

A.P. Polyvianchuk, V.L. Khreshchenetskyi, O.P. Antonuk, M.V. Mitko, A.V. Dmitrieva

IMPROVING THE ACCURACY OF SYSTEMS FOR GRAVIMETRIC CONTROL OF PARTICULATE MATTER IN EXHAUST GASES OF TRANSPORT DIESEL ENGINES

The requirements of regulatory documents - UNECE Regulations R-49, R-96, international standard ISO 8178, etc. were analyzed regarding the technical characteristics and conditions of use of reference full-flow and alternative partial-flow systems (tunnels) for diluting the exhaust gases of transport diesel engines with air and carrying out gravimetric control of the content of solid particles in them. The world and domestic experience of operating dilution tunnels of various types - full-flow with 1st and 2nd dilution lines and partial-flow mini- and micro-tunnels and partial-flow mini- and micro-tunnels were studied, which made it possible to establish empirical dependencies for evaluating the degree of influence of the temperature regimes of gas sampling on the accuracy of measurements of mass emissions particulate matter in different modes of diesel operation. Mathematical models have been developed to determine the sample temperatures of diluted exhaust gases in tunnels of various types and to estimate the resulting measurement error of the normalized average operational emission of diesel particulate matter - the PM indicator. Based on the results of environmental tests of transport diesel engines 1Ch12/14 and 4ChN12/14 according to the 13-step ESC test cycle and developed mathematical models, calculation studies were carried out to assess the effect on the accuracy of a mini-tunnel with a diameter of 10 cm and a micro-tunnel with a diameter of 3 cm of the sampling temperature regimes, which were compared with a reference tunnel with a diameter of 46 cm. The research results proved the expediency of adjusting the temperature of the sample in the micro-tunnel to increase its accuracy by eliminating the significant methodical errors of measuring the PM indicator, which amount to -1.6 ... -1.7%. It was established that in the mini-tunnel the corresponding errors are not significant and amount to -0.3 ... -0.4%, which indicates that there is no need to adjust the temperature of the sample in this system.

Key words: transport diesel; environmental diagnostics; exhaust gases; particulate matter; dilution tunnel.

Introduction

When using compact systems for environmental diagnostics of transport diesel engines - mini- and microtunnels, the requirement to ensure their accuracy should be met: relative deviations of the measurement results of the normalized indicator PM - mass emission of particulate matter with exhaust gases (EG), determined by compact (partial flow) and reference (full flow) systems should not exceed $\pm 5\%$ [1, 2]. When using compact tunnels to measure the PM index, a methodological error arises in measuring this value - δPM_i , due to a change in the temperature of diluted HS in the tunnel, on which the mass of the soluble organic fraction (SOF) in the PM composition depends [3-5]. The δPM_i error can be eliminated by using sample temperature controllers in compact systems that provide the conditions for dilution of the EG corresponding to the reference system. Since such regulators are expensive, high-tech devices, the installation of which complicates and increases the cost of measuring systems, the feasibility of their use should be investigated.

Formulation of the problem

The purpose of the work was to assess the feasibility of sample temperature control in compact systems - mini- and microtunnels based on studies of their accuracy, taking into account the methodological error in measuring the PM index. To achieve this goal, the following tasks were solved: 1) analysis of literary sources on the research topic; 2) development of mathematical models for determining the temperature of a sample of diluted EG in the tunnel and the resulting

measurement error of the PM index - δPM_i ; 3) study of the feasibility of sample temperature control in mini- and microtunnels.

Analysis of recent research and publications

In accordance with the requirements of regulatory documents - UNECE Regulation R-49, international standard ISO 8178, etc. measurement of mass emissions of PM from automotive diesel engines can be carried out using various measuring systems [1]: reference full-flow tunnels with 1 and 2-fold dilution of EG with clean air and compact partially flow tunnels, which are divided into minitunnels (have a diameter of 7.5 ... 12 cm and a length of 75...120 cm) and micro-tunnels (they have a diameter of 2.5...4 cm and a length of 25...40 cm). The best-known partially flow tunnels include: a minitunnel with an isokinetic sampler MT 474 (AVL), a multi-pipe type minitunnel (Mitsubishi), microtunnels with a differential method for determining the mass flow of EG - SPC 472 (AVL), PTR 200 [6-9].

