SLOVENSKI STANDARD
SIST-TP CEN/TR 13205-3:2014

01-september-2014

Nadomešča:
SIST EN 13205:2002

Izpostavljenost na delovnem mestu - Ocenjevanje lastnosti merilnikov za merjenje koncentracij lebdečih delcev - 3. del: Analiza podatkov o učinkovitosti vzorčenja

Workplace exposure - Assessment of sampler performance for measurement of airborne particle concentrations - Part 3: Analysis of sampling efficiency data

Exposition am Arbeitsplatz - Bewertung der Leistungsfähigkeit von Sammlern für die Messung der Konzentration luftgetragener Partikel - Teil 3: Analyse der Daten zum Probenahmewirkungsgrad

Exposition sur les lieux de travail - Évaluation des performances des instruments de mesurage des concentrations d'aérosols - Partie 3: Analyse des données d'efficacité de prélèvement

Ta slovenski standard je istoveten z: CEN/TR 13205-3:2014

ICS:

13.040.30	Kakovost zraka na delovnem mestu	Workplace atmospheres

SIST-TP CEN/TR 13205-3:2014 **en,fr,de**

TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CEN/TR 13205-3

June 2014

ICS 13.040.30

Supersedes EN 13205:2001

English Version

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This Technical Report was approved by CEN on 14 January 2013. It has been drawn up by the Technical Committee CEN/TC 137.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. CEN/TR 13205-3:2014 E

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Foreword

This document (CEN/TR 13205-3:2014) has been prepared by Technical Committee CEN/TC 137 “Assessment of workplace exposure to chemical and biological agents”, the secretariat of which is held by DIN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document together with EN 13205-1, EN 13205-2, EN 13205-4, EN 13205-5 and EN 13205-6 supersedes EN 13205:2001.

EN 13205, *Workplace exposure — Assessment of sampler performance for measurement of airborne particle concentrations*, consists of the following parts:

— *Part 1: General requirements;*

— *Part 2: Laboratory performance test based on determination of sampling efficiency;*

— *Part 3: Analysis of sampling efficiency data* [Technical Report] (the present document);

— *Part 4: Laboratory performance test based on comparison of concentrations;*

— *Part 5: Aerosol sampler performance test and sampler comparison carried out at workplaces;*

— *Part 6: Transport and handling tests.*

Introduction

EN 481 defines sampling conventions for the particle size fractions to be collected from workplace atmospheres in order to assess their impact on human health. Conventions are defined for the inhalable, thoracic and respirable aerosol fractions. These conventions represent target specifications for aerosol samplers, giving the ideal sampling efficiency as a function of particle aerodynamic diameter.

In general, the sampling efficiency of real aerosol samplers will deviate from the target specification, and the aerosol mass collected will therefore differ from that which an ideal sampler would collect. In addition, the behaviour of real samplers is influenced by many factors such as external wind speed. In many cases there is an interaction between the influence factors and fraction of the airborne particle size distribution of the environment in which the sampler is used.

This Technical Report presents how data obtained in a type A test (see EN 13205-2) can be analysed in order to calculate the uncertainty components specified in EN 13205-2.

The evaluation method described in this Technical Report shows how to estimate the candidate sampler's sampling efficiency as a function of particle aerodynamic diameter based on the measurement of sampling efficiency values for individual sampler specimen, whether all aspirated particles are part of the sample (as for most inhalable samplers) or if a particle size-dependent penetration occurs between the inlet and the collection substrate (as for thoracic and respirable samplers).

The document shows how various sub-components of sampling errors due non-random and random sources of error can be calculated from measurement data, for example, for individual sampler variability, estimation of sampled concentration and experimental errors.

1 Scope

This Technical Report specifies evaluation methods for analysing the data obtained from a type A test of aerosol samplers under prescribed laboratory conditions as specified in EN 13205-2.

