BS EN 15445:2008

Fugitive and diffuse emissions of common concern to industry sectors — Qualification of fugitive dust sources by Reverse Dispersion Modelling

ICS 13.040.40

National foreword

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Fugitive and diffuse emissions of common concern to industry sectors - Qualification of fugitive dust sources by Reverse Dispersion Modelling

Emissions fugitives et diffuses concernant divers secteurs industriels - Estimations des taux d'émissions fugitive de poussières par Modelisation de Dispersion inverse

Fugitive und diffuse Emissionen von allgemeinem Interesse für Industriebereiche - Berechnung fugitiver Emissionsquellstärken aus Immissionsmessungen mit der RDM (Reverse Dispersion Modelling)-Methode

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Foreword

This document (EN 15445:2008) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2008, and conflicting national standards shall be withdrawn at the latest by July 2008.

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 European Standard has been elaborated under a mandate of the European Commission/DG Enterprise to support essential requirements of the IPPC Directive (96/61/EC) and by voluntary action of industry.

The horizontal approach of common concern to industrial sectors is to gather industries concerned by diffuse/fugitive emissions and to develop methods suiting their needs. The industries of three trade associations have participated: EUROFER, EUROMETAUX and CEFIC. For practical reasons the two developed measurement methods, one for dusts and the other for gases are published as two separate standards. This standard has not been developed for Air Quality Control purposes and therefore shall not be used for monitoring by authorities.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This standard specifies a Reverse Dispersion Modelling method to qualify the fugitive emission rates of diffuse fine and coarse dust sources of industrial plants or areas. The application needs calculations using a dispersion model, and the definition of a sampling experimental set-up taking into account field data such as number, height and width of diffuse dust sources, sampling distances, and meteorological information.

The RDM method does not allow quantification in absolute figures of the dust emission rates because of an undetermined accuracy depending on various site conditions, but it is a tool which enables each industrial plant to identify its dust sources that emit the most, and then to implement actions reducing their importance by self-control and related improvement process as part of environmental management.

In this framework, the RDM method should not be used to control or verify any compliance with air quality threshold global values which might be contained in an operating permit, or to carry out comparison between different plants belonging to the same industrial sector.

2 Normative references

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

EN 12341, *Air Quality – Determination of the PM10 fraction of suspended particulate matter – Reference method and field test procedure to demonstrate reference equivalence of measurement methods*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
fugitive dust emission
uncontrolled dust emission to the atmosphere from diffuse emission.

EXAMPLE Windblown dust from stock piles, diffuse dust from workshop buildings, dust from handling dry bulk goods, re-suspension by traffic etc.

3.2
suspended particulate matter
SPM
notion of all particles surrounded by air in a given, undisturbed volume of air

3.3
PM10
fraction of SPM corresponding to a sampling target specification as defined in EN 12341

3.4
aerodynamic diameter (D_{ae})
to any particle, characterized by a physical diameter D_{ph} and a density, corresponds a D_{ae}: it is the diameter of a spherical particle of a specific mass of 1 g/cm^3, which would have the same limit falling velocity in undisturbed air

3.5
fine dust
fraction of SPM which particles display a physical diameter (D_{ph}) lower than 10 µm

NOTE If appropriate sampling devices are used, PM10 is applicable as fine dust, remembering that PM10 corresponds to the SPM fraction defined on the basis of aerodynamic diameter of particles (D_{ae}).

3.6
coarse dust
fraction of SPM in which particles display a physical diameter (D_{ph}) equal or higher than 10 µm. No upper limit is defined because the size of the suspended particles depends on the density of particulate matter

3.7
background dust
dust that is not related to the industrial activities of a plant, and generally coming from surrounding local and far-away sources outside the plant under investigation

3.8
dispersion factor α of a dust source
corresponds to the ratio between the contribution of a dust source *i* to the dust concentration (µg/m³) at a sampling location, and the emission rate *e* (g/s) of this dust source

$$c_i = \alpha_i e_i \quad (1)$$

3.9
correlation coefficient, R_α
correlation coefficient obtained between sets of calculated dispersion factors of two dust sources; the value of R_α indicates if two dust sources are independent or not

EXAMPLE When a dust sampler is located between two dust sources, for the one located upwind the dispersion factor value is higher than zero ($\alpha>0$) and for the other one downwind the dispersion factor value is zero ($\alpha=0$). When the wind is blowing from the opposite direction, it is the reverse for α. Then their dispersion factors are not correlated.

