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Investigation of processes in the WLTC test of a passenger car with a diesel engine

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The test results and their analysis was discussed in this article. The tests were carried out in accordance with the WLTP (Worldwide Light Duty Test Procedure), on a passenger car with a compression ignition engine. The analysis was conducted doe the following variables: vehicle speed, exhaust emission rate and fuel consumption volumetric rate. The subject of the research are exhaust emission components that are harmful to the health of living organisms: carbon monoxide, hydrocarbons and nitrogen oxides, as well as greenhouse gases. The research results have shown a very large range of values for carbon monoxide, organic compounds and nitrogen oxides emission rate characteristics. The average distance-specific emissions values of carbon monoxide, organic compounds and nitrogen oxides were very small and were in line with the Euro 6 requirements within a large margin. Correlation studies of the measured variables were conducted – between vehicle speed and exhaust emission rate as well as volumetric fuel consumption rates, and between exhaust emission rates and volumetric fuel consumption rates. The correlation studies have shown that the highest coefficient of determination in relation to vehicle speed was found for volumetric fuel consumption and carbon dioxide emission rate, and the weakest correlation for carbon monoxide emission rate and nitrogen oxides emission rate. The correlation between the rate of volumetric fuel consumption and carbon dioxide emission, as well as for hydrocarbon emission and methane emission rates, was found to be the strongest. The carbon monoxide emission rate was the least correlated with all the other measured variables. Dimensionless statistical characteristics of the measured variables were determined, such as: extreme values, range, mean value, median, standard deviation, kurtosis, skewness and coefficient of variation. For all of them, the mean value was much greater than the median, and the standard deviation was greater still, than both of those values. The numerical distributions for the values of exhaust emission rate and volumetric fuel consumption turned out to be leptokurtic and have right-sided asymmetry. The coefficient of variation analysis made it possible to assess that the most dynamic properties could be observed in organic compounds emission rate, followed by carbon monoxide and nitrogen oxides emission rates, and finally – the vehicle speed. Histograms of the examined processes were determined. The vehicle speed histogram was characterized by relative uniformity apart from the dominance of the idle speed. Histograms of exhaust emission rate variables were most frequently dominated by small values. The zero values occurred less frequently for the fuel consumption volumetric rate histogram. Based on the conducted research and the obtained data, a set of conclusions was drawn.

Key words: *diesel engine, exhaust emission, WLTC test*

1. Introduction

Type approval tests for LDV (Light Duty Vehicle) are carried out on a chassis dynamometers in the WLTC (Worldwide Light Duty Test Cycle) test in the European Union. This test is the replacement of the previous NEDC (New European Driving Cycle) test. This change took place along with the introduction of the Euro 6c standard – starting on September 1, 2017.

Results of the distance-specific emission obtained in the new test may be about (10–20)% greater than for the NEDC test. The entire WLTC test procedure is more dynamic, and the driving distance on which the measurements are recorded is almost twice as long. At the same time, the average speed in the new test is about 40% greater, and the share of complete stops has been halved.

Typically, emission and fuel consumption measurements obtained in driving tests mainly concern the averaged values of distance-specific exhaust emissions in tests or in individual phases. Exhaust emission rate data, expressed in relation to time, is less commonly included. These tests are made more difficult due to the fact that modern internal combustion engines tend to emit very low concentrations of exhaust components in many of their operating states, sometimes close to the lower boundary of measurement accuracy. Despite this, it is advisable to conduct research not only on the averaged values of exhaust emission characteristics, because the search for new possibilities of further reducing the exhaust emission limits from internal combustion engines always remains relevant.

2. Literature review and research goals

Paper [15] investigated typical dynamic vehicle traffic conditions in WLTC tests [6, 17] in order to simulate the PM emission from tribological elements in a car. Driving conditions have been found to have a major impact on particulate matter generation as a result of brake and tire wear processes. The testing approach proposed in the paper was to evaluate the impact of the share of acceleration and deceleration on particulate matter emissions.

Paper [1] analyzes the effectiveness of the FEV SimEx simulation software for simulating the operation of the drive system and the exhaust aftertreatment system in vehicles with compression ignition engines, in order to meet the requirements of the WLTP and RDE (Real Driving Emissions) procedures.

In [8], the engine operating states were analyzed in the rotational speed – torque coordinates in the operating conditions present in the WLTC test. The obtained results were used for a comparative assessment between various shares of LPG fuel in a dual-fuel diesel engine.

Paper [11] presents the results of the NEDC and WLTC tests of 14 passenger cars in order to analyze the carbon dioxide emissions. The tests were carried out in the years 2014–2016 at the request of the Dutch Ministry of Infrastructure and Environment and were aimed at examining the impact that the choice of test procedures had on exhaust emissions.

Another cited paper [16] used its research results to analyze the carbon dioxide emissions from the engines of a passenger car and a light truck in the WLTC test. Simulation tests were also carried out using CO_2MPAS (CO_2 Model for Passenger and Commercial Vehicle Simulation).

Simulation tests of a turbocharged diesel engine in the WLTC test were analyzed in [5]. The results of the simulation tests were verified with the results obtained in empirical tests. The research results concerned energy and economic characteristics as well as exhaust emissions.

The authors of [14] undertook the task of evaluating the discrepancies in the results of exhaust emission and fuel consumption in type approval tests and other vehicle driving conditions. For this purpose, comparative tests were carried out in the WLTC test and in the CADC (Common Artemis Driving Cycle) test [17]. The paper presents the results of engine operating states expressed in the coordinates vehicle speed and acceleration.

The article [7] presents the method of verification of EURO III standard in real life conditions for special vehicles. The test object qualified as a special vehicle of N3G category was tested in road conditions along a defined route, and then the obtained measurement results were compared to the exhaust emission standard (EURO III) applicable for this vehicle in transient testing mode. A method of comparing the emission factors in road conditions with the indicators obtained on the engine dynamometer was proposed. An AVL mobile exhaust gas analyzers (PEMS) dedicated for the Real Driving Emissions (RDE) road tests were used in the research.

In paper [12] presents NO_x, CO, and solid particulate number PN emissions of 53 gasoline and diesel passenger cars type-approved in the EU after the entry into force of the WLTP and RDE (i.e., meeting the Euro 6d-TEMP and Euro 6d standards). Emissions data over WLTP and RDE tests on in-use vehicles was collected by the Joint Research Center (JRC) of the European Commission in the period 2018-2021. Emissions are characterized by powertrain, fuel type, and test procedure. All vehicles comply well with Euro 6 emission limits and no statistically significant differences are found in NO_x, CO, and PN emissions measured over the complete WLTP and RDE tests, both for gasoline and diesel vehicles.

