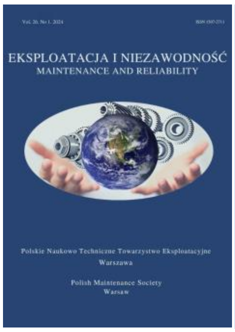

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Research on the results of the WLTP procedure for a passenger vehicle

Indexed by: Web of Science Group

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Highlights

- Assess the properties of processes describing the variables of passenger car speed.
- Exhaust emissions from the combustion engine and fuel consumption in the WLTC dynamic test.
- Homologation procedures for exhaust emissions.

Abstract

The article considers variables registered in the WLTP procedure. The test results of a passenger car with a compression-ignition engine have been analysed. The tests were carried out on a chassis dynamometer. The tests were performed for engine cold start and ran up to the point of reaching stabilized operating conditions. The average specific distance emissions and volumetric fuel consumption were assessed for individual test phases as well as for the entire test. It was found that the results in the first test phase, which corresponded to the engine cold start up to stabilized operating conditions, had the most significant impact on the overall exhaust emission and fuel consumption results in the test. The specific distance emissions of carbon monoxide, non-methane hydrocarbons and nitrogen oxides were by far the highest in the first phase of the test. In the fourth phase of the test, the specific distance emissions of methane and carbon dioxide turned out to be the highest, as well as the operational volumetric fuel consumption being the highest.

Keywords
WLTP, exhaust emissions, passenger vehicle

1. Introduction

The introduction of increasingly stringent emission norms of toxic exhaust gases and the widespread emphasis on reducing greenhouse gas emissions in the European Union directs research and development works towards the development of new, low-emission vehicles, the use of alternative fuels, the development of new types of engines and increasing the efficiency of currently produced drive systems [13, 17, 20, 23, 25].

Particularly controversial is the Fit for 55 package [10, 12], accelerating the energy transformation and the implementation of the European Union's climate policy, which included proposals to ban the sale of new vehicle s with internal combustion engines from 2035. In turn, the planned introduction of the Euro 7 emission standard has already proven to be a challenge for vehicle manufacturers [11, 21]. It demands the reduction of exhaust emissions and CO_2 emissions (fuel consumption) by at least 50%, which would force manufacturers to incur significant costs in the process of

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development and improvement of their vehicles [19].

Here it must be stated, that the European Commission cannot agree on the relationship between 'Fit for 55' and Euro 7. If the proposal of "removal" of vehicles with internal combustion engines from 2035 was maintained, then the sense of introducing strict Euro 7 regulations only for a couple of years would be debatable. Manufacturers of vehicles and engines would probably not be willing to accept the high costs of adapting to the Euro 7 standard in such case.

At the end of March this year, the Council of the European Union finally passed legislation that assumes a 100% reduction in carbon dioxide emissions for new vehicles after 2035, which would mean a ban on the purchase and registration of a new vehicle with an internal combustion engine [1]. However, there will be an exception to this rule, which was pushed through by Germany – vehicles with petrol engines will be allowed, as long as they are powered by ecological fuel, in the production of which carbon dioxide was recovered from the atmosphere.

Considering the above, the key issue in engine research is engine operation in dynamic conditions, which determine the emission of harmful exhaust components and fuel consumption [17, 26]. Such tests for LDV (Light Duty Vehicles) are primarily WLTC (Worldwide harmonized Light duty Test Cycle) and RDE (Real Driving Emissions).

The scientific aim of the article was to assess the properties of processes describing the variables of passenger car speed, exhaust emissions from the combustion engine and fuel consumption in the WLTC dynamic test, used in homologation procedures for exhaust emissions.

The research problem in the article concerned the passenger vehicle properties in various phases of the WLTC test [14, 27], which differ significantly in terms of vehicle traffic conditions. The tests concerned engine exhaust emissions and the engine fuel consumption. Significant differences in the traffic conditions present for particular test phases relate to [2, 3, 5-8]:

- the engine thermal state in connection with the cold engine start-up in the test instead of at a stabilized temperature,
- vehicle velocity properties in particular phases of the test; these differences related mainly to the average velocity and the dynamic properties of the vehicle velocity, which determine the dynamic properties of the engine operating states.

In general, the operating states of an combustion engine refer to the following properties [5-8]:

- engine control – engine control is described by physical quantities corresponding to the operator's control of the engine; in the case of a engine speed, it may be, for example, the position of the accelerator pedal;
- cycle frequency – the measure is the engine speed or the angular speed of the engine crankshaft;
- engine load – the measure includes for example: useful power, torque or mean effective pressure (MEP);
- thermal state – the measure of the thermal state is a set of temperatures of engine parts and its operating factors; usually the thermal state of the engine can be described by the thermal state parameters of the engine, e.g. the temperature of the cooling liquid or engine oil.

The engine operating states can be classified according to their dependence on time. The engine operating states that are constant in time are known as static states, while those that are processes in time are dynamic [5].

As it is known, the engine operating conditions have a strong impact on the engine performance, in particular on the engine exhaust emissions as well as its overall efficiency and, consequently, on the vehicle fuel consumption [2, 3, 5-8].

In order to assess the properties of a passenger vehicle, processes determining and characterizing exhaust emissions and fuel consumption were considered in various phases of the test in dynamic conditions.

2. STATE OF CURRENT KNOWLEDGE

The research results of this publication are generally not found in international literature. Typically, only the test results are analyzed in the test, without assessing the properties depending on the engines operating states, determined by the velocity of the vehicles. Some publications with the results of exhaust emission tests in the WLTC can be found in [2-4, 14, 15, 16, 24, 28].

Typically, emissions and fuel consumption tests in driving tests mainly concern the averaged values of specific distance emissions. Research on the exhaust emission intensity in relation to time and the correlation relationships between the processes characterizing the vehicle motion conditions, engine operating states, exhaust emission and fuel consumption are relatively rare. There are also few publications on the statistical properties of these processes, as well as their frequency properties. Few publications focus on researching of these processes in term of their value.

Research on processes other than exhaust emission and fuel consumption are all the more difficult because combustion engines are characterized by low concentrations of pollutants in many operating states, sometimes near the limit of the measurement accuracy.

The properties of a passenger vehicle engine in the WLTC and RDE (Real Driving Emissions) tests [3, 9] were compared in paper [3]. A large difference in the results of exhaust emissions and the number of particulate matter was found. It turned out that a cold engine start had a greater impact on the results in the case of the WLTC.

Publication [2] presents the test results of a vehicles with a Diesel engine. The publication presents, among others: the results of correlation studies between the vehicle velocity, pollutant emission intensity, the particle number intensity and the volumetric fuel consumption intensity.

In [4] the effectiveness of the simulation software was analyzed for simulating the operation of the drive system and the exhaust aftertreatment system in vehicles with Diesel engines, in order to meet the requirements of the RDE procedures.

Paper [15] compares the test results of two light vehicles in the WLTC and NEDC (New European Driving Cycle) tests [9, 27]. Engine operating conditions, exhaust emissions and fuel consumption were measured. A significant difference in the test results was noted in both tests.

