ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.4331

COMPARATIVE ANALYSIS OF NEDC AND WLTC HOMOLOGATION TESTS FOR VEHICLE TESTS ON A CHASSIS DYNAMOMETER

Maciej Gis

Motor Transport Institute
Jagiellonska Street 80, 03-301 Warsaw, Poland
tel.: +48 22 4385400, fax: +48 22 4385401
e-mail: maciej.gis@its.waw.pl

Mateusz Bednarski

Warsaw University of Technology
Faculty of Automotive and Construction Machinery Engineering
Narbutta Street 84, 02-524 Warsaw, Poland
tel.: +48 22 2348517, fax: +48 22 8490303
e-mail: m.bednarski@simr.pw.edu.pl

Piotr Wiśniowski

Motor Transport Institute
Jagiellonska Street 80, 03-301 Warsaw, Poland
tel.: +48 22 4385400, fax: +48 22 4385401
e-mail: piotr.wisniowski@its.waw.pl

Abstract

In 2015, the number of vehicles in the world exceeded 1.1 billion units. In the coming years, it is expected that the largest increase in the number of vehicles will take place in developing countries. This is a problem in particular in terms of emissions of harmful substances from vehicles. Considering that all manufactured vehicle models have to undergo a detailed homologation and meet the exhaust emission requirements before placing on the market, it is necessary to refine test procedures, including test cycles, in which vehicle emissions are determined. At present, the NEDC approval test is valid in Europe. It is a cycle reproduced on a chassis dynamometer in steady conditions. It consists of an urban section repeated four times and an extra urban part. From 2019, a new test procedure will take effect, which uses the WLTC cycle, also reproduced on a chassis dynamometer in fixed conditions. It is much more complex and better reflects the real traffic conditions. For a better illustration of the differences that occur between the current NEDC cycle and the new WLTC, the article presents a comparative analysis of both driving cycles. This is to present the justifiability of using a new driving cycle and to present its complexity. The article presents own research of a vehicle with a spark-ignition engine, which has been tested both in the NEDC and WLTC cycle. On the basis of the obtained data, it was possible to determine the differences in the emission of harmful exhaust gas components and indicate how the new homologation procedure affects the emissions from the vehicle.

Keywords: *combustion engines, homologation procedure, NEDC test, WLTC test, exhaust emissions*

1. Introduction

It is estimated that about 7.3 billion people live on Earth. In 2015, the number of cars exceeded 1.1 billion. These data show that there is one car per 6.5 inhabitants of the Earth. However, the number of cars is growing rapidly from year to year. According to estimates, in 2025 there will be 1.5 billion, and in 2040 – 2 billion. The number of cars does not spread evenly over the entire globe. Their number is related to the economic strength of the state. 320 million people in the

United States, which is the cradle of the automotive industry, own more than 265 million cars. According to a report by the World Health Organization in 2015, the largest number of vehicles per citizen is in San Marino. There are almost two cars for every resident there. According to ACEA, 54.1% of European vehicles are powered by petrol, 40.97% diesel, alternative fuels account for 4.94%. In Poland, the share of alternative fuels is over 13%, fewer cars are powered by diesel. [1]. There are already 21.7 million passenger cars in Poland. That is 564 cars per 1000 inhabitants. The highest car saturation is recorded in central Poland, especially in Wielkopolska and north-eastern Mazovia [2]. In the capital of Poland, estimates based on the data for 2016 indicate that every day, a million cars pass through Warsaw [3]. This shows how important it is to control the amount of harmful substances produced by vehicles.

2. Exhaust emission norms

For years, standards for the emission of harmful substances emitted by vehicles with internal combustion engines have been applied worldwide. Not only is the emission from engines driving vehicles traveling on public roads, but also emissions from non-road or stationary engines are normalized. The concentrations of the following compounds are checked: carbon oxide, non-combusted hydrocarbons, non-combusted non-methane hydrocarbons, nitrogen oxides, and particulate matter. This article will treat the emission of engines in road vehicles. In Europe, the approval of vehicles is carried out on the basis of the requirements set out in the EURO standards. EURO norms have been in force since 1991 and set different requirements for passenger cars and other for trucks. The changes of requirements are presented in Tab. 1.

