CHARACTERISTICS OF UNIT EMISSIONS "e_j" OF TOXIC COMPOUNDS IN VEHICLES

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Abstract

This study presents the proposal for calculations of overall characteristics of unit HC emissions from passenger vehicles. Inspiration for the project was derived from the author's own research and the research works by the selected centres, both in Poland and abroad. Overall, (static) characteristics, with maps of unit emissions of HC, CO and NO_x were employed as a basis. This assumption is based on different profiles of fuel consumption and emissions in driving and non-driving phases.

In calculations for driving conditions, static overall characteristics of unit emissions were complemented with characteristics of changes in ΔHC, ΔCO and ΔNO_x for non-stationary engine working conditions. The author based on the results obtained by other authors has already developed these partial characteristics. Development of reliable characteristics requires implementation of expensive research program (in cooperation with main research centres in Poland), which will require changes in a leading control parameter. In particular, uncorrected, corrected, dynamic correction maps for emissions of HC, examples of dynamic characteristics for emissions from vehicles, characteristics of HC emissions for 5 run-up phases in higher gears and engine braking, numbers for vehicle driving and non-driving phases considered in calculations, coverage of operation field for the engine, static overall characteristics of unit HC emissions, effect of equivalence ratio on performance of three-way catalytic exhaust converter are presented in the paper.

Keywords: *unit emissions, characteristics of unit emissions, passenger vehicles*

1. Introduction

In recent years, energy-consumption and ecological aspects in vehicles has played increasingly important role. Their multidimensional meaning expresses care for energy resources and maintenance of satisfactory conditions of living on the Earth. One of its manifestations is incessant modification of standards and regulations, which stipulate permissible level of emissions of toxic substances. Numerous studies carried out by means of special research programs have discussed in detail the assessment of global emissions in each country [1-7].

However, the results of measurements of global emissions of toxic compounds from means of transports typically depend on the method of measuring emissions levels from each source, i.e. drive unit. Currently and in nearest future, main emitter of toxins in drive units include conventional internal combustion engines with spark ignition (SI) and compression ignition (CI). In order to improve energy parameters, their design is frequently subject to more or less thorough modification e.g. in SI GDI engines or in the engines, which feature downsizing.

Environmental solutions aimed at improvement in the quality of exhaust gas are at variance with energy-efficient activities. Three-way catalytic exhaust converters (TWC), antipollution filter or selective catalytic reduction (SCR) converters deteriorate the steady or unsteady exhaust conditions. It has not been confirmed so far how this affects engine performance maps.

Development of dynamic isoparametric overall characteristics of emissions of harmful compounds for working conditions in the vehicle can be important for practical applications.

These characteristics might allow for limitation of the disadvantages, which have so far resulted from currently used emission maps, presented as engine's angular velocity vs. angular acceleration [8] or vehicle speed vs. acceleration [9].

2. Limitations of emission maps

2.1. Angular velocity vs. angular acceleration maps

The authors attempted to generalize emissions of toxic compounds and CO_2 in exhaust fumes as a function of working conditions. The best situation is when this generalization can be characterized with mathematical equations. A priority of generalized mathematical description obscured the accuracy of reproduction of the emissions level by means of these equations [10]. The examples of this approach include emission maps for CO_2, CO and HC represented by means of 3rd order polynomials, presented in Fig. 1a. A drawback of this solution is their determination for specific conditions of investigations of both vehicle and road in the simulation research station. It is difficult to determine the effect of changes in vehicle weight or rolling resistance force (on e.g. slippery road) on the value of emissions.