The methods can be applied to all samplers used for the health-related sampling of particles in workplace air.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1540, *Workplace exposure — Terminology*

EN 13205-1:2014, *Workplace exposure — Assessment of sampler performance for measurement of airborne particle concentrations — Part 1: General requirements*

EN 13205-2:2014, *Workplace exposure — Assessment of sampler performance for measurement of airborne particle concentrations — Part 2: Laboratory performance test based on determination of sampling efficiency*

3 Terms and definitions

For the purpose of this document, the term and definitions given in EN 1540, EN 13205-1 and EN 13205-2 apply.

NOTE With regard to EN 1540, in particular, the following terms are used in this document: total airborne particles, respirable fraction, sampling efficiency, static sampler, thoracic fraction, measuring procedure, non-random uncertainty, random uncertainty, expanded uncertainty, standard uncertainty, combined standard uncertainty, uncertainty (of measurement), coverage factor, precision and analysis.

4 Symbols and abbreviations

4.1 Symbols

4.1.1 Latin

$A\left(D_{\mathrm{A}},\sigma_{\mathrm{A}},D\right)$ relative lognormal aerosol size distribution, with mass median aerodynamic diameter D_{A} and geometric standard deviation σ_{A}, $[1/\mu\mathrm{m}]$

NOTE The word “relative” means that the total amount of particles is unity [-], *i.e.* $\int_0^\infty A\left(D_{\mathrm{A}},\sigma_{\mathrm{A}},D\right)\mathrm{d}\,D=1$.

A_p integration of aerosol size distribution A between two particle sizes, [-] – (polygonal approximation method)

$A_{t,p}$ integration of aerosol size distribution A between two particle sizes, calculated using set t of the simulated test particle sizes, [-] – (polygonal approximation method)

$b_{ipr}, b_{ipr}^{\mathrm{left}}, b_{ipr}^{\mathrm{right}}, b_{ipr}^{\mathrm{top}}, b_{ipr}^{\mathrm{front}}$ coefficients in Formula (19) to estimate the test aerosol concentration at a specific sampler position e.g. in a wind tunnel based on nearby concentrations (to the left, right, above and in front of) the sampler measured by thin-walled sharp-edged probes, [-]

b_q — regression coefficient q for calibration of particle counter/sizer or similar, [dimension depends on particle counter], (curve-fitting method)

C_{is} — sampled relative aerosol concentration, calculated to be obtained when using the candidate sampler individual s, for aerosol size distribution A at influence variable value ς_i, [-] – (curve-fitting method)

$C_{is,t}$ — sampled relative aerosol concentration, calculated to be obtained when using the candidate sampler individual s, for aerosol size distribution A at influence variable value ς_i, using simulated set t of test particle sizes, [-] – (curve-fitting method)

$\bar{C}_{i,t}$ — mean sampled relative aerosol concentration, calculated to be obtained when using the candidate sampler, for aerosol size distribution A at influence variable value ς_i, using simulated set t of test particle sizes, [-] – (polygonal approximation method)

$c_{\text{Ref}_{is[r]}}$ — correction factor for the measured efficiency values if the total airborne aerosol concentration varies between repeats, [-] – (curve-fitting method)

D — aerodynamic diameter, [µm]

D_{A} — mass median aerodynamic diameter of a lognormal aerosol size distribution A, [µm]

D_{A_a} — mass median aerodynamic diameter a of a lognormal aerosol size distribution A, [µm]

D_c — aerodynamic particle size of calibration particle c (c=1 to N_{C}), [µm] – (curve-fitting method)

$D_{\max}$ — diameter of the end of the integration range of the sampled aerosol, [µm] –and H

$D_{\min}$ — diameter of the beginning of the integration range of the sampled aerosol, [µm]

D_p — aerodynamic diameter of test particle p (p=1 to N_{P}), [µm]

$D_{t,p}$ — simulated test particle size, [µm]

D_u — aerodynamic particle size of small particles u (u=1 to N_{U}) for which the sampling efficiency is known to be e_0, [µm]– (curve-fitting method)

E_{ip} — expectation value of the efficiency for test particle size p at influence variable value ς_i, [-] – (polygonal approximation method)