Tab. 1. Emission standards for passenger cars in [g/km] [3]

Level	Effective date	CO	HC	NMHC	NO_x	$HC+NO_x$	PM
Vehicles with compression-ignition engines							
Euro 1	June 1992	2.720	–	–	–	0.970	0.140
Euro 2	January 1996	1.000	–	–	–	0.700	0.080
Euro 3	January 2000	0.640	–	–	0.500	0.560	0.050
Euro 4	January 2005	0.500	–	–	0.250	0.300	0.025
Euro 5[1]	September 2009	0.500	–	–	0.180	0.230	0.005
Euro 6[2]	September 2014	0.500	–	–	0.080	0.170	0.0045
Vehicles with spark-ignition engines							
Euro 1	July 1992	2.720	–	–	–	0.970	–
Euro 2	January 1996	2.200	–	–	–	0.500	–
Euro 3	January 2000	2.300	0.200	–	0.150	–	–
Euro 4	January 2005	1.000	0.100	–	0.080	–	–
Euro 5[1]	September 2009	1.000	0.100[3]	0.068	0.060	–	0.005
Euro 6[2]	September 2014	1.000	0.100[3]	0.068	0.060	–	0.0045*
where: CO – carbon oxide, HC – non-combusted hydrocarbons, NMHC – non-combusted non-methane hydrocarbons, NO_X – nitrogen oxides, PM – particulate matter, [1] Euro 5a, [2] Euro 6b/6c (PN 6.0·E11/km), [3] THC, * for engines with direct injection							

3. NEDC cycle

The ECE + EUDC test cycle was used to test emissions and fuel consumption of light duty vehicles under EU type-approval [4]. The test is carried out on a chassis dynamometer. The entire cycle includes four ECE segments (Fig. 2) repeated non-stop, followed by one EUDC segment (Fig. 3). Before the test, the vehicle must remain for at least 6 hours at a test temperature of 20-30ºC. Since 2000, the idle period has been eliminated, i.e. the engine starts in 0 s and sampling begins at the same time. This modified cold start procedure is referred to as the new European driving cycle (NEDC) [5].

The full test begins with four ECE cycle repeats (Fig. 1). ECE is an urban driving cycle, also known as UDC. It was developed to represent the driving conditions in the city, e.g. in Paris or Rome. It is characterized by low vehicle speed, low engine load, and low exhaust gas temperature [10]. The full test starts with four repetitions of the ECE cycle (Fig. 2). The ECE is an urban driving cycle, also known as UDC. It was devised to represent city driving conditions, e.g. in Paris or Rome. It is characterized by low vehicle speed, low engine load, and low exhaust gas temperature [5].

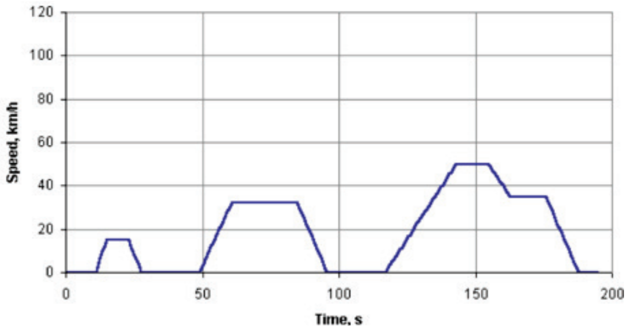

Fig. 1. ECE 15 Cycle [5]

The Extra Urban Driving Cycle (ECDC) segment was added after the fourth ECE cycle to account for more aggressive high-speed driving modes. The maximum EUDC cycle speed is 120 km/h (Fig. 2). An alternative EUDC cycle was also determined for vehicles with low energy consumption, with a maximum speed limited to 90 km/h (Fig. 3) [5].