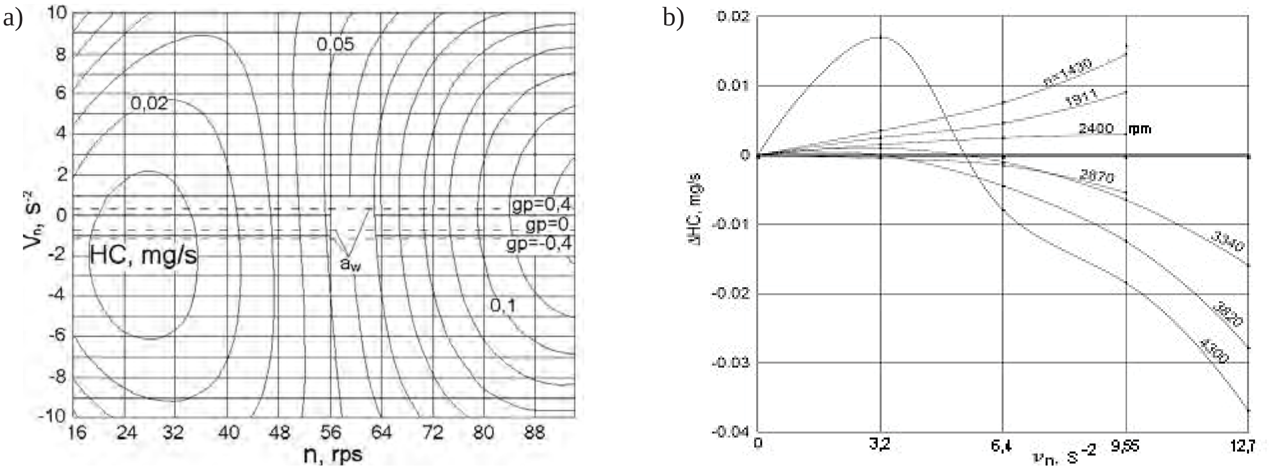

Fig. 1. Uncorrected (a) and corrected (Fig. 6) and dynamic correction maps for emissions of HC (b) presented as engine speed vs. acceleration v_n for the vehicle weight 1750 kg with 1.6 SI engine with marked neutral limit a_w for three road slopes [3, 8, 14]

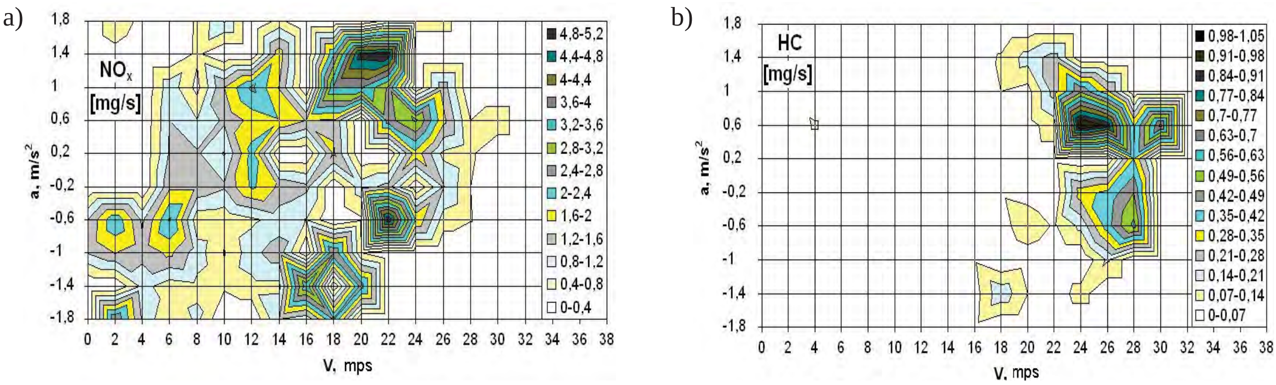

Fig. 2. Examples of dynamic characteristics for emissions from vehicles with 1.4 SI engine obtained in discrete intervals of vehicle speed vs. acceleration for real traffic conditions [9]

Difficulties of this approach include non-linear changes in engine's working conditions at the border of driving and non-driving phases. Moreover, under conditions of real traffic (road) one should also take into consideration a road slope [9, 11]. Because of its reliability, this type of research is more and more popular today. Consideration of road slope causes that the limit of load and emissions for engine's driving and non-driving states is liquid, which is presented in the characteristics of acceleration for three values of linear road slope ($g \cdot p$ = 0, 0.4, -0.4 m/s^2). In the case of engine breaking, emissions of toxic compounds equals zero after several seconds (Fig. 3).

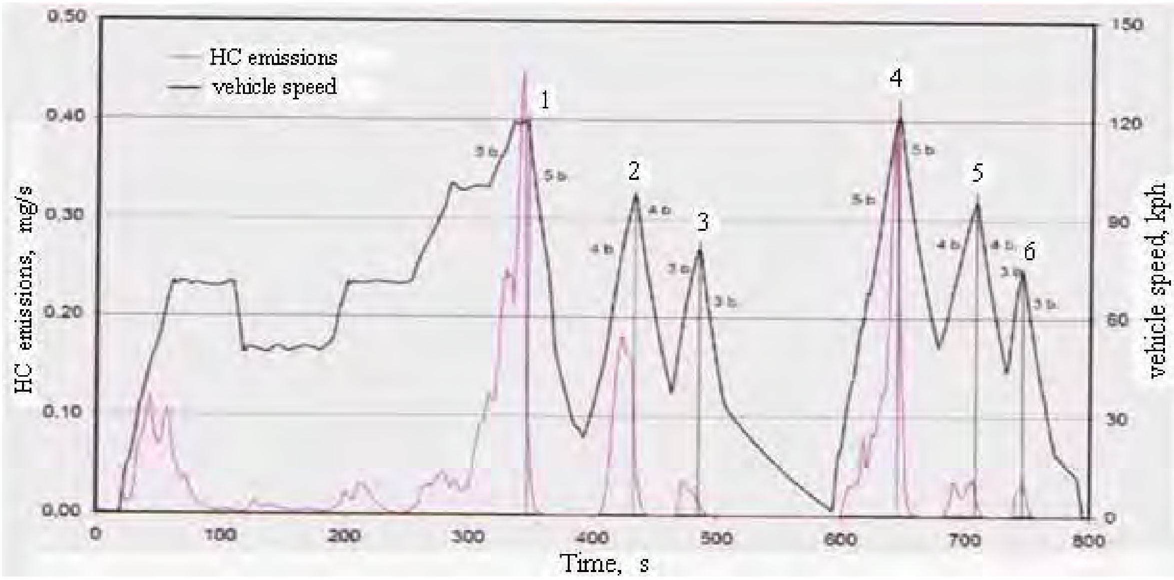

Fig. 3. Characteristics of HC emissions for 5 run-up phases in higher gears and engine braking after EUDC cycle, carried out on chassis dynamometer

