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Standard Practice for Evaluating the Performance of Diffusive Samplers¹

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1. Scope

1.1 This practice covers the evaluation of the performance of diffusive samplers of gases and vapors for use over sampling periods from 4 to 12 h and for wind speeds less than 0.5 m/s. Such sampling periods and wind speeds are the most common in the indoor workplace setting. This practice does not apply to static or area sampling in wind speeds less than 0.1 m/s, when diffusion *outside* the sampler may dominate needed convection from the ambient air to the vicinity of the sampler. Given a suitable exposure chamber, the practice can be extended to cover sampler use for other sampling periods and conditions. The aim is to provide a concise set of experiments for classifying samplers primarily in accordance with a single sampler accuracy figure. Accuracy is defined (3.2.1) in this standard so as to take into account both imprecision and uncorrected bias. Accuracy estimates refer to conditions of sampler use which are normally expected in a workplace setting. These conditions may be characterized by the temperature, atmospheric pressure, humidity, and ambient wind speed, none of which may be constant or accurately known when the sampler is used in the field. Furthermore, the accuracy accounts for the effects of diffusive loss of analyte on the estimation of time-weighted averages of concentrations which may not be constant in time. Aside from accuracy, the samplers are tested for compliance with the manufacturer's stated limits on capacity, possibly in the presence of interfering compounds.

1.2 This practice is an extension of previous research on diffusive samplers (1-14)² as well as Practices D4597, D4598, D4599, and MDHS 27. An essential advance here is the estimation of sampler accuracy under actual conditions of use. Furthermore, the costs of sampler evaluation are reduced.

1.3 Knowledge gained from similar analytes expedites sampler evaluation. For example, interpolation of data characterizing the sampling of analytes at separated points of a

homologous series of compounds is recommended. At present the procedure of (9) is suggested. Following evaluation of a sampler in use at a single homologous series member according to the present practice, higher molecular weight members would receive partial validations considering sampling rate, capacity, analytical recovery, and interferences. The test for diffusive analyte loss can be omitted if the effect is found negligible for a given sampler or analyte series.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:³

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

D4597 Practice for Sampling Workplace Atmospheres to Collect Gases or Vapors with Solid Sorbent Diffusive Samplers

D4598 Practice for Sampling Workplace Atmospheres to Collect Gases or Vapors with Liquid Sorbent Diffusional Samplers (Withdrawn 1995)⁴

D4599 Practice for Measuring the Concentration of Toxic Gases or Vapors Using Length-of-Stain Dosimeters

2.2 International Standards:

CEN EN 838 European Standard, Workplace atmospheres - Diffusive samplers for the determination of gases or vapours - Requirements and test methods⁵

MDHS 27 Protocol for assessing the performance of a

¹ This practice is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.04 on Workplace Air Quality.

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² The boldface numbers in parentheses refer to the list of references at the end of this standard.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

⁴ The last approved version of this historical standard is referenced on www.astm.org.

⁵ Available from CEN Central Secretariat, rue de Stassart 36, B-1050 Brussels, Belgium.

diffusive sampler, Health and Safety Laboratory, United Kingdom⁶

MDHS 80 Volatile organic compounds in air, Health and Safety Laboratory, United Kingdom⁶

3. Terminology

3.1 Definitions:

3.1.1 For definitions of terms used in this practice, refer to Terminology **D1356**.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *Symmetric Accuracy Range A*—the fractional range, symmetric about the true concentration c , within which 95 % of sampler measurements are to be found (**14-19**). In terms of the bias Δ relative to true concentrations and the total (true) relative standard deviation RSD (sometimes designated as $TRSD$), the accuracy range A is closely approximated (**19**) by:

$$A = \begin{cases} 1.960 \times \sqrt{\Delta^2 + RSD^2}, & \text{if } |\Delta| < RSD/1.645 \\ |\Delta| + 1.645 \times RSD, & \text{otherwise} \end{cases} \quad (1)$$

3.2.1.1 *Discussion*—In the case that bias is corrected, leaving only an uncorrectable residual bias due to uncertainty in the correction, 95 %-confidence limits on A play the role of the expanded uncertainty in (**20**). As described in (**14**), such an interpretation is an extension of (**20**) for measurement, as in occupational hygiene, of concentrations which are neither spatially nor temporally constant. Rather than continually re-evaluating a method through estimate replicates, the accuracy provides confidence intervals bracketing (true) concentrations at greater than a given probability (95 %) for a fixed confidence (95 %) in the initial sampler evaluation. Such intervals with double confidence levels (in both measurement and evaluation) are related to a branch of statistics known as the theory of tolerance or prediction intervals.