3.10
correlation coefficient R_c between two sampling locations
correlation coefficient obtained between measured dust concentrations in two sampling locations; the value of R_c indicates the relative contribution of the plant dust sources and background dust

3.11
coefficient R^2_d of multiple determination
coefficient calculated from the multiple determination regression for a source. For each source taken into account, the value of R^2_d represents the fraction of the variations in measured dust concentrations (source contribution) explained by the dispersion model

$$c_{rd}(t) = \Sigma_i c_{ird}(t) = \Sigma_i \alpha_{irdt} e_{id} \quad (2)$$

3.12
residue
difference between a measured dust concentration at a sampling location, and the calculated dust concentration at the same location by using the mean emission rate of each investigated dust source

4 Principle

Fugitive dust sources are not emitted at a fixed flow rate and the emitted matter is dispersed in air. In many cases, different dust sources contribute to the dust concentration in a sampling location.

Reverse-Dispersion Modelling is a method to obtain the mean emission rate estimation of each source by statistic treatment of:

— measured dust concentrations in different sampling locations;

— calculated dispersion factors α;
to solve this equation:

$$c_{rd}(t) = \Sigma_i c_{ird}(t) = \Sigma_i \alpha_{irdt} e_{id} \quad (3)$$

where

c_{ird} is the concentration of particles with the aerodynamic diameter d (equal D_{ae}), due to the source i at a sampling location r;

α_{irdt} is the dispersion factor of particles with the aerodynamic diameter d (equal D_{ae}), between source i and sampling location r;

e_{id} is source i emission rate of particles with the aerodynamic diameter d (equal D_{ae}), that we try to find out.

The dispersion of emitted matter is influenced by the location and geometry of the dust source, weather conditions, land roughness and the aerodynamic diameter d of particles. With an appropriate dispersion model and default emission rate e of 1 g/s, the dispersion factor α can be calculated in different locations around a dust source.

Contributions of different sources can be distinguished by simultaneous sampling in several locations, and calculation of correlation coefficient R_α between their sets of dispersion factors.

The measurements of dust concentrations comprise a background dust contribution which the exact origin is mostly not well known. Nevertheless areas shall be defined as potential background sources to be taken into account for calculations.

5 Measurement Equipment

5.1 Fine dust sampler

Devices used to measure the fine dust concentration at the sampling locations shall provide data with a sampling time resolution of 1 h, and shall collect the dust particles on a filter membrane (quartz fibre or PTFE) with a separation efficiency higher than 99,5 %.

If the device is not sampling PM 10 according to EN 12341, but a sampler which determines the proportion of particles with D_{ph} < 10 µm, a comparative measuring campaign with a PM 10 reference sampler shall determine a conversion factor to convert the D_{ph} data to D_{ae} data. (see A.1)

5.2 Coarse dust sampler

Devices used to measure the coarse dust concentrations at the sampling locations shall provide data with a sampling time resolution of 1 h, and they shall present a particle size resolution capable of distinguishing between three size fractions, preferably the physical diameter (D_{ph}) classes 10 µm to 30 µm, 30 µm to 70 µm and higher than 70 µm.

To obtain the corresponding D_{ae} size fractions data needed for the dispersion model calculations, a wind tunnel test shall be carried out for the dust under consideration, using an appropriate Tunnel Impactor, to determine a conversion factor allowing converting the D_{ph} data to D_{ae} data (see A.2).

6 Dispersion model

Dispersion models used to calculate the dispersion factors α shall be valid for the topological environment of the industrial area to be investigated.

The minimum requirements for the selection of the model are:

— locations, heights and size of the dust sources;

— particle size data where a distinction between particle size is required;

— locations and heights of the sampling locations;

— hourly data of wind speed, wind direction, stability of the atmosphere;

— hourly calculations of dispersion factor α.