The results of [28] include testing a vehicle with a plug-in hybrid drive and a gasoline engine. The tests were carried out in the WLTC, the urban phase of the WLTC and CLTC-P (China light-duty vehicle Test Cycle for Passenger car) [9, 27]. It was found that the specific distance emissions was the highest in the urban phase of the WLTC, the lowest in the overall WLTC and intermediate in the CLTC-P.

In [24], typical dynamic conditions of vehicle motion in WLTC [3, 9] were studied in order to simulate the emission of particulate matter from tribological pairs in a vehicle.

In another paper [2], the engine operating states were analyzed under the WLTC conditions of vehicle operation. The results of the work were used for a comparative evaluation of various shares of LPG (Liquefied Petroleum Gas) [9, 27] in a dual-fuel Diesel engine.

Paper [16] presents the results of the NEDC and WLTC of 14 vehicles in order to analyze their CO_2 emissions. The research was carried out for the Ministry of Infrastructure and the Environment of the Netherlands.

In the publication [13] presents an overview of the latest research and a comparison of commonly used methods for testing exhaust gas emissions from engines and methods that can comprehensively supplement them. The use of biological methods including methods of microscopic analysis of cells in the assessment of exhaust gas toxicity can be an innovative approach to the problem of air pollution.

3. RESEARCH METHODOLOGY

Research methodology concerns empirical research and the interpretation of the obtained results with particular emphasis on statistical methods [18].

The subject of empirical research was a passenger vehicle powered by a Diesel engine.

The tests were carried out on a chassis dynamometer in accordance with the WLTP (Worldwide Harmonized Light Vehicles Test Procedure) [3, 15] with the use of equipment that meets the requirements of type-approval tests. The engine was powered using commercial fuel.

The variables registered were:

- vehicle velocity,
- exhaust emission rate of pollutants,
- volumetric fuel consumption rate.

The emission of substances harmful to the health of living organisms was measured for:

- carbon monoxide – CO,
- hydrocarbons (volatile organic compounds) – HC,
- non-methane hydrocarbons (non-methane volatile organic compounds) – NMHC,
- nitrogen oxides reduced to nitrogen monoxide – NO_x.

The exhaust emissions of greenhouse gasses was also measured for:

- methane – CH_4,
- carbon dioxide – CO_2.

The recorded processes were subjected to low-pass filtration using the Savitzky-Golay filter [22].

The evaluation of the test results was performed in the domains of time and process value.

The following was determined in the time domain:

– characteristics of the travel duration, distance travelled by the vehicle and the mean vehicle velocity in individual phases and in the entire test;
– statistical characteristics of the test duration, the distance travelled by the vehicle, the vehicle travel velocity in the test as well as the pollutant emission intensity and volumetric fuel consumption intensity in the test [5]:
- Min – minimum value,
- Max – maximum value,
- R – range; R = Max - Min,
- AV – mean,
- M – median,
- D – standard deviation,
- W – coefficient of variation; W = D/AV,
- K – kurtosis,
- S – skewness;

– specific distance emission of substances and operational volumetric fuel consumption in individual test phases and in the entire test.

In the domain of process values [5], histograms of vehicle velocity, pollutant emission intensity and volumetric fuel consumption intensity were determined.

The work uses the concept of a relative difference in the size of "x" and "y":

$$\delta = 2 \cdot |x - y| / (x + y) \quad (1)$$

4. EMPIRICAL RESULTS

Figure 1 is the vehicle travel velocity in the WLTC.

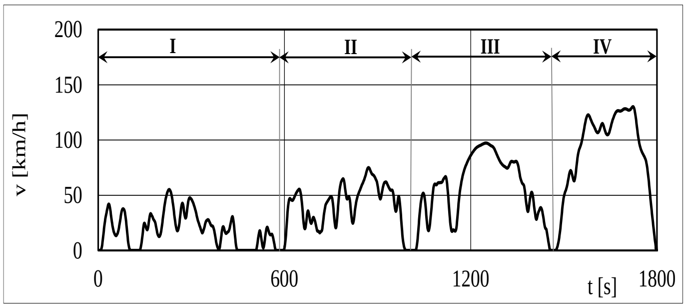


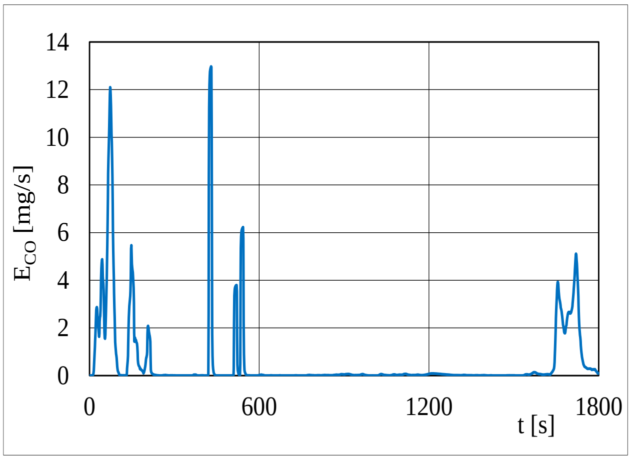
Fig. 1. Vehicle travel velocity in WLTC.

The figure shows four test phases corresponding to the driving conditions in:

– congested urban conditions,
– regular urban conditions,
– rural conditions,
– highways and motorways.

Exhaust emission in the test were compiled in Figures 2a–f shows the volumetric fuel consumption.

The emission intensity of individual components and the intensity of volumetric fuel consumption differ significantly. For CO, HC, NMHC and CH_4, a very low exhaust emission intensity has been observed through most of the test. NO_x emissions were similar, but diverged in intensity. The CO_2 emission intensity was approximately linearly dependent on the intensity of fuel consumption. The nature of these processes was significantly different from the nature of the emission intensity of other pollutants. Volumetric fuel consumption and CO_2 emission intensities were the highest in the fourth phase of the test – with the highest average travel velocity and the highest engine load.