${}^{\text{est}}E_{is}^{\text{inlet}}$ — fitted sampling efficiency curve (of the inlet stage) of the candidate sampler individual s at influence variable value ς_i, [-] – (curve-fitting method)

${}^{\text{est}}E_{is}^{\text{pen}}$ — fitted penetration curve (of the separation stage) of the candidate sampler individual s at influence variable value ς_i, [-] – (curve-fitting method)

${}^{\text{est}}E_{is}^{\text{tot}}$ — fitted sampling efficiency curve (of the combined inlet and penetration stages) of the candidate sampler individual s at influence variable value ς_i, [-] – (curve-fitting method)

${}^{\text{est}}E_{is,t}$ — fitted sampling efficiency curve of the candidate sampler individual s at influence variable value ς_i using simulated set t of N_{P} particle sizes, [-] – (curve-fitting method)

$e_{ipr[s]}$ and $e_{ips[r]}$ experimentally determined efficiency value, with notation for polygonal approximation and curve-fitting methods, respectively. The subscripts are for influence variable value ς_i, particle size p (p=1 to N_P), sampler individual s (s=1 to N_S) and repeat r (r=1 to N_R), [-] – (notation for polygonal approximation and curve-fitting methods, respectively)

e_0 known efficiency value for small particle sizes, [-] – (curve-fitting method)

$F_{\mathrm{LoF}_{is}}$ test variable for “lack of fit” for the regression model $\hat{E}_{is}$ for the sampling efficiency of candidate sampler individual s and influence variable value ς_i, [-] – (curve-fitting method)

$F_{\mathrm{CandSamplVar}_i}$ test variable for the check whether the individual sampler variability exceeds that of the uncertainty of the calculated concentrations, for influence variable value ς_i, [-]

$F_{0.95}\left(\nu_\mathrm{N}, \nu_\mathrm{D}\right)$ 95-percentile of F distribution with ν_N and ν_D degrees of freedom, [-]

$f_k\left(\Xi\right)$ functions (of Ξ) used to build the regression model of the efficiency curve (index k=1 to N_K), [-] – (curve-fitting method)

$f_k^\mathrm{inlet}\left(\Xi\right)$ functions (of Ξ) used to build the regression model of the efficiency curve of the inlet stage (index k=1 to N_K), [-] – (curve-fitting method)

$f_k^\mathrm{pen}\left(\Xi\right)$ functions (of Ξ) used to build the regression model of the penetration curve of the separation stage (index k=1 to N_K), [-] – (curve-fitting method)

$G_{\mathrm{LoF}_{is}}$ uncertainty inflation factor for the “lack of fit” uncertainty of the regression model for candidate sampler individual s and influence variable value ς_i, [-]

$G_{\mathrm{pe}_{is}}$ uncertainty inflation factor for the “pure error” uncertainty of the regression model for candidate sampler individual s and influence variable value ς_i, [-]

h_{ip}^left, h_{ip}^right, h_{ip}^top, h_{ip}^front nearby thin-walled sharp-edged probe concentrations measured in order to be able to estimate the test aerosol concentration at a specific sampler position, e.g. in a wind tunnel (to the left, right, above and in front of) the candidate sampler (see Formula (19)), [mg/m^3] or [1/m^3] depending on the application

${}^\mathrm{est}h_{ipr}$ total airborne aerosol concentration estimated from the sharp-edged probe values; the subscripts are for influence variable value i (i=1 to N_IV), particle size p (p=1 to N_P) and repeat r (r=1 to N_R)

N_C number of sizes for calibration particles – (curve-fitting method)

N_CR number of regression coefficients for calibration of particle counter/sizer or similar – (curve-fitting method)

N_IV number of values for the other influence variables at which tests were performed

N_K number of regression coefficients in the model for the candidate sampler – (curve-fitting method)

$N_\mathrm{K}^\mathrm{inlet}$ number of regression coefficients in the model (inlet stage) for the candidate sampler – (curve-fitting method)