2.2. Vehicle speed vs. acceleration maps

Even more problems arise in the case of emissions maps prepared for vehicle speed vs. acceleration chart [9]. Actual level of emissions determined for any discrete interval in Fig. 2 is additionally distorted with probable variability of reduction ratio of the gearbox. In the discrete interval v-a in both directions, extended value of emissions is caused by road slope (extended load zone) and changes in reduction ratio of the gearbox (extended engine speed zone). Emissions in the engine do not depend on these two parameters. They are much more affected by unrecognized factors. Therefore it can be treated as stochastic and probabilistic value which is subject only to statistical analysis [3, 13].

The fewest drawbacks in relation to the above-mentioned emissions maps can be observed in the maps in the form of static overall characteristics and dynamic characteristics [16]. Based on temporal characteristics for emissions of CO, HC and NO_x for the car with 1.6 SI engine manufactured in 2004, the profile of static overall characteristics of e_{HC} was developed and comparative calculations of HC emissions behind three-way catalytic exhaust converter (TWC) were made by means of the methods proposed by the authors [14-18].

3. Calculation of overall characteristics of unit emissions of HC in the vehicle with 1.6 SI engine

Investigations of emissions of toxic compounds in cars with SI and CI engines are much more complex than measurement of fuel consumption. Under actual road conditions, engines work under very differentiated and unsteady conditions. Emissions of pollutants are particularly sensitive to working conditions of internal combustion engines. Therefore, the author accepted higher calculation error (22%) compared to fuel efficiency (4-5%) [19].

Objective evaluation of emissions properties in the vehicles calls for the investigations under real road conditions. The author proposed determination of static overall characteristics of unit emissions e_j for individual compounds, complemented with correction characteristics of the effect of unsteady working conditions on unit emissions Δe_j (Fig. 2). In order to achieve this, characteristics of emissions E_j for individual toxic compounds presented in [3, 16] were employed. To confirm the thesis, the author will calculate overall characteristics of unit emissions of HC based on the characteristics presented in Fig. 3 [16]. This solution seems to be rational due to lack of resources allocated for the author's research from KBN (State Committee for Scientific Research in Poland).

In calculations, which have been frequently emphasized by the author, in order to improve accuracy of calculations, the division into driving and non-driving phases was employed. This was proved in further part of the study. In order to verify calculations from 800s measuring section, a 400s section was separated as identical with New European Driving Cycle (NEDC). The work [3] provides relevant information on the value of its emissions of HC: $b_{HC} = 0.002$ g/km.

Despite low dynamics of European driving cycles, including NEDC, working points cover the area of full range of engine load, which is visible in Fig. 5. Despite this fact, unsteady working conditions ν_n are limited to its low values, which can be observed in the Fig. 6. High dynamics of vehicle C accelerations is typical of American driving cycles, where for 55 km/h the vehicle accelerates 4.2 m/s^2 ($a \cdot v = 70$ m^2/s^3) [17, 18]. Therefore, it can be adopted that in NEDC engine drives the vehicle under quasi-steady working conditions. Without data on emissions of E_{HC} in American driving cycles, it will be difficult to determine dynamic characteristics of unit emissions of Δe_{HC} [17].

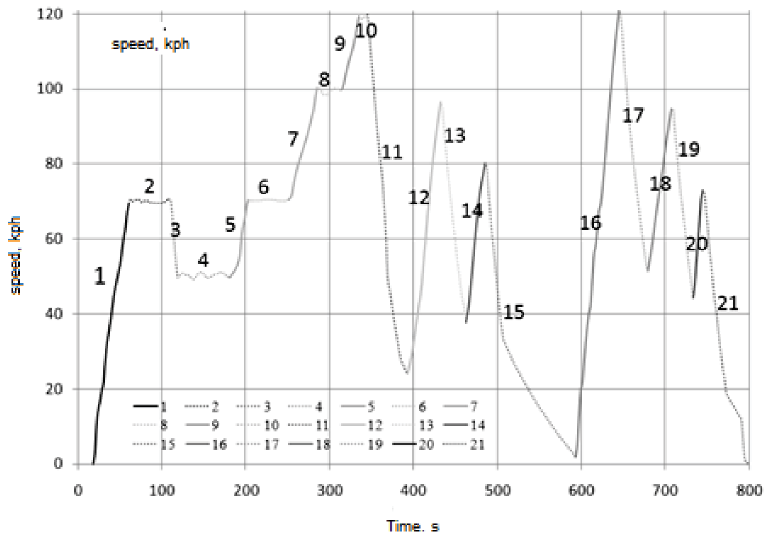

Fig. 4. Numbers for vehicle driving and non-driving phases considered in calculations