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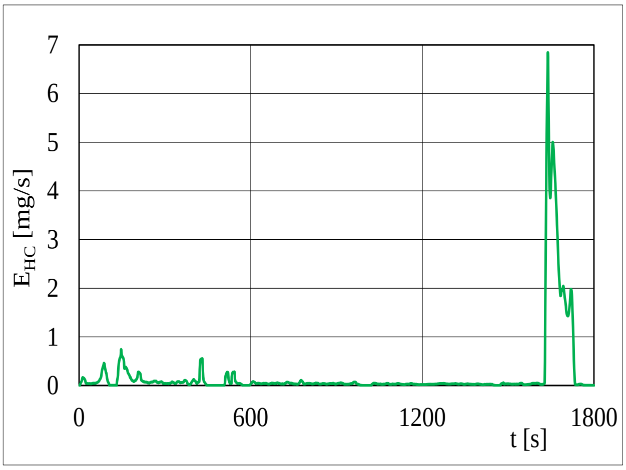

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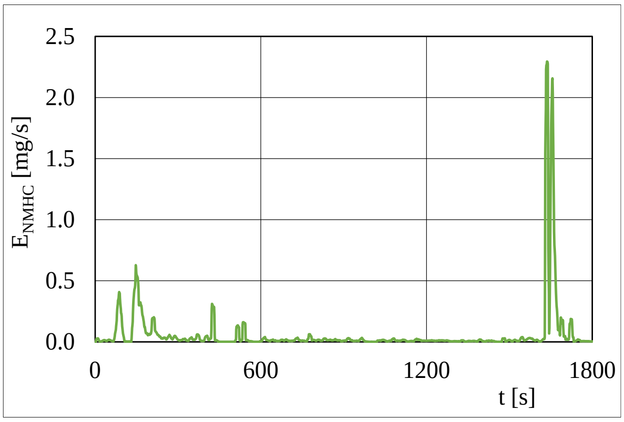

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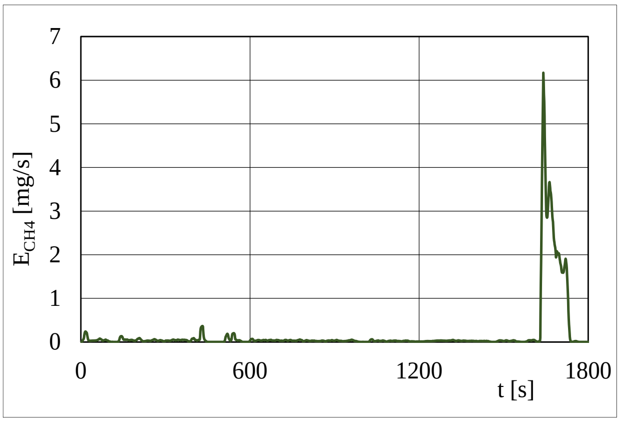

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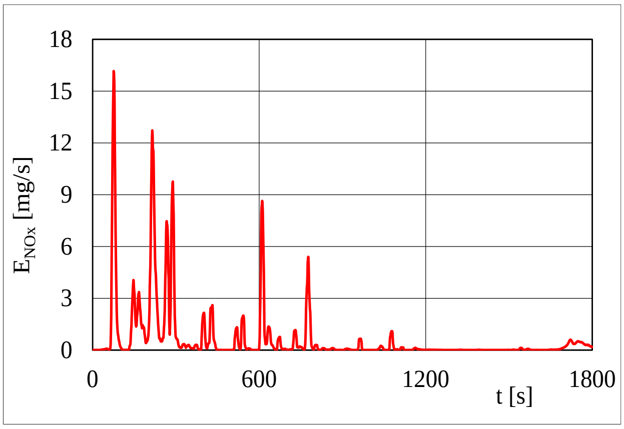

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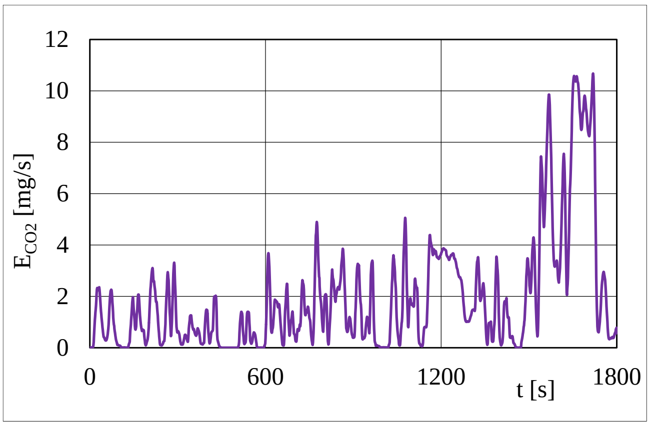

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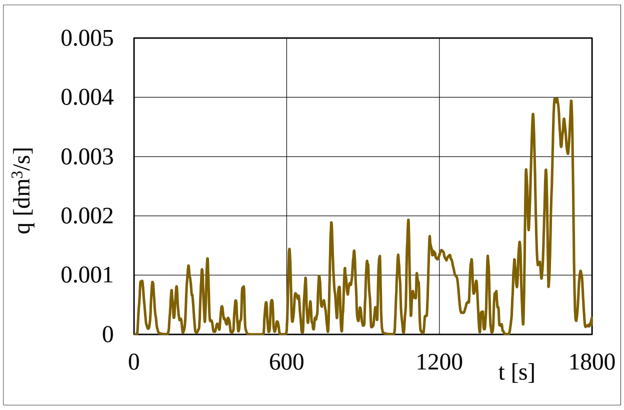


g)

Fig. 2. Processes of emission intensity: a) CO, b) THC, c) NMHC, d) CH_4, e) NOx, f) CO_2, and g) volumetric fuel consumption in WLTC.

5. RESULTS ANALYSIS

The distance travelled by the passenger vehicle in the performed test reached close to 25 km (Figure 3).

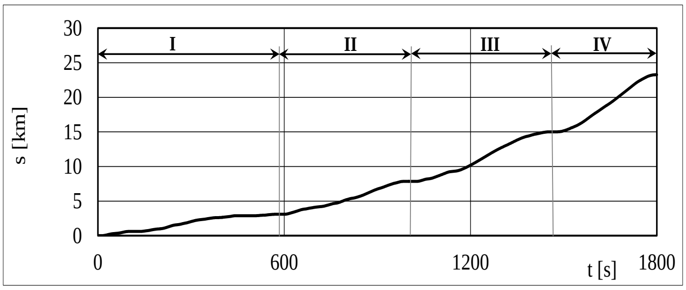


Fig. 3. Road distance travelled by the vehicle in the WLTC.

The characteristics of the duration, distance travelled, and the average velocity of the vehicle in individual test phases as well as for the whole test were compiled into Table 1.

Tab. 1. The duration, distance travelled, and the average velocity of the vehicle in individual test phases as well as for the whole test

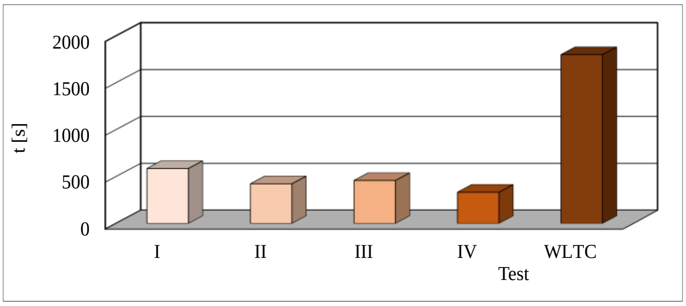
	t	s	v_{AV}
	[s]	[km]	[km/h]
I	586	3.09	19.01
II	423	4.76	40.48
III	458	7.16	56.29
IV	333	8.25	89.23
WLTC	1800	23.27	46.53

Values of the test duration, distance travelled, and average vehicle velocity for each of the test phases were compared with the overall WLTC values (Figure 4).