To determine the normalized environmental indicator PM - the average operational mass emission of PM from the EG, bench tests of automotive diesel engines are carried out according to regulated test cycles, consisting of normalized engine operation modes with specified values of the crankshaft speed - n , engine shaft load - L , weight factor WF , taking into account the relative time of operation of the diesel engine in the mode during operation, and the duration of the test mode - τ . At the same time, various modes of diluting EG by air can be used in tunnels: D1 - mode with a constant mass flow rate of diluted EG or CVS-mode;

D2 - CVS-mode with external air cooling of the tunnel; D3 - mode with a constant dilution factor of EG; D4 - mode with a constant dilution ratio of the EG and external air cooling of the tunnel.

The degree of influence of the temperature of the sample in the tunnel on the controlled mass emission of PM can be estimated from the results of experimental studies of foreign and domestic authors [7,9,10], indicating the following: 1) an increase in the temperature of diluted EG in front of the filters - t_f leads to a decrease in the PM emission controlled by the weight of the PM sample - m_f and vice versa; 2) the influence of temperature t_f on the value of m_f can be taken into account using the established empirical linear dependences [7, 10]; 3) the value of the coefficient of proportionality of these dependencies depends on the mode of operation of the engine: with an increase in diesel power, their value decreases.

Presentation of the main material of the study

At the heart of the mathematical model for determining the temperature of a sample of diluted EG in the tunnel is t_f . the heat balance equation for the process of heat exchange of heated gas in a cylindrical

pipeline with ambient air was used [11]. As a result of the transformation of this equation, the main calculation formula was obtained to determine the temperature of the gas flow at the end of the pipelines for the flow of diluted EG. Sequential calculation of the final temperatures of gas flows in all pipelines of the EG dilution system makes it possible to determine the sample temperature before the filter - t_f .

The mathematical model for determination of the resulting error of PM indicator measurements - δPM provides determination of this quantity as sum of its instrumental - δPM_{in} and methodical - δPM_t components: The magnitude δPM_{in} is determined by the dependence for calculation of the error of indirect measurement result [10]. The error δPM_t is numerically equal to the relative deviation of the controlled mass emission of PM determined at the actual temperature t_{fi} from the mass emission of PM determined at the temperature t_{foi} , taken as the reference and corresponding to the dilution of HB in the reference system at $t_{dil} = 20$ °C, $t_{f(max)} = 52$ °C [12].

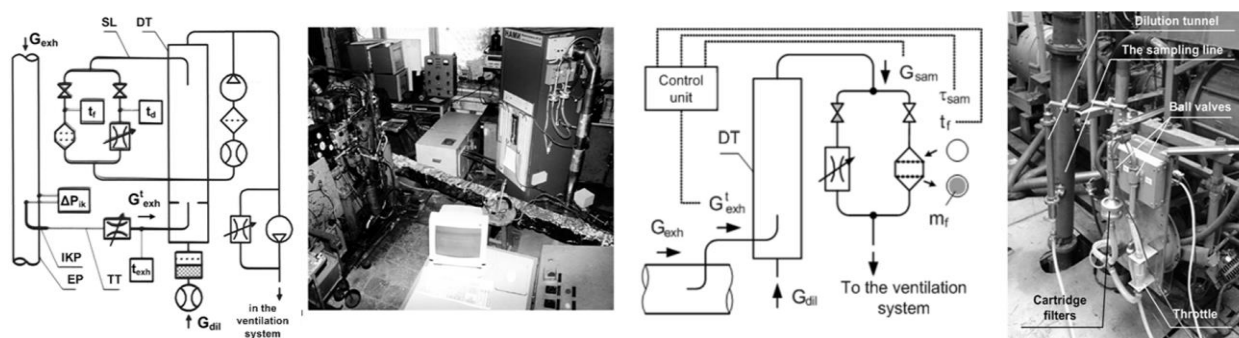


Fig. 1. Schematic diagrams and general views of the MT-1 minitunnel and MKT-2 microtunnel [5]

Studies of the feasibility of regulating the temperature of the sample in mini- and microtunnels were carried out on the criterion of relative deviation of the results of measurements of the RM by partial-flow and reference systems - δPM^* . Based on the results of environmental tests of diesels 1Ch12/14, equipped with a minitunnel MT-1, and 4ChN12/14, equipped with a microtunnel MKT-2 (fig. 1) [5, 10, 12] on a 13-stage ESC cycle using these mathematical models calculated calculations of absolute temperature deviations samples in a full-flow system with a diameter of 46 cm from similar temperatures in a minitunnel with a diameter of 10 cm and a microtunnel with a diameter of 3 cm - Δt_f , as well as the resulting methodological errors in measuring mass emissions of PM - m_f (fig. 2).

The results of the studies indicate the following: thermal conditions of dilution of hydrogen sulfide in a

minitunnel and a reference system are approximately equal: deviations of sample temperatures in these systems are less than 0.7 °C, resulting in methodical errors of PM measurements do not exceed 0.4 % and do not affect significantly the resulting error of the tunnel; thermal conditions of hydrogen sulfide dilution in a microtunnel and a reference system have significant differences: sample temperature deviations in these systems reach 2.5 °C, the resulting methodological errors of RM measurements are 1.6 - 1.7%, which leads to an increase in the resulting error up to $\pm 5.9\%$. Thus, adjustment of the sample temperature in minitunnels can be not used, but in a microtunnel it is expedient and allows to provide the necessary accuracy of PM measurements.

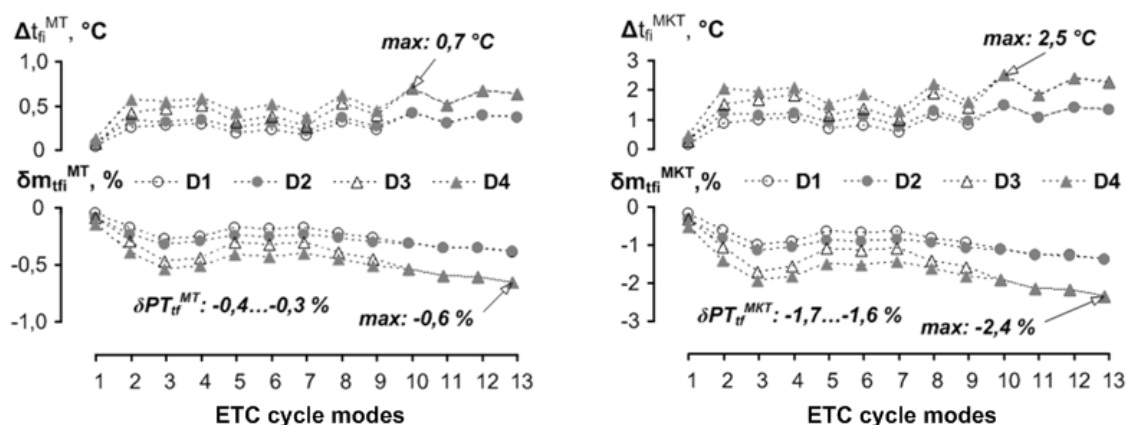


Fig. 2. Results of experimental studies of the accuracy of mini- and microtunnels

Conclusions

1. Based on the results of the analysis of regulatory documents - UNECE Rules R-49, R-96, international standard ISO 8178, etc., world and domestic experience in the use of dilution tunnels, the following were established: technical characteristics and operating conditions of reference full-flow and partial-flow tunnels, empirical dependences of the degree of temperature impact samples in the tunnel for the accuracy of measurements of mass emissions of PM in different operating modes of the diesel engine.

2. Mathematical models have been developed to determine: the temperature of a sample of EG diluted with air in tunnels of various types, the resulting error in determining the average operational PM emission - the PM indicator, taking into account the influence of the sample temperature in the tunnel on the accuracy of PM measurements.