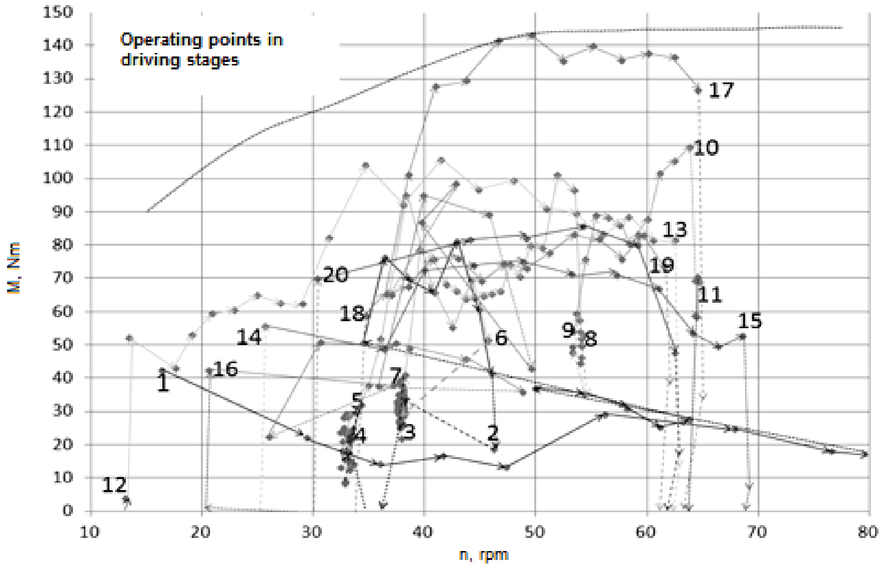

Fig. 5. Coverage of operation field for the engine with 2-sec intervals of loading and unit emissions of HC in driving phases

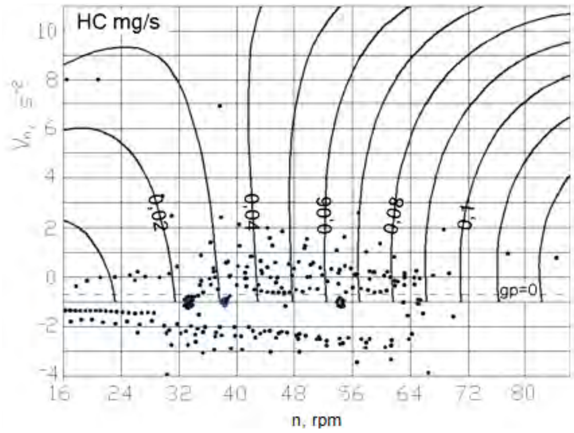

Fig. 6. Coverage of modified dynamic emission maps with working points in driving cycle from Fig. 3

Tab. 1. Selected features of vehicle B/K class and a vehicle C

Specification	vehicle B/K	Vehicle C
Year of production	2004	2005
Engine type and displacement, - /dm^3	SI/1.6	SI/1.6
Torque, N·m	150	145
Vehicle weight, kg	1400	1750
Tyres	195/60xR15	175/70xR14
Rolling resistance coefficient, -	0.13	0.012
Coefficient $K^* = 0.6 \cdot C_x \cdot A$, kg/m	0.374	0.624
Total ratios in each gears (1-5):	13.95, 8.00, 5.27, 4.525, 3.329	15.12, 8.34, 5.72, 4.33, 3.56

For the cars with 1.6 SI engine emissions of four compounds (CO_2, CO, HC and NO_x) was registered in a cycle extended with 400s of EUDC cycle. Based on speed profile, usable vehicle's parameters were calculated, which allowed for calculation of instantaneous values of unit emissions e_j for the listed compounds. The calculations took into consideration 3.6s interval of delay of registration of the value of emissions in relation to instantaneous vehicle speed [4]. Fig. 7 presents the overall characteristics of unit emissions of HC determined by means of low-pass filtering [13]. The attempts to determine the effect of unsteady engine's working conditions for fixed engine rotational speed ν_M on unit emissions of HC in phases 2+6 as well as 4 and 8 were also made.