Phase I lasted the longest, phase IV was the shortest and phases II and III had similar durations. In general, there was not much difference in the duration of the individual phases – the coefficient of variation of the duration of the individual phases was 0.13.

The fourth phase of the test had the longest distance travelled by the vehicle. The lower the average velocity in the test phases, the shorter the distance covered by the vehicle . The coefficient for the distance traveled in the individual test phases was 0.35.

The average vehicle velocity differed significantly in the individual test phases. The average velocity in the first phase of the test was the lowest – about 19 km/h, the highest was found for the fourth phase – about 89 km/h. The average vehicle velocity in the entire test was approximately 46.5 km/h. The coefficient of variation of the average velocity of the vehicle in the individual test phases was about 0.50.



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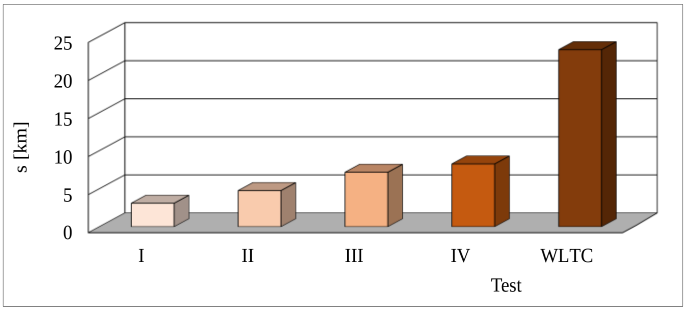

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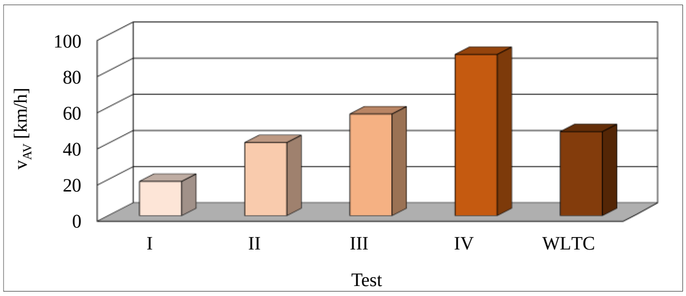


c)

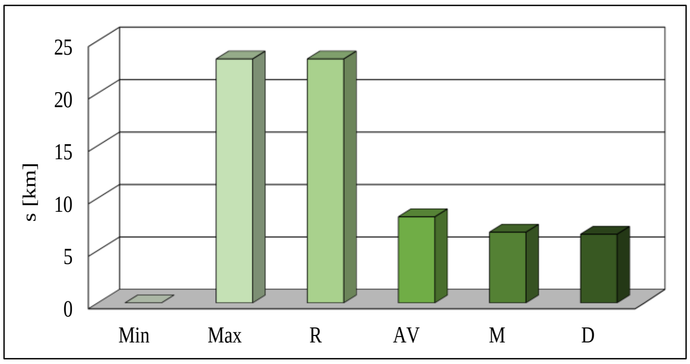
Fig. 4. WLTC characteristic: a) time duration, b) distance travelled by the vehicle, c) average vehicle driving velocity in the WLTC and each test phase.

Statistical values of the test duration, distance travelled, and average vehicle velocity for each of the test phases and the overall test results were provided (Table 2).

Tab. 2. Statistical values of the distance travelled, and average vehicle velocity for each of the test phases and the overall test.

	s	v
	[km]	[km/h]
Min	0	0
Max	23.27	130.26
R	23.27	130.26
AV	8.22	46.53
M	6.75	40.35
D	6.56	35.75
W	0.798	0.768
K	-0.688	-0.508
S	0.676	0.627

Statistical values of the distance travelled, and average vehicle velocity for each of the test phases and the overall WLTC were also given for analysis (Figure 5). The ratio of the mean value and the range was 0.5. The median was equal to the mean value. These properties result from the fact that the investigated process was linear. The ratio of the average value and the range for the distance covered by the passenger vehicle in the WLTC was about 0.35. The mean value was greater than the median in this case. The relative difference between the mean value and the median was approximately 0.20. The ratio of the average value and the range for the vehicle travel velocity in the WLTC was about 0.36. The mean value was greater than the median. The relative difference between mean and median was approximately 0.14.



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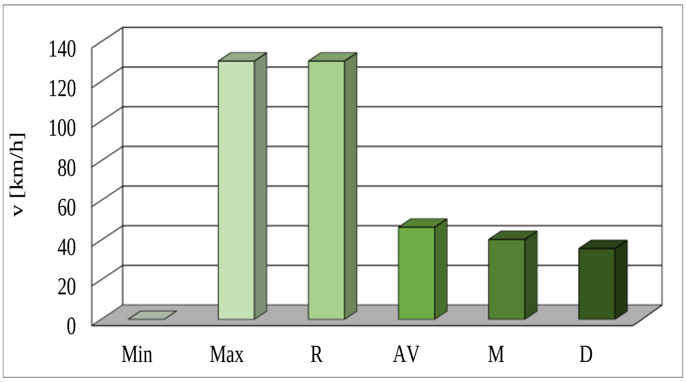
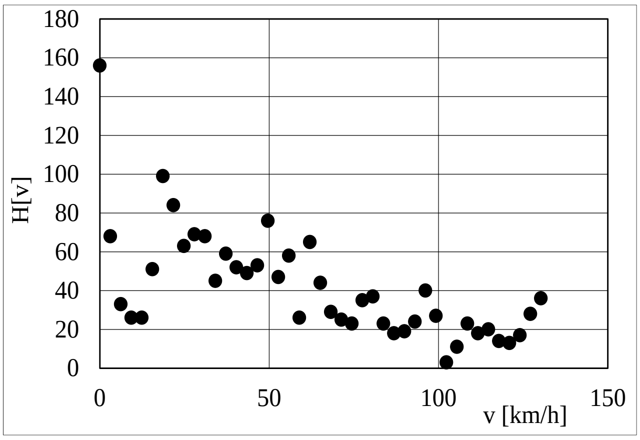


b)

Fig. 5. Statistical parameters: a) test distance, b) vehicle velocity in the WLTC test.

For the studied processes, the coefficient of variation is relatively large, which results from the strong dynamic properties of the car speed process.

The histograms of vehicle velocity, pollutant emission intensity, and volumetric fuel consumption intensity in the WLTC were presented in Figure 6. The top value on the histogram corresponded with 0 velocity. All other velocity values in the histogram did not differ significantly. Histograms of CO, THC and NO_x emissions were mostly influenced by the very small values of the emission processes. The ratio of the maximum value of the histogram to the average of the other values was approximately 250. The nature of the histogram of the CO_2 emission intensity and the volumetric fuel consumption intensity was very similar, mostly due to the approximately linear relationship between these processes. The histograms of these quantities differ significantly from the histograms of the emission intensity of other exhaust components.



