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The comparison of harmful substances emission from flex-fuel vehicle during NEDC and WLTC test cycles

The beginning of this article describes the NEDC and WLTC test cycles and basic differences between them. The following presents, the test stand and test objects, which were bioethanol fuels E10, E40 and E85. At the end were presented and discussed results of tests of these fuels in the flex-fuel vehicle in NEDC and WLTC test cycles.

Key words: *flex-fuel, bioethanol fuels, NEDC, WLTC, WLTP*

1. Introduction

Environmental protection is currently one of the main directions of technology development in the automotive industry. The aim is always to reduce emissions of harmful substances in vehicle exhaust gases. In the EU Commission Regulation No. 459/2012 of 29 May 2012, Euro emission standards specify the maximum emission of harmful components in exhaust gases, such as: NO_x, CO, HC, PM and PN in test cycles. In subsequent years, the maximum emission limits for these substances are constantly reduced. One of the ways to meet the rigorous standards is the use of alternative fuels for internal combustion engines. Bioethanol and its mixtures with motor gasoline are alternative fuels over which research is carried out on a wider scale [2, 6].

2. NEDC test cycle

NEDC (New European Driving Cycle), is a normalized test cycle, used to determine the content of harmful substances in the exhaust gases and the fuel consumption of combustion engines in passenger cars. This test cycle was supposed to imitate the conditions of driving a passenger car in a typical European city. Introduced in 1997, it was a mandatory test for car manufacturers to obtain approval of their vehicle in Europe. Complete NEDC cycle is a combination of four consecutive UDC (Urban Driving Cycle) cycles and one EUDC (Extra Urban Driving Cycle) cycle. For the first time, the UDC cycle was presented in 1970. It represents the behavior of a car moving in high-traffic. The characteristic features of the UDC cycle are: low engine load, relatively low exhaust gases temperature, driving speed not exceeding 50 km/h and frequent stops. The EUDC cycle was presented in 1990. It was supposed to represent a faster and more aggressive style of driving a passenger car, which is usually occurring in extra-urban conditions. The maximum vehicle speed in this cycle is 120 km/h.

Figure 1 shows the speed of the car during the entire NEDC test cycle divided into parts UDC and EUDC. Table 1 lists the basic parameters of the entire NEDC test cycle and its individual parts [1].

Table 1. Basic parameters of the NEDC test cycle and its parts UDC and EUDC test cycles [1]

	Unit	Test cycle		
		UDC	EUDC	NEDC
Distance	[km]	4052	6955	11007
Total time	[s]	780	400	1180
Average speed	[km/h]	18.7	62.6	34
Maximum speed	[km/h]	50	120	120

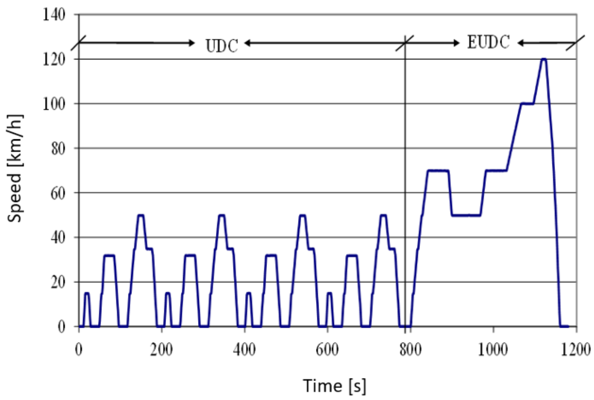

Fig. 1. The vehicle speed during NEDC test cycle [1]

3. WLTC test cycle

WLTC (Worldwide harmonized Light vehicles Test Cycles) is a test cycle designed to imitate real driving conditions for a car during a chassis dynamometer test. It is part of the procedure called WLTP (Worldwide Harmonized Light Vehicles Test Procedure) which is used to measure fuel consumption and emissions of harmful substances in the exhaust gases of passenger cars. The WLTP procedure was developed by the UN-ECE (United Nations Economic Commission for Europe) and published in 2014. Since September 2017, it replaces the current NEDC test cycle in the homologation process of new cars. There are several types of WLTC test cycles. The cycle type depends on the category to which the car is assigned on the basis of its PMR (Power to mass ratio) and the maximum vehicle speed specified in the manufacturer's specification. Table 2 shows the categories according to which the WLTP cycle type is determined along with the corresponding PMR coefficient values [1].