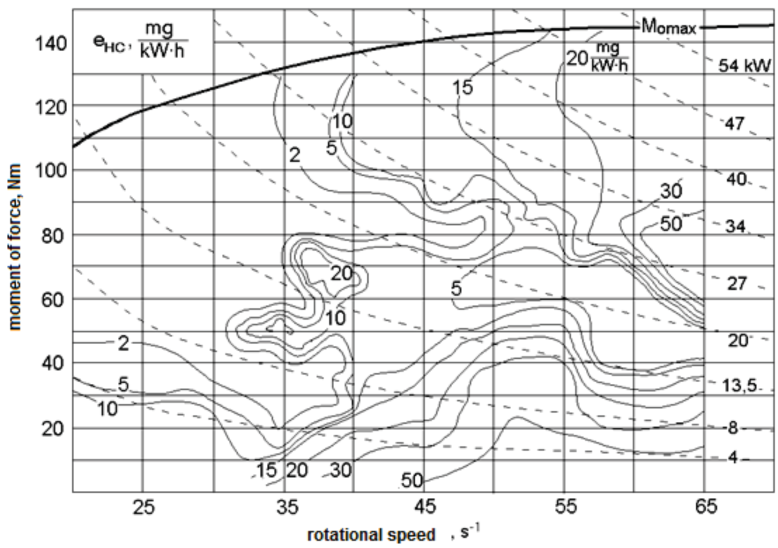

Fig. 7. Static overall characteristics of unit emissions of HC from drive unit of the vehicle with 1.6 SI engine (m = 1600 kg)

4. Accuracy of calculations of emissions b_{hc} in NEDC cycle

The use of overall characteristics for unit emissions e_j considerably simplifies calculations of emissions of *j* component of exhaust components in vehicles with SI engine in driving phases. In order to carry out the calculations it is necessary to determine the stream of emissions of *j* components before and after the catalytic converter, one can additionally determine the efficiency of TWC under steady (Fig. 9) and unsteady engine's working conditions [14].

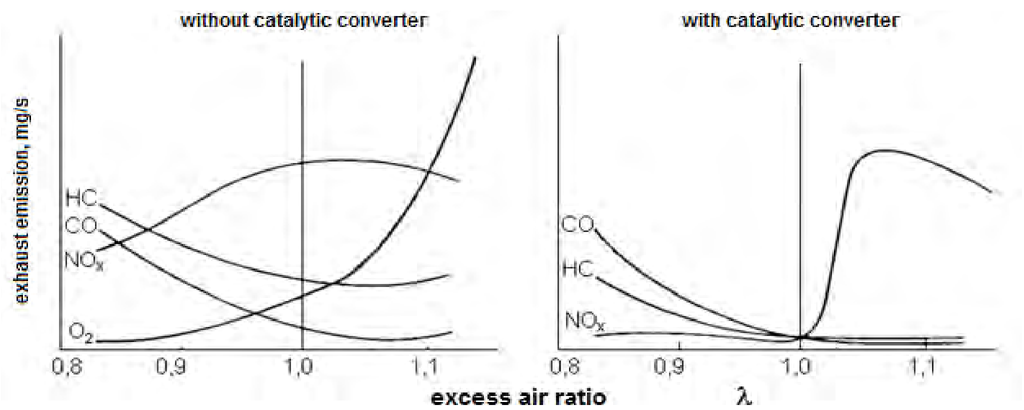

Fig. 8. Approximate effect of equivalence ratio on performance of three-way catalytic exhaust converter (TWC) in SI engine

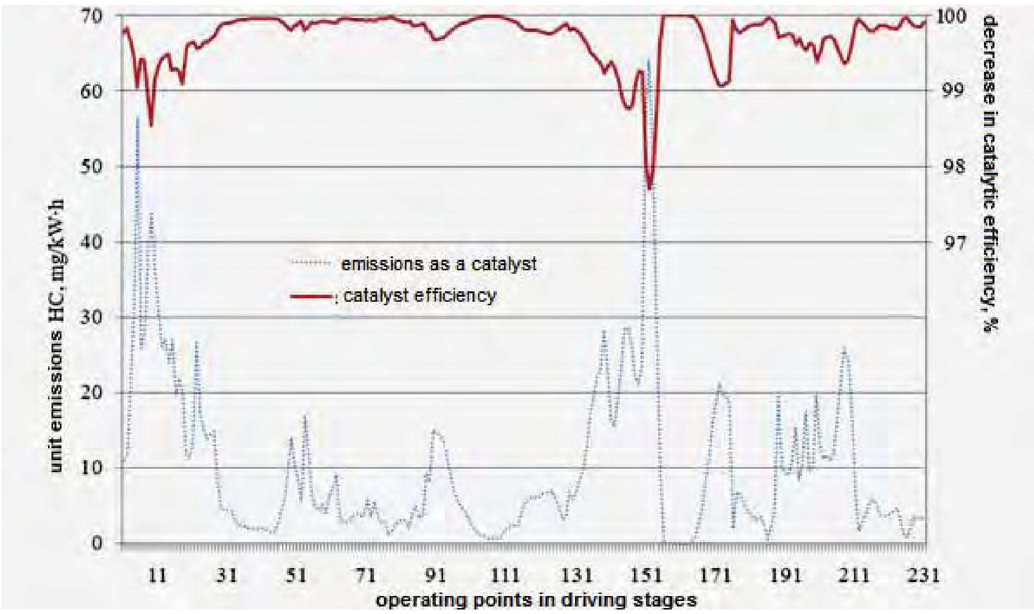

Fig. 9. Calculated approximate performance in TWC converter in each working point of 1.6 SI engine

In most of cases of homologation European driving cycles these conditions are quasi-steady, for which the coefficient of unsteady working conditions at constant rotational speed ν_n and constant load ν_M does not exceed the values, which have effect on Δe_j [4, 14, 15]. Unsteady engine's working conditions occur in NEDC cycle during acceleration of the car in first two gears, which was reported by the studies [11]. Accuracy of calculation of HC emissions in NEDC cycle using overall characteristics of unit emissions of HC and dynamic emission maps (Fig. 2, 6 and 7) are presented in Fig. 10 and 11 and in Tab. 2.