7 Procedure

7.1 Experimental set-up

7.1.1 Dust sources location

The industrial dust sources to be investigated shall be defined (size, heights, nature, label …) and precisely located on a detailed map of the area. Additionally, background sources are defined, inside and surrounding the plant.

7.1.2 Sampling locations

The number and the locations of dust sampling depend on the location and number of industrial dust sources to be investigated. A minimum of two sampling locations are required for the emission rate estimation of one dust source.

The distance between the plant dust sources and dust samplers should be in the range 50 m to 300 m, depending on the density of the dust particles (chemical compound) of sources under consideration.

To distinguish different dust sources, it is highly recommended to select the sampling locations in between the plant dust sources, preferably on the axis of the most frequent wind direction.

The experimental set-up (locations of samplers) can be checked before beginning of dust sampling measurements by using the dispersion model and historical mean meteorological data for the measurement period (see 8.2.2 and 8.2.3)[1)]

7.1.3 Number of samplers and sampling campaigns

The number of sampling campaigns depends on the number of plant dust sources to be investigated and number of dust samplers available as one set for simultaneous measurements at different sampling locations. A set of two dust samplers as a minimum, shall be used.

Several cases are presented in Table 1:

1) The sampling locations and positioning of dust samplers may be dependent upon the plant services (i.e. power utilities).

Table 1

Number of plant dust sources	Number of dust samplers available as one set		
	2	**3**	**4**
1	*1*	*1*	*1*
2	*2*	*1*	*1*
3	*3*	*2*	*1*
4	*4*	*3*	*2*
5	*5*	*4*	*3*
	Number of sampling campaigns		

7.2 Measurement campaign

7.2.1 General

The duration of a measurement campaign is at least 4 weeks, covering a typical period of meteorological conditions.

A meteorological station is needed as close as possible to the investigated site to collect hourly weather data during the campaign (wind speed, wind direction, stability of the atmosphere), and also to obtain weather predictions and the wind direction distribution for several previous years to adjust the sampling locations to the expected major wind direction.

The campaign shall include hourly registration of dust concentration measurements for the coarse and/or fine dust using the appropriate sampling devices (5.1 and 5.2).

If the fine dust samplers are not a PM10 reference sampler, and for coarse dust samplers, then the beginning of the campaign shall start with several days of specific 24 h measurements dedicated to a practical determination of a conversion factor D_{ph} data to D_{ae} data for each sampler (see Annex A).

7.2.2 Dust concentration measurements

7.2.2.1 Fine dust

If the fine dust samplers are not PM10 reference sampler (i.e. laser particle size samplers), the hourly measurements [volume % of particle fraction D_{ph} lower than 10 µm] registered by each sampler are converted to corresponding D_{ae} mass % concentrations (µg/m^3) by using the conversion factor determined for each sampler by simultaneous measurement campaign with a PM10 reference sampler (see A.1).

The use of these conversion factors also allows for compensation for possible efficiency differences between the samplers by standardization of their dust concentration measurements versus one reference sampler.