Another paper [9] presents the test results of three cars equipped with spark-ignition engines with the same displacement. Both NEDC and WLTC tests were performed. The test results showed an ambiguous impact of the test type on fuel consumption. The average distance-specific exhaust emissions turned out to be higher in the WLTC test except for hydrocarbons, for which the results turned out inconclusive.

The goal of paper [3] was to analyze the correlation between carbon monoxide, hydrocarbons, nitrogen oxides and carbon dioxide emissions in different operating conditions of an internal combustion engine vehicle. The engine performance was tested on a chassis dynamometer in tests simulating real driving conditions for different vehicles, such as: traffic jams, non-congested urban traffic, extra-urban traffic and travel on highways and expressways. An analysis of the correlation dependence of the exhaust emission rate on the useful engine power and the correlation interdependence between the emission rate of individual exhaust components was carried out. Pearson's linear correlation, The Authors calculated and provided the Spearman's rank correlation, Kruskal's gamma correlation and Kendall's tau correlation coefficients. It was found that the exhaust emission rate in the test drive tests strongly depended on the dynamic states of engine operation.

Paper [4] presents the results of diesel particulate filters efficiency testing in order to reduce the number of emitted particles. The tests were carried out in real conditions, in an RDE test. using a passenger car. The results of this study confirmed the effectiveness of using particulate filters in accordance with the test procedure applicable in RDE tests.

The results found in the literature concern in most cases only the dimensionless characteristics of the exhaust emission and fuel consumption variables, which are the functionals of these processes such as the average value. In the literature on the subject, basically no works could be found that would discuss the properties of the vehicle and engine operating states and the processes describing the exhaust emissions and fuel consumption, taking into account their dynamic properties.

Active grille shutter (AGS) design and implementation has been discussed in paper [2], a work that Tata Motors European Technical Centre (TMETC) has led for Tata Motors, and we have found that it improves the vehicle fuel economy in the real world. The program of work includes vehicle efficiency; fuel economy improvement, starting from optimizing current energy balance; vehicle level performance; investigation of parasitic losses; and introducing technologies, which can crawl back losses and increase the efficiency, thereby improving real-world fuel economy while reducing emissions.

Along with the stated research aim, with results as presented in this article, another aim was to learn about the properties of the vehicle speed characteristic, the exhaust emission rate, and the volumetric fuel consumption in the WLTC test. The main objectives of this research significantly exceed just determining the mean distance-specific exhaust emissions, that are commonly the main subjects of such studies in the literature, which characterize their originality.

The objectives of researching these variables were to relate to their statistical properties, correlations between variables, and their properties in the aspect of the obtained data.

3. Method

A passenger car with a four-cylinder diesel engine, a displacement of 1.5 dm^3 was the main test object used in this research. The vehicle's engine had a rated power of 96 kW and was eco-class for exhaust emissions meeting the norm Euro 6 AP. The car was equipped with a 6-gear manual gearbox. During the tests, fuel used in accordance with the applicable standards for diesel oil (PN-EN 590:2022-08).

The tests were carried out on a single roller chassis dynamometer. The emission tests concerned substances that were:
- harmful to the health of living organisms, such as: carbon monoxide, organic compounds and nitrogen oxides,
- promoting the formation of gasses driving the greenhouse effect, such as: carbon dioxide and methane.

The exhaust emission measurement system used: CFV-CVS exhaust gas sampling system, a set of analyzers equipped with dual-range analyzers, that enabled the measurement of concentrations of: carbon monoxide, hydrocarbons, non-methane hydrocarbons and methane, nitrogen oxides and carbon dioxide.

The measurements were made in a WLTC test. The following quantities were measured:
- vehicle speed – v,
- carbon monoxide exhaust emission rate – E_{CO},
- hydrocarbons exhaust emission rate – E_{HC},
- non-methane hydrocarbons exhaust emission rate E_{NMHC},
- methane exhaust emission rate – E_{CH4},
- nitrogen oxides exhaust emission rate – E_{NOx},
- carbon dioxide exhaust emission rate – E_{CO2},
- fuel consumption volumetric rate – q.

The analysis of the obtained data included:
- determining the average distance-specific exhaust emission – b and the average operational volumetric fuel consumption – Q,
- correlation studies between the exhaust emission rate and volumetric fuel consumption rate and the vehicle speed data,
- determining dimensionless statistical characteristics of the variables such as: vehicle speed, exhaust emission rate and volumetric fuel consumption rate,
- measuring the data values of: vehicle speed, exhaust emission rate and volumetric fuel consumption.

The total test exhaust emission – m is the integral of the emission rate of the substance measured in the time domain:

$$m = \int_0^T E(t)dt \tag{1}$$

where: T – test duration.

Volumetric fuel consumption in the test – V is:

$$V = \int_0^T q(t)dt \tag{2}$$

The road distance covered by the vehicle in the test was calculated using:

$$\mathbf{L = \int_0^T v(t)dt} \tag{3}$$

The average distance-specific exhaust emission in the test is the ratio of the exhaust emission to the distance traveled by the vehicle:

$$b = \frac{m}{L} \tag{4}$$

The average in-service volumetric fuel consumption in the test is the ratio of the volumetric fuel consumption and the distance traveled by the car:

$$Q = \frac{V}{L} \tag{5}$$

The determination coefficients between the exhaust emission rate and volumetric fuel consumption rate data, and the speed characteristic were obtained as a result of correlation studies between these variables.

The determined dimensionless characteristics of the measured parameters included: minimum value, maximum value, range, mean value, median, standard deviation, kurtosis, skewness and coefficient of variation.

Research on the measured variable values, such as: vehicle speed, exhaust emission rate and volumetric fuel consumption rate included determining the histograms of these variables.

4. Research results

The research results were obtained for: vehicle driving speed in the test, the exhaust emission rate and the volumetric fuel consumption rate. In order to reduce the share of high-frequency noise in the signals they were then subjected to a low-pass filtration with a fifth-order non-recursive filter [8]. Data analyzes were performed on already filtered signals.

Figure 1 shows the vehicle driving speed characteristic as measured in the test.

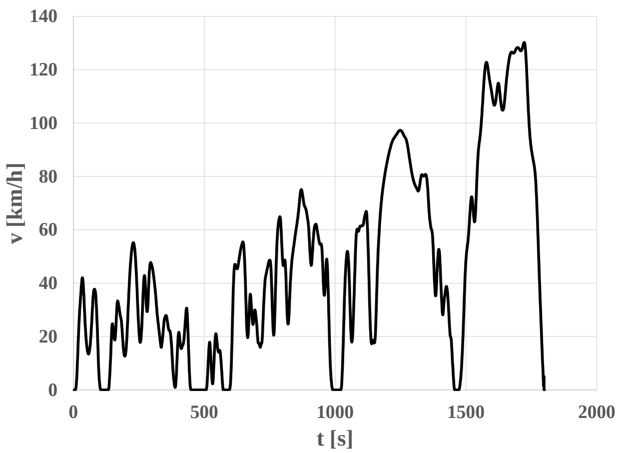

Fig. 1. Vehicle speed – v in the test

Figures 2–7 display the exhaust emission rates obtained in the test.