3.2.2 *diffusive sampler*—a device which is capable of taking samples of gases or vapors from the atmosphere at a rate controlled by a physical process such as gaseous diffusion through a static air layer or permeation through a membrane, but which does not involve the active movement of air through the sampler. As such, direct-reading dosimeters, as well as samplers requiring lab analysis, are considered diffusive samplers within this practice.

3.3 Symbols:

A	= symmetric accuracy range as defined in terms of bias and imprecision
\hat{A}	= estimated symmetric accuracy range A
$A_{95\%}$	= 95 % confidence limit on the symmetric accuracy range A
$c(\text{mg}/\text{m}^3)$	= true or reference analyte concentration
$\bar{c}(\text{mg}/\text{m}^3)$	= mean of (four) concentration estimates (including (p, T) -corrections) obtained in accordance with instructions of sampler manufacturer
h	= humidity (expressed as partial pressure)
n	= number of diffusive samplers tested for measuring sampler capacity
p	= atmospheric pressure

RSD	= overall (true) relative standard deviation of concentration estimates (dependent on assumed environmental variability) expressed relative to a “true” concentration
RSD_{run}	= relative standard deviation characterizing inter-run chamber variability
RSD_s	= inter-sampler imprecision (relative to the reference concentration)
\hat{RSD}_s	= estimated inter-sampler imprecision RSD_s
RSD_t	= pulse-induced imprecision
\hat{RSD}	= estimated overall relative standard deviation RSD
$\hat{RSD}_{95\%}$	= 95 % confidence limit on the overall relative standard deviation RSD
s	= estimated standard deviation characterizing inter-sampler imprecision
$t_{0.95}(v)$	= value which, at probability 95 %, exceeds random variables distributed according to the studentized t -distribution with v degrees of freedom
T	= temperature
v (m/s)	= ambient wind speed
α_x	= concentration estimate dependence on environmental variable x (T, h, v , or c).
Δ	= bias relative to reference concentration c
$\hat{\Delta}$	= estimated bias Δ
$\hat{\Delta}_{95\%}$	= 95 % confidence limit on the bias Δ
Δ_t	= bias associated with concentration pulse
v	= degrees of freedom in determining RSD_s
v_{eff}	= effective number of degrees of freedom in determining RSD
σ_c	= assumed concentration variability
σ_h	= assumed humidity variability
σ_T	= assumed temperature variability
σ_v	= assumed ambient wind speed variability

4. Summary of Test Method

4.1 Bias, Inter-sampler Imprecision and the Effects of Environmental Uncertainty:

4.1.1 This practice gives a procedure for assessing the effects of variability in the following workplace variables: temperature T , humidity h (expressed in terms of the water vapor partial pressure to minimize interaction with the temperature), the ambient wind speed v across the sampler face (see **4.7** regarding wind direction), and concentration c . An experiment is carried out which provides information about the concentration estimates’ dependencies on these variables near conditions of intended sampler use (T_0, h_0, v_0 , and c_0). Testing is required at the concentration c_0 of intended use, as well as at concentrations reduced at least to $c_0/2$. Furthermore, the sampler bias and the inter-sampler standard deviation are measured. Finally, the effect of diffusion of material out of the sampler is measured. Pressure effects result in correctable bias and are not evaluated in this practice (**4.6**).

4.1.2 Using four samplers for each of five experimental runs (the minimum possible), the sensitivities $\alpha_T, \alpha_h, \alpha_v$, and α_c (relative to the chamber reference concentration and target environmental parameters) to changes in T, h, v , and c are measured, following the sampler manufacturer’s instructions

⁶ Available from HMSO Books, PO Box 276, London, England, SW8 5DT.

regarding p - and T - corrections (if any). These experiments also give a value for the estimated sampler bias Δ relative to the chamber reference concentration (defined for the target conditions). Two further runs describing time-effects (4.2.5) from diffusive loss of analyte are also carried out. The chamber reference concentration must be traceable to primary standards of mass and volume.

4.1.3 Error in the estimates of the sensitivities α_T , α_h , α_v , and α_c will exist on account of inter-sampler relative standard deviation RSD_s and an inter-run chamber standard deviation RSD_{run} . The latter results in part from uncertainty in the reference concentration. RSD_s is obtained by pooling the variance estimates from each run and therefore is estimated with $7 \times 3 = 21$ degrees of freedom (or 15 degrees of freedom if the reverse diffusion experiment is omitted (1.3)). So as to avoid re-measurement at each sampler/analyte evaluation, RSD_{run} is obtained by a separate characterization of the chamber with several runs at (for example) fixed environmental conditions. An example in which the sensitivities α and RSD_s , are estimated is presented in the [Annex A1](#).

