INTERNATIONAL STANDARD

ISO 21683

First edition
2019-02

# Pigments and extenders — Determination of experimentally simulated nano-object release from paints, varnishes and pigmented plastics

*Pigments et matières de charge — Détermination de la libération simulée de nanoobjets présents dans des peintures, des vernis et des plastiques pigmentés*

Reference number
ISO 21683:2019(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

# Contents

# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 256, *Pigments, dyestuffs and extenders*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Introduction

The possible release of nano-objects (nanoscale pigments and extenders) from paints, varnishes and pigmented plastics into surrounding air or liquid is an important consideration in health and safety, for the end user and the environment. Therefore, it is important to obtain data about the propensity of pigmented paints and plastics to release nano-objects, thereby allowing exposure to be evaluated[10], controlled and minimized. This property will likely depend on both the physico-chemical properties of the nano-objects and the matrix containing the nano-objects.

The currently available methods to assess the propensity of pigmented paints, varnishes and plastics to release nano-objects into the air require energy to be applied to a sample to induce abrasion, erosion or comminution, which cause dissemination of the particles into the gaseous phase, i.e. generation of aerosols.

Due to their higher sensitivity, the particle number concentration and the number-weighted particle size distribution are necessary for the quantification of the release of nano-objects since the particle mass depends on the cubed particle diameter and the mass concentrations of nano-objects are too low in order to detect them with currently commercially available instruments. Further measurements, such as the total particle surface concentration, e.g. References [11] and [12], can be helpful for the interpretation e.g. in regard to health aspects. If the shape, morphology, porosity, and density of the particle material are known, an exact conversion into the different quantity types is possible by measuring the total particle size distribution.

Beside the selection of appropriate measurement instrumentation, a quantitative assessment of process-induced particle release requires furthermore detailed information on the samples, the introduced stress and the kind of interconnection with the instruments. Figure 1 shows for example the single stages, which have to be considered for the quantitative characterization of airborne particulate release.

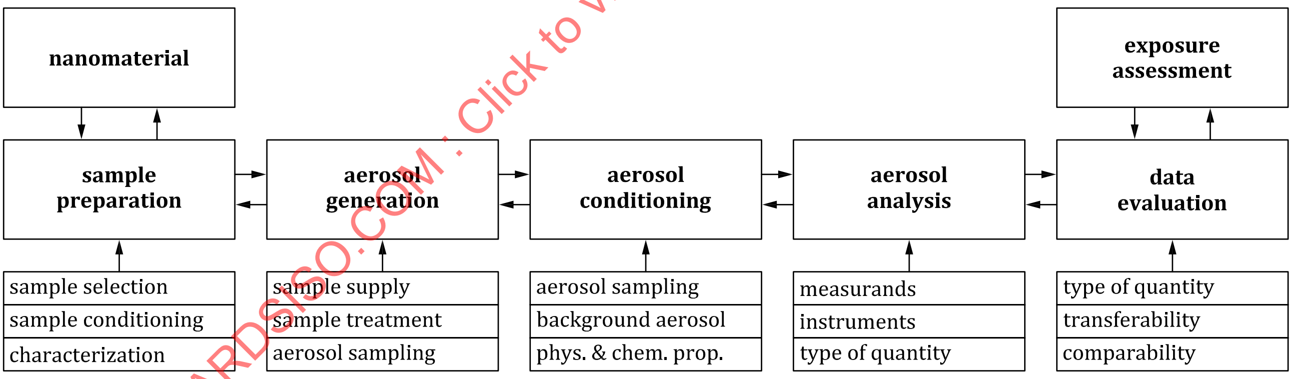


Figure 1 — Stages for the characterization of process-induced airborne particulate release[5]

# Pigments and extenders — Determination of experimentally simulated nano-object release from paints, varnishes and pigmented plastics

## 1 Scope

This document specifies a method for experimental determination of the release of nanoscale pigments and extenders into the environment following a mechanical stress of paints, varnishes and pigmented plastics.

The method is used to evaluate if and how many particles of defined size and distribution under stress (type and height of applied energy) are released from surfaces and emitted into the environment.

The samples are aged, weathered or otherwise conditioned to simulate the whole lifecycle.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 9