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Determination of the Convergence of Intra-Laboratory Measurements of Dust Content on a Construction Site

Elena A. Korol [1], **Evgeniy N. Degaev** [1] ✉, **Sergey L. Pushenko** [2]
[1] National Research Moscow State University of Civil Engineering, Moscow, Russian Federation
[2] Don State Technical University, Rostov-on-Don, Russian Federation
✉ degaev@inbox.ru

Abstract

Introduction. Intra-laboratory comparison tests play an important role in ensuring the quality and reliability of research outcomes in laboratories. These tests allow researchers to evaluate the accuracy and reproducibility of the methods they use in their work, as well as to identify potential sources of error and inconsistency. The results of these tests are shared with experts to confirm competence within the accreditation. Typically, comparison tests are carried out in laboratory conditions in a familiar and calm environment for the testers. However, when laboratories conduct research as part of a special assessment of working conditions (SAWC) they are required to conduct on-site comparisons at real-world facilities, where customers may unwittingly disrupt the process and directly affecting the quality of the measurements. The aim of this study is to evaluate the quality of on-site intra-laboratory comparison tests using the example of determining the dust content in a bricklayer's work environment on a construction site, and to determine the minimum number of measurements necessary and sufficient for this purpose.

Materials and Methods. To determine the dustiness of the bricklayer's workplace, a weighing method was used. This involved collecting dust on filters and then weighing them to determine the concentration. The quality assessment of intra-laboratory tests was conducted in accordance with GOST R ISO 5725-1-2002 "Accuracy (trueness and precision) of measurement methods and results. Part 1. General principles and definitions".

Results. At the bricklayer's workplace, a 1.6-fold excess of the one-time maximum permissible dust concentration was detected. The average dust concentration at the workplace under study was: $K_{p2} = 9.57 \pm 0.81$ mg/m^3, the convergence of the results obtained was $r = 8.68\%$, the relative error $\delta = 8.50\%$. It was revealed that the maximum allowable difference between the results of the two tests was 0.84 mg/m^3. The difference in direct measurements of the mass of the two samples should be no more than 0.1 mg.

Discussion and Conclusion. The results obtained demonstrated the possibility of conducting a minimum number of measurements that, under reproducible conditions, are considered satisfactory and could be provided to experts for confirming the competence of the laboratory. As part of a special assessment of working conditions, employees of the object under study are recommended to use personal respiratory protection equipment that offers protection against highly dispersed dust particles.

Keywords: convergence, intra-laboratory control, dust content, construction site, workplace, special assessment of working conditions (SAWC)

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Научная статья

Определение сходимости внутрилабораторных результатов измерений запыленности строительной площадки

Е.А. Король [1], **Е.Н. Дегаев** [1] ✉, **С.Л. Пушенко** [2]

[1] Национальный исследовательский Московский государственный строительный университет, г. Москва, Российская Федерация

[2] Донской государственный технический университет, г. Ростов-на-Дону, Российская Федерация

✉ degaev@inbox.ru

Аннотация

Введение. Внутрилабораторные сличительные испытания являются важным и актуальным мероприятием для обеспечения качества и достоверности результатов исследований в лабораториях. Они позволяют оценить точность и воспроизводимость применяемых в лаборатории методов, а также выявить возможные источники ошибок и несоответствий в ее работе. Результаты внутрилабораторных сличительных испытаний предоставляются экспертам при подтверждении компетентности в рамках аккредитации. Как правило, сличительные испытания проводят в лабораторных условиях в привычной и спокойной для испытателей обстановке. Однако лаборатории, проводящие исследования в рамках специальной оценки условий труда (СОУТ), вынуждены проводить выездные сличительные испытания на реальных объектах, где за испытаниями наблюдают заказчики, которые невольно отвлекают работников лаборатории, что напрямую влияет на качество измерений. Целью данной работы является оценка качества проведения выездных внутрилабораторных сличительных испытаний на примере определения запыленности рабочего места каменщика на строительной площадке и определение минимально необходимого и достаточного для этого количества измерений.

Материалы и методы. Для определения запыленности рабочего места каменщика использовался весовой метод, который заключается в сборе пыли на фильтры с последующим взвешиванием и определением концентрации. Оценка качества проведения внутрилабораторных испытаний производилась согласно ГОСТ Р ИСО 5725-1-2002 «Точность (правильность и прецизионность) методов и результатов измерений. Часть 1. Основные положения и определения».

Результаты исследования. На рабочем месте каменщика выявлено превышение разовой предельно допустимой концентрации пыли в 1,6 раза. Средняя концентрация пыли на исследуемом рабочем месте составила: $К_{п2}$ = 9,57 ± 0,81 мг/м^3, сходимость полученных результатов, r = 8,68 %, относительная погрешность, δ = 8,50 %. Выявлено, что максимально допустимая разница результатов двух испытаний составляет 0,84 мг/м^3. Разница прямых измерений массы двух образцов должна быть не более 0,1 мг.

Обсуждение и заключение. Полученные результаты показали возможность проведения минимального количества измерений, что по условиям воспроизводимости испытания признаются удовлетворительными и могут предоставляться экспертам для подтверждения компетентности лаборатории. В рамках СОУТ работникам исследуемого объекта рекомендуется использовать средства индивидуальной защиты органов дыхания, предохраняющие от высокодисперсной пыли.

Ключевые слова: сходимость, внутрилабораторный контроль, запыленность, строительная площадка, рабочее место, специальная оценка условий труда (СОУТ)

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Introduction. Measurements on dustiness of workplaces are carried out as part of a special assessment of working conditions (SAWC) at the construction site in order to identify and assess harmful and hazardous production factors, as well as to develop measures to eliminate or minimize them [1]. The results of a special assessment of working conditions are the basis for the development and implementation of appropriate measures to improve working conditions [2]. This may be a change in work processes, the use of new technologies, updating equipment or improving sanitary conditions [3]. It is important to implement these measures taking into account the opinions of employees and meeting their needs [4].

Special assessment of working conditions on a construction site has its own characteristics related to the nature and working conditions [5]. Such features include:

– outdoor work, which can lead to exposure to adverse weather conditions;

– use of construction machinery and equipment that can create noise, vibration, dust and other contaminants;

– work at height, which requires special training and certification of personnel;

– work with various materials and substances that may be dangerous to the health of employees;

– need to comply with occupational health and safety requirements, including the use of personal protective equipment.

The result of SAWC is that classes of working conditions for each profession are established as well as measures are recommended to minimize the identified risks and consequences of the influence of harmful factors [6]. According to SAWC, the management of the organization develops measures to improve working conditions and safety. The amount of additional payments for workers employed in production with unfavorable or risky conditions is also determined [7]. In instrumental study of workplaces, measurements and analysis of noise, degree of dustiness, natural and artificial illumination, temperature, humidity, etc. are carried out [8].

Organizations with appropriate accreditation and experience have the right to conduct SAWC. These organizations can be either specialized organizations or laboratories engaged in studying working conditions.

In accordance with Federal Law No. 426 dated December 28, 2013 "On special assessment of working conditions", an organization engaged in SAWC must:

– have at least five full-time employees with a valid certificate for the right to conduct SAWC;

– be registered in the register of organizations conducting SAWC, which is maintained by the Ministry of Labor and Social Protection of the Russian Federation;

– have a quality management system (QMS) conforming to GOST ISO/IEC 17025-2019 "General requirements for the competence of testing and calibration laboratories" and GOST R 54934-2012/ OHSAS 18001:2007 "Occupational health and safety management systems. Requirements";

– have an accredited testing laboratory that carries out research and measurements of hazardous and harmful factors.

Testing laboratory (TL) must have a valid accreditation certificate, an appropriate accreditation scope reflecting the possibility of studying harmful and hazardous factors of production and working conditions, as well as certified testing equipment (TE) and certified measuring instruments (MI) [9]. According to Decree of the Government of the Russian Federation dated November 26, 2021 No. 2050 "On approval of the rules for accreditation in the national accreditation system ..." accredited laboratories, as part of the confirmation of competence, must conduct comparative tests to determine the convergence of measurement results. The convergence of measurement results during a special assessment of working conditions is one of the key indicators that determine the quality of measurements.

Previous research in this area has mainly focused on interlaboratory comparative tests (ILC) and has not considered intra-laboratory comparative tests. Thus, in the work of A.V. Kozlov, the results of ILC of geosynthetic material are presented [10]. The author points out the expediency of rationing the requirements of precision tests. In the study of M.M. Lekomtseva and E.V. Shendaleva the analysis of the results of ILC of petroleum products was carried out, according to the results of which it was recommended to convert data into a linear dependence in order to obtain a constant value of the standard deviation [11]. Yasin Durgut's work notes that interlaboratory comparative tests conducted in accordance with GOST ISO/IEC 17025-2019 "General requirements for the competence of testing and calibration laboratories" are performed more efficiently than comparative measurements in accordance with GOST ISO/IEC 17043 "Conformity assessment. General requirements for proficiency testing" [12].

Meanwhile, according to GOST ISO/IEC 17025-2019 "General requirements for the competence of testing and calibration laboratories", the results of intra-laboratory comparative tests are also very important, since they are used to carry out corrective measures, improve quality of laboratory work and increase accuracy of the results [13]. Therefore, the aim of this work is to assess the quality of on-site intra-laboratory comparison tests. Such an assessment is presented by the example of determining the dustiness of a bricklayer's workplace on a construction site. Laboratories operating within the SAWC framework are forced to conduct on-site intra-laboratory comparative tests, and their conditions differ significantly from the laboratory ones. Laboratory staff is limited by the time of admission to the facility, so it is important for them to perform research not only qualitatively, but also with a minimum number of tests. In this regard, the task of the authors of the article was to determine the minimum necessary and sufficient number of such tests.

Materials and Methods. General sanitary and hygienic requirements for the air of the working area, as well as methods for monitoring microclimate indicators and the content of harmful substances in the air, are regulated by GOST 12.1.005-88 "Interstate Standard. Occupational safety standards system. General sanitary requirements for working zone air". To determine the dust content, a weight method was used[1], which consists in collecting dust on filters, followed by weighing and determining the concentration.

Mass concentration K_p of dust is determined by formula:

$$K_p = \frac{(m_n - m_0)\cdot 1000}{V_{20}}, \tag{1}$$

where K_p — concentration of dust in the air, mg/m^3; m_0 — mass of the clean filter, mg; m_n — mass of the filter with settled dust particles, mg; V_{20} — volume of air brought to standard conditions, dm^3.

$$V_{20} = \frac{V_t \cdot 293 \cdot P}{(273+T)\cdot 101.33}, \tag{2}$$

where V_t — volume of air passed through the filter, dm^3; P — atmospheric pressure, kPa; T — workplace air temperature, °C.

According to the recommendations of the state system for ensuring the uniformity of measurements[2], a reduction method can be used to process the results of determining the dustiness of the workplace, which assumes the presence of the values of the measured arguments obtained as a result of multiple measurements.

The result of indirect measurement $\tilde{A}$ is found by formula:

$$\tilde{A} = \sum_{j=1}^{L} \frac{A_j}{L}, \tag{3}$$

where L — number of partial values of the measured value; A_j — *j-th* value of the measured value; j — serial measurement number from 1 to L.

Mean square deviation $S(\tilde{A})$ of random errors of the indirect measurement result is calculated using the following formula:

$$S(\tilde{A}) = \sqrt{\sum_{j=1}^{L} \frac{(A_j - \tilde{A})^2}{L(L-1)}}. \tag{4}$$

With a normal distribution of individual values of the measured value, the confidence limits of random errors are determined by formula:

$$\Delta = t_p \cdot S(\tilde{A}), \tag{5}$$

where t_p — Student's coefficient, depending on the confidence probability and the number of observation results.

Precision is estimated by the indicator of repeatability (relative standard deviation of repeatability), σ_r, and by the indicator of accuracy (limits of relative error), δ:

$$\sigma_r = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \tilde{x})^2}{n-1}}, \tag{6}$$

where x_i — *i-th* test result obtained under repeatability conditions; $\tilde{x}$ — arithmetic mean of n test results under conditions of repeatability (convergence).

$$\delta = \frac{\Delta}{\tilde{x}} 100\% \le 25\%. \tag{7}$$

The percentage of convergence is determined in accordance with expression:

$$r = \frac{\sigma_r}{\tilde{x}} 100\%. \tag{8}$$

To evaluate the convergence of the results of two measurements, it is necessary to use formula:

$$r_2 = \frac{|x_1 - x_2|}{\tilde{x}} 100\%, \tag{9}$$

where x_1, x_2 — results of two parallel measurements.

The measurement results obtained under convergence conditions are considered satisfactory if the obtained convergence r is less than or equal to the normative convergence r_{norm}:

$$r \le r_{\text{norm}} = 15\%. \tag{10}$$

[1] *Metodika izmerenii massovoi kontsentratsii pyli gravimetricheskim metodom dlya tselei spetsial'noi otsenki uslovii truda.* MI APFD-18.01.2018. URL: https://normativ.kontur.ru/document?moduleId=1&documentId=390372 (accessed: 25.11.2023). (In Russ.).

[2] *Rekomendatsiya. Gosudarstvennaya sistema obespecheniya edinstva izmerenii. Izmereniya kosvennye. Opredelenie rezul'tatov izmerenii i otsenivanie ikh pogreshnostei. MI 2083–90.* Moscow: Committee of Standardization and Metrology of the USSR; 1991. URL:https://znaytovar.ru/gost/2/MI_208390_GSI_Izmereniya_kosve.html (accessed: 25.11.2023). (In Russ.).

Expression (8) is taken as the result:

$$x = \tilde{x} \pm \Delta \,. \tag{11}$$

The minimum number of observations depends on the coefficient of variation, i.e. the ratio of the standard deviation to the average value, and is selected previously from the experimental data. The error in determining the average value (statistical measurement error) must be sought under the assumption that the distribution law of the general set of measurements is normal. If we know the error and confidence probability, it is possible to unambiguously establish a confidence interval for the average value and estimate the maximum statistical error of measurements as the ratio of half the difference between the boundaries of the error of the average value to the average value from the experimental data [14].

Results. Measurements were carried out to determine the dust content of the construction site during the construction of an apartment building. Sampling was carried out at the bricklayer's workplace in the masonry wall area with AFA type filters (analytical aerosol filters) using two PU-4E aspirators, providing sampling with a given volume flow through an absorber through four parallel channels. To establish the statistical error of measurements by instruments and laboratory staff at a given confidence probability P = 0.95 eight parallel measurements were performed, the results of which are shown in Table 1.

Table 1

Results of eight parallel tests

Measurement no.	Filter weight, m_0, mg	Filter weight, m_n, mg	Air consumption, l/min	Atmospheric pressure, kPa	Measurement time, min.	Air temperature in the work area, °C	Partial values of dust concentration, mg/m^3	Average dust concentration, mg/m^3	Mean square deviation, mg/m^3	Relative error, δ, %	Convergence of results, r, %
n=8											
No.1	30965.6	30966.5	2	102.2	60	21.1	7.46	9.33	1.39	10.29	14.85
No.2	31346.8	31347.8	2	102.2	60	21.1	8.29				
No.3	33980.5	33981.6	2	102.2	60	21.1	9.12				
No.4	35572.3	35573.6	2	102.2	60	21.1	10.78				
No.5	34926.9	34928.3	2	102.2	60	21.1	11.61				
No.6	30477.7	30479.0	2	102.2	60	21.1	10.78				
No.7	32678.4	32679.5	2	102.2	60	21.1	9.12				
No.8	32678.4	32679.6	2	102.2	60	21.1	9.95				

To check whether the data obeyed the normal distribution law, a frequency histogram was constructed as one of the ways to visually represent the distribution of data (Fig. 1). The histogram has the shape of a bell and is close to the curve of normal distribution (Fig. 2)

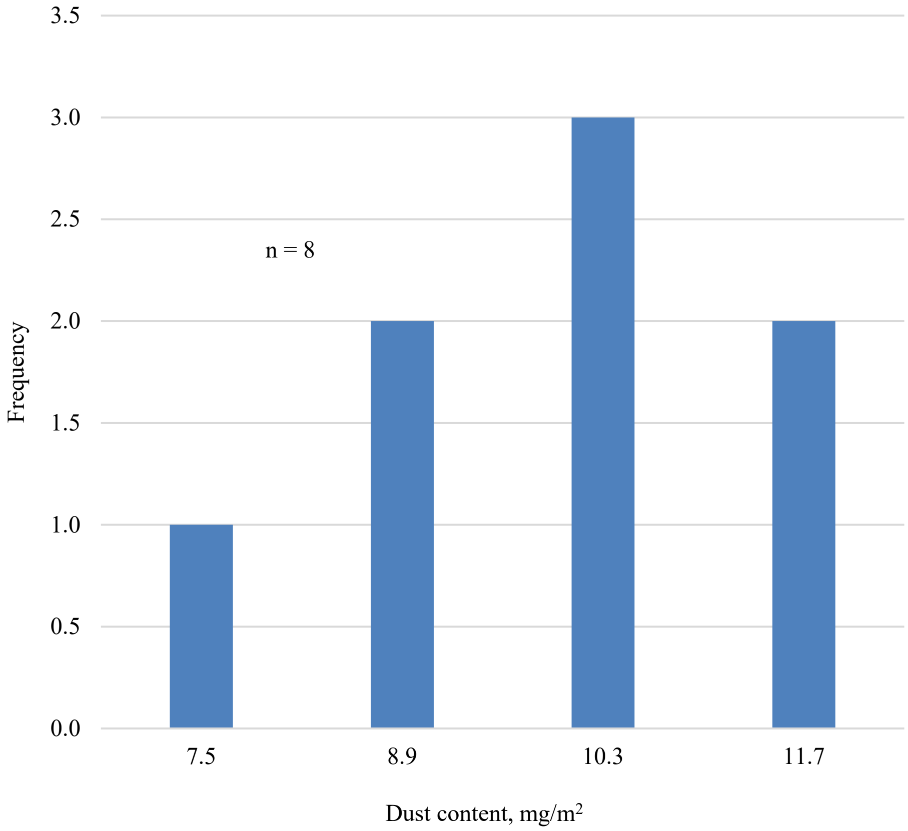

Fig. 1. Frequency histogram at $n = 8$

The average value and confidence interval of the measurements were calculated and shown on the graph of density functions of normal distribution (Fig. 2).

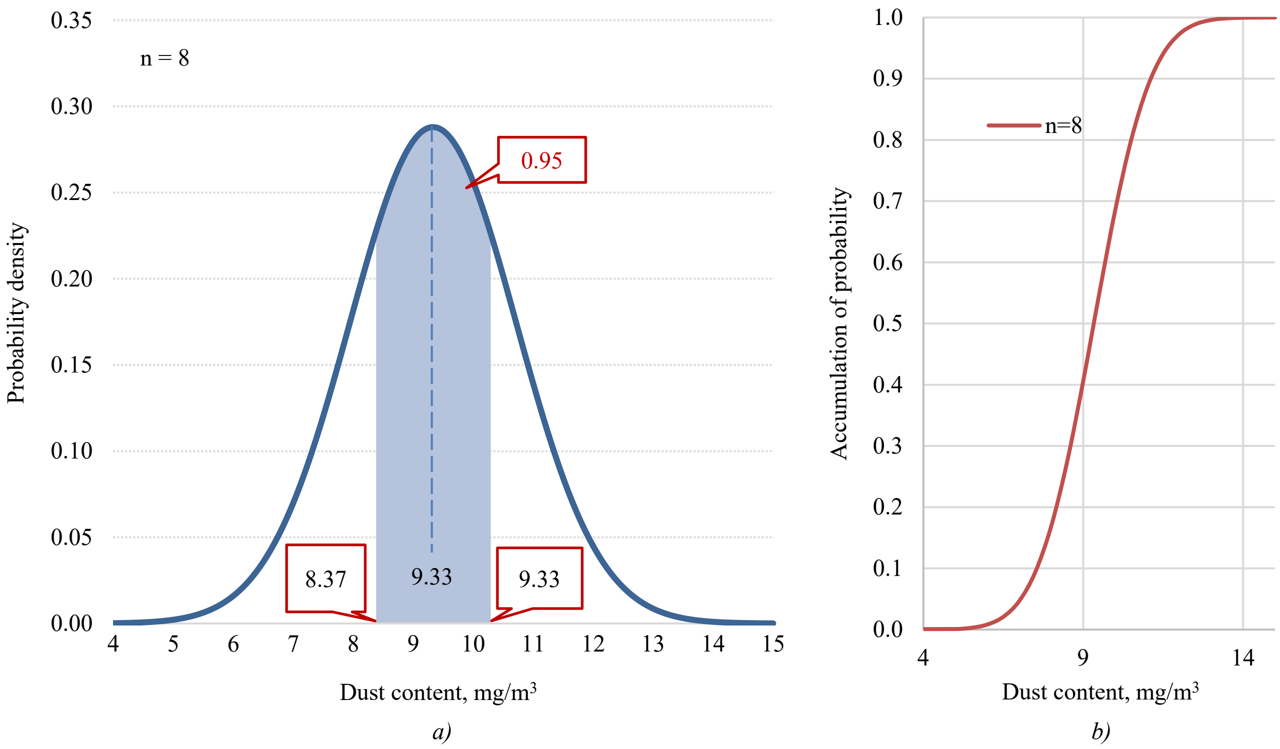

Fig. 2. Graphs of normal distribution a$n = 8$: *a* — density function of normal distribution; *b* — integral distribution function

The average value is taken as the result, indicating the confidence interval:

$$K_{p8} = 9.33 \pm 0.96 \text{ mg}/\text{m}^3 .$$

To determine the minimum number of measurements, the coefficient of variation, the average sampling error and the marginal sampling error were found (Fig. 3). The maximum statistical error was 0.26 mg/m^3. $\mu = \pm 1.16$ mg/m^3

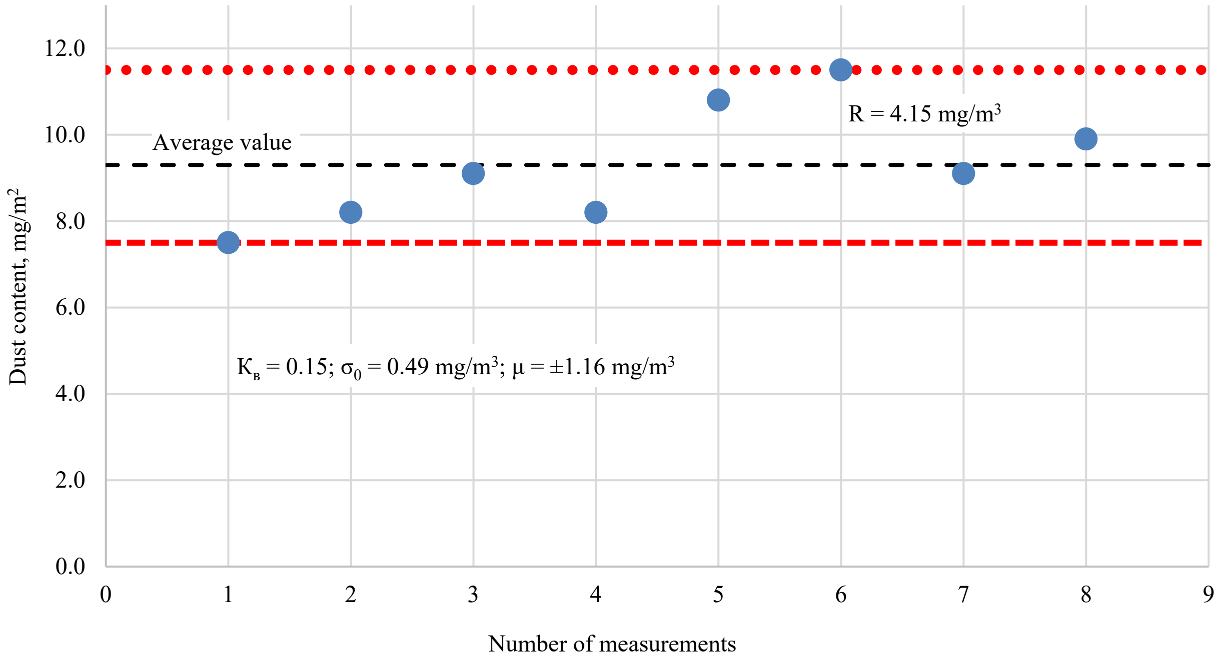

Fig. 3. Scope of measurement results

The minimum number of measurements is determined by formula [11]:

$$n_{min} = \frac{t^2 K_{\text{в}}^2}{\delta^2}, \tag{12}$$

$$n_{min} = 1.20 \approx 2.$$

According to the obtained value of the minimum number of tests, two parallel tests were carried out to determine dust concentration at the bricklayer's workplace (Table 2).

Table 2

Results of two parallel tests

Measurement no	Filter weight, m_0, mg	Filter weight, m_n, mg	Air consumption, l/min	Atmospheric pressure, kPa	Measurement time, min.	Air temperature in the work area, °C	Partial values of dust concentration, mg/m^3	Average dust concentration, mg/m^3	Mean square deviation, mg/m^3	Relative error, δ, %	Convergence of results, r, %
n=2											
No.1	34563.8	34565.0	2	102.2	60	22.0	9.98	9.57	0.59	8.50	8.68
No.2	30654.3	30655.4	2	102.2	60	22.0	9.15				

Confidence interval of the results of two tests to determine dust concentration with a probability of 0.95 was 0.81 mg/m^2 (Fig. 4).

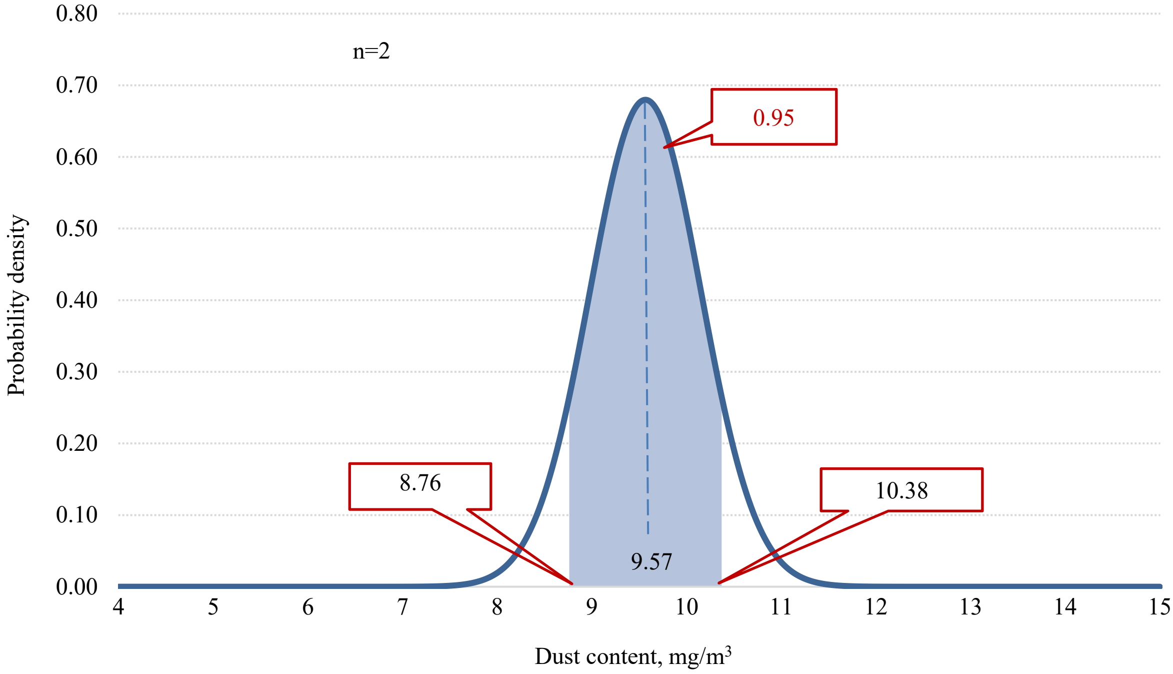

Fig. 4. Density function of normal distribution

According to convergence conditions in conformity with GOST R ISO 5725-1-2002 "Accuracy (trueness and precision) of measurement methods and results. Part 1. General principles and definitions" and GOST R 51672-2000 "Metrological ensuring of product testing for the assurance of conformity. General principles" the results of parallel measurements can be considered satisfactory, since conditions (7) and (10) are fulfilled (Fig. 5):

$$r_2 = 8.68\% < r_{\text{norm}} = 15\%,\ \delta_2 = 8.50\% < \delta_{\text{norm}} = 25\%.$$

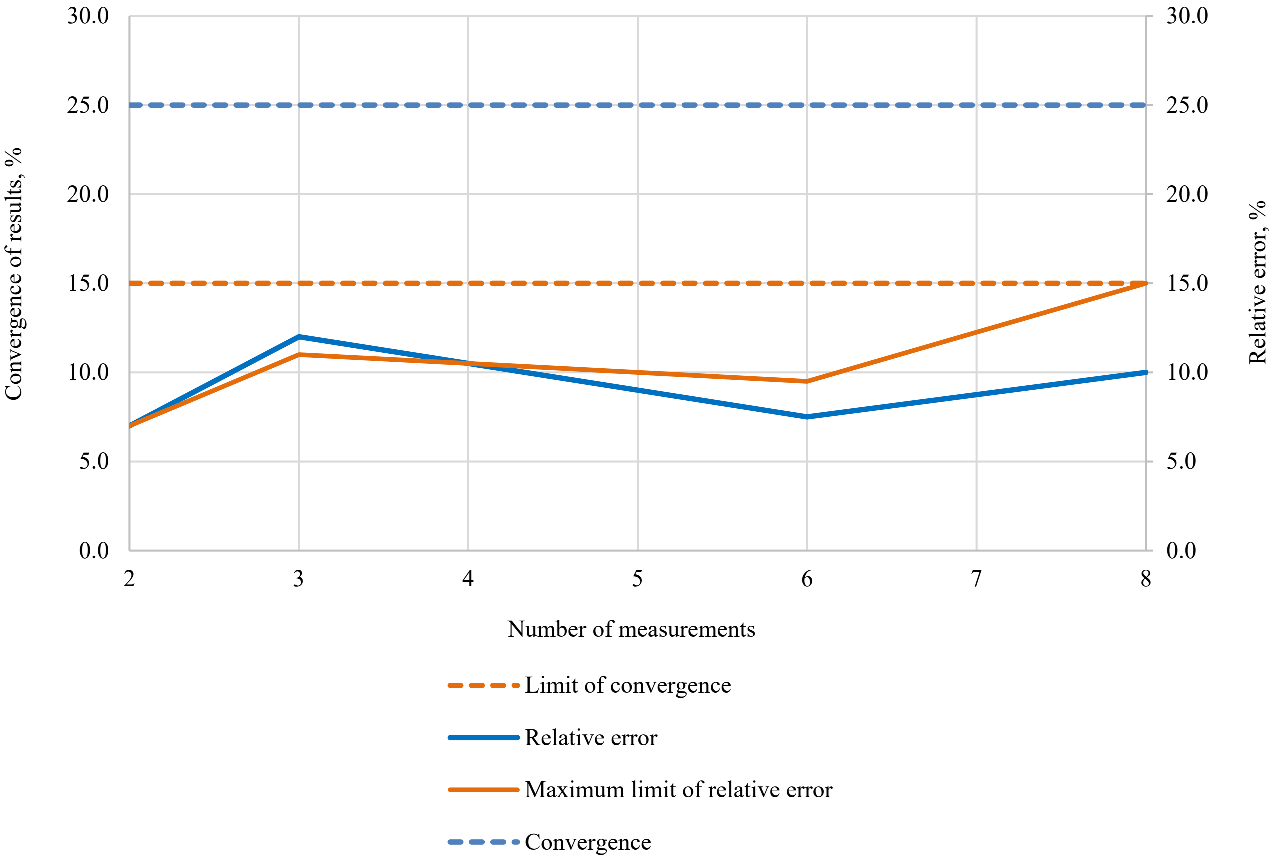

Fig. 5. Dependence of the convergence of measurement results and relative error on the number of tests

Based on the results of processing, it is accepted:

$$K_{p2} = 9.57 \pm 0.81 \text{ mg/m}^3.$$

Determination of dust concentration by the weight method has a sufficiently high component of errors of measuring instruments used and operations performed. The maximum allowable difference between the results of two measurements is 0.84 mg/m^3. The difference in direct measurements of the mass of two samples should be no more than 0.1 mg. With a mass difference of 0.2 mg, the convergence rate of the results of two parallel measurements becomes more than 18% and does not meet the precision conditions. When conducting tests to determine dust content of the considered technique, it is possible to limit two parallel measurements, while the measurement error will be equal to the instrumental error.

Construction dust is classified as low-hazard (Class IV), the single maximum permissible concentration (MPC) is 6 mg/m^3, the daily concentration is 10 mg/m^3. According to the test results, a 1.6-fold excess of the one-time maximum permissible concentration was revealed. To reduce the concentration of dust at the bricklayer's workplace, comprehensive measures are recommended to reduce dust formation on the construction site, since the main sources of dust are access roads, places of unloading and loading of building materials, as well as technological processes related to the processing and cutting of construction materials [15]. It is necessary to take measures to reduce the concentration of dust on the construction site and beyond [16].

Hygienic standard GN 2.1.6.3492-17 "Maximum permissible concentrations of pollutants in the atmospheric air of urban and rural settlements" establishes a single maximum permissible concentration of construction dust in urban air of no more than 0.5 mg/m^3.

Discussion and Conclusion. Determination of dust concentration by the weight method has a sufficiently high component of errors of measuring instruments used and operations performed. It was revealed that the maximum allowable difference between the results of two tests was 0.84 mg/m^3. The difference in direct measurements of the mass of two samples should be no more than 0.1 mg.

Processing of test results showed the possibility of carrying out two measurements to determine dustiness of the bricklayer's workplace on the construction site. The convergence of test results within the framework of laboratory competence confirmation is an important indicator of the quality of the assessment and indicates the reliability of the data obtained, therefore, it is recommended to use at least six measurements within the framework of intra-laboratory comparison tests [17]. The higher the convergence of the results, the less likely errors and inaccuracies in the assessment of working conditions. This, in turn, provides more objective information about the state of working conditions in the workplace and allows you to take reasonable measures to improve them [18].

Employees of the investigated facility are recommended to use personal respiratory protection equipment that protects against highly dispersed dust. To reduce the concentration of construction dust on the construction site, as well as outside it, it is necessary to spray the construction site with water to settle highly dispersed dust, to spray water on access roads, to wash the wheels of vehicles both at the entrance to the construction site and at the exit [19].

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About the Authors:

Elena A. Korol, Dr. Sci. (Eng.), Professor, Head of the Housing and Communal Sector Department, National Research Moscow State University of Civil Engineering (NRU MGSU) (26, Yaroslavskoe Shosse, Moscow, 129337, RF), SPIN-code: 3795-1053, ORCID, KorolEA@mgsu.ru

Evgeniy N. Degaev, Cand. Sci. (Eng.), Associate Professor of the Housing and Communal Sector Department, National Research Moscow State University of Civil Engineering (NRU MGSU) (26, Yaroslavskoe Shosse, Moscow, 129337, RF), SPIN-code: 1471-9700, ORCID, degaev@inbox.ru

Sergey L. Pushenko, Dr. Sci. (Eng.), Professor, Head of the Safety of Technological Processes and Productions Department, Don State Technical University (1, Gagarin Sq., Rostov-on-Don, 344003, RF), SPIN-code: 7292-1956, ORCID, slpushenko@yandex.ru

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Об авторах:

Елена Анатольевна Король, доктор технических наук, профессор, заведующий кафедрой жилищно-коммунального комплекса Национального исследовательского Московского государственного строительного университета (НИУ МГСУ) (129337, г. Москва, Ярославское шоссе, 26), SPIN-код: 3795-1053, ORCID, KorolEA@mgsu.ru

Евгений Николаевич Дегаев, кандидат технических наук, доцент кафедры жилищно-коммунального комплекса Национального исследовательского Московского государственного строительного университета (НИУ МГСУ) (129337, г. Москва, Ярославское шоссе, 26), SPIN-код: 1471-9700, ORCID, degaev@inbox.ru

Сергей Леонардович Пушенко, доктор технических наук, профессор, заведующий кафедрой безопасности технологических процессов и производств Донского государственного технического университета (344000, РФ, г. Ростов-на-Дону, пл. Гагарина, 1), SPIN-код: 7292-1956, ORCID, slpushenko@yandex.ru

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