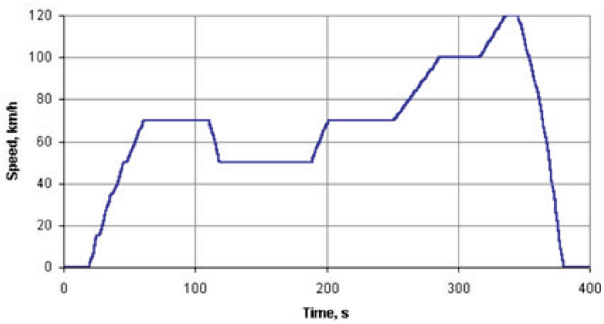

Fig. 2. EUDC Cycle [5]

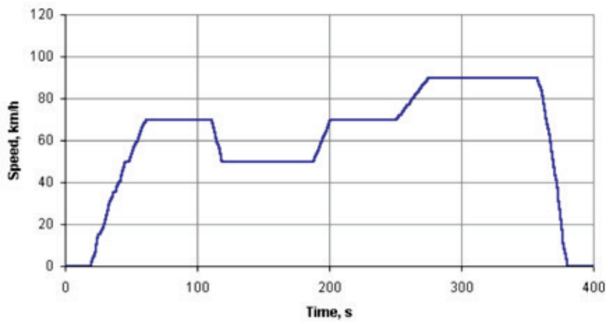

Fig. 3. EUDC Cycle for Low Power Vehicles [5]

Emissions are collected during the cycle in accordance with the constant volume sampling technique (CVS), analysed and expressed in g / km for each pollutant. Tab. 2 summarizes selected parameters for ECE 15, EUDC and NEDC cycles [5].

Tab. 2. Characteristic of ECE 15, EUDC and NEDC test [5]

Characteristics	Unit	ECE 15	EUDC	NEDC[2]
Distance	km	0.9941	6.9549	10.9314
Total time	s	195	400	1180
Idle (standing) time	s	57	39	267
Average speed (incl. stops)	km/h	18.35	62.59	33.35
Average driving speed (excl. stops)	km/h	25.93	69.36	43.10
Maximum speed	km/h	50	120	120
Average acceleration[1]	m/s^2	0.599	0.354	0.506
Maximum acceleration[1]	m/s^2	1.042	0.833	1.042
[1] Calculated using central difference method, [2] Four repetitions of ECE 15 followed by one EUDC				

Type I, II and III tests. The urban driving cycle – ECE 15 (Fig. 2) – represents the type I test according to the original ECE 15 emission procedure. The type II test is a warm, idle CO test of the tailpipe performed immediately after the fourth type I cycle. The type III test is, for example, two-speed (idle and 50 km/h) testing of the chassis dynamometer to determine emissions from the crankcase [5].

4. WLTP Test

Under conditions defined by EU law, the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) laboratory test is used to measure fuel consumption and CO_2 emissions from passenger cars, as well as their pollutant emissions [6].

WLTP replaces the European procedure based on NEDC for light vehicle type approval tests, with the transition from NEDC to WLTP in 2017-2019 [5, 7-9].

WLTP procedures include several WLTC test cycles applicable to the vehicle category with different power to mass ratio (PMR), Tab. 3. The PMR parameter is defined as the ratio of rated power (W) / curbs mass (kg). Curb weight (or curb weight) means “unloaded mass” as defined in ECE R83. The cycle definitions may also depend on the maximum speed (v_max), which is the maximum vehicle speed declared by the manufacturer (ECE R68) and not the use limitation or safety-related restriction. Cyclical modifications are allowed to include steering problems for vehicles with power to mass indicators near boundary lines or at maximum speeds limited to values below the maximum speed required by cycle [5, 7-10].

Tab. 3. WLTC test cycles [5, 7-9]

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

4.1. 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. 4, and the vehicle speed for Class 3b is shown in Fig. 5 [5, 7-9].