Figure 12 presents instability of engine working points in the selected phases of constant speeds in NEDC driving cycle. 'Manual' control of speed leads to unsteady engine working conditions at constant rotational speed ν_M, however, ν_n also changes within insignificant range, which was demonstrated in Tab. 3.

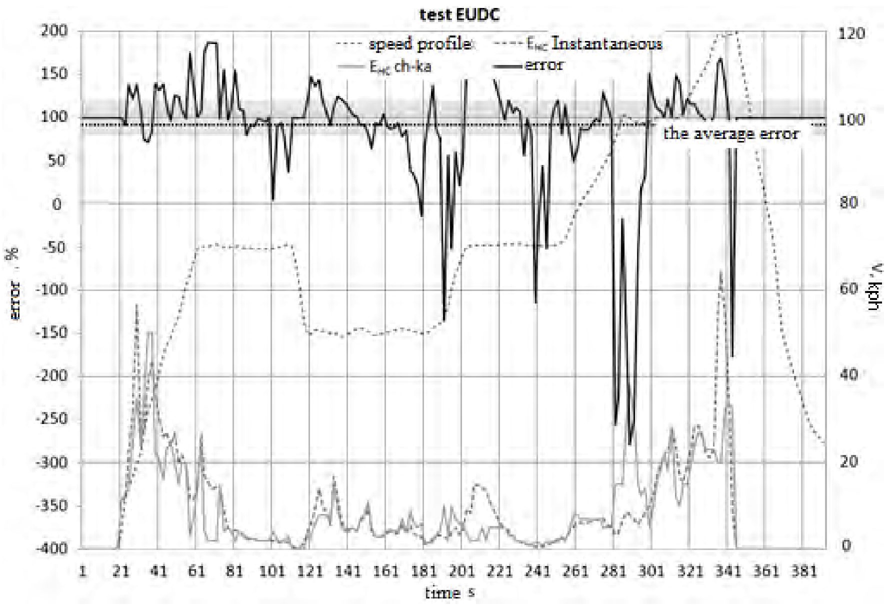

Fig. 10. Calculation's errors for emissions of E_{HC} determined by means of overall characteristics e_{HC} (Fig. 7) in driving working points of the vehicle C driven with 1.6 SI engine in NEDC cycle

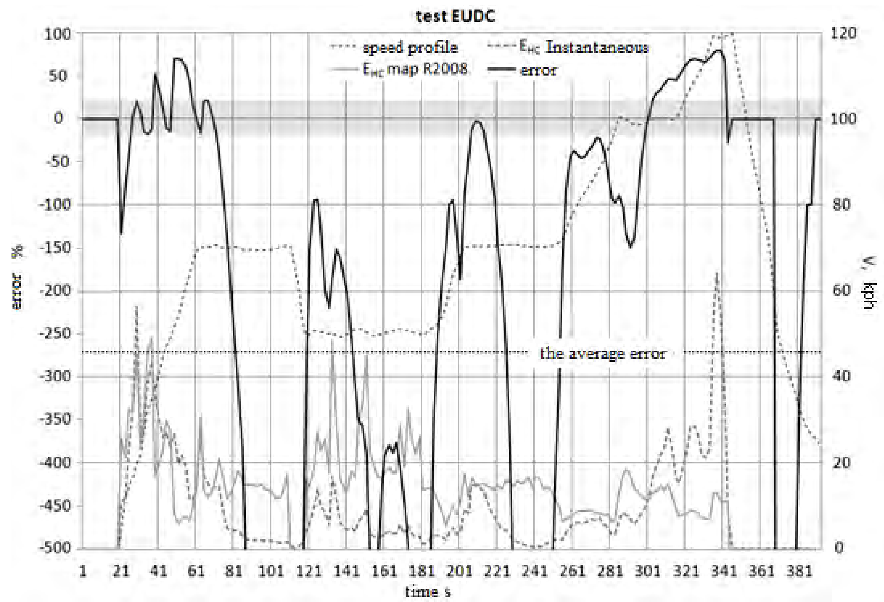

Fig. 11. Error in calculations of emissions of E_{HC} by means of dynamic E_{HC} emissions maps (Fig. 1) in driving working point of vehicle C driven with 1.6 SI engine for NEDC driving cycle

The author proposed extended measurements in terms of investigations of the effect of unsteady engine's working conditions at constant rotational speed on overall engine efficiency and emissions of toxic compounds in cars [4]. The latter call for mobile exhaust analyses [9], analysis of Fig. 3, 7 and the results of Tab. 3 reveals considerable complexity of the issues of the value of stream of emissions of HC as a function of load.