The very large range of values for carbon monoxide, organic compounds and nitrogen oxides emission rate was characteristic of this test.

Modern automotive diesel engines are characterized by very low distance-specific exhaust emission – to the point where sometimes the pollutants concentration in the exhaust gas diluted with air in the measuring system nears the concentration of pollutants in the air used for the dilution itself. Hence the emission rate of carbon monoxide, organic compounds and nitrogen oxides was close to zero in many parts of the test. This was not the case with carbon dioxide, the concentration of which was much greater than the concentration of other measured exhaust components.

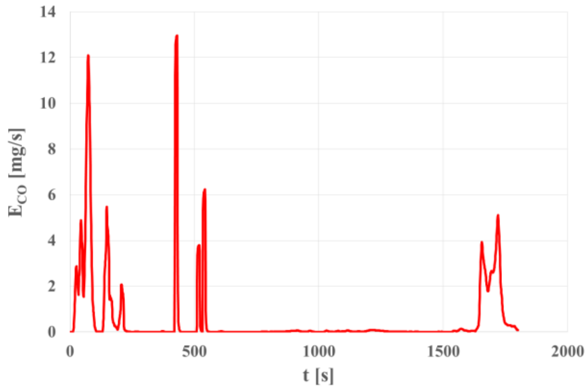

Fig. 2. Carbon monoxide exhaust emission intensity – E_{CO} in the test

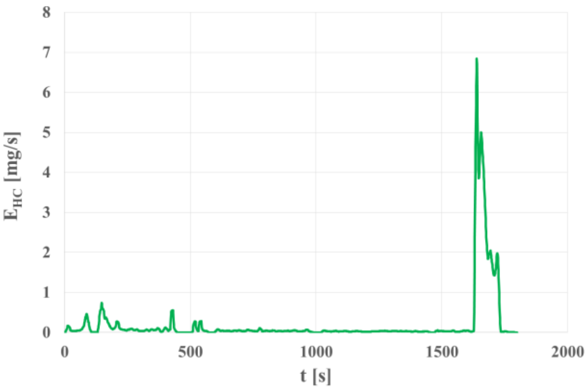

Fig. 3. Hydrocarbons exhaust emission intensity – E_{HC} in the test

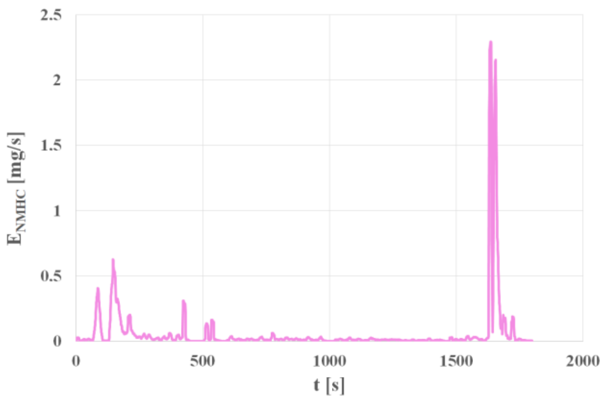

Fig. 4. Non-methane hydrocarbons exhaust emission intensity – E_{NMHC} in the test

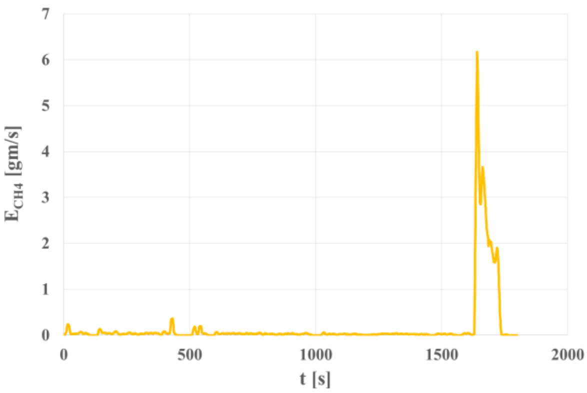

Fig. 5. Methane exhaust emission intensity – E_{CH4} in the test

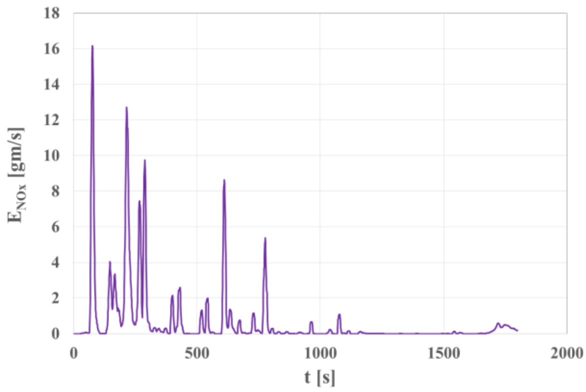

Fig. 6. Nitrogen oxides exhaust emission intensity – E_{NOx} in the test

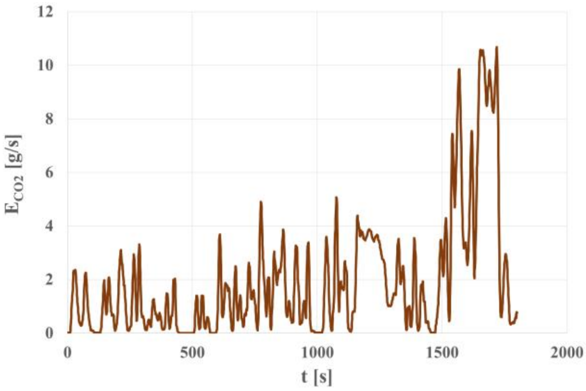

Fig. 7. Carbon dioxide exhaust emission intensity – E_{CO2} in the test

The volumetric fuel consumption by the car engine in the test was also measured (Fig. 8).

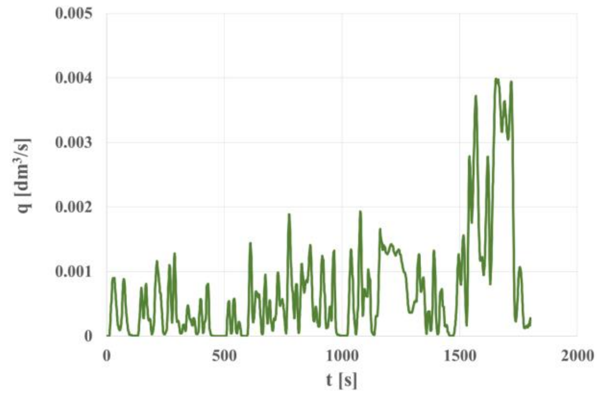

Fig. 8. Volumetric fuel consumption rate – q of the vehicle engine in the test

The volumetric fuel consumption rate was obviously strongly correlated with the fuel consumption rate.