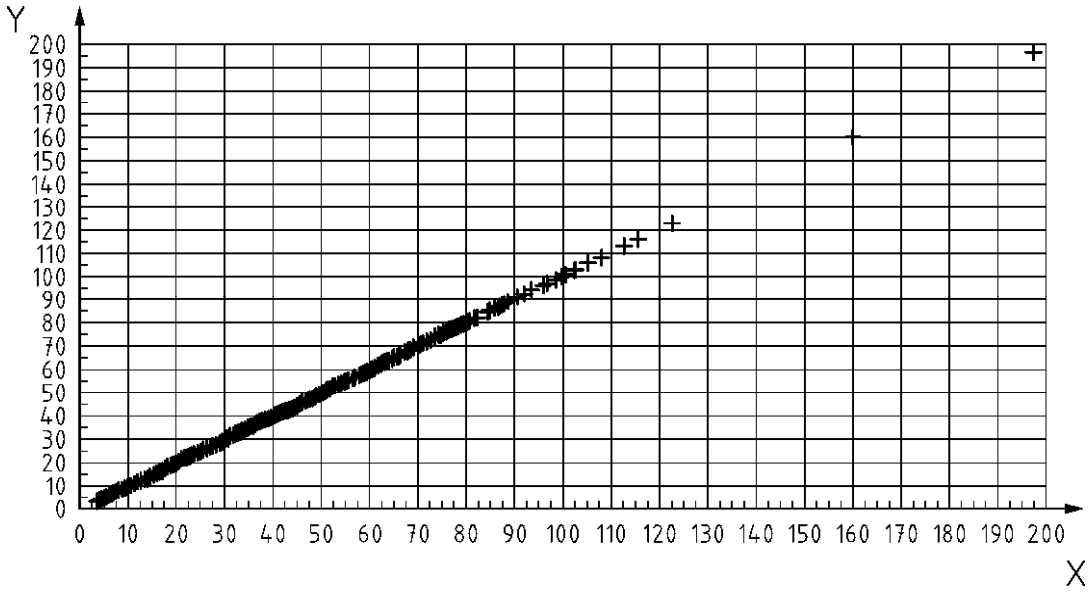
7.2.2.2 Coarse dust

If the coarse dust samplers provide hourly concentrations (µg/m^3) for D_{ph} size particle fractions 10 µm to 30 µm, 30 µm to 60 µm and higher than 70 µm, these concentrations shall be converted to D_{ae} size fraction concentrations by using the conversion factors determined by dust sampling measurements with a tunnel impactor see A.2).

8 Calculations

8.1 Contribution of background dust sources

The contribution of background sources is best evaluated by comparing the dust concentrations results (µg/m^3) from the samplers at different sampling locations. When the dust concentrations of two samplers are dominated by background dust, their dust concentrations are highly correlated: see figure 1, R_c = 1. On the other hand, when the dust concentrations are caused by a plant dust source in between two sampling locations, the correlation between the dust concentrations measured by the two corresponding samplers is very low: see figure 2.

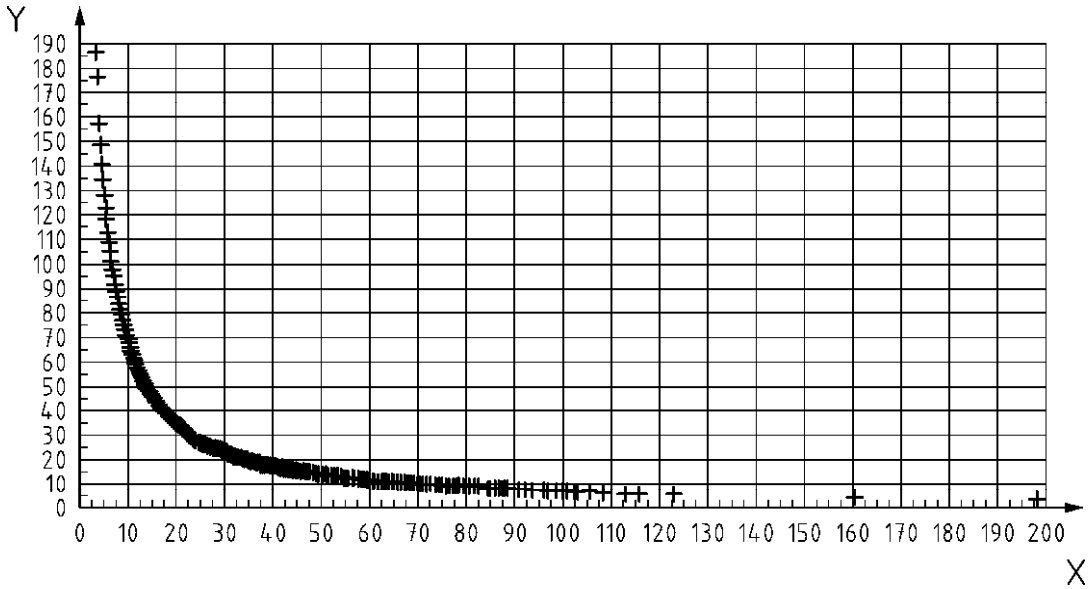


Key

X Measured concentration at receptor 1 [µg/m^3]

Y Measured concentration at receptor 2 [µg/m^3]

Figure 1 — Background dust sources



Key

X Measured concentration at receptor 1 [µg/m^3]

Y Measured concentration at receptor 2 [µg/m^3]

Figure 2 — Local dust sources

8.2 Estimation of the mass emission rate of dust sources

8.2.1 General

Remembering that each dust concentration measurement at each sampling location includes contribution from different sources,

$$c = \alpha_1 e_1 + \alpha_2 e_2 + \alpha_3 e_3 + \alpha_4 e_4 + \alpha_5 e_5 ... \quad (4)$$

two steps are needed to estimate the mass emission rates of dust sources:

— determination of dispersion factors α for each dust source at each sampling location, and calculation of correlation coefficients R_α; then

— calculation of the emission rates of the sources.

