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Improvement of standardized method of particulate matter emission control from the exhaust gases of vehicle diesel engines

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Summary. The standard environmental diagnostic procedure for automotive diesel engine was analyzed. The resulting measurement error of one of the main environmental indicators for diesel engine – average in-use emission of suspended particulate matter in the exhaust gases was researched. Measures for its reduction were proposed. Instrumental and methodical components of this error were evaluated. The effectiveness of proposed measures was confirmed.

Key words: diesel engine, exhaust gases, suspended particulate matter, average in-use emission, resulting error.

INTRODUCTION

With the introduction of the EURO norms in 1993 the average in-use emissions of suspended particulate matter (PM) with exhaust gases (EG) was added to the main environmental indicators of diesel engine. This value is designated as PT (from "particles") and its measurement unit is g/kWh [1]. Due to the high toxicity of PM [2] (a relative aggressiveness measure of a given substance compared to carbon monoxide is equal to 200 [3,4]) norms on PT rate during the period between 1993 and 2015 were decreased by 72 times (from 0.36 to 0.005 g/kWh). This has led to the emergence of a resulting error measurement increase problem for PT – δPT: during the tests within the same laboratory the rate differs from ±3% to ±12%, during inter-laboratory tests – from ±12% to ±50% [5–8].

As the results of foreign [9-11] and domestic studies [12-17] showed, the δPT error includes both the instrumental component due to the inaccuracy of the measuring equipment, and methodical components, due to the influence of test conditions of diesel engine on the measurement value of EG average in-use emissions. Accounting for the methodical error components in δPT error when testing allows to improve accuracy of measurements of the PT rate. It increases the effectiveness of this important method of environmental studies as gravimetric analysis [18,19].

RESEARCH PROBLEM

The purpose of the research is to evaluate the resulting measurement error of the average in-use emissions of PM from the EG of a diesel engine taking into account the importance of the separate components and to propose measures for its reduction. In order to achieve this the following tasks must be solved:

1) to study the standard procedures of measuring the PT rate;

2) to develop the mathematical model of δPT error;

3) to propose measures to improve the accuracy of measurements of PT rate;

4) to create a method for the evaluation of the δPT error and significance of its components;

5) assessment of δPT error and efficiency of measures for its reduction.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Procedure for determining the average in-use emissions of particulates. The PT rate is determined during the execution of the European Stationary Cycle (ESC), which consists of 13 modes with a defined number of revolutions n, load L, the weight factor WF (takes into account relative time of operation of the diesel engine in-use) and the test duration – τ (table 1).

Table 1. ESC test cycle modes

Mode	n	L	WF	τ, min
1	idle	-	0,15	4
2	A	100	0,08	2
3	B	50	0,10	2
4	B	75	0,10	2
5	A	50	0,05	2
6	A	75	0,05	2
7	A	25	0,05	2
8	B	100	0,09	2
9	B	25	0,10	2
10	C	100	0,08	2
11	C	25	0,05	2
12	C	75	0,05	2
13	C	50	0,05	2

The number of rotations A, B and C (fig. 1) is calculated according to these formulas:

$$A = n_{lo} + 0{,}25 \cdot (n_{hi} - n_{lo}); \; B = n_{lo} + 0{,}50 \cdot (n_{hi} - n_{lo});$$
$$C = n_{lo} + 0{,}75 \cdot (n_{hi} - n_{lo}),$$

where: n_{lo} – the lowest rotation frequency, with which 50% of certified effective output of the engine is achieved – P;
n_{hi} – the highest rotation frequency, with which 75% from P value is achieved.

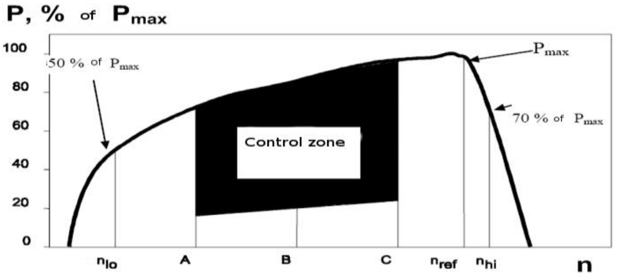

Fig. 1. Determination of values of A, B and C

For each testing cycle mode the sampling of the PM from the EG of a diesel engine, previously diluted in a special pipeline-tunnel with clean air which has a temperature t_{dil} = 25±5 °C is made. The temperature of the diluted EG upstream from a filter for PM intake (a single filter for the entire cycle is used) must not exceed 52 °C, but must be more than 42 °C.