5. Research analysis

Table 1 contains the mean distance-specific exhaust emission of the measured components as well as the average operating fuel consumption in the test.

The mean distance-specific emissions of carbon monoxide, organic compounds and nitrogen oxides measured had a very small value, which is characteristic trait of modern diesel engines. The same applies to operational fuel consumption.

Table 1. Mean distance-specific exhaust emissions and mean operational fuel consumption in the WLTC test

b_{CO}	mg/km	45.62
b_{HC}		17.13
b_{NMHC}		4.96
b_{CH4}		13.71
b_{NOx}		50.95
b_{CO2}	g/km	150.92
Q	$dm^3/100$ km	5.66

The distance-specific exhaust emission in the WLTC test allowed the vehicle to reach the Euro 6 norm limits with a large margin. The measured emissions could increase without exceeding the norm limits:

– for carbon monoxide emissions, the measured value would be permitted to increase by over 90%,
– for total hydrocarbons and nitrogen oxides, the measured value would be permitted to increase by 60%,
– for nitrogen oxides, the measured value would be permitted to increase by almost 40%.

Calculations were made to determine the correlation between the exhaust emission rate, the volumetric fuel consumption rate and the vehicle speed. Table 2 shows the coefficient of determination [5] between these variables.

The volumetric fuel consumption and carbon dioxide emission rate were most strongly correlated with the vehicle speed. While carbon monoxide and nitrogen oxide emission rates were the least correlated with vehicle speed. The correlation was stronger in the case of organic compounds – the coefficients of determination between vehicle speed and hydrocarbon emission rate, as well as between the vehicle speed and methane emission rate, were found to have a similar value.

Table 2. Coefficient of determination – R^2 between the exhaust emission rate, the volumetric fuel consumption rate and the vehicle speed

	R^2
E_{CO}	0.0028
E_{HC}	0.1708
E_{NMHC}	0.0499
E_{CH4}	0.1943
E_{NOx}	0.0077
E_{CO2}	0.5799
q	0.5834

Figures 9–12 include correlation diagrams between exhaust emission rates and volumetric fuel consumption rate and vehicle speed.

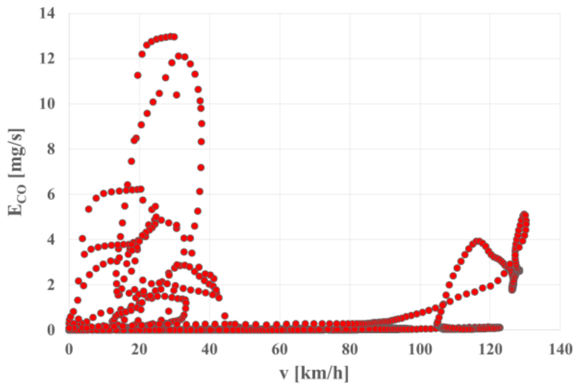

Fig. 9. Correlation between carbon monoxide emission rate – E_{CO} and vehicle speed – v

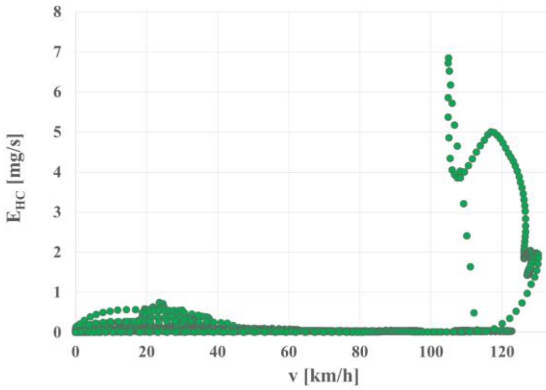

Fig. 10. Correlation between hydrocarbon emission rate – E_{HC} and vehicle speed – v

Correlation between the exhaust emission rates and the volumetric fuel consumption rate was also calculated. The coefficient of determination between these variables was calculated for each combination (Table 3).

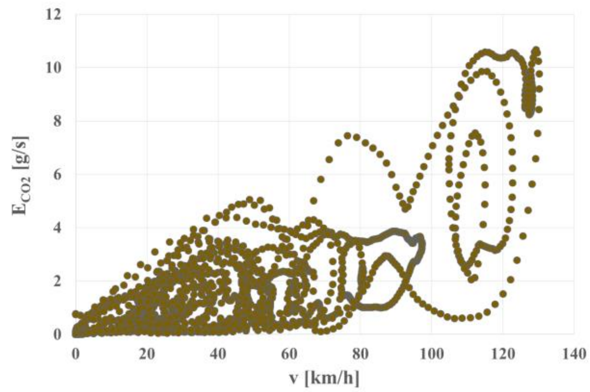

Fig. 11. Correlation between carbon dioxide emission rate – E_{CO2} and vehicle speed – v

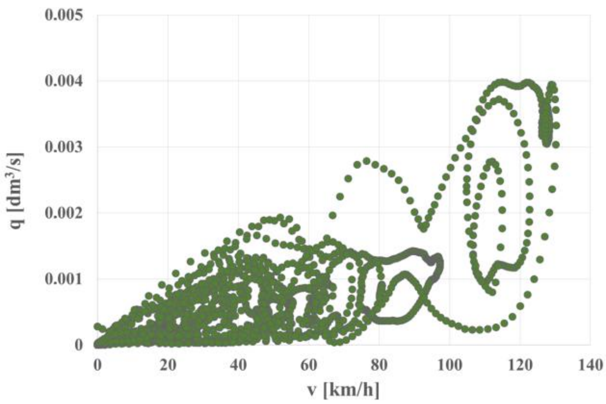

Fig. 12. Correlation between volumetric fuel consumption rate – q and vehicle speed – v

The volumetric fuel consumption and carbon dioxide emission rate were the most strongly correlated. There was obviously also a very strong correlation between the hydrocarbon emissions rate and the methane emissions rate. Strong correlation was also found between the emission rates of other measured hydrocarbon components. The correlation between the hydrocarbon emission rate, methane emission rate, carbon dioxide emissions rate and the volumetric fuel consumption rate were all also relatively strong.