8.2.2 Dispersion factors determination

The dispersion factors of sources for each sampling location are calculated with the Dispersion Model on the basis of emission rates e = 1 g/s, by using the experimental set-up data (locations and geometrical dimensions of sources and their height levels of dust emission, locations and height levels of dust samplers used), and hourly meteorological data covering the measurement campaign (direction and speed of wind, stability class).

Since emission rates e = 1 g/s, the concentrations obtained by calculation with the Dispersion Model are equal to the dispersion factors α.

For example, for one source at one sampling location, $c_1 = \alpha_1 e_1$ become $c_1 = \alpha_1$.

8.2.3 Determination of independent dust sources

Calculation of the correlation coefficient values R_α for sets of two sources provides data on emissions from a specific dust source: the dispersion factors of distinct sources shall be independent. Sources are regarded to be independent when their correlation coefficient R_α is lower than 0,5. When sources are correlated (R_α > 0,5), they shall be combined to one source or one of the two sources shall be neglected. Otherwise, the experimental set-up shall be adjusted by performing more measurements depending on the objectives and plant facilities.

After grouping two or several sources, resulting dispersion factors shall be recalculated for this group as one source for each sampling location.

8.2.4 First emission rate estimates

By using the dispersion factor values obtained for each dust source (or group) for each sampling location, and all dust D_{ae} fraction hourly concentrations corresponding to the measurements of samplers at the different sampling locations, the emission rates *e* are calculated by stepwise, multiple regression to solve this equation:

$$c = \alpha_1 e_1 + \alpha_2 e_2 + \alpha_3 e_3 + \alpha_4 e_4 + \alpha_5 e_5 \ldots \quad (5)$$

The emission rate of a source can only be estimated, when during a long period of time the dispersion factor is higher than 1. This is achieved when at least one sampling location has been downwind of the source for some time and is not too far from the source.

The first step of stepwise regression consists of looking for the source that contributes most significantly to the model. At each subsequent step, the next best source is added until all significant sources are included. Thus, not all area sources are necessarily involved in the model.

The F test for significance of regression is a test to determine whether there is a linear relationship between the concentration *c* and the dispersion factors α_i. The appropriate hypotheses are:

H_0: $e_{1=}\ e_{2=}\ e_{3=.....=}\ e_{k\ =0}$

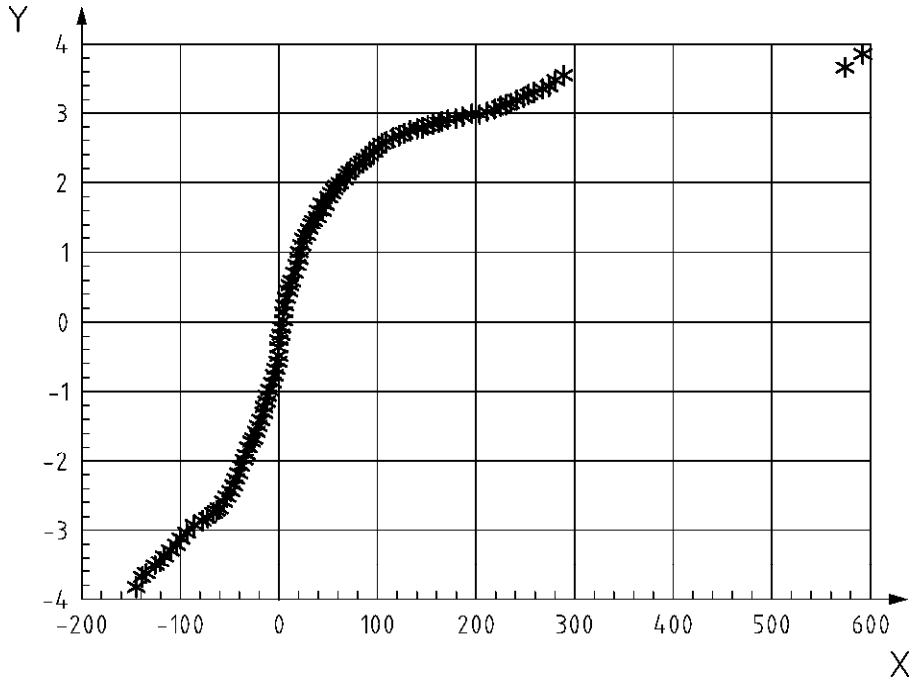
H_1: $e_i \neq 0$ for at least one source *i*