The calculation of PT value is made according to the testing results:

$$PT = \frac{PT_{mass}}{\sum_{i=1}^{13}(P_i \cdot WF_i)}, \text{ g/kWh,} \quad (1)$$

where: PT_{mass} – average mass PM emission during the cycle:

$$PT_{mass} = \frac{m_f}{m_{sam}} \cdot \frac{\overline{G_{edf}}}{1000}, \text{ g/h,} \quad (2)$$

where: m_f – mass of PM, accumulated on the filter during the cycle, mg;
m_{sam} – mass of diluted EG sample, which went through the filter during the cucle (on condition of proportionality of sample quantity on each mode to the corresponding weight factor), g;
$\overline{G_{edf}}$ – average equivalent diluted EG mass-flow rate:

$$\overline{G_{edf}} = q_i \cdot G_{exhi}, \text{ kg/h,} \quad (3)$$

where: q_i – EG dilution coefficient in i-mode – ratio of mass-flow rate of diluted and undiluted EG in the tunnel;
G_{exhi} – EG mass-flow rate of a engine in i-mode, kg/h.

To calculate the effective output P_i the following formula is used:

$$P_i = \frac{n_i \cdot M_{ki}}{9550} - P_{auxi}, \text{ kWt,} \quad (4)$$

where: M_{ki} – the torque factor on i-mode, n*m;
P_{auxi} – output, which is used for auxiliary systems operation in i-mode, kWt.

Before the determination of the m_f rate the filter with PM must be weathered to stabilize its mass in a special chamber or room at constant temperature t_{st} and a relative humidity of φ_{st} of air (can be in range: t_{st} = 22±3°C, φ_{st} = 45±10%) during the time span τ_{st} = 1...80 h.

When performing the said procedures different modes of dilution of EG can be maintained in the tunnel.

D1 – CVS mode (Constant Volume Sampling), in which the mass-flow rate of diluted EG in the tunnel is constant:

$$G_{edfi} = G_{edf} = const\,;\; q_i = q_a \cdot \frac{G_{exha}}{G_{exhi}},$$

where: a – test mode index, on which the rate of EG emission is highest, while q_a – the absolute minimum of the various possible EG dilution ratios.

Before EURO-3 norms implementation this mode was primary and was used in reference systems for average in-use PM emissions control – full-flow tunnels (in which all the EG of a diesel engine are diluted). Since year 2000, with the implementation of the 3rd series of amendments to R-49 Rules the variety of EG dilution modes used in tunnels was widened. During the use of D1 mode the filter accumulates the minimum allowed mass of PM trial sample, which equals 0.25 mg.

D2 – CVS mode with air cooling. Tunnel coolant systems used nowadays allow to reduce the sample temperature upstream of the PM intake filter to the permissible level of 52 °C, which may exceed that level by $\Delta t_{f(52)}$ = 0…20 °C; because of this in comparison to D1 mode the q_i coefficients drop, and PM concentration in diluted EG and the variable m_f increase up to 0…56% accordingly; and thus the accuracy of PT value is increased.

D3 – EG dilution mode with constant coefficient q:

$$q_i = q = const.$$

As a result of EG dilution with current method the PM concentration in diluted EG in test cycle modes is increased in comparison to CVS-dilution by (G_{exha} / G_{exhi}) times, what enables us to increase the PM trial sample mass up to 37% – m_f and increase the accuracy of PT value measurement.

D4 – EG dilution mode with constant coefficient q and with tunnel air cooling. With the use of this mode the accuracy of PT variable measurement increases as a result of increase of m_f value in 2.1 times in comparison to D1 mode; this result is achieved by the lowering of ENG dilution coefficient, at which the temperature of the sample upstream of the filters does not exceed 52 °C (air coolant system allows to decrease the current temperature on $\Delta t_{f(52)}$ = 0…20 °C).