Table 3. Coefficients of determination – R^2 between the exhaust emission rates of all the measured exhaust components

	R^2						
	ECO	EHC	ENMHC	ECH_4	ENO_x	ECO_2	q
ECO							
EHC	0.0773						
ENMHC	0.0692	0.6621					
ECH_4	0.0626	0.9258	0.4012				
ENO_x	0.1590	0.0004	0.0054	0.0030			
ECO_2	0.0467	0.3638	0.1130	0.4040	0.0010		
q	0.0487	0.3691	0.1186	0.4082	0.0019	0.9966	

The lowest coefficient of determination was found for the correlation of carbon monoxide emission rate with all other variables except the nitrogen oxides emission rate. Also, the nitrogen oxides emission rate was very weakly correlated with other processes, apart from the emission rate of carbon monoxide.

Figures 13–17 are examples of correlation graphs between the exhaust emission rate and the volumetric fuel consumption rate.

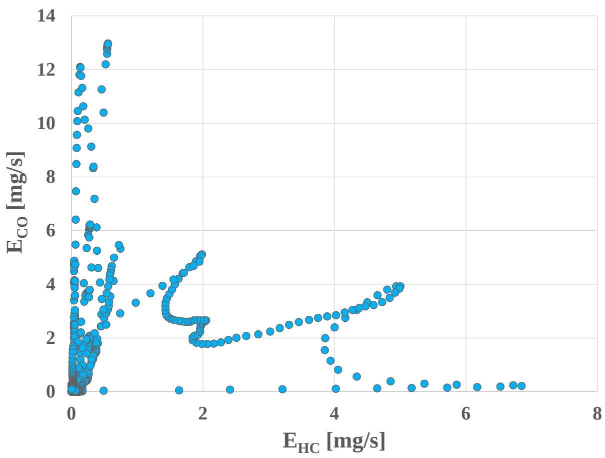

Fig. 13. Correlation between carbon monoxide exhaust emission rate – E_{CO} and hydrocarbon exhaust emission rate – E_{HC}

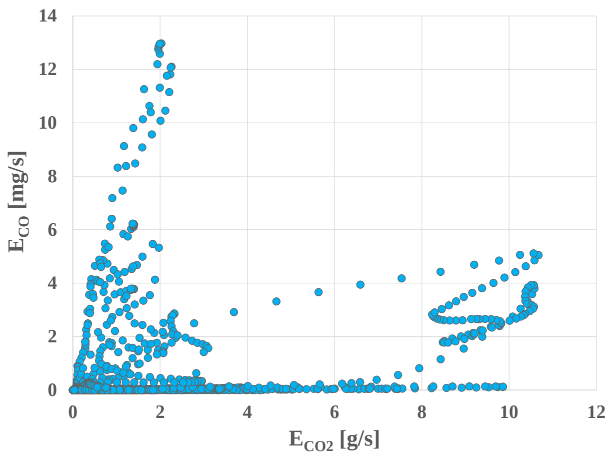

Fig. 14. Correlation between carbon monoxide exhaust emission rate – and carbon dioxide exhaust emission rate – E_{CO2}

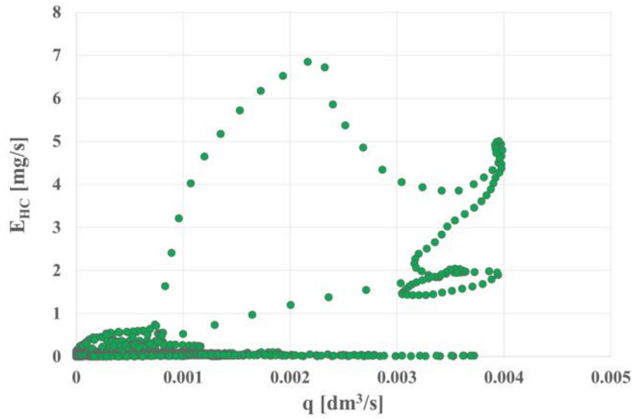

Fig. 15. Correlation between hydrocarbons exhaust emission rate – EHC and volumetric fuel consumption rate – q

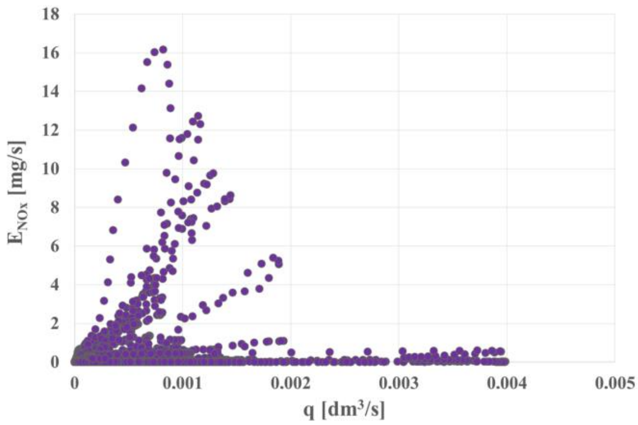

Fig. 16. Correlation between nitrogen oxides exhaust emission rate – ENO_x and volumetric fuel consumption rate – q

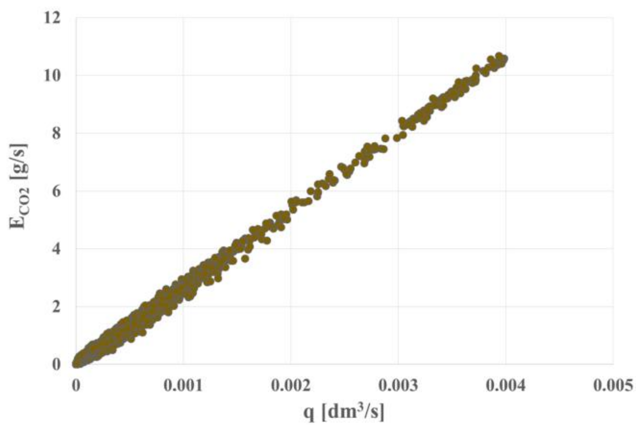

Fig. 17. Correlation between carbon dioxide exhaust emission rate – ECO2 and volumetric fuel consumption rate – q

Figure 18 shows the dimensionless statistical characteristics of the vehicle speed.

A characteristic of the vehicle speed data is that the median speed is close to the average speed in value.

Dimensionless characteristics of the statistical exhaust emission rates were also calculated (Fig. 19–24).