Apart from the calculated delay in registration of HC emissions of 3.6s, the effect of different factors is visible: their description requires an independent study. Lack of correlation between emissions E_{HC} and unsteady engine's working conditions (Fig. 12) might prove overriding, non-functional or operational relationships between each other. Emission E_{HC} might be smoothed by the direction of changes in position of air throttle, which was suggested by Professor Chłopek [13] or unrecognized working conditions of catalyst converter in driving and non-driving working phases (author).

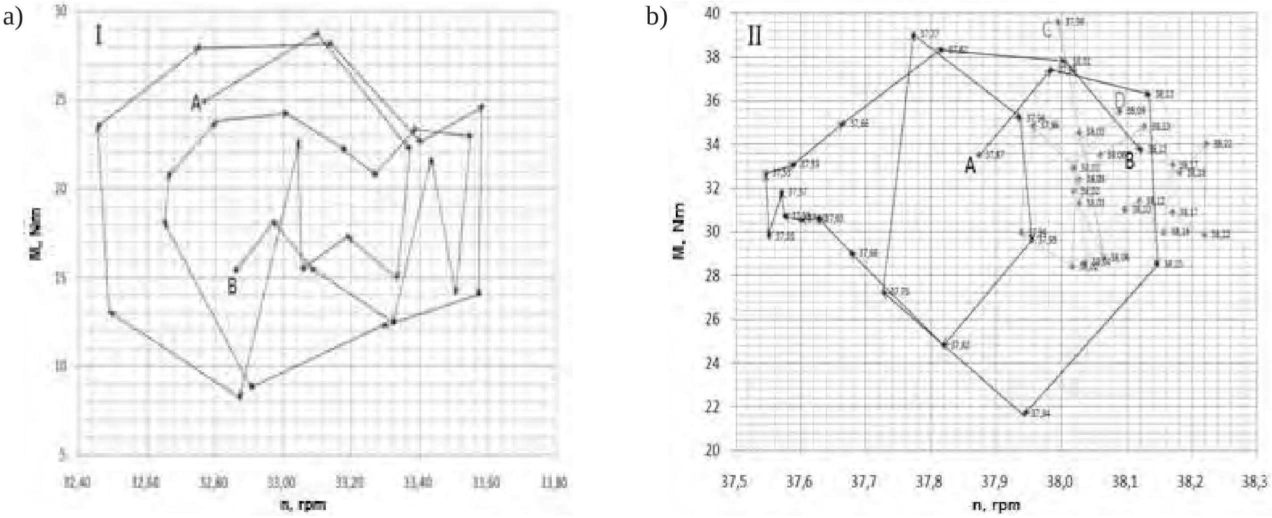

Fig. 12. Working points in 1.6 SI engine for phases of constant speeds (2+6, 4) of NEDC driving cycle performed using a vehicle with m = 1600 kg in chassis dynamometer (Fig. 4)

Tab. 2. Characteristics of emissions of HC in vehicle C with 1.6 SI engine calculated by means of characteristics for EUDC cycle

Feature	Overall characteristics (Fig. 7)	Characteristics by Romaniszyn (Fig. 1)	
		Year 2007	Year 2008
Emissions, driving phases 316s	13.85 mg	8.58 mg	13.32 mg
Mean value, driving phase	0.044 mg	0.027 mg	0.042 mg
Emissions, non-driving phase 58s[1)]	0.70 mg	1.17 mg	1.5 mg
Calculation relative error	0.00	0.67	1.14
Mean value, non-driving phases	0.012	0.020	0.026
Total emissions	14.55 mg	9.75 mg	14.82
Total emissions of b_{HC} [mg/km][2)]	2.08 mg/km	1.39 mg/km	2.12 mg/km
Calculation relative error	0.04	0.39	0.08
[1)] in non-driving phases, additionally 26 of switched-off injection, [2)] value of mileage emissions HC b_{HC} = 0.002 g/km			

Tab. 3. Searching for correlation between unsteady engines's working conditions ν_M at constant rotational speed and emissions E_{HC} in EUDC driving cycle

Features of the phase of constant v in EUDC	50 km/h	70 km/h		100 km/h	120 km/h
Phase number	4	2	6	8	10
Time interval	2s	2s	2s	2s	1s
Positive range $\sqrt{}_M$ (N·m)/s	0.01 – 0.65 [1)]	0.00 – 0.62	0.03 – 0.31	0.10 – 0.81	
Number of points	16	12	13	8	9
Correlation, R^2	0.52	0.60	0.36	0.75	
Assessment of R according to Koller	lack of correlation	lack of correlation	lack of correlation	lack of correlation	
Negative range $\sqrt{}_M$ (N·m)/s	-0.63 – -0.02	-0.41 – -0.03	-0.57 – -0.02	-0.58 – -0.07	
Number of points	14	9	9	7	
Correlation, R^2	0.77	0.49	0.94	0.35	
Assessment of r according to Koller	lack of correlation	lack of correlation	good	lack of correlation	
[1)] investigations it was possible to obtain ν_M in positive range of 1.35-4.19 (N·m)/s					