Rejection of H_0 means that at least one of the sources contributes significantly to the dust concentration. H_0 is rejected if the probability that it is correct is less than 5 %.

8.2.5 Analysis of residues

By multiplying the mean emission rate values by the dispersion factor for each source and each sampling location, the expected dust concentrations at the sampling locations are obtained for each hour. The differences between the concentration measured values and these concentration calculated values correspond to the residues.

A normal distribution of the residues is assumed when a mean emission rate is calculated; then a probability plot of the residues should show a straight line. When this is not the case like in the graph example (see figure 3), this is due to some very high values of residues.



Key

X Residue (µg/m³)

Y Rank of variable residue

Figure 3 — Analysis of residues

The high negative values mostly correspond to events with very low hourly dust concentrations, and the high positive values indicate events with extremely high hourly dust concentrations.

These events generally correspond to short time inconsistent activities (background or industrial) to be identified because their dust contributions affect the calculated mean emission rate estimates which then do not correspond to the regular emission rates of sources.

8.2.6 Regular mass emission rate estimates

After calculation and plotting of residues, and identification of events corresponding to the high residue values, the rejection of the data (emission dispersion coefficients and dust concentrations) related to these particular events allow for the definition of a data subset corresponding to the regular fugitive emissions.

Then, recalculation of the emission rates for this set, and of the new calculated dust concentrations and residues, usually provides a normal distribution of residues; in this case the new calculated emission rates correspond to the regular mass emission rates of the investigated sources.

8.2.7 Coefficient of multiple determination

For each of all sources (background included) the coefficient of multiple determination R^2_d is calculated for each dust source.

As in the simple linear regression case, the value of R^2_d varies between 0 and 1, and it is expressed in %. The value represents the fraction of the variations in measured dust concentrations (source contribution).

The sum of R^2_d of all dust sources, plant sources as well as background ones, indicates the total percentage of the variations in measured concentrations that is explained by the model.

Several reasons can explain the low contribution of a source:

— mean emission rate of the source is relatively low.

— variations in the emission rates are high.

— distance of the source to the sampling site is large. In other words, the experimental set up is not optimal to quantify this source.

— amount of useful data is too low; this might be due to the weather conditions (wind direction).

9 Precision

9.1 General

The precision parameters are calculated according to ISO 5725 based on an a round robin test (RRT) in a steel plant, involving five laboratories (four European countries), each measuring hourly fine dust concentrations in three different sampling locations (experimental set-up) by using three appropriate samplers. All labs were performing the calculation of emission rate estimates of dust sources using the dispersion model Fugitive Dust model (FDM) built by EPA. The same type of calculation was carried out on measurements of coarse dust concentrations obtained with a set of four coarse dust samplers.

9.2 Repeatability

During this test:

— repeatability uncertainty of 9 % to 18 % was found for the determination of fine dust emission rates, depending on the source under investigation;

— repeatability uncertainty of 5 % to 21 % was found for the determination of coarse dust emission rates, depending on the source under investigation.

9.3 Reproducibility

During this test:

— reproducibility uncertainty of 14 % to 92 % was found for the determination of fine dust emission rates, depending on the size fraction and the source under investigation;

— reproducibility uncertainty of 7 % to 97 % was found for the determination of coarse dust emission rates, depending on the size fraction and the source under investigation.