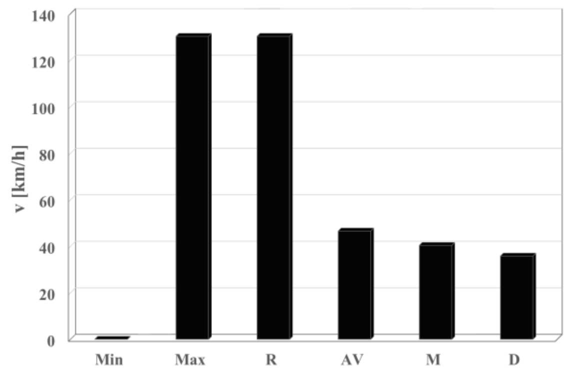

Fig. 18. Dimensionless statistical characteristics of the vehicle speed – v

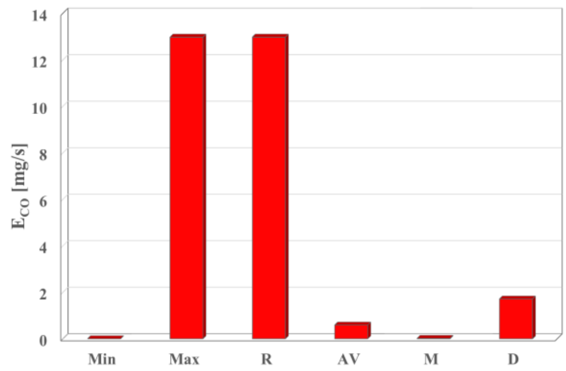

Fig. 19. Dimensionless statistical characteristics of carbon monoxide emission rate – E_{CO}

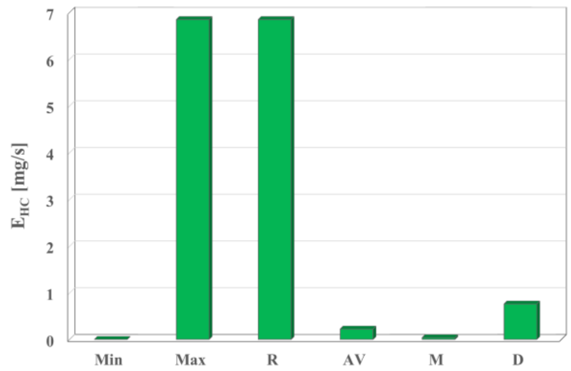

Fig. 20. Dimensionless statistical characteristics of hydrocarbons emission rate – E_{HC}

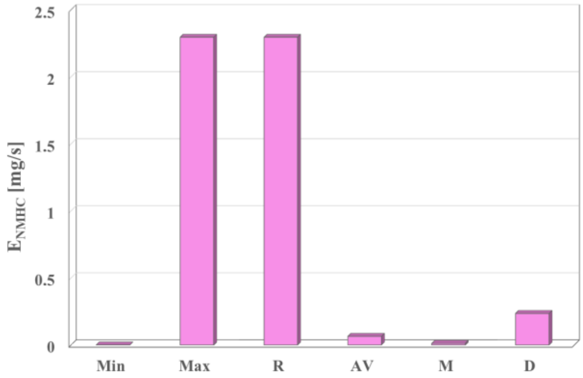

Fig. 21. Dimensionless statistical characteristics of non-methane hydrocarbons emission rate – E_{NMHC}

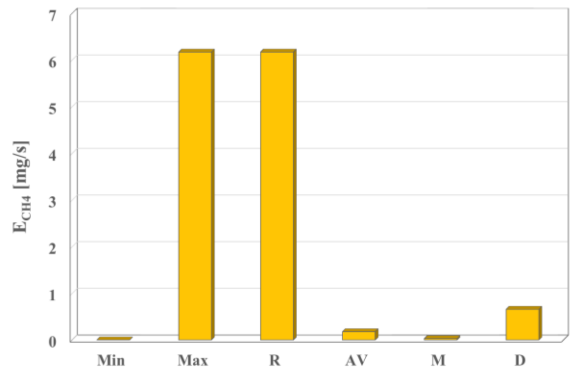

Fig. 22. Dimensionless statistical characteristics of methane emission rate – E_{CH4}

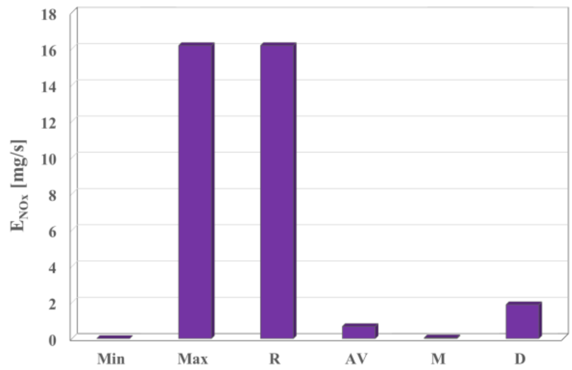

Fig. 23. Dimensionless statistical characteristics of nitrogen oxides emission rate – E_{NOx}

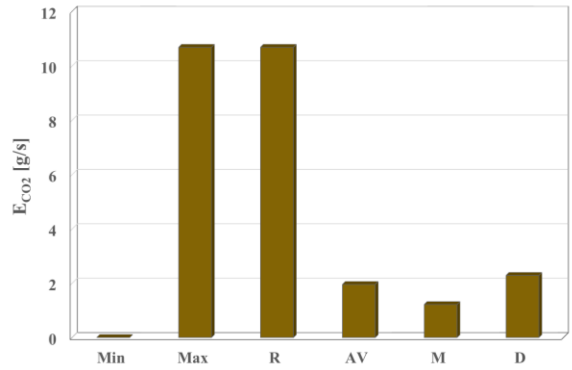

Fig. 24. Dimensionless statistical characteristics of carbon dioxide emission rate – E_{CO2}

For every substance's exhaust emission rate, the average value was much greater than the median, and the standard deviation of both of these values was much greater. The smallest differences occurred in the case of carbon dioxide emission rate.

Figure 25 presents dimensionless statistical characteristics of the volumetric fuel consumption rate.

The relationships between mean value, median and standard deviation for the volumetric fuel consumption rate were similar to those for the carbon dioxide emission rate.

Further on, kurtosis, skewness and coefficient of variation of the measured variables were determined (Fig. 26–28).

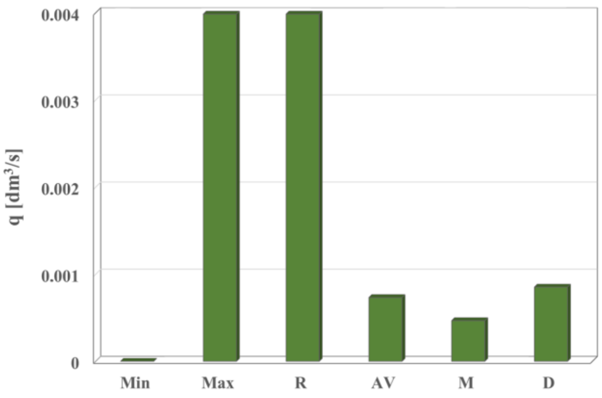

Fig. 25. Dimensionless statistical characteristics of the volumetric fuel consumption rate – q