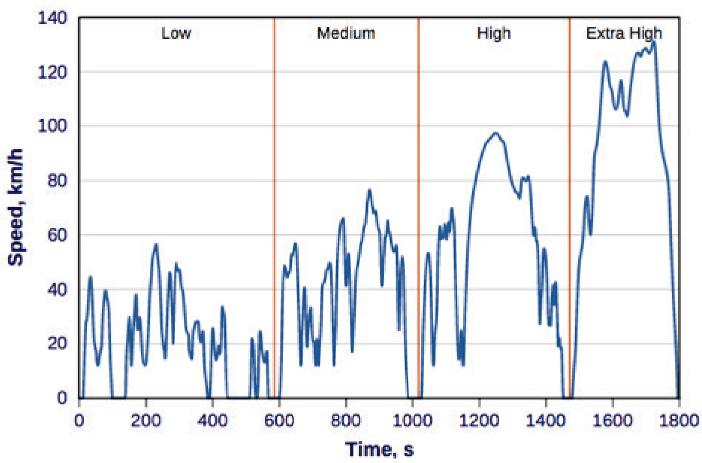

Fig. 4. WLTC cycle for Class 3b vehicles [5, 7-9]

Tab. 4. WLTC Class 3 cycle: selected parameters [5, 7-9]

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						
Class 3a (v_max < 120 km/h)									
Low 3	589	156	3095	26.5%	56.5	25.7	18.9	-1.47	1.47
Medium 3-1	433	48	4721	11.1%	76.6	44.1	39.3	-1.47	1.28
High 3-1	455	31	7124	6.8%	97.4	60.5	56.4	-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	23194						

4.2. Class 2 Cycle

Class 2 is representative of vehicles driven in India and of low power vehicles driven in Japan and Europe. Selected parameters of the Class 2 cycle are given in Tab. 5, and the vehicle speed is shown in Fig. 5 [5, 7-9].

Tab. 5. WLTC Class 2 cycle: selected parameters [5, 7-9]

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
Low 2	589	155	3101	26.3%	51.4	25.7	19.0	-0.94	0.90
Medium 2	433	48	4737	11.1%	74.7	44.3	39.4	-0.93	0.96
High 2	455	30	6792	6.6%	85.2	57.5	53.7	-1.11	0.85
Extra-High 2	323	7	8019	2.2%	123.1	91.4	89.4	-1.06	0.65
Total	1800	240	22649						

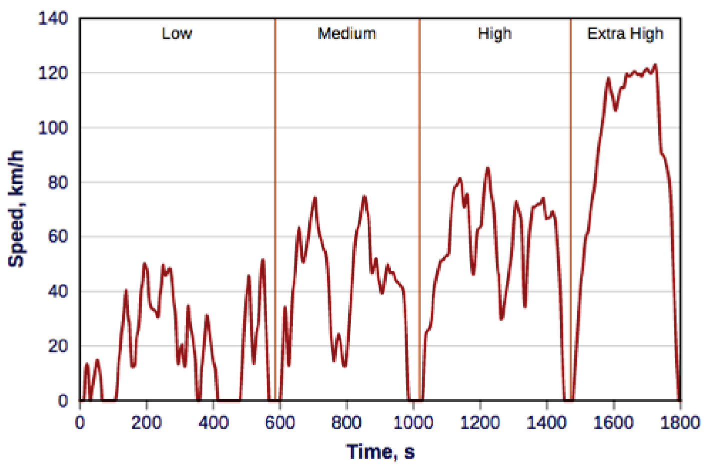

Fig. 5. WLTC cycle for Class 2 vehicles [5, 7-9]

4.3. Class 1 Cycle

With the lowest power-to-mass ratio, Class 1 is representative of vehicles driven in India. Selected parameters of the Class 1 cycle are given in Tab. 6, and the vehicle speed is shown in Fig. 7 [5, 7-9].

Tab. 6. WLTC Class 1 cycle: selected parameters [5, 7-9]

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
Low 1	589	154	3330	26.1%	49.1	27.6	20.4	-1.00	0.76
Medium 1	433	48	4767	11.1%	64.4	44.6	39.6	-0.53	0.63
Low 1	589	154	3330	26.1%	49.1	27.6	20.4	-1.00	0.76
Total	1611	356	11428						