NOTE 1—It is up to the user as to how traceability is established. Within (12) the concentration estimate as calculated from the chamber's analyte generation parameters is regarded as the benchmark, although an independent estimate is required and must be within 5 % of the calculated estimate. If these estimates differ, then a third independent estimate is required to establish the reference concentration through agreement with one of the other independent estimates. One possibility for such an independent estimate is the mean of at least five independent, active sampler estimates per run within the chamber. Experiment (12) on the accuracy of such reference measurements using sorbent tubes indicates that a relative standard deviation of the order of 2 % can be achieved for the individual measurements. Alternatively, (3) requires averaging of at least two independent methods (possibly including calculated estimates) with at least four samples per method. EN 838 has adopted the looser requirement that calculated and independent measurements must agree within 10 %.

4.1.3.1 A further consolidation of tests may be made by observing that the dependence of concentration estimates on the wind speed, v , is only sampler specific, that is, does not depend on the specific analyte. Therefore, after a single measurement for a given sampler type, the set of tests can be narrowed.

4.2 Reverse Diffusion:

4.2.1 A potential problem with diffusive samplers is presented by the possibility of reverse diffusion (sometimes denoted as *back diffusion* or *off-gassing*) of analyte. Reverse diffusion is generally only significant in the case that an analyte is weakly bound to the sorbent (6). Therefore, inaccuracy associated with these effects may generally be minimized through proper sorbent selection and sampler design.

4.2.2 Because of reverse diffusion, estimates of a varying concentration may in some cases be biased. The worst-case situation occurs with the concentration in the form of an isolated pulse at either the beginning or end of the sampling period. A pulse at the beginning of the period allows the entire sampling period (4 to 12 h) for sample loss, possibly resulting in a low estimate relative to a pulse at the end of the period.

4.2.3 In some cases, the time-dependence of a workplace concentration correlates strongly with the sampling period. For example, a cleanup operation at the end of a workday could

introduce solvent only then. This could imply a positive bias in the concentration estimates obtained from a day's sampling. For simplicity, however, this practice is set up for assessing performance of samplers for use in a concentration with stationary fluctuations, so that time-dependent effects are treated simply as components of sampler variance. Specifically, the effect of an isolated 0.5-h pulse occurring at random within the sampling period is estimated.

4.2.4 Challenging samplers to 0.5-h pulses is similar to tests suggested by NIOSH (3) and CEN (EN 838).

4.2.5 Let Δ_i (>0) represent one-half the bias between estimates from a 0.5-h pulse at the end versus the beginning of the sampling period, relative to the mean of the estimates. Assume, conservatively (see, for example, (6)), that the bias in the estimates of 0.5-h pulse occurring at random within (for example, an 8-h sampling period) ranges uniformly between $-\Delta_i$ and $+\Delta_i$. Then the variance RSD_i^2 associated with sampling a 0.5-h pulse at random within the sampling period is as follows:

$$RSD_i^2 = \frac{1}{3} \Delta_i^2 \quad (2)$$

4.3 Capacity; Control of Effects from Interfering Compounds:

4.3.1 This practice provides a test for confirming a manufacturer's claimed sampler capacity under stated conditions of use. Such conditions would normally refer to a specific sampling period and to environmental extremes, such as 80 % relative humidity at a temperature equal to 30°C. Additionally, a manufacturer may claim a value of capacity for sampling in the presence of specific interferences at stated concentrations.

4.3.2 Capacity is defined here as the sampled mass (or equivalently as the concentration at a specific sampling period) at which concentration estimates are 10 % low. Specifically, capacity is considered not exceeded if concentration estimates, corrected for correctable bias, are above 90 % of the true concentration at the 95 % confidence level.

4.3.3 An example of the test follows. Eight diffusive and eight active samplers with estimated inter-sampler imprecision, s , are exposed to the analyte of concern under the stated environmental conditions. Then, neglecting variability in the reference sampler mean, the 95 % confidence limit $\Delta\mu_{95\%}$ on the difference in the (unknown) mean concentration estimates is:

$$\Delta\mu_{95\%} = \Delta c - s \times t_{0.95}(v) / \text{Sqrt}[n] \quad (3)$$

where Δc is the estimated mean difference between diffusive and active results, $n = 8$, and $v = n - 1 = 7$. Then $\Delta\mu_{95\%}$ must be greater than $-10\% \times c$, where c is the mean concentration estimate from the reference samplers.

4.3.4 As a specific example, suppose the inter-sampler imprecision $RSD_s = 5\%$,

$$(s/c) \times t_{0.95}(v) / \text{Sqrt}[n] = 3.3\% \quad (4)$$

Therefore, in this case the mean value of the diffusive results must be greater than 93.3 % of the reference concentration.

NOTE 2—As capacity strongly correlates with sampled mass, a limit on the capacity expressed as sampled mass at one stated sampling period is generally applicable to a range of sampling periods.