RESEARCH METHODOLOGY

Mathematical model of resulting error in PT variable measurement. On the basis of analysis of research made by Mitsubishi [10] and AVL [21] companies, and also the results of our own research [12-17], the author would like to propose a mathematical model of δPT error, in which the current variable is regarded as a result of the sum of three components:

$$\delta PT = \delta PT_{in} + \delta PT_{tf} + \delta PT_{st}, \quad (5)$$

where: δPT_{in} – instrumental error, caused by the inaccuracy of measurements of values which are involved in the calculation of PT value;

δPT_{tf} – methodical error, caused by the effect of temperature of a sample upstream of the PM intake filter on the measurement of PT value;
δPT_{st} – methodical error, caused by the effect of the working filter stabilization process parameters before its weighting on the result of PM value measurement: air temperature – t_{st} and the time of filter weathering – τ_{st}.

δPT_{in} value is defined as the error of indirect measurements result:

$$\delta y = \sqrt{\sum_{i=1}^{m}\left(\frac{\partial y}{\partial x_i}\cdot\frac{x_i}{y}\cdot\delta x_i\right)^2}\,, \qquad (6)$$

where: y – a value which can be measured indirectly according to a known dependency – y = f(x_1, x_2, …, x_m);
x_i – values with the help of which we calculate y, m – their quantity.

δPT_{tf} error is numerically equal to δm^{tf}_f value – relative departure of PM trial sample mass – m^{tf}_f, измеренной при фактических значениях температур t_{fi}, от массы навески ВЧ - m^{tf0}_f, измеренной при значениях температур t_{f0i}, принимаемых за базовые и соответствующих CVS-разбавлению ОГ при t_{dil} = 20 °C, $t_{f(max)}$ = 52 °C:

$$\delta PT_{tf} = \delta m_f^{tf} = \frac{m_f^{tf} - m_f^{tf0}}{m_f^{tf0}}\cdot 100\% = \sum_{i=1}^{13}\delta m_{fi}^{tf}\,, \qquad (7)$$

where: δm^{tf}_{fi} – relative departure of PM trial sample mass in i–mode of testing:

$$\delta m_{fi}^{tf} = \frac{m_{fi}^{tf} - m_{fi}^{tf0}}{m_f^{tf0}}\cdot 100\%\,. \qquad (8)$$

δPT_{st} error is numerically equal to the δm^{st}_f value – the relative departure of PM trial sample mass – m^{st}_f, which is measured at factual fluctuations of values t_{st} and τ_{st}, compared with the PM trial sample mass – m^{st0}_f, measured at values equal to t_{st0} = 20 °C and τ_{st0} = 2h, taking as basic values the following:

$$\delta PT_{st} = \delta m_f^{st} = \frac{m_f^{st} - m_f^{st0}}{m_f^{st0}}\cdot 100\%\,. \qquad (9)$$

In order to calculate the values δm^{tf}_f and δm^{st}_f the author's observed dependences are used [22-29]:

$$\delta m_{fi}^{tf} = -\left(1{,}20 + 0{,}148\cdot \bar{n}_i - 0{,}552\cdot \bar{L}_i\right)\cdot\left(t_{fi} - t_{f0i}\right), \qquad (10)$$

where: $\bar{n}_i$, $\bar{L}_i$ – relative number of rotations and engine shaft load in i-mode;

$$\delta M_f^{st} = -5{,}72\cdot\left(1 + 0{,}071\cdot\left(t_{st} - t_{st0}\right)\right)\cdot \lg\left(\frac{\tau_{st}}{\tau_{st0}}\right). \qquad (11)$$

Values $\bar{n}_i$, $\bar{L}_i$ are calculated according to the formulas:

$$\bar{n}_i = \frac{n_i - n_{idle}}{n_{nom} - n_{idle}}\,,\ \bar{L}_i = \frac{M_{ki}}{M_{k(\max)}}\,, \qquad (12)$$

where: n_{idle} and n_{nom} – engine shaft number of rotations on idle and on rated output;

$M_{k(max)}$ – the maximum torque factor on the engine shaft with the given n.