$N_\mathrm{K}^\mathrm{pen}$ number of regression coefficients in the model of the penetration through the separation stage for the candidate sampler – (curve-fitting method)

N_{P}	number of test particle sizes
N_{R}	number of repeats per tested individual sampler
N_{Ref}	number of reference samplers (thin-walled sharp-edged probes) used per experiment – (polygonal approximation method)
N_{Rep}	number of repeats at particle size p for candidate sampler individual s at influence variable value ς_i – (in the polygonal approximation method N_{Rep} equals the number of repeats, whereas in the curve-fitting method it equals the number of repeats per candidate sampler individual)
$N_{\mathrm{Rep}}{}^{*}$	recalculated number of repeats if the variation among candidate samplers statistically does not exceed that of the uncertainty of the calculated concentration – (curve-fitting method)
N_{S}	number of candidate sampler individuals – (in the polygonal approximation method N_{S} equals the number of sampler individuals tested per repeat, whereas in the curve-fitting method it equals the total number of sampler individuals tested.)
N_{SD}	number of aerosol size distributions A according to EN 13205-2:2014, Table 2
N_{Sim}	number of simulated sets of N_{P} test particle sizes
N_{SR}	number of repeats per sampler individual tested – (polygonal approximation method, see Formula (24))
$N_{\mathrm{S}}{}^{*}$	recalculated number of candidate samplers if the variation among candidate samplers statistically does not exceed that of the uncertainty of the calculated concentration – (curve-fitting method)
N_{TSI}	number of different sampler individuals tested – (polygonal approximation method, see Formula (24))
N_{U}	number of small particle sizes at which the efficiency is known to be e_0 – (curve-fitting method)
Q^0	nominal flow rate of sampler, [l/min]
$RSD_{\mathrm{Est[Ref]}}(\varsigma_i)$	pooled relative standard deviation of the estimate of the thin-walled sharp-edged probe concentration at influence variable ς_i, [-] – (polygonal approximation method)
$RSD_{\mathrm{CandSampl}}(\varsigma_i)$	pooled relative standard deviation of the concentrations sampled by the candidate sampler at influence variable ς_i, [-], (polygonal approximation method)
$RSD_{\mathrm{Ref}}(\varsigma_i)$	pooled relative standard deviation of the thin-walled sharp-edged probe concentrations at influence variable ς_i, [-], (polygonal approximation method)
$s_{\mathrm{CalibrRes}}$	residual standard deviation of the calibration of particle counter/sizer or similar, [dimension depends on particle counter] – (curve-fitting method)
$s_{\mathrm{CandSampl\text{-}Calibr}_{ia}}$	combined non-random and random uncertainty (of measurement) of the calculated sampled concentration, due to the calibration uncertainty of the experiment, for aerosol size distribution A at influence variable value ς_i, [-]
$s_{\mathrm{CandSampl\text{-}Eff}}$	uncertainty of calculated sampled concentration due to uncertainty of efficiency for aerosol size distribution A at influence variable value ς_i, [-] (polygonal approximation method)

$s_{\text{CandSampl-Eff(inlet)}}$ uncertainty of calculated sampled concentration (at the inlet stage) due to uncertainty of efficiency for aerosol size distribution A at influence variable value ς_i, [-] – (polygonal approximation method)

$s_{\text{CandSampl-Eff(pen)}}$ uncertainty of calculated sampled concentration (at the separation stage) due to uncertainty of efficiency for aerosol size distribution A at influence variable value ς_i, [-] – (polygonal approximation method)

$s_{\text{CandSampl-ModelCalc}_{ia}}$ random uncertainty (of measurement) of the calculated sampled concentration, due to the uncertainty of the fitted model, for the a^{th} aerosol size distribution A at influence variable value ς_i, [-]

$s_{\text{CandSampl-PGapprox}}$ uncertainty of calculated sampled concentration due to polygonal approximation for aerosol size distribution A at influence variable value ς_i, [-] – (polygonal approximation method)