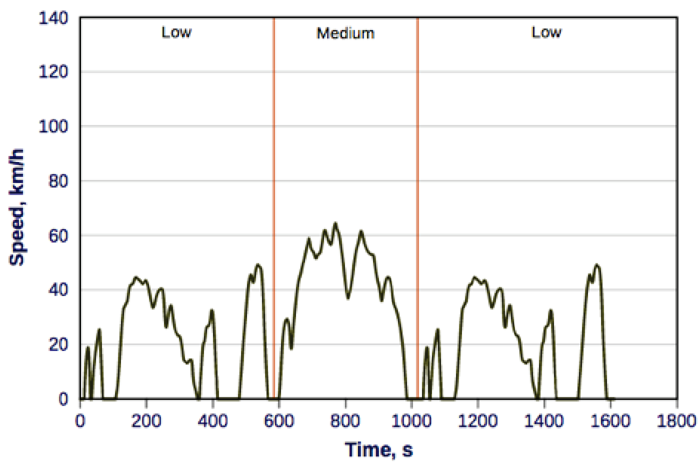

Fig. 6. WLTC cycle for Class 1 vehicles [5, 7-9]

5. NEDC/WLTP comparison

The homologation tests carried out in laboratory conditions in the chassis dynamometer are aimed at determining the average exhaust gas emission and fuel consumption in newly produced vehicles. So far, the NEDC cycle has been considered too "easy" to reflect real road conditions. For this reason, work has begun on a new WLTP testing procedure. Comparing WLTC with NEDC, you can see that many changes have been made. First of all, the effect of additional equipment and different engine configuration versions was taken into account, as well as the type of gearbox used in the vehicle (the gearbox change in the case of the manual gearbox is calculated). However, it is not everything. The distance and duration of the cycle have been extended. Now it is extended by 10 minutes (WLTC – 30 minutes, NEDC – 20 minutes) and longer by 12 km (WLTC – 23 km, NEDC – 11 km). The downtime has been shortened. Accurate tests have shown that in real traffic conditions, the vehicle's idle time is shorter than previously assumed. For this reason, it was reduced from 25% in NEDC to 13% in the WLTP cycle [11, 12].

An important change is the introduction of differences in the cycle depending on the vehicle's power and the mass ratio in the tested vehicle. Three categories were distinguished. It should be noted, however, that in a larger number of cases, the third category applies to vehicles sold in Europe – above 34 kW/ton [12]. Fig. 7 shows the most important differences between WLTP and NEDC tests.