3. Based on the test results of diesel engines 1Ch12/14 and 4ChN12/14 in the ESC cycle and the developed mathematical models, computational studies were carried out to assess the effect on the accuracy of a minitunnel and a microtunnel with diameters of 10 cm and 3 cm, respectively, of the temperature regimes of sample preparation, which were compared with a diameter of 46 cm. The results of the research proved the expediency of controlling the temperature of the sample in the microtunnel to eliminate significant methodological errors in the measurements of the PM index, which amount to -1.6 ... -1.7%. In the minitunnel, the corresponding errors are not significant: -0.3 ... -0.4%, so there is no need to control the sample temperature in this system.

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Полив'ячук Андрій Павлович – доктор техн. наук, проф., професор кафедри екології, хімії та технологій захисту довкілля Вінницького національного технічного університету, Вінниця, Україна; e-mail – app.prosperity@gmail.com; <http://orcid.org/0000-0002-9966-1938>;

Крещенецький Володимир Леонідович – канд. техн. наук, доцент, доцент кафедри автомобілів та транспортного менеджменту Вінницького національного технічного університету, Вінниця, Україна; e-mail – rozrah@ukr.net;

Антонюк Олег Павлович – канд. техн. наук, старший викладач кафедри автомобілів та транспортного менеджменту Вінницького національного технічного університету, Вінниця, Україна; e-mail – AntonukOP@gmail.com;

Митко Микола Васильович – канд. техн. наук, старший викладач кафедри автомобілів та транспортного менеджменту Вінницького національного технічного університету, Вінниця, Україна; e-mail – mytko@vntu.edu.ua;

Дмитрієва Алла Володимирівна – асистент кафедри автомобілів та транспортного менеджменту Вінницького національного технічного університету, Вінниця, Україна; e-mail – dmitrieva1963@ukr.net.

ПІДВИЩЕННЯ ТОЧНОСТІ СИСТЕМ ГРАВИМЕТРИЧНОГО КОНТРОЛЮ ТВЕРДИХ ЧАСТИНОК У ВІДПРАЦЬОВАНИХ ГАЗАХ ТРАНСПОРТНИХ ДИЗЕЛІВ

А.П. Полив'ячук, В.Л. Крещенецький, О.П. Антонюк, М.В. Митко, А.В. Дмитрієва

Проаналізовано вимоги нормативних документів – Правил ЄЕК ООН R-49, R-96, міжнародного стандарту ISO 8178 та ін. щодо технічних характеристик та умов використання еталонних повнопотокових та альтернативних частково-потокових систем (тунелів) для розбавлення відпрацьованих газів транспортних дизелів повітрям і проведення гравіметричного контролю вмісту в них твердих частинок. Досліджено світовий та вітчизняний досвід експлуатації розбавляючих тунелів різних типів – повнопотокових з 1-ю і 2-ма лініями розбавлення та частково-потокових міні- і мікро- тунелів, що дозволило встановити емпіричні залежності для оцінювання ступенів впливу температурних режимів відбору газових проб на точність вимірювань масових викидів твердих частинок на різних режимах роботи дизеля. Розроблено математичні моделі для визначення температур проби розбавлених відпрацьованих газів в тунелях різних типів та оцінювання результуючої похибки вимірювання нормованого середньоексплуатаційного викиду дизельних твердих частинок – показника РМ. На основі результатів екологічних випробувань транспортних дизелів 1Ч12/14 та 4ЧН12/14 за 13-ступінчастим випробувальним циклом ESC та розроблених математичних моделей проведено розрахункові дослідження з оцінювання впливу на точність мінітунелю з діаметром 10 см та мікротунелю з діаметром 3 см температурних режимів пробовідбору, які порівнювались з режимами еталонного тунелю з діаметром 46 см. Результати досліджень довели доцільність регулювання температури проби в мікротунелі для підвищення його точності шляхом усунення суттєвих методичних похибок вимірювань показника РМ, які складають -1,6 ... -1,7 %. Встановлено, що в мінітунелі відповідні похибки є не суттєвими і складають -0,3 ... -0,4 %, що свідчить про відсутність потреби в регулюванні температури проби в цій системі.

Ключові слова: транспортний дизель; екологічна діагностика; відпрацьовані гази; тверді частинки; розбавляючий тунель.