The methodological basis for error δPT research taking into account the recommendations for its decrease. Based on the reasons for methodical errors appearance analysis for δPT_{tf} and δPT_{st} the following recommendations for their decrease and, consequently, for the increase of PT measurement accuracy were put forward.

a) decrease in 5 times of ranges of variation of diluting air temperature – to the interval t_{dil} = 20..22 °C and maximum sample temperature upstream of the filter (in mode with the highest heat generation) – to the interval $t_{f(max)}$ = 50…52 °C; this would allow to shorten the temperature variation intervals t_{fi}.

b) implementation of temperature control in the tunnel to maintain the temperature of the sample before the filter in all test modes, corresponding to the EG CVS-dilution; this will allow to reduce temperature departure Δt_{fi} and errors δm^{tf}_{fi} (see formula (10));

c) decrease of ranges of variation of PM filter stabilization temperature in 3 times – to the interval t_{st} = 20…22 °C and duration of stabilization period from 79 up to 2 h – to the interval τ_{st} = 6…8 h (with such τ_{st} the fluctuations of PM trial sample mass does not exceed ±0,5%); this allow to reduce δPT_{st} error.

Evaluation of the resulting measurement error of the average in-use PM emissions and the effectiveness of the recommendations is made according to the following algorithm.

1. The establishment of basic data for research – the results of testing of the diesel engine in the ESC cycle, specifying all the parameters that affect the accuracy of PT value measurement.

2. Consistent calculation using the formula (6) of the measurement errors of values, which are defined by dependencies (1) – (4); the calculations result in the calculated values of the errors δPT_{in} for each EG dilution mode.

3. The definition of the ranges of variation of the methodical error δPT_{tf} for each EG dilution mode; to do this, we must use the expression (7) and a method of two-factor experiment planning [20,26] are defined:

– for dilution modes D1 and D2 – dependencies δPT_{tf} = f (t_{dil}, $t_{f(max)}$) with the range of function setting: t_{dil} = 20…30 °C, $t_{f(max)}$ = 42…52 °C;

– for dilution modes D3 and D4 – dependencies δPT_{tf} = f (t_{dil}, $\Delta t_{f(52)}$) with the range of function setting: t_{dil} = 20…30 °C, $\Delta t_{f(52)}$ = 0…20 °C.

Absolute deviation values for δPT_{tf} which are calculated using the obtained dependencies, from the values calculated by the formula (7), shall not exceed ±0,05%.

4. Definition by means of the dependence (9) of the range of variation of the methodical error δPT_{st} in the range of the allowed values of t_{st} and τ_{st}.

5. The definition of the range of variation of the resulting error δPT (using the expression (5)) and the widths of the ranges of variation of this error – δPT^{sum} and its components – δPT_{in}^{sum}, δPT_{tf}^{sum} and δPT_{st}^{sum}:

$$\delta PT^{sum} = \delta PT_j^{+} + \delta PT_j^{-}\,;\ \delta PT_{in}^{sum} = \delta PT_{inj}^{+} + \delta PT_{inj}^{-}\,;$$

$$\delta PT_{tf}^{sum} = \delta PT_{tfj}^{+} + \delta PT_{tfjj}^{-}\,;\ \delta PT_{st}^{sum} = \delta PT_{stj}^{+} + \delta PT_{stj}^{-}\,,$$

where: indexes «+» and «-» correspond to boundary values of ranges of variation of the following errors in zones of positive and negative values;

j – EG dilution mode index.

6. Defining of relative contribution (in %) in resulting error δPT of each of its components – R_{in}, R_{tf} and R_{st}:

$$R_{in} = \frac{\overline{\delta PT_{in}^{sum}}}{\overline{\delta PT^{sum}}},\ R_{tf} = \frac{\overline{\delta PT_{tf}^{sum}}}{\overline{\delta PT^{sum}}},\ R_{st} = \frac{\overline{\delta PT_{st}^{sum}}}{\overline{\delta PT^{sum}}}$$

where: $\overline{\delta PT_{in}^{sum}}$, $\overline{\delta PT_{tf}^{sum}}$, $\overline{\delta PT_{st}^{sum}}$ and $\overline{\delta PT^{sum}}$ – average wideness values of ranges of variation of corresponding errors for all EG dilution methods.