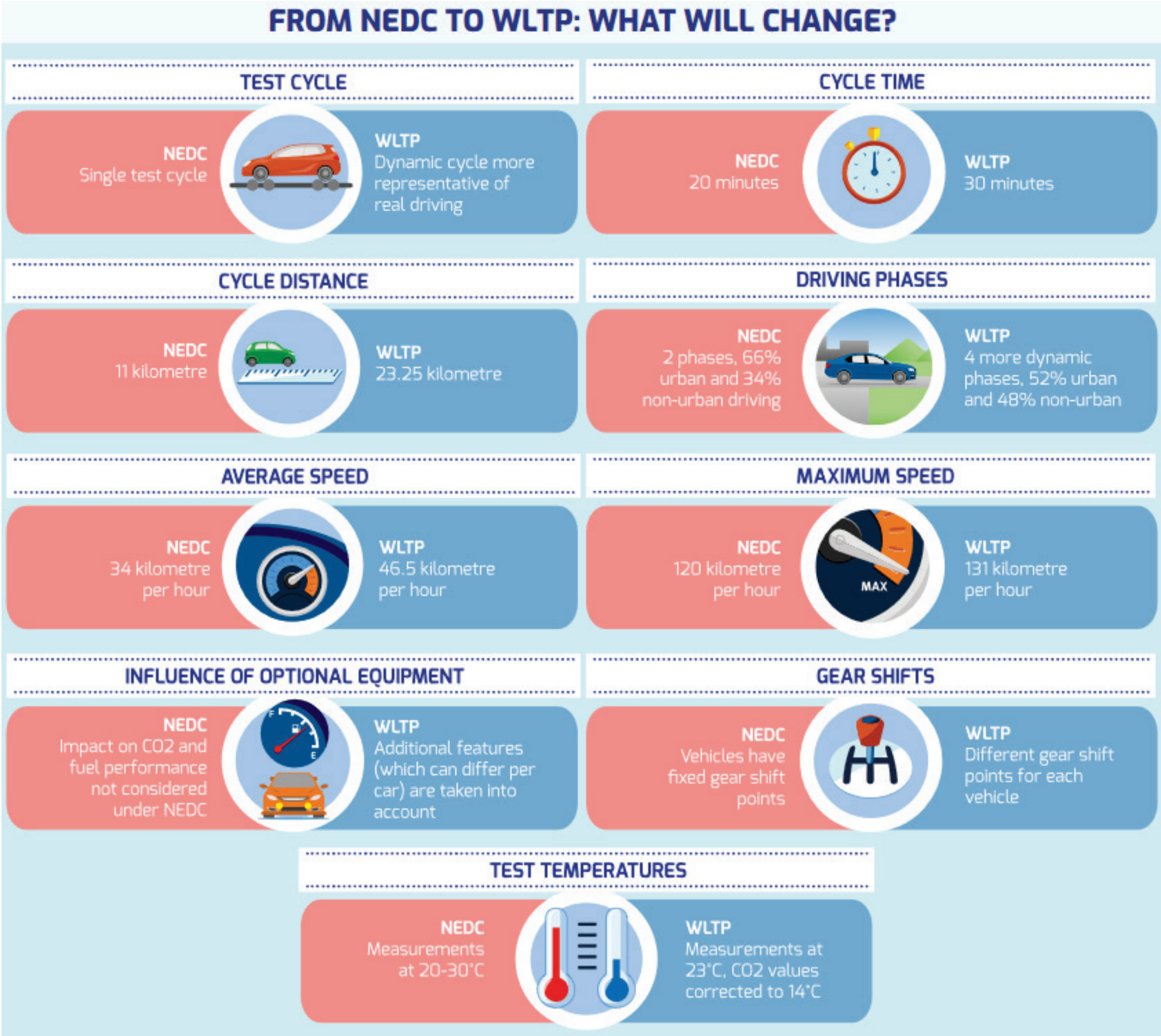

Fig. 7. Differences between WLTP and NEDC [13]

6. Research

To verify whether the introduction of a new more complex cycle has impact on the value of road emission and fuel consumption, tests were carried out in laboratory conditions in a chassis dynamometer in the Motor Transport Institute.

The tests were repeated several times to verify the results and the possibility of averaging. In the first part of the tests, a series of repetitions was performed in both driving cycles (NEDC and WLTC Class 3) in cold-start. In the second part of the studies, tests were performed in warm engine start-up in the tested vehicle. As previously, also here a series of tests had been performed based on which average values of exhaust emissions and fuel consumption were determined.

7. Conclusions

Analysis Figs. 8-11 show:

- in most cases a similar amount of CO_2 with a tendency to reduce it in the case of the NEDC test,
- CO emission drops significantly for the WLTC test only for the Cold Start-up procedure,
- nearly six times higher NOx emission was observed for vehicle in the cold start-up procedure,
- the THC emission in each case was lower for WLTC,
- fuel consumption for 3 out of 4 cases was higher for WLTC except for a vehicle in the cold start-up procedure.

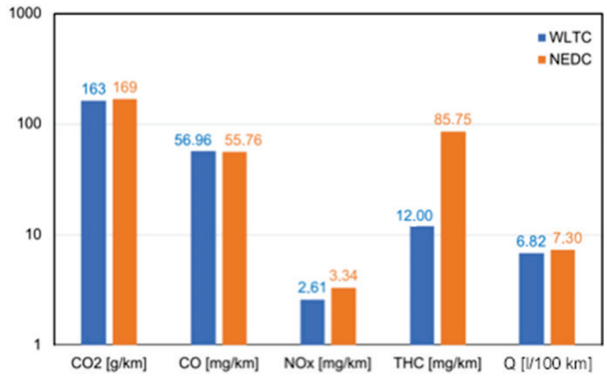

Fig. 8. Average results of exhaust emissions and fuel consumption in the tested vehicle in WLTC and NEDC – cold start-up procedure