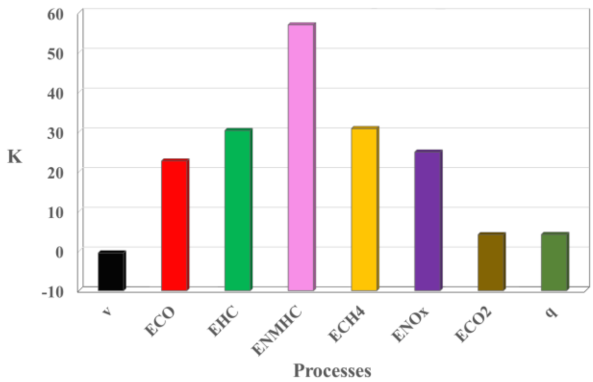

Fig. 26. Kurtosis – K of the measured variables

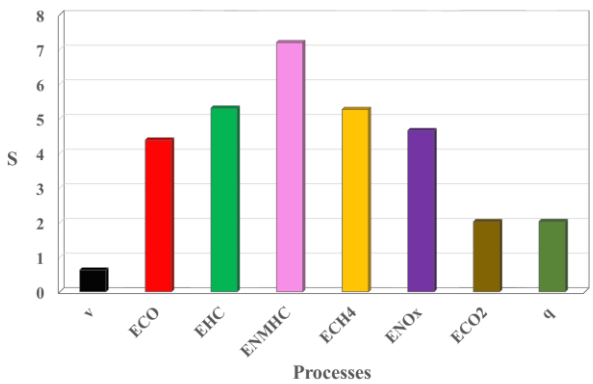

Fig. 27. Skewness – S of the measured variables

Kurtosis took on positive values for all the variables that have been measured in this research, except for the vehicle speed, so these are leptokurtic distributions. The kurtosis of the vehicle speed was slightly negative – it equalled –0.5, so the negative flattening of the distribution was not significant. Kurtosis of organic compounds emission rate was the highest in value, positive kurtosis of carbon dioxide emission rate and volumetric fuel consumption rate was the smallest.

The distribution skewness of all the variables presented was positive, so these distributions had a right-sided asymmetry. As in the case of kurtosis, the highest value of skewness was for the organic compounds emission rate, the smallest – for the vehicle driving speed, carbon dioxide emission rate and volumetric fuel consumption rate.

The coefficient of variation varies in their respective values significantly. The organic compounds emission rate had the strongest dynamic properties, followed by carbon monoxide and nitrogen oxides. The least dynamic properties were found for the vehicle speed, followed by the carbon dioxide emissions rate and the volumetric fuel consumption rate.

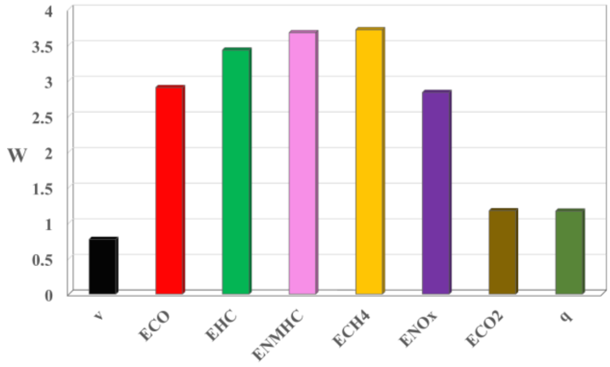

Fig. 28. Coefficients of variation – W of the measured variables

The results of the variables obtained in the study, in terms of their values, were made into histograms. This includes the histogram of the vehicle speed (Fig. 29).

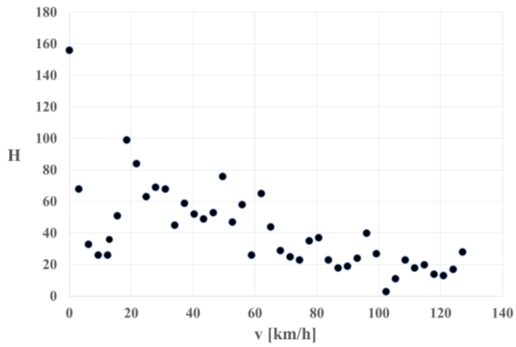

Fig. 29. Histogram – H of vehicle speed – v

The vehicle driving speed histogram was characterized by a relative uniformity, apart from the clear prominence of the zero speed point.

Figures 30–35 provide the remaining histograms of all the measured pollutants exhaust emission rates.

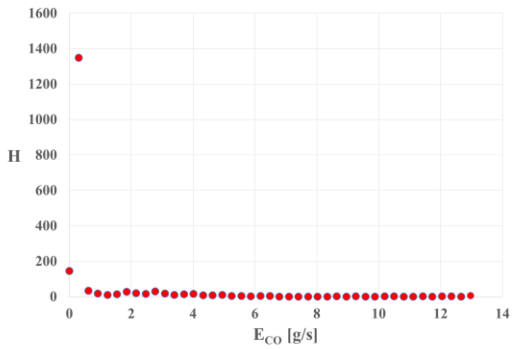

Fig. 30. Histogram – H of carbon monoxide exhaust emission rate – ECO

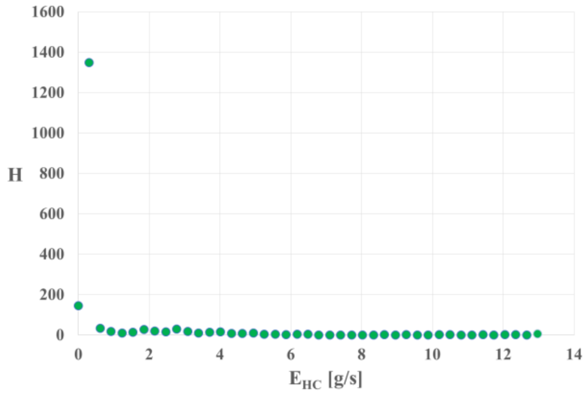

Fig. 31. Histogram – H of hydrocarbons exhaust emission rate – E_{HC}

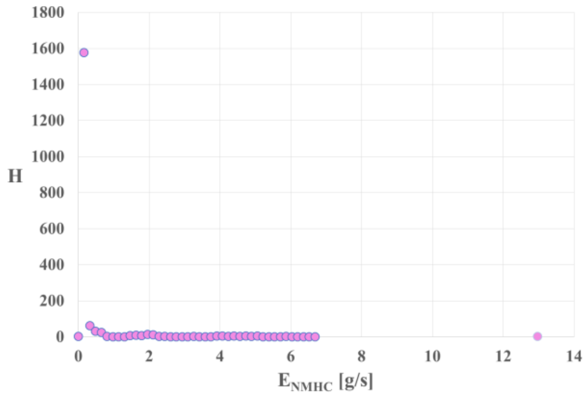

Fig. 32. Histogram – H of non-methane hydrocarbons exhaust emission rate – E_{NMHC}