Table 2. WLTC test cycle categories with corresponding PMR coefficients and maximum speed values [1]

Category	PMR, W/kg	v_max, km/h
3b	PMR > 34	v_max ≥ 120
3a		v_max < 120
2	34 ≥ PMR > 22	–
1	PMR ≤ 22	–

The vast majority of cars in Europe qualify for category 3b. The test cycle of this category is divided into four phases. Each phase has different range of vehicle speed (small, medium, high, very high). Figure 1 shows the course of the car speed during the WLTC category 3b test cycle divided into individual phases.

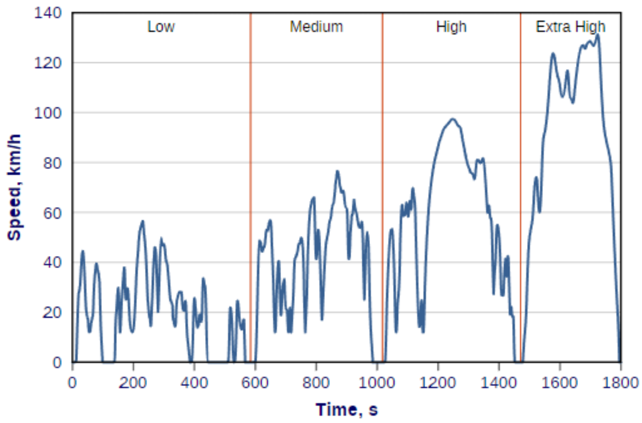

Fig. 2. The speed of the car during the WLTC category 3b cycle with the division into phases [1]

4. Test stand description

The tests were carried out on a chassis dynamometer at the Institute of Motor Transport in Warsaw. The research object was a Ford Focus passenger car. The vehicle has a spark-ignition engine with a displacement volume of 1798 cm^3, factory equipped with a Flex Fuel system that allows it to operate on bioethanol fuels with a maximum bioethanol content of 85% (v/v). Before starting the tests, the vehicle's engine was warmed up to operating temperature.

The benchmark emission tests (Fig. 3) were carried out on a 2-roller chassis dynamometer 2PT220EX type, manufactured by Jaroš with two rollers with a diameter of 372 mm, with electric simulation of motion resistance and mechanical simulation of inertia placed in the low temperature chamber. This dynamometer allows the examination of vehicles (also at ambient temperature up to –14°C) with the following parameters:

- maximum net power on wheels up to 220 kW,
- maximum speed of 130/200 km/h,
- pressure on the drive axle up to 2400 kg,
- drive for one axle or more than one axis with the possibility of disconnecting the drive,
- maximum wheelbase of the drive axle: 2100 mm,
- maximum vehicle height 2900 mm, maximum distance of the rear drive axle from the front of the car 5000 mm.

The engine of the tested vehicle was powered by composed bioethanol fuels E10, E40 and E85. Table 3 presents the basic parameters of the mentioned fuels.

Fig. 3. The benchmark tests

Table 3. Basic parameters of E10, E40 and E85 fuels

	E10	E40	E85
Research octane number, RON	95	101	105
Heat value	42 MJ/dm^3	30.6 MJ/dm^3	22.7 MJ/dm^3
Density	730 kg/m^3	751 kg/m^3	782.2 kg/m^3
Bioethanol content (V/V)	10%	40%	85%

5. Test results

Figures 4 and 5 present the results of emission measurements of NO_x and CO respectively from the vehicle tested in NEDC and WLTC test cycles, the engine of which was powered sequentially by E10, E40 and E85. In the graphs, it can be observed that the higher content of bioethanol in the fuel makes that the tested vehicle emitted less NO_x and CO in the exhaust gases. In WLTC test cycle, reduction in emissions when using E85 fuel was about 7% for NO_x and about 13% for CO compared to E10 fuel. For both NO_x and CO, the emission value in the WLTC test cycle increases significantly compared to emissions in the NEDC cycle. The biggest change can be observed for NO_x emissions when fueled with E40, the value of this emission from the WLTC cycle increases by approx. 175% compared to the NEDC cycle.