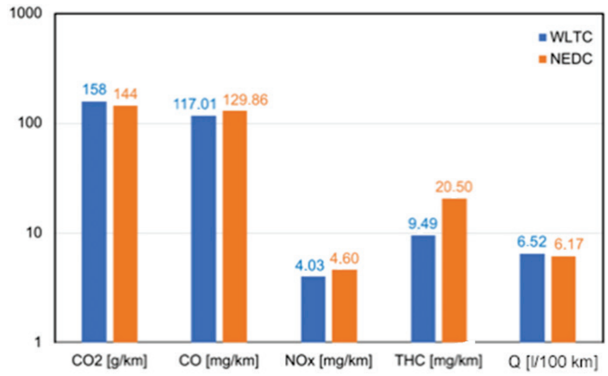

Fig. 9. Average results of exhaust emissions and fuel consumption in the tested vehicle in WLTC and NEDC – warm start-up procedure

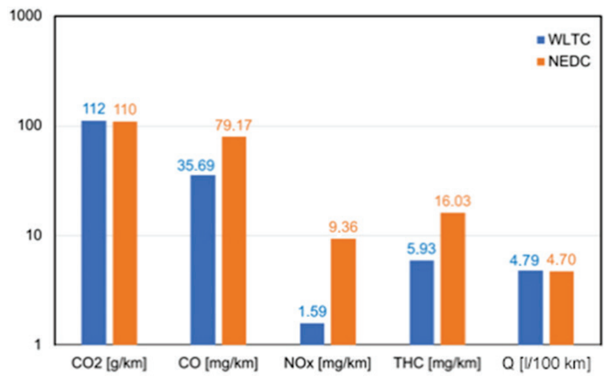

Fig. 10. Average results of exhaust emissions and fuel consumption in WLTC and NEDC – cold start-up procedure

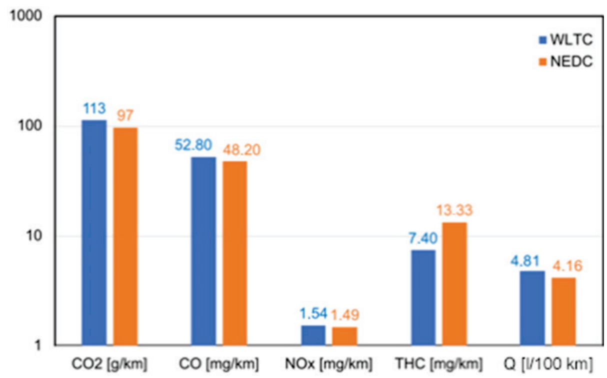

Fig. 11. Average results of exhaust emissions and fuel consumption in WLTC and NEDC – warm start-up procedure

References

[1] http://www.polskatimes.pl/motofakty/a/ile-jest-samochodow-na-swiecie,10496459/.

[2] http://biqdata.wyborcza.pl/biqdata/7,159116,22775299,stan-polskiej-motoryzacji-duzo-starych-samochodow.html.

[3] www.gazeo.pl.

[4] EEC Directive 90/C81/01, 2016 Committee of Inquiry into Emission Measurements in the Automotive Sector.

[5] www.dieselnet.com.

[6] http://wltpfacts.eu/what-is-wltp-how-will-it-work/.

[7] *EC 2017 Commission Regulation (EU) 2017/1151*, Official Journal of the European Union, 7.7.2017, L 175, 1-643, http://data.europa.eu/eli/reg/2017/1151/oj.

[8] *UNECE 2012 Worldwide harmonized Light vehicles Test Procedure (WLTP)*, UN ECE; website, viewed 21-Dec-2012.

[9] Pielecha, I., Wislocki, K., Cieslik, W., Bueschke, W., Skowron, M., Fiedkiewicz, L., Appl. Therm. Eng., 132 188, 2018.

[10] www.moto.pl

[11] Jakubiak-Lasocka, J., Lasocki, J., Badyda, A. J., *The influence of particulate matter on respiratory morbidity and mortality in children and infants*, Advances in Experimental Medicine and Biology, 849, pp. 39-48, 2015.

[12] Pielecha, J., Jasinski, R., Magdziak, A., 2017 MATEC Web of Conferences, 118 00021.

[13] http://wltpfacts.eu/from-nedc-to-wltp-change/.

Manuscript received 09 May 2018; approved for printing 14 August 2018