7. The evaluation of error δPT change and its components as a result of implementation of the PT value measurement accuracy increase recommendations.

RESULTS AND ANALYSIS

Based on the results of diesel engine 1 CH 12/14 tests on ESC cycle (table 2) in accordance with the described method the following values were determined:

– the ranges of variation, their width for the δPT error and its components (table 3, fig. 2-4);

– the relative contribution of instrumental and methodical components on the resulting δPT error,

– the effectiveness of the proposed recommendations (fig. 2).

The analysis of results showed that:

a) when using permissible EG dilution modes the resulting error δPT ranges from -18.0...19.7%, the width of this range is 37,7%, at the same time the largest contribution to δPT is made by methodical components – a total of 76%; the contribution of the instrumental component is 24%;

b) the implementation of these recommendations results in decrease of δPT error up to -4,0… 4,2 %, the wideness of the range of variation of this variable (8.2%) is decreased 4,6 times; with it, the part of the instrumental component in δPT increases up to 73%, and the total percentage of the methodical components is decreased to 27%.

Table 2. The results of tests on a cycle ESC diesel engine 1CH12/14 at t_{dil} = 20 °C, $t_{f(max)}$ = 52 °C

Mode	Diesel parametres					Parameters of exhaust gas dilution			
	n, min^{-1}	M_k, N·m	G_{exh}, kg/h	t_{exh}, °C	PT_{mass}, g/h	q		t_f,°C	
						D1	D2	D1	D2
1	800	0	40,3	85	4,6	14,6	8,6	23,9	26,6
2	1010	50	50,8	317	12,8	11,6	8,6	40,0	47,0
3	1185	25	59,8	302	11,3	9,8	8,6	42,5	45,8
4	1185	37,5	59,0	325	13,1	9,9	8,6	43,8	47,6
5	1010	25	50,4	244	9,0	11,6	8,6	35,6	41,1
6	1010	37,5	50,8	291	10,9	11,6	8,6	38,5	44,9
7	1010	12,5	51,1	210	8,1	11,5	8,6	33,6	38,2
8	1185	50	59,4	342	14,9	9,9	8,6	45,0	48,8
9	1185	12,5	59,8	254	10,5	9,8	8,6	39,2	42,0
10	1360	50	68,4	386	16,7	8,6	8,6	52,0	52,0
11	1360	12,5	68,4	285	13,1	8,6	8,6	44,5	44,5
12	1360	37,5	68,0	371	15,2	8,6	8,6	50,8	50,9
13	1360	25	68,2	349	13,7	8,6	8,6	49,5	49,4

Table 3. Calculation results of the instrumental error δPT_{in}

Error	The expression for calculation errors	Error value at various modes of dilution EG, %				
		D1 (2 cycles)	D1	D2	D3	D4
δM_f	$\Delta M_f / M_f$	2,1	4,1	2,8	3,4	2,4
δM_{sam}	$\delta M_{sami} \cdot (\sum_{i=1}^{13} WF_i^2)^{0,5}$	0,4	0,6	0,6	0,6	0,6
δq_i	$\sqrt{2} \cdot \delta G_i \cdot (q_i - 1)$	3,8	3,8	2,3	2,2	1,2
δG_{edfi}	$\sqrt{\delta q_i^2 + \delta G_{exhi}^2}$	4,6	4,6	3,6	3,3	2,8
$\delta \overline{G_{edf}}$	$(\sum_{i=1}^{13} (WF_i \cdot k_{Gedfi} \cdot \delta G_{edfi})^2)^{0,5}$	1,0	1,4	1,1	1,3	1,1
δPT_{mass}	$(\delta M_f^2 + \delta M_{sam}^2 + (\delta \overline{G_{edf}})^2)^{0,5}$	2,4	4,4	3,1	3,7	2,7
δP_{ei}	$(\delta n^2 + \delta M_k^2)^{0,5}$	3,6	3,6	3,6	3,6	3,6
$\delta \overline{P_e}$	$\delta N_{ei} \cdot (\sum_{i=1}^{13} (WF_i \cdot k_{Nei})^2)^{0,5}$	1,2	1,2	1,2	1,2	1,2
δPT_{in}	$(\delta PT_{mass}^2 + (\delta \overline{N_e})^2)^{0,5}$	2,6	4,5	3,3	3,9	3,0