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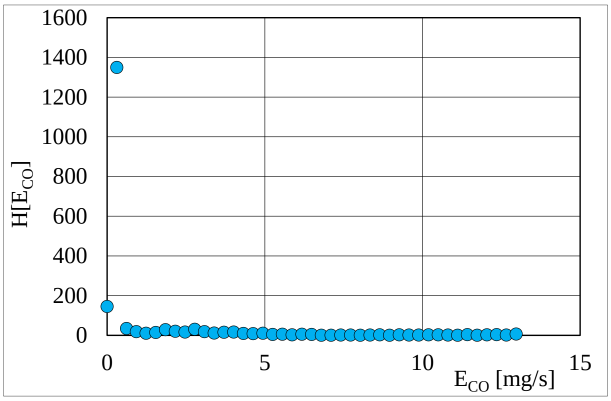

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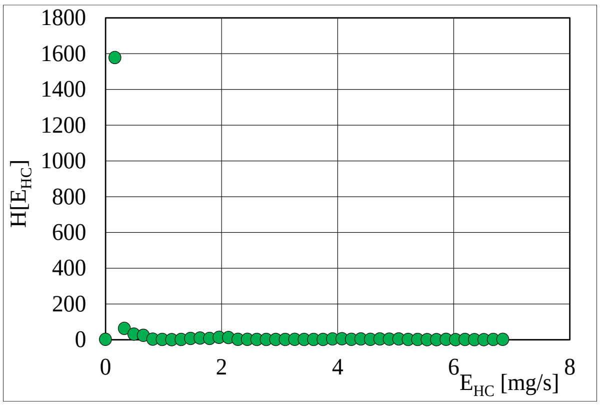

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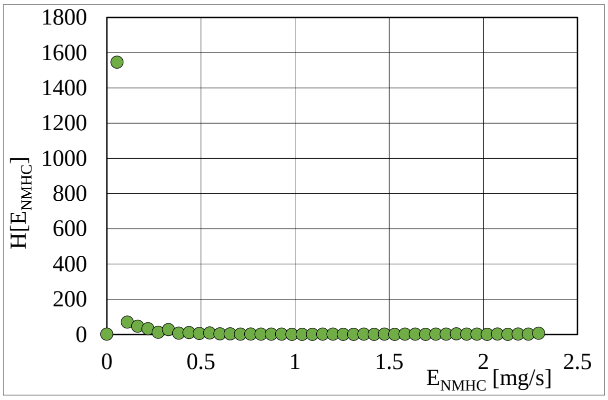

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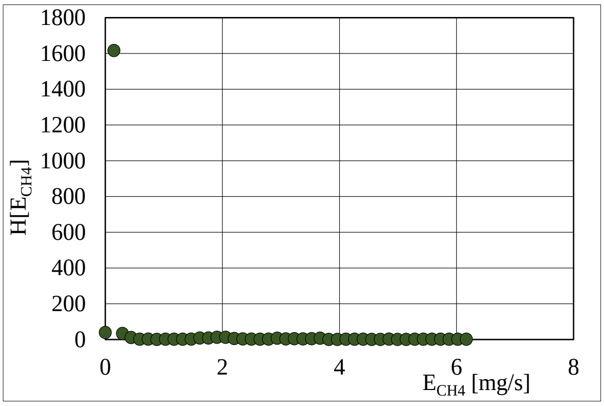

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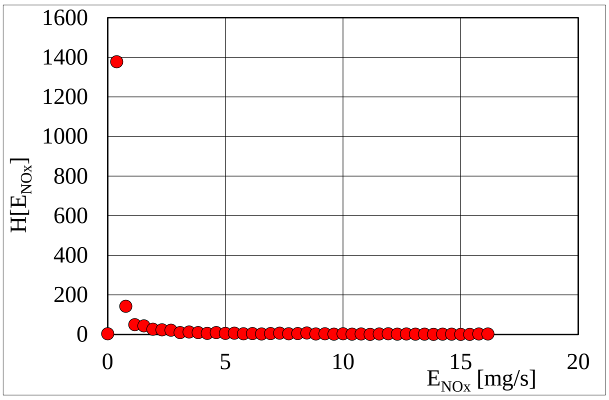

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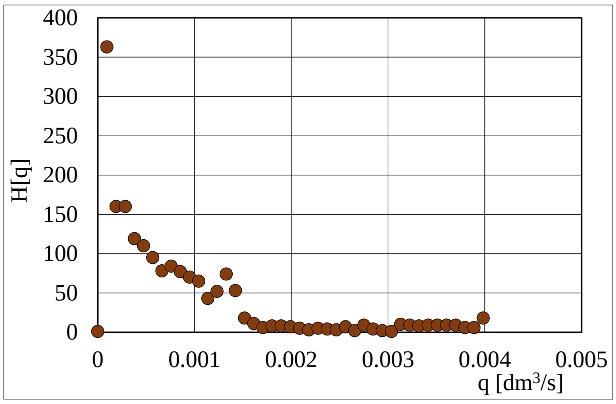

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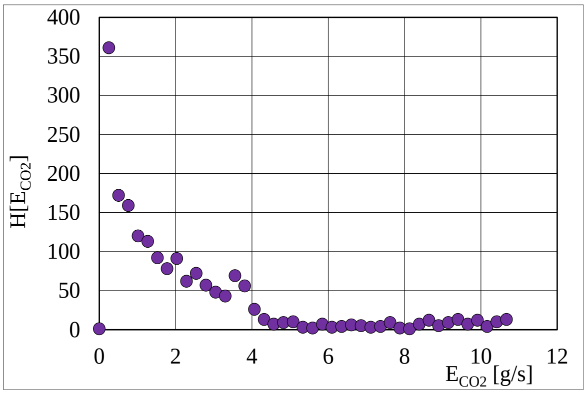


g)

Fig. 6. Histogram of processes in the WLTC: a) vehicle speed, emission intensity: b) CO, c) THC, d) NMHC, e) CH_4, f) NOx, g) CO_2 and h) intensity of volumetric fuel consumption.

Table 3 shows the statistical characteristics of the pollutant emission intensity and the volumetric fuel consumption intensity.

Tab. 3. Statistical characteristics of the pollutant emission intensity and the intensity of volumetric fuel consumption.

	E_{CO}	E_{HC}	E_{NMHC}	E_{CH4}	E_{NOx}	E_{CO2}	q
	[mg/s]					[g/s]	[dm^3/s]
Min	12.97	0	0	0	0	2.83	0
Max	12.97	6.847	2.294	6.17	16.16	24.86	0.00398
R	0.59	6.847	2.294	6.17	16.16	4.65	0.00398
AV	0.02	0.221	0.064	0.18	0.66	2.83	0.00073
M	1.71	0.037	0.012	0.03	0.04	24.86	0.00047
D	12.97	0.758	0.235	0.66	1.86	4.65	0.00085
W	2.90	3.42	3.67	3.71	2.83	1.17	1.16
K	22.62	30.29	56.87	30.77	24.86	4.09	4.13
S	4.38	5.30	7.19	5.26	4.65	2.02	2.03

The statistical characteristics of the pollutant emission intensity in the WLTC were analyzed (Figure 7). The measured volumetric fuel consumption intensity was shown in Figure 30, and the coefficient of variation, kurtosis and skewness of the tested processes has been included (Figure 8).