10 Report

The report shall contain at least the following items:

— description of the experimental set-up (dust sources data, sampling localisation, map) and type of dust samplers used for measurements;

— frequency distribution of wind speed, wind direction and rainfall during the measuring campaign;

— mean and maximum dust concentrations of the D_{ae} size fractions under consideration at the different receptor sites;

— evaluation of the background contribution by calculating the correlation coefficient values R_c between the dust concentrations at different sampling locations;

— values of the correlation coefficient R_α calcutated between the dust sources and, if necessary, adjustment of the dust sources number (grouping);

— values of first emission rate estimates of the dust sources by stepwise, multiple regression, including their coefficients of multiple determination R^2_d (in %);

— residues analysis and distinction between particular events and regular dust emissions;

— recalculated emission rate estimates values of sources for the regular emission dust concentrations, including the coefficients of multiple determination R^2_d (in %).

Annex A
(informative)

Determination of conversion factors D_{ph} data to D_{ae} data

A.1 Conversion factor for fine dust samplers

Generally, “laser dust samplers” are used to carry out the hourly fine dust concentration measurements; the reason for this is that such equipment is simple to install. It can be fixed to almost everything, it is easily mounted on a flat roof of building, and it only requires a low power supply. These set up characteristics are often necessary in a complex industrial environment.

However, due to physical parameters (low sampling rate, small inlet, laser wave length, small diffraction angle), this type of sampler provides D_{ph} size distribution (in volume %) of dust from 0,3 µm to about 20 µm, range which can be assimilated to that of SMP recovered on a glass fibre filter.

To convert the hourly volume% concentrations measured for D_{ph} particle fraction < 10 µm, to D_{ae} mass % fraction, the set of samplers used is compared to a reference PM10 sampler by carrying out simultaneous sampling at the same sampling location during at least 5 days.

Every 24 h the filter of the reference PM10 sampler and of the other samplers are removed (and replaced by a new one) to determine the mass of collected dust: PM10 referring to D_{ae} for the reference sampler, and D_{ph} SMP for the other samplers.
The respective concentrations are calculated (in µg/m^3) using the air volume sampled in 24 h (depending on the sampling flow rates), and a conversion factor is calculated for each “laser dust sampler” and each daily filter:

f_c = PM10 concentration / D_{ph} SMP concentration.

The final conversion factor F_c for each sampler corresponds to the average of the daily factors f_c .
The conversion is obtained by multiplying the hourly measurements of “dust samplers” (volume % particle fraction < D_{ph} 10 µm) by the factor F_C.

As the Fc factor of each sampler refers to a same reference sampler, this factor allows a standardization of the “laser dust samplers” between them.

A.2 Conversion factor for coarse dust samplers

Exercises in coarse dust measurement concentrations have already been carried out with a “coarse dust sampler” which capture the particle fraction D_{ae} < 70 µm by using a wind tunnel (constant air sampling speed) and collection on a dynamic strip (hourly segmentation).

After a sampling period, image analysis of this strip gives the D_{ph} size distribution in a measured %, in particular fractions D_{ph} 10 µm to 30 µm, 30 µm to 70 µm, and < 70 µm, which can be transformed into volume % on the basis of spherical particles (assuming a constant particle density).

These D_{ph} fraction volume % have to be converted to D_{ph} fraction mass concentrations. For that:

— total volume of collected dust is calculated from the counting size distribution (image analysis);

— total dust is washed off the strip and collected on a filter, then the mass of total dust is determined; and

— total dust volume is compared to the total dust mass divided by the corresponding sampled air volume (µg/m^3);

— this is done for several periods with low and high dust concentrations in air, to calculate a regression line resulting in a factor for mass concentration conversion of the D_{ph} fraction volume %.

A second conversion factor is determined to convert these D_{ph} concentrations to D_{ae} concentrations.

Using a wind tunnel impactor, the dust under consideration is collected on strips with different widths and well-known sampling efficiency curves for D_{ae}. The strips are analysed by image analysis and the D_{ph} size distributions of particles on the strips are calculated. These are compared to the D_{ae} curves, resulting in a conversion factor for D_{ph} concentrations to D_{ae} concentrations.

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