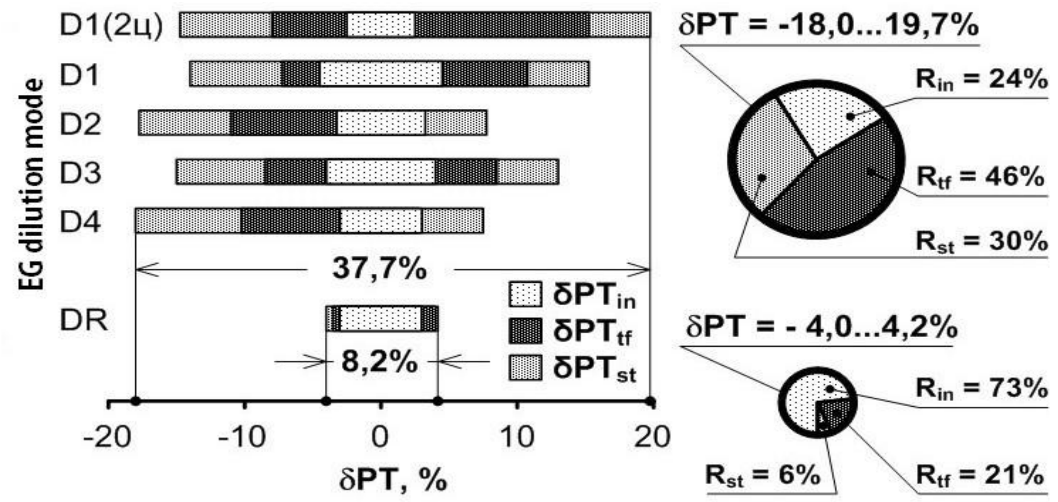

Fig. 2. The results of research of resulting error δPT

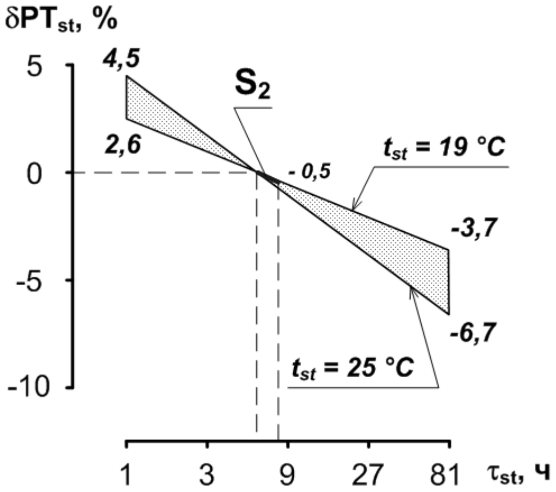

Fig. 3. The range variation of methodical error δPT_{st}:
S_2 – the zone of recommended value for τ_{st} and t_{st}.

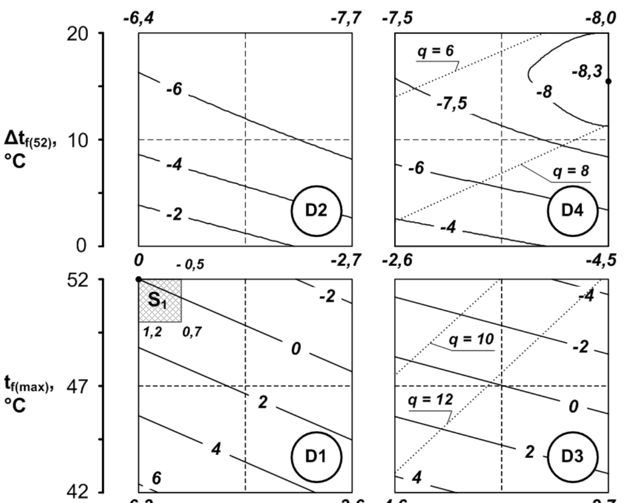

Fig. 4. The ranges variation of methodical error for δPT_{tf}:
S_1 – the zone of recommended value for t_{dil} and $t_{f(max)}$.