$s_{\text{CandSampl-Ref}}$ uncertainty of calculated sampled concentration due to uncertainty of measured total airborne concentrations for aerosol size distribution A at influence variable value ς_i, [-] – (polygonal approximation method)

$s_{\text{CandSampl-Ref(inlet)}}$ uncertainty of calculated sampled concentration (at the inlet stage) due to uncertainty of measured total airborne concentrations for aerosol size distribution A at influence variable value ς_i, [-] – (polygonal approximation method)

$s_{\text{CandSampl-Ref(pen)}}$ uncertainty of calculated sampled concentration (at the separation stage) due to uncertainty of measured total airborne concentrations for aerosol size distribution A at influence variable value ς_i, [-] – (polygonal approximation method)

$s_{\text{CandSampl-Variability}_{ia}}$ random uncertainty (of measurement) of the calculated sampled concentration, due to individual sampler variability, for the a^{th} aerosol size distribution A and influence variable value ς_i, [-]

s_{D} RMS value of all relative uncertainties of the actual sizes of the monodisperse test aerosols, [-]

$s_{\text{D}c}$ relative uncertainty of the actual size of calibration particle c, [-] – (curve-fitting method) [If the particle size is specified to be within the relative size interval $\pm\beta_c$, then $s_{\text{D}c}$ can be calculated as $s_{\text{D}c} = \beta_c / \sqrt{3}$.]

s_{D_p} relative uncertainty of the actual size of monodisperse test aerosol p, [-] – [If the particle size is specified to be within the relative size interval $\pm\beta_p$, then $s_{\text{D}p}$ can be calculated as $s_{\text{D}_p} = \beta_p / \sqrt{3}$.]

$s_{\text{LoF}_{is}}$ standard deviation pertaining to the possible lack of fit of the regression model for the Ω-transformed sampling efficiency of candidate sampler individual s at influence variable value ς_i, [-] – (curve-fitting method)

$s_{\text{ModelCalc-LoF}_{is}}$ random uncertainty (of measurement) of the calculated sampled concentration, due to the “lack of fit” of the model for candidate sampler individual s, for aerosol size distribution A at influence variable value ς_i, [-]

$s_{\text{ModelCalc-pe}_{is}}$ random uncertainty (of measurement) of the calculated sampled concentration, due to the “pure error” of the experiment for candidate sampler individual s, for aerosol size distribution A at influence variable value ς_i, [-]

$s_{\text{pe}_{is}}$ “pure error” standard deviation of the Ω-transformed experimental data of

	candidate sampler individual s at influence variable value ς_i, [-] – (curve-fitting method)
$s_{\text{RefCorr}_{is}}$	random uncertainty (of measurement) of the calculated sampled concentration, due to the correction of measured sampler efficiency values because of variations in e.g. time, for candidate sampler individual s, at influence variable value ς_i, [-]
$s_{\text{res}_{is}}$	residual standard deviation of the regression model for the Ω-transformed sampling efficiency of candidate sampler individual s at influence variable value ς_i, [-] – (curve-fitting method)
$s_{\text{res(Est[Ref])}_{ip}}$	residual standard deviation of the model for the estimation of the total airborne aerosol concentration for particle size p at influence variable ς_i, [mg/m^3] or [1/m^3] depending on the application – (polygonal approximation method)
$SS_{\text{pe}_{is}}$	"pure error" sum of squares of the Ω-transformed experimental data of candidate sampler individual s at influence variable value ς_i, [-] – (curve-fitting method)
$SS_{\text{res}_{is}}$	residual sum of squares of the regression model for the Ω-transformed sampling efficiency of candidate sampler individual s at influence variable value ς_i, [-] – (curve-fitting method)
$u_{\text{CandSampl-ModelCalc}_i}$	standard uncertainty (of measurement) of the calculated sampled concentration (random errors), due to the uncertainty of the fitted model, calculated as the RMS of the corresponding relative uncertainties over all N_{SD} aerosol size distributions A at influence variable value ς_i, [-]
$u_{\text{CandSampl-Variability}_i}$	standard uncertainty (of measurement) of the sampled concentration (random errors) due to differences among candidate sampler individuals at influence variable value ς_i, [-]
W_p	weighted average of integration of aerosol size distribution A between two particle sizes, [-] – (polygonal approximation)
$W_{t,p}$	weighted average of integration of aerosol size distribution A between two particle sizes, calculated using set t of the simulated test particle sizes, [-] – (polygonal approximation method)
y	instrument response of calibrated particle counter/sizer or similar, [dimension depends on particle counter] – (curve-fitting method)
$z_{t,p}$	random number with a normal distribution, with expectation value equal to zero and standard deviation equal to unity, [-]