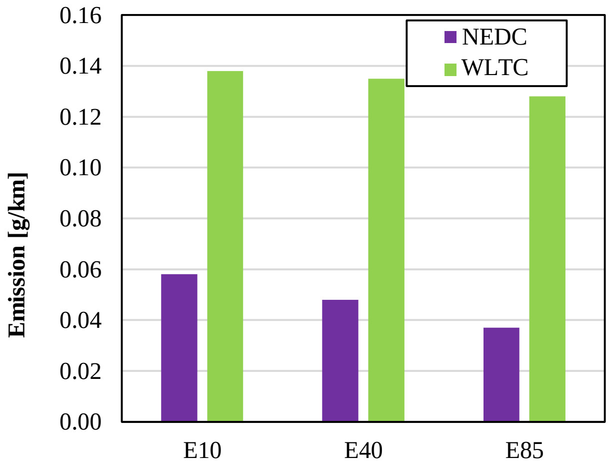

Fig. 4. NO_x emission values from a vehicle with a SI engine powered by E10, E40 and E85 fuel in the NEDC and WLTC test cycle

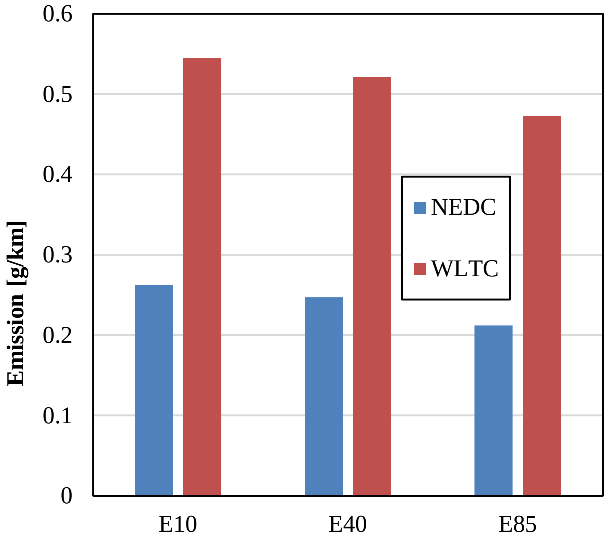

Fig. 5. CO emission values from a vehicle with a SI engine powered by E10, E40 and E85 fuel in the NEDC and WLTC test cycle

Figures 6 and 7 present the results of emission measurements of THC and CO_2 respectively from the vehicle tested in NEDC and WLTC test cycles, the engine of which was powered sequentially by E10, E40 and E85. Analyze of THC emission measurements has shown a reduction in THC emissions along with an increase in bioethanol content in the fuel. In the WLTC test cycle, with the E85 fuel, the THC emission was about 9% lower compared to the THC emission with the E10 fuel supply. The impact of bioethanol content in fuel on the value of CO_2 emissions was lower than in the emissions of previously discussed substances. In WLTC test cycle, with E85 fuel supply, the CO_2 emission value was about 5% lower compared to CO_2 emission values when fueled with E10 fuel. For each of the tested fuels in the WLTC test cycle, the THC emission value was significantly higher compared to the values of these emissions in the NEDC test cycle. For E85 fuel, THC

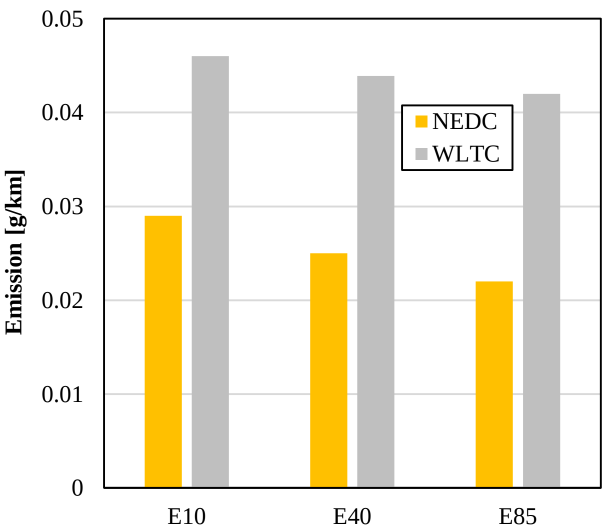

Fig. 6. THC emission values from a vehicle with a SI engine powered by E10, E40 and E85 fuel in the NEDC and WLTC test cycle