CONCLUSIONS

1. The resulting error of average in-use PM emission of diesel EG (δPT) was calculated – it amounts to 37,7%; and only 24% of the given variable is a part of instrumental component and the rest 76% are a part of its methodical components.

2. The measures for PT value measurement accuracy increase – narrowing of the ranges of variation of values $t_{f(max)}$, t_{st} and τ_{st}: from $t_{f(max)}$ = 42…52 °C up to 50…52 °C; from t_{st} = 19…25 °C up to 20…22 °C; from τ_{st} = 1…80 h up to 6…8 h. This allows to decrease the δPT error to 8,2%, i.e. in 4,6 times, and the part of the instrumental component of given value increases to 73%, and the sum part of methodical components decreases to 27%.

REFERENCES

1. **Regulation No 49. Revision 5. 2011.** Uniform provision concerning the approval of compression ignition (C.I.) and natural gas (NG) engines as well as positive-ignition (P.I.) engines fuelled with liquefied petroleum gas (LPG) and vehicles equipped with C.I. and NG engines and P.I. engines fuelled with LPG, with regard to the emissions of pollutants by the engine. – E/ECE/TRANS/505.
2. **Mundt D.J., Nauss K.H., Gohen A.J., Greenbaum D.S. 2013.** Diesel emission and lung cancer: epidemiology and quantitative risk assessment. A special report of the Institute Diesel Epidemiology Expert Panel / Health Effect Institute.
3. **Bystrov F.S., Varankin V.V., Vilenskiy V.A. et al. 1986.** Temporary typical method of determining the cost-effectiveness of the implementation of environmental protection measures and assess the economic damage caused to the national economy pollution / M.: «Economy» (in Russian).
4. **Polivyanchuk A., Shtepak E., Titova E. 2007**. Study degree of toxicity of pollutants, emissions are standardized European environmental standards / Herald of NTU "KhPI". - №2. (in Russian).
5. **Zvonov V., Kornilov G., Kozlov A., Simonova E. 2005.** Assessment and emission control particulate matter from the exhaust gases of diesel engines / M.: «Prima press» (in Russian).
6. **Burtscher H. 2001.** Literature Study on Tailpipe Particulate Emission Measurement for Diesel Engines / GRPE.

Fachhochschule Aargau, University of Applied Science, Windisch, Switzerland.
7. **Alozie N., Peirce D. 2014.** Comparative Influences of Air and Nitrogen as Dilution Gases in Measurement of Diesel Engine Particle Number Concentrations / SAE Technical Paper № 2014-01-1576.
8. **Alozie N., Peirce D., Lindner A. et al. 2014.** Influence of Dilution Conditions on Diesel Exhaust Particle Measurement Using a Mixing Tube Diluter / SAE Technical Paper № 2014-01-1568.
9. **Tsugio A., Tatsuji S., Morimasa H.. 1989.** Particulate matter emission characteristics under transient pattern driving // SAE Techn. Pap. Ser. №890468.
10. **Hirakouchi N., Fukano I., Shoji T. 1989.** Measurement of Diesel Exhaust Emissions with Mini-Dilution Tunnel / SAE Technical Paper Series № 890181.
11. **Kittelson D., Megan A., Watts W. 2009.** Review of diesel particulate matter sampling methods: Final Report / University of Minnesota, Minneapolis, MN.
12. **Polivianchuk A.P. 2012.** Uncertainty estimate in the results of measurement of particulate emissions during the environmental testing of diesel engines / Visnik of the Volodymyr Dahl East Ukrainian national university. –- №5 (176), Part 2. (in Russian).
13. **Polivianchuk A.P. 2014.** Improving the efficiency of emission control dispersed particles from diesel exhaust gases / Journal of Kharkov National University name of V. Karazin. - № 1140. – Vol. 11.
14. **Polivianchuk A. P., Parsadanov I.V., Rykova I.V. 2009.** Determination and analysis of the levels of emissions of particulates with exhaust gases of automotive diesel engine in steady running / Internal combustion engines. - №1. (in Russian).
15. **Polivianchuk A.P. 2010.** Improving accuracy of gravimetric measurement method for specific emission of particulate matter with exhaust gases of a diesel engine / Internal combustion engines. - №2 (in Russian).
16. **Polivianchuk A.P. 2015.** Improving the efficiency of particulate emissions control systems with the exhaust gases of diesel engines / Kharkiv: KhNAHU (in Ukrainian).
17. **Polivyanchuk A.P., Parsadanov I.V. 2015.** Experimental verification of microtunnel MKT-2 on the brake stand autotractor diesel engine / Industrial technology and engineering. – Republic of Kazakhstan. – №2 (15).
18. **Batluk V. A. and Romantsov E. V. and Klymets V. M. 2013.** The problem of highly effective cleaning of air from dust // ECONTECHMOD/ Vol. 2, №2.
19. **Dvulit, O. Bojko. 2014.** Towards sustainable transport in Ukraine: main obstacles and directions of development // ECONTECHMOD/ Vol. 3, №2.
20. **Sidnjaev N.I. 2015.** The theory of experimental design and analysis of statistical data / M.: «Jurajt» (in Russian).
21. **Lianga Z., Tiana J., Zeraati Rezaeia S. et al. 2015.** Investigation of SVOC nanoparticle emission from light duty diesel engine using GC×GC-ToF-MS / School of Mechanical Engineering, University of Birmingham, UK.
22. **Marchenko A., Parsadanov I., Polivyanchuk A. 2012.** Influence of modes of an autotractor diesel engine on the particulate emissions from the exhaust gases / Vestnik of National Transport University. - №25, 151-155. (in Russian).
23. **Polivyanchuk A.P., Ignatov O.R. 2012.** The analysis of the influence of stabilization conditions of working filters on the sample mass of diesel particulates / Combustion engines. – Poznan, – № 1(148), 48–52.
24. **Polivyanchuk A.P., Lvov S.A. 2013.** Improving the accuracy of the gravimetric method of measurement of particulate emissions from diesel engine exhaust gases / Internal combustion engines. - №1, 101-105. (in Russian).
25. **Polivyanchuk A.P., Parsadanov I.V., Holkina E.A., Grechishkina E.A. 2015.** The study of particulate emissions in the exhaust gases to the transient operating conditions of autotractor diesel / Internal combustion engines. - №2, 93-97. (in Russian).
26. **Polivyanchuk A. 2016.** Application of multi-criteria analysis in evaluating the efficiency of diesel particulate filters / TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE. – Vol. 16, No.3, 15-20.
27. **Zablodskij N., Pliugin V., Lettl J., Fligl S. 2013.** Dynamic Simulation of the Double-Stator Induction Electromechanical Converter with Ferromagnetic Rotor / "Power Engineering". – P. 1448 – 1453.
28. **Pliugin V., Shilkova L., Letl J., Buhr K. 2015.** Analysis of the Electromagnetic Field of Electric Machines Based on Object-oriented Design Principles / PIERS 2015, Prague. – P. 2522 - 2527.
29. **Zablodskiy N., Pliugin V. 2015.** 3D magnetic filed distribution in a screw double-stator induction motor / N. Zablodskiy, // CPEE 2015, Lviv. – P. 239 – 241.

СОВЕРШЕНСТВОВАНИЕ СТАНДАРТИЗОВАННОГО МЕТОДА КОНТРОЛЯ ВЫБРОСОВ ТВЕРДЫХ ЧАСТИЦ С ОТРАБОТАВШИМИ ГАЗАМИ ТРАНСПОРТНЫХ ДИЗЕЛЕЙ

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Проанализирована стандартная процедура экологического диагностирования автомобильных дизелей. Исследована результирующая погрешность измерений одного из основных экологических показателей дизеля – среднеэксплуатационного выброса взвешенных частиц с отработавшими газами. Предложены мероприятия по ее уменьшению. Оценены инструментальная и методические составляющие данной погрешности. Подтверждена эффективность предложенных мероприятий.

Ключевые слова: дизель, отработавшие газы, твердые частицы, среднеэкслуатационный выброс, результирующая погрешность.