration of hydrocarbons emissions of a hybrid vehicle at cold start

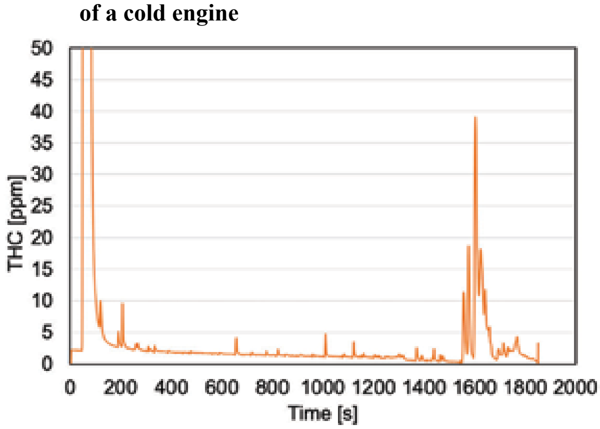

Fig. 9. The concentration of the hydrocarbons emission of a vehicle with a spark-ignition engine at the start of a cold engine

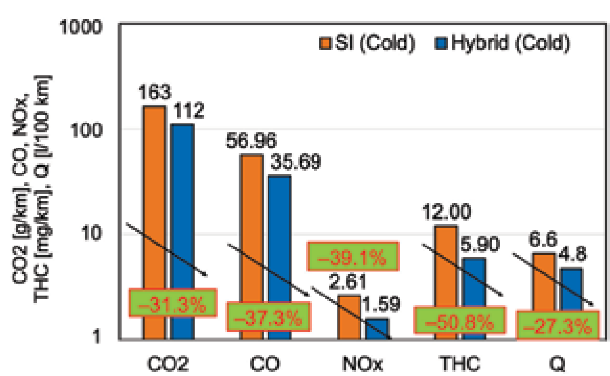

Fig. 10. Average results of exhaust emissions and fuel consumption in the tested hybrid vehicle in WLTC – cold start-up procedure

cycle. The greatest benefits of using vehicles equipped with hybrid systems are found in the case of nitrogen oxides (-39.1%) and hydrocarbons (-50.8%). This is extremely important, because nowadays, apart from particulate matter emission (PM and PN), a significant problem is the emission of nitrogen oxides (NOx).

Conclusions

The conducted research confirms the legitimacy of using hybrid systems to power vehicles. There is a noticeable reduction in emissions of pollutants as well as in fuel consumption. The tests carried out on the chassis dynamometer in the WLTC cycle showed that the tested object with a hybrid system was characterized by lower emission of carbon dioxide by more than 31%, carbon monoxide by over 37%, nitrogen oxides by over 39%, and hydrocarbons by more than 50%, in relation to a research facility equipped with a classic drive system. It can, therefore, be concluded that an increase in the share of hybrid vehicles would have a positive impact on the reduction of emissions of pollutants from transport. This would also translate into air quality in cities.

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