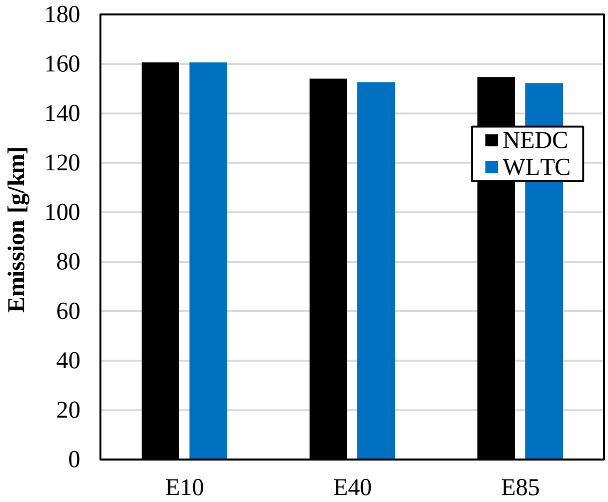

Fig. 7. CO_2 emission values from a vehicle with a SI engine powered by E10, E40 and E85 fuel in the NEDC and WLTC test cycle

emission in the WLTC test cycle was about 91% higher than the THC emissions in the NEDC test cycle. In the case of CO_2 emissions, the type of test cycle did not have a significant impact on their values.

Figure 8 shows the consumption values of E10, E40 and E85 fuels by the vehicle engine tested in NEDC and WLTC cycles. The higher content of bioethanol in the fuel caused its higher consumption. Such regularity occurred both in the NEDC and WLTC test cycles. The difference between consumption of E10 fuel and consumption of E85 fuel in the WLTC test cycle was about 37%. The results of fuel consumption measurements in the WLTC test cycle have higher values than in the NEDC test cycle for the corresponding fuels.

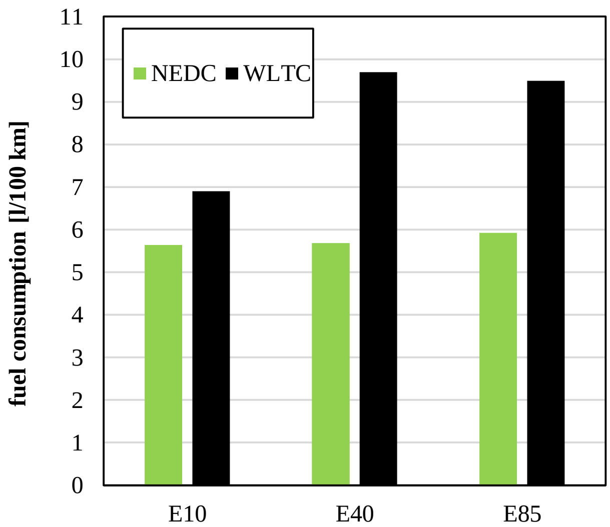

Fig. 8. Fuel consumption of a vehicle with a SI engine powered by E10, E40 and E85 fuel in the NEDC and WLTC test cycle

6. Summary

On the basis of the conducted research, it is possible to notice a significant (even over 100%) increase in NO_x, CO and THC emissions in the WLTC test cycle in comparison to the emission values of these substances in the NEDC test cycle. This is due to the fact that the tested vehicle in the WLTC test cycle reaches higher maximum speeds and the speed change is more dynamic. Instead, CO_2 emission values were compared in both of these test cycles.

Fuel consumption measurements of the vehicle's engine in the WLTC test cycle showed higher values compared to the fuel consumption in the NEDC test cycle. The largest difference occurred for E40 and E85 fuels, where the increase in their consumption in the WLTC cycle amounted to approx. 70% and approx. 61% respectively in comparison to consumption in the NEDC cycle.

The impact of bioethanol in fuel on measured emissions of exhaust gases was similar in both the NEDC and WLTC test cycles. With increase of bioethanol content in fuel, a distinct reduction in NO_x, CO and THC emissions was observed. The value of CO_2 emission in exhaust gases decreased minimally for engine powered by E40 and E85 fuels.

Nomenclature

EUDC	Extra Urban Driving Cycle
NEDC	New European Driving Cycle
PMR	Power to mass ratio
UDC	Urban Driving Cycle
UN-ECE	United Nations Economic Commission for Europe
WLTC	Worldwide harmonized Light vehicles Test Cycles
WLTP	Worldwide Harmonized Light Vehicles Test Procedure

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