5. Conclusions

Based on the presented material, one might draw two main conclusions:

1. Overall characteristics of unit emission e_j, if divided into driving and non-driving phases, show opportunities for universal practical application for calculation of emissions from vehicles under actual road conditions.
2. Correlation of unit emissions e_j in the vehicles with conditions of engine load in driving phases is of more operational rather than functional nature and determination of contour line e_j for overall characteristics of emissions is much more difficult and more difficult than in the case of g_e.

References

[1] Silva, C. M. et al., *EcoGest – Numerical modelling of the dynamic, fuel consumption and tailpipe emissions of vehicle equipped with spark ignition engines*, Instituto Superior Tecnico, Portugal 2002.

[2] Romaniszyn, K. M., *The use of piston engine brake as related to the emission of selected Exhaust gas components*, Combustion Engines, No. 1, pp. 32-38, 2008.

[3] Chłopek, Z., *Modelowanie procesów emisji spalin w warunkach eksploatacji trakcyjnej silników spalinowych*, Prace naukowe, Mechanika z. 173, s. 193, Politechnika Warszawska, Warszawa 1999.

[4] Ubysz, A., Łazarz, B., Flekiewicz, M., *Analiza warunków pracy i emisji wybranych składników spalin w obszarze fazy hamowania pojazdu silnikiem ZI*, European Congress KONES, Zakopane 2009.

[5] Ahn, K., *Microscopic fuel consumption and emission modeling*, Virginia, USA 1998.

[6] Kropiwnicki, J., *The aplication of spline funktion for approximation of engine charakterystics*, Archiwum Motoryzacji, Nr 4, s.235-242, 2000.

[7] Van Mierlo, J., Magnetto, G., Van de Burgwal, E., Gense, R., *Driving style and traffic measures-influence on vehicle emissions and fuel consumption*, Proc Inst Mech Eng D, J Automob Eng, 218, pp. 43-50, 2006.

[8] Romaniszyn, K., *Test dynamiczny ruchu pojazdu a emisja składników spalin przy alternatywnym zasilaniu benzyną i gazem CNG*, Zeszyty Naukowe BOSMAL, Nr 38, 2007.

[9] Romaniszyn, K., *Alternatywne zasilanie samochodów benzyną oraz gazami LPG i CNG*, s. 178, WNT, Warszawa 2007.

[10] Merkisz J., Pielecha J., Gis, W.: *Investigations on vehicle exhaust emissions under real road conditions*. Combustion Engines 2009-SC1, s. 43-53.

[11] Ubysz, A., *Problem dokładności obliczeń zużycia paliwa w samochodzie na podstawie map emisji CO_2*, Zeszyty naukowe Pol. Śl., serii Transport, z.64, s. 95-102, Gliwice 2009.

[12] Ubysz, A., *Energochłonność samochodu a zużycie paliwa w złożonych warunkach ruchu*, Monografia, Pol. Śl., Gliwice 2003.

[13] Chłopek, Z., *Badania emisji zanieczyszczeń z silnika autobusu miejskiego*, Journal of KONES, Vol. 15, No. 3, s. 67-74, 2008.

[14] Ubysz, A., *B.S.F.C. map in nonstationary operating conditions of car engine*, European Congress KONES, Zakopane 2009.

[15] Ubysz, A., *Analysis of operating conditions and emissions of the selected components of exhaust gas during SI engine braking phase*, European Congress KONES, Zakopane 2009.

[16] Parczewski, K., Romaniszyn, K., Wnęk, H., *A dynamic test of a vehicle In motion and Exhaust gas emission Turing alternative fuelling with gasoline end CNG*, Combustion Engines No. 3, pp. 52-60, 2008.

[17] Romaniszyn, K., *Ocena różnic w określaniu zużycia paliwa samochodu na podstawie charakterystyki uniwersalnej i dynamicznej*, Silniki Spalinowe, Nr 2, s. 48-54, 2004.

[18] Romaniszyn, M. K., *Charakterystyka dynamiczna zużycia paliwa i emisji związków szkodliwych spalin*, ZN OBRSM Bosmal, Nr 21, I-II, s. 29-36, 2003.
[19] Joumard, R., *Methods of estimation of atmosferic emission from transport: European scientific state of the art*, Action COST 319 final report, INRETS report LTE 9901, 1999.
[20] Ubysz, A., *Dynamiczne charakterystyki emisji w samochodzie osobowym*, Projekt własny do KBN seria 56, 2008.
[21] Ubysz, A., *Examinations of effective efficiency of a car engine in nonstationary work conditions from torque load*, Journal of KONES Powertrain and Transport, Vol. 16, No. 4, pp. 463-8, 2009.