The ratio of the average value and the range for the emission intensity of CO, THC and NO_x was between 0.29–0.40. The obtained mean value was much greater than the median.

The relative difference between the mean and median was approximately 1.59.

The statistical characteristics of CO_2 emission intensity and volumetric fuel consumption intensity were significantly different from the statistical emission intensity characteristics of other exhaust components. The ratio of mean value and range equaled about 0.18, where the mean value was greater than the median. The relative difference between mean and median was approximately 0.45.

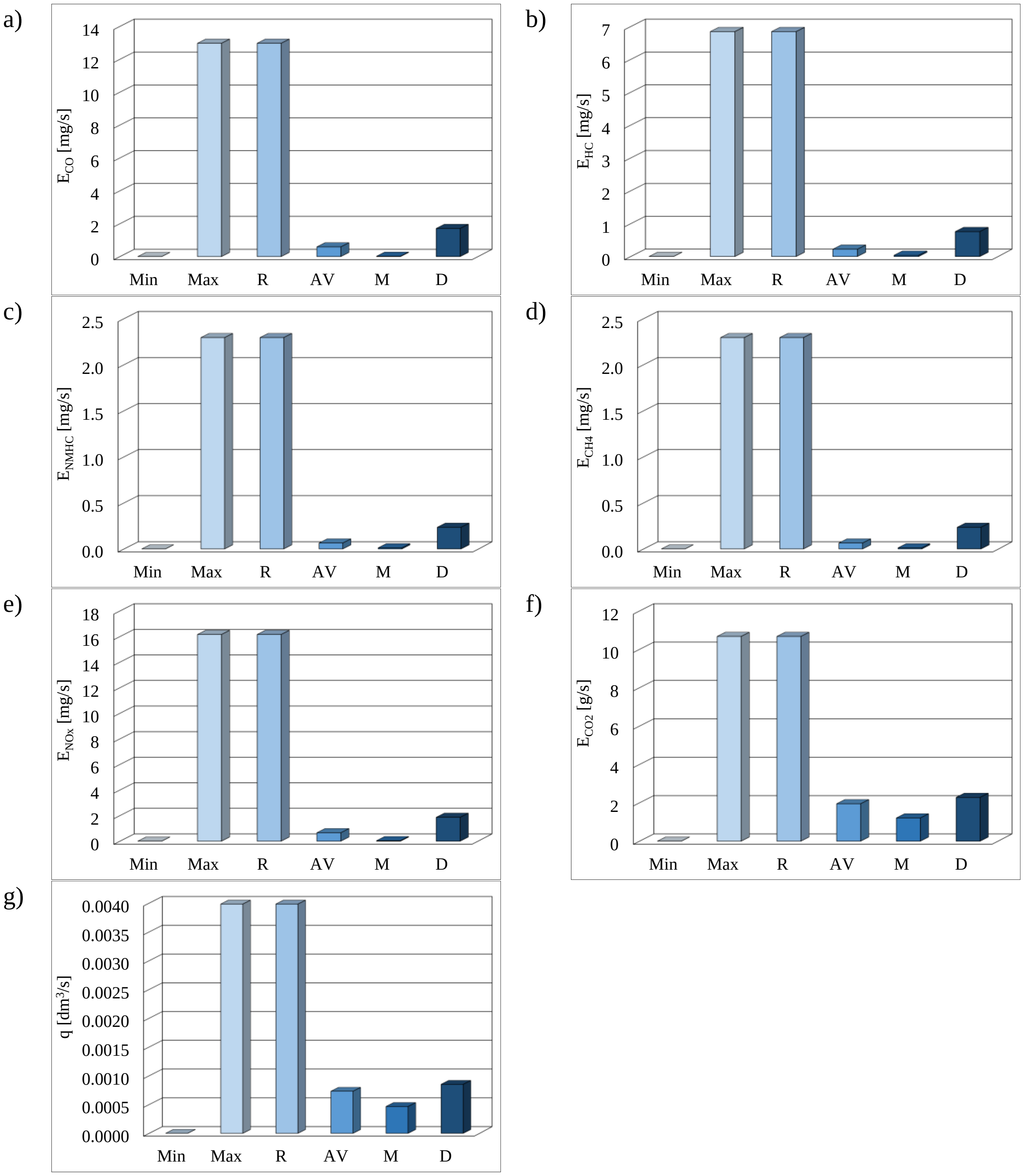


Fig. 7. Characteristics of processes intensity: a) CO, b) HC, c) NMHC, d) CH_4, e) NOx, f) CO_2, g) volumetric fuel consumption intensity in the WLTC test.

Dimensionless statistical characteristics of the examined processes were presented (Figure 8), along with the coefficient of variation, kurtosis and skewness. The largest coefficient of variation value was observed for the HC emission intensity, followed by its respective values for CO and NO_x. The coefficient of variation for the CO_2 emission intensity and the volumetric fuel consumption intensity was much smaller. The coefficient of variation for the test duration, the distance travelled by the vehicle and the vehicle velocity were the smallest. The greatest kurtosis value was observed for HC, followed by NO_x and CO. Significantly lower kurtosis was found for carbon dioxide emissions and volumetric fuel consumption intensity. The kurtosis of the vehicle velocity, the distance travelled and test duration had a small negative value. Thus, the processes of pollutant emission intensity and volumetric fuel consumption intensity had a leptokurtic distribution, and the distributions of the remaining processes were determined to be platykurtic. The process skewness ranged from largest value for HC emission intensity, followed by large values for NO_x and CO emission intensity. The skewness of the CO_2 emission intensity and the volumetric fuel consumption intensity were much smaller. The skewness for the test duration was practically zero, and for the distance travelled and vehicle velocity they were slightly positive. Thus, the examined processes, apart from the test duration, were characterized by a right-sided asymmetry distribution.