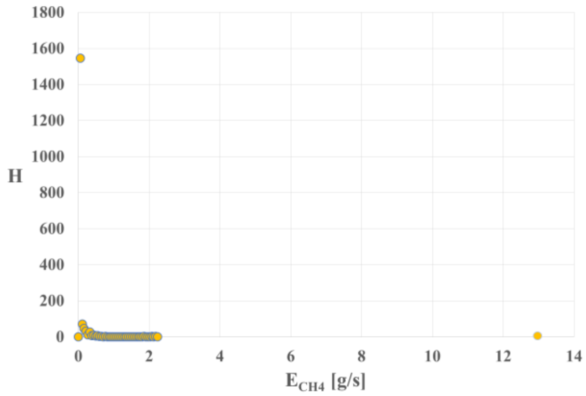

Fig. 33. Histogram – H of methane exhaust emission rate – E_{CH4}

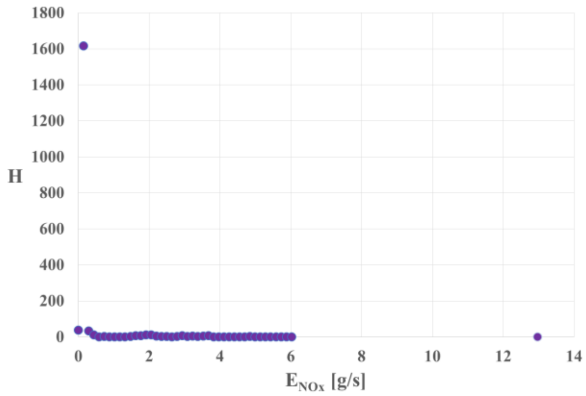

Fig. 34. Histogram – H of nitrogen oxides exhaust emission rate – E_{NOx}

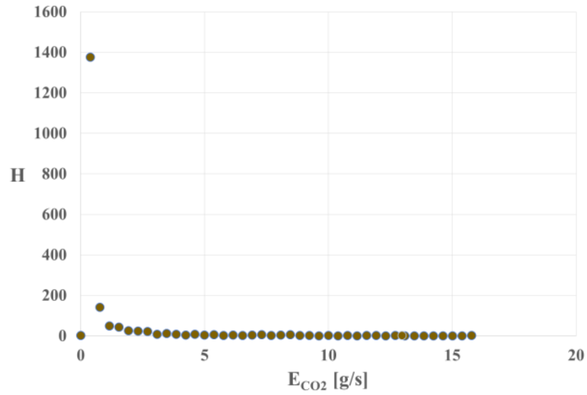

Fig. 35. Histogram – H of carbon dioxide exhaust emission rate – E_{CO2}

Histograms of exhaust emission rates were characterized by a clearly large share of points with small emission values. This was due to the very high values of the local maxima for these variables.

Figure 36 shows the histogram of the volumetric fuel consumption rate.

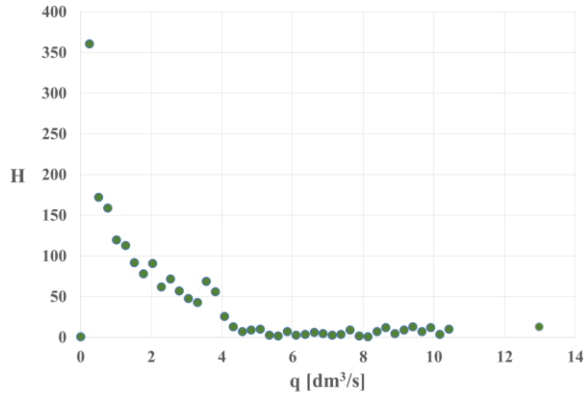

Fig. 36. Histogram – H of the volumetric fuel consumption rate – q

The volumetric fuel consumption rate histogram was notably different from the histograms of the exhaust emission rates, but a predominance in representation of low values could still be seen.

6. Conclusion

The recorded data of exhaust emission rates of measured substances, with the exception of carbon dioxide, were characterized by very low values, bordering on the measurement accuracy, for a significant share of the test duration. This should be expected in the case of modern diesel engines that meet the Euro 6 emission norm. The exhaust emissions were measured in the WLTC test, which led the authors to conclude the following:

1. The distance-specific emission of measured substances in the WLTC test was low enough to meet the Euro 6 requirements with a large safety margin: in the case of distance-specific emissions of carbon monoxide, that margin was over 90% of the limit value, even for distance-specific emissions of nitrogen oxides the margin was almost 40% of the limit.
2. The vehicle speed was weakly correlated with the carbon monoxide, nitrogen oxides and non-methane hydro-

carbons emission rates, while also being strongly correlated with the volumetric fuel consumption rate and the carbon dioxide emission rate.

3. The volumetric fuel consumption rate and carbon dioxide emission rate were found to be most strongly correlated. The correlation between the emission rates of organic compounds was also very strong. The carbon monoxide emission rate was the least correlated with all measured emission rates, except the emission rate of nitrogen oxides.
4. For all the obtained exhaust emission rates, the mean value was much greater than the median, while the standard deviation was much greater than both of those. The median value was close to the average value only in the case of the vehicle speed. For all the examined variables, except for the vehicle speed, kurtosis was positive. The kurtosis of the vehicle velocity was slightly negative, so the negative flattening of the distribution was not significant; the kurtosis value was observed for the organic compound emission rate, while the smallest positive kurtosis value could be seen for the carbon dioxide emission rate and the volumetric fuel consumption rate.
5. The skewness of all the measured variables distributions was positive. Hence these distributions had a right-sided asymmetry. As in the case of kurtosis, the highest value of skewness was found for the organic compounds emission rate, and the smallest – for the vehicle speed, carbon dioxide emission rate and volumetric fuel consumption rate.
6. Analysis of the coefficient of variation showed that the organic compounds exhaust emission rate had the most dynamic properties, followed by carbon monoxide and nitrogen oxides, and the vehicle speed was the least dynamic.
7. The vehicle speed histogram was characterized by a relative uniformity, apart from the very significant share of the point of zero speed. Histograms of exhaust emission rates were characterized by a clearly significant share of the small emission values; which was caused by the very large values of local maxima. The fuel consumption volumetric rate histogram was visibly different from the histograms of the exhaust emission rates, but the predominance of low process values was still observed.

Nomenclature

AV	average value
CH_4	methane
CO	carbon oxide
CO_2	carbon dioxide
D	standard deviation
E	pollutant emission rate
H	histogram frequency
HC	hydrocarbons
K	kurtosis
M	median
Max	maximum value
Min	minimum value
NMHC	non-methane hydrocarbons
NO_x	nitrogen oxides
q	volumetric fuel consumption rate
R	range
R^2	coefficient of determination
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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