4.4 Capacity Overload Detection:

4.4.1 The capability of *detecting* capacity overload (for example, by the use of a second sorbent or by employing paired samplers with different sampling rates) may be advantageous in some sampling situations. In the case of active samplers, such detection is easily effected through the use of back-up sections. The point is that practicality precludes testing of the samplers under all conditions of use, such as in an arbitrary multi-analyte environment. The capability of voiding a sample result when interferences become demonstrably problematic may therefore be useful. At present the efficacy of such overload detection is not evaluated. Evaluation tests may be developed in the future for this purpose.

4.5 Desorption Efficiency:

4.5.1 A further control of the effects from interfering compounds is afforded by restricting the permissible desorption efficiency. As in (3) the desorption efficiency, in the case of solvent extraction, must be > 75 % at the concentration of intended application of the sampler. This requirement is expected to control the potential variation of the desorption efficiency induced by other interfering compounds. The use of internal standards to compensate for the effect of desorbent evaporation is also generally recommended.

4.5.2 In the case of thermal desorption, the efficiency must be > 95 %. (MDHS 80)

4.6 Atmospheric Pressure:

4.6.1 Most diffusive sampler manufacturers provide a formula for correcting for the difference between atmospheric pressure at points of sampler application and calibration. Unlike the case with temperature, where sorbent properties may be temperature-dependent, the formula is simple. For diffusion through air, the sampling rate (mL/s) is inversely proportional to the pressure, whereas if the sampling rate is determined by a semi-permeable membrane rather than air, the rate is independent of pressure. The difference is because of the differing expansion coefficients of the media comprised of the scattering molecules.

NOTE 3—With diffusion through air, the concentration expressed as ppm is independent of the pressure during sampling, unlike the mass concentration (mg/mL).

4.6.2 If the sampling rate is more complicated than with diffusion through air alone or through a semi-permeable membrane alone, justification for the given correction formula shall be made available by the sampler manufacturer.

4.7 Wind Direction:

4.7.1 For use in personal sampling, the wind direction is expected to generally have an insignificant effect on concentration estimates, since the air flow near the body will be usually across the face of the sampler. Therefore, experiments are done with wind parallel with the sampler face.

5. Significance and Use

5.1 Gas or vapor sampling is often accomplished by actively pumping air through a collection medium such as activated charcoal. Problems associated with a pump—inconvenience, inaccuracy, and expense—are inextricable from this type of sampling. The alternative covered by this practice is to use

diffusion for moving the compound of interest onto the collection medium. This approach to sampling is attractive because of the convenience of use and low total monitoring cost.

5.2 However, previous studies have found significant problems with the accuracy of some samplers. Therefore, although diffusive samplers may provide a plethora of data, inaccuracies and misuse of diffusive samplers may yet affect research studies. Furthermore, worker protections may be based on faulty assumptions. The aim of this practice is to counter the uncertainties in diffusive sampling through achieving a broadly accepted set of performance tests and acceptance criteria for proving the efficacy of any given diffusive sampler intended for use.

6. Apparatus

6.1 Exposure Chamber Specifications:

6.1.1 *Chamber Capacity*—The chamber must be capable of exposing candidate samplers with less than 5 % depletion of test analyte by the samplers at the lowest air flow.

6.1.2 *Exposure Time*—The chamber must be capable of maintaining conditions for up to 12 h.

6.1.3 *Analyte Generation*—Equipment must be provided for the measured delivery of gases, or the vaporization and measured dilution in a mixing chamber of controlled amounts of mixtures of test analytes, liquid over normal room temperature ranges.

6.1.4 *Reference Concentration Measurement*—Provision must be made for monitoring of the analyte concentration from at least five locations within the chamber.

6.1.5 *Construction Materials*—The chamber interior and all parts exposed to the test analytes must be corrosion-resistant and fireproof. Polypropylene is a likely candidate for this purpose.

6.1.6 *Monitoring Equipment to be Included with the Chamber*—Monitors for measuring the environmental conditions listed in 6.2 must be included with the chamber.

6.2 Controlled Environmental Conditions:

6.2.1 *Air Flow*—Air flows up to 0.5 m/s must be attainable as face velocities across the sampler face as representative of the local conditions when the sampler is used as a personal sampler.

6.2.2 *Humidity Variation*—Relative humidity equal to 25 ± 5 %, 50 ± 5 %, and 80 ± 5 % must be attainable at 20°C.

6.2.3 *Temperature*—Temperatures equal to 10 ± 3 °C, 20 ± 3 °C, and 30 ± 3 °C must be attainable and maintainable. If the chamber is manufactured of stainless steel, then insulation of the chamber or conditioning of the air entering the walk-in hood may be necessary.

6.2.4 *Pressure*—Atmospheric pressure in the chamber must be constant to 1 % within any run.

6.3 *Inter-run Variability*—The chamber must be characterized as to inter-run variability RSD_{run} through one of several possible experimental designs. One possibility is through analysis of variance of data from 16 runs with four samplers