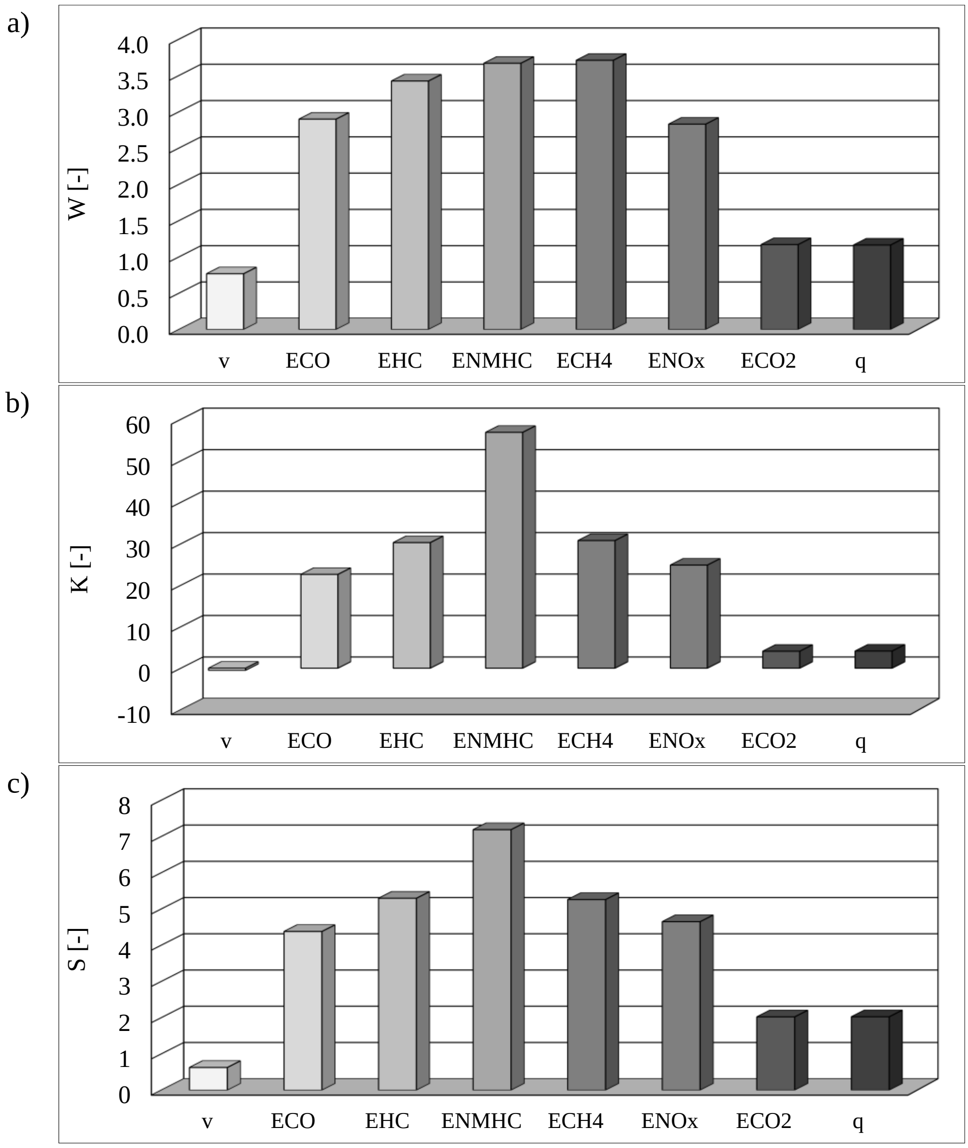


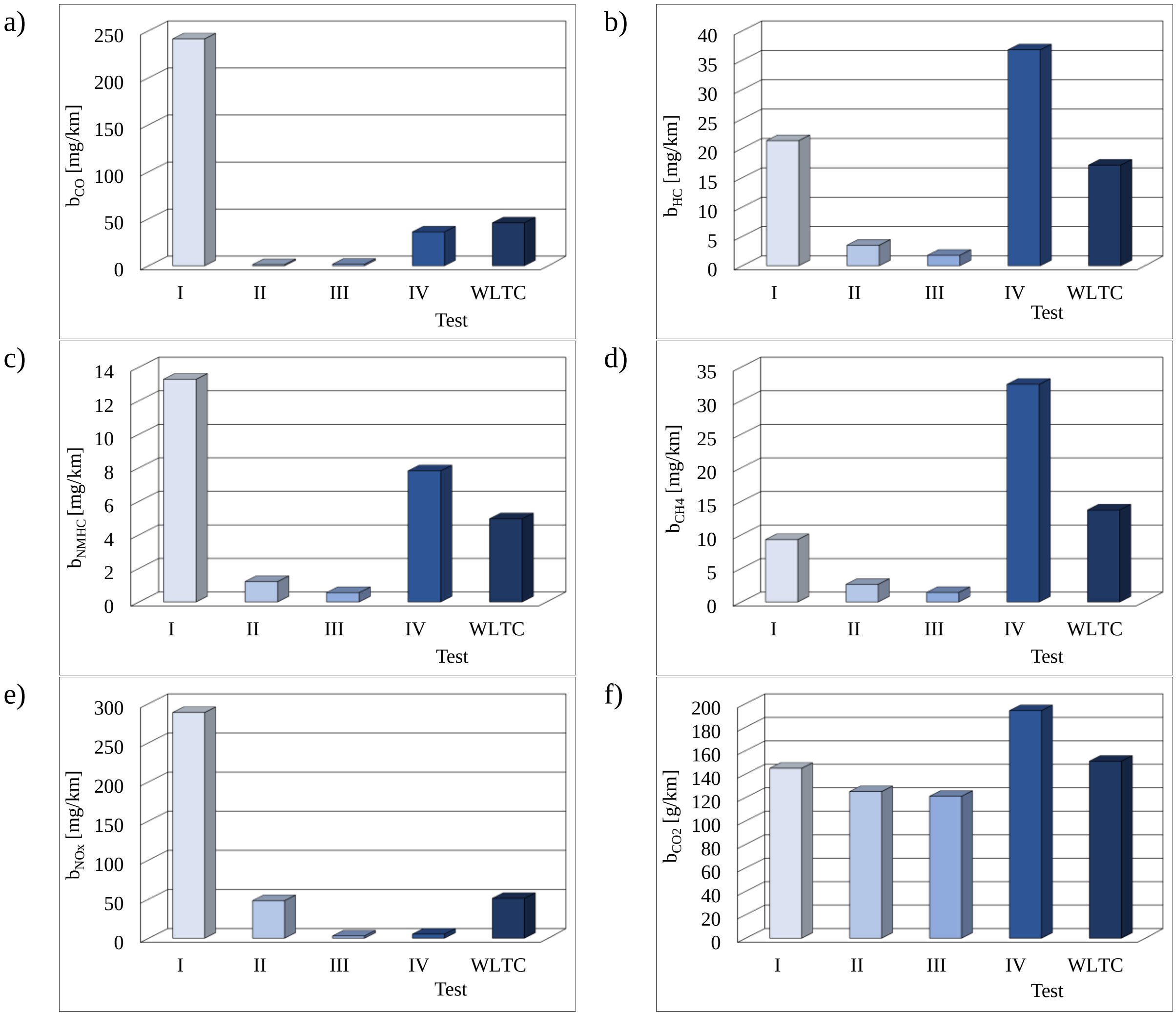
Fig. 8. Dimensionless statistical characteristics of: a) coefficients of variation, b) kurtosis, c) skewness of the processes measured in the WLTC.

Table 4 shows the specific distance emission and the operational volumetric fuel consumption in individual phases and in the WLTC.

Tab. 4. Specific distance emission and the operational volumetric fuel consumption in individual phases and in the WLTC.

	b_{CO}	b_{HC}	b_{NMHC}	b_{CH4}	b_{NOx}	b_{CO2}	Q
	[mg/km]						[dm^3/100 km]
I	241.31	21.29	13.28	9.29	288.66	144.91	5.57
II	1.20	3.49	1.21	2.62	48.09	125.00	4.75
III	1.61	1.77	0.55	1.41	2.88	121.01	4.50
IV	36.04	36.76	7.81	32.42	5.19	194.05	7.22
WLTC	45.62	17.13	4.96	13.71	50.95	150.92	5.66

Specific distance emissions measured for each of the exhaust components have been provided, along with the volumetric fuel consumption for each phase of the test as well as the entire WLTC (Figure 9). The highest specific distance emission of CO was found in the first phase of the test, which was related to the cold engine start-up and the significant variability of the vehicle's acceleration. The specific distance emission of CO was the highest in the fourth phase of the test – at heavy engine load. The coefficient of variation of CO specific distance emissions in the individual test phases reached 1.43. The dispersion of CO specific distance emission values in particular test phases was also very large. Specific distance emission values of HC in individual test phases were ambiguous. This was due to the very high CH_4 emissions in the fourth phase of the test, corresponding to a high engine load. Therefore, the specific distance emission of HC was also the highest in the 4th test phase, however, the specific distance emission of NMHC was the highest in the 1st phase of the test. The coefficient of variation for the HC specific distance emission values in the individual test phases was as much as 0.90, where for NMHC it was 0.91, and for methane 1.09. A large dispersion of specific distance emission values was found. The specific distance emission of NO_x was greater by a large margin in the first phase of the test, similarly to the specific distance emission of CO. The obtained coefficient of variation for the specific distance emission of NO_x in the individual test phases was 1.37, so the dispersion of values was very large. The CO_2 specific distance emission and the operational volumetric fuel consumption differ significantly for the individual test phases from the observed specific distance emission values of other measured exhaust components. The highest value of operational volumetric fuel consumption and specific distance CO_2 emissions was associated with the 4th phase of the test. The coefficient of variation of specific distance emission of CO_2 and operational volumetric fuel consumption in particular phases of the test was about 0.20. This was a small dispersion of values.



g)

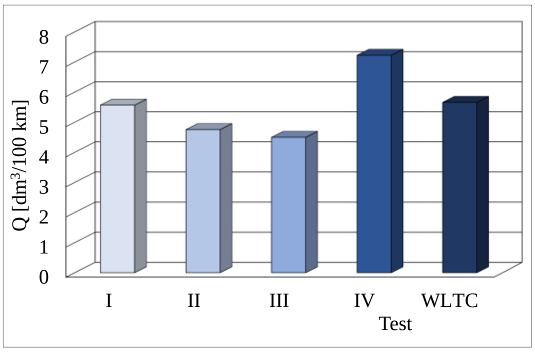


Fig. 9. Specific distance emissions of: a) CO, b) HC, c) NMHC, d) CH_4, e) NOx, f) CO_2, g) fuel consumption in the WLTC.

A clear pattern can be observed, where for CO, NMHC, and NO_x the cold start of the engine had the most significant impact on their values along with the associated dynamic vehicle motion, which resulted in dynamic engine operating states. Naturally, volumetric fuel consumption and CO_2 emission reached their highest values for situations where the engine operated with the highest load value, so mostly when the vehicle travelled at high velocity on highways and motorways.

6. CONCLUSIONS

Based on the conducted tests and the analysis results, taking the existing understanding of the processes involved into account, the following conclusions can be drawn about the properties of the processes characterizing the vehicle driving conditions in the phases of the WLTC, which differed in their properties, and about the processes characterizing the exhaust emission and fuel consumption:

1. The traffic conditions in the WLTC, corresponding to driving in urban areas with higher traffic, in urban areas with less traffic, in rural areas, and on motorways and highways, were characterized by a significant differentiation of properties, primarily the average velocity and dynamic vehicle velocity changes. The vehicle velocity values determine the engine operating states, which in turn determine the values of processes such as exhaust emission and fuel consumption. The low vehicle average velocity and the strong dynamic velocity profile were conducive to high emissions of CO, NMHC and NO_x. High average vehicle travel velocity and, therefore, high engine load contribute to increased emissions of nitrogen oxides, methane and carbon dioxide along with high fuel consumption.
2. The exhaust emission intensity of CO and HC, followed by NO_x, was characterized by a large share of data points that had very low value, along with local maxima. The nature of the CO_2 emission intensity and the fuel consumption intensity were fundamentally different – the values were approximately linearly dependent on each other. These differences were clearly visible in the histograms of pollutant exhaust emission intensity and fuel consumption intensity.
3. The static characteristics of the measured processes differed significantly. In the case of the duration of individual test phases, the distance travelled by the vehicle and the velocity in these phases, the ratio of the average value and the range was large (0.35–0.5), and the mean value was slightly higher than the median. These processes had a small corresponding coefficient of variation value, and they had a leptokurtic distribution with a small kurtosis and a slight right-sided asymmetry. For the emission intensity of CO, HC and NO_x, the ratio of the average value and the range of values was small (0.29–0.40). The mean value was much greater than the median. These processes were characterized by a very high value of the coefficient of variation, they have a leptokurtic distribution with a high kurtosis and a significant and noticeable right-sided asymmetry. The statistical properties of the carbon dioxide emission intensity and fuel consumption intensity had an indirect relationship with the properties of test duration for the individual test phases, the distance travelled by the vehicle and the travel velocity for each of them, as well as with the exhaust emission of CO, HC and NO_x.
4. Specific distance emission of CO, NMHC and NO_x was the highest for cold engine start-up conditions and

dynamic vehicle acceleration, which corresponded to the dynamic states of engine operation. Of course, fuel consumption and CO_2 emissions were highest when the engine was under heavy load, i.e. when the vehicle was in motion on motorways and highways.

The conclusions formulated based on the conducted research are original and have not been found upon literature review. The results of statistical studies of processes that characterize the WLTC test, as well as the results of measured variables values, are considered as being of particular value. So far, research was limited mainly to the assessment of road emission values averaged in the tests, without paying attention to the properties of the processes characterizing vehicle traffic conditions, exhaust emissions and fuel consumption. The Authors consider it important to continue this type of research, also in the frequency domain, to enable the assessment of the frequency properties of these processes and variables. It would also be valuable to undertake work on assessing the repeatability of the obtained research results.

Nomenclature

AV – average value
b – specific distance emission
CH_4 – methane
CLTC-P – China light-duty vehicle Test Cycle for Passenger car
CO – carbon monoxide
CO_2 – carbon dioxide
δ – relative difference
D – standard deviation
E – pollutant emission intensity
H – histogram frequency
HC – hydrocarbons
K – kurtosis
LDV– Light Duty Vehicles
M – median
Max – maximum value
MEP– mean effective pressure
Min – minimum value
NEDC – New European Driving Cycle
NMHC – non-methane hydrocarbons
NO_x – nitrogen oxides
Q – operational volumetric fuel consumption
q – volumetric fuel consumption intensity
R – range
S – skewness
t – time
v – vehicle velocity
W – coefficient of variation
WLTC – Worldwide Harmonized Light Vehicles Test Cycle
WLTP – Worldwide Harmonized Light Vehicles Test Procedure

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