4.1.2 Greek

ΔD_p	specified size range within which actual particle size is found with high probability for monodisperse test aerosols with nominal particle size D_p, [µm]
δD_c	relative adjustment of calibration particle size c to obtain a smooth spline, [-] – (curve-fitting method)
$\varepsilon_{ipr[s]}$ and $\varepsilon_{ips[r]}$	random experimental error at particle size p, repeat r and candidate sampler s at influence variable value ς_i, [-] – (notations for polygonal approximation and curve-fitting methods, respectively)
ς	value of other influence variable values, as for example wind speed and mass loading of

sampler, with values for i=1 to N_{IV}, [various dimensions]

ς_i — i^{th} value of another influence variable

NOTE The dimension of each ς_i depends on the influence variable. The dimension selected, however, is not critical, as the values are never part in any calculation.

${}^{est}\theta_{isk}$ — regression coefficient number k for candidate sampler individual s at influence variable value ς_i, [dimension depends on selected regression model for the sampling efficiency] – (curve-fitting method)

${}^{est}\theta_{isk}^{inlet}$ — regression coefficient number k for model of inlet stage efficiency for candidate sampler individual s at influence variable value ς_i, [dimension depends on selected regression model for the sampling efficiency] – (curve-fitting method)

${}^{est}\theta_{isk}^{pen}$ — regression coefficient number k for model of penetration through the separation stage for candidate sampler individual s at influence variable value ς_i, [dimension depends on selected regression model for the sampling efficiency] – (curve-fitting method)

$\nu_{\mathrm{pe}_{is}}$ — number of degrees of freedom for the “pure error” standard deviation of the experimental data of candidate sampler individual s at influence variable value ς_i – (curve-fitting method)

$\nu_{\mathrm{res}_{is}}$ — number of degrees of freedom for the residual standard deviation of the regression model for the Ω-transformed sampling efficiency of candidate sampler individual s at influence variable value ς_i, (curve-fitting method)

Ξ — transformation of particle size, [dimension depends on transformation] – (curve-fitting method)

Ξ^{inlet} — transformation of particle size for inlet stage, [dimension depends on transformation] – (curve-fitting method)

Ξ^{pen} — transformation of particle size for separation stage, [dimension depends on transformation] – (curve-fitting method)

σ_{A} — geometric standard deviation of a lognormal aerosol size distribution A from EN 13205-2:2014, Table 2, [-]

σ_{A_a} — Geometric standard deviation a of a lognormal aerosol size distribution A, [µm]

Φ^{-1} — inverse of normal distribution function, [-] – (curve-fitting method)

Ω — transformation of efficiency data, [-] – (curve-fitting method)

Ω^{-1} — inverse Ω-transformation of regression model of the Ω-transformed efficiency curve, [-] – (curve-fitting method)

$\Omega_{\mathrm{inlet}}^{-1}$ — inverse Ω-transformation of regression model of the Ω-transformed efficiency curve for the inlet stage, [-] – (curve-fitting method)

$\Omega_{\mathrm{pen}}^{-1}$ — inverse Ω-transformation of regression model of the Ω-transformed efficiency curve for the separation stage, [-] – (curve-fitting method)

4.2 Enumerating subscripts

a — for test aerosols

c — for calibration particle

i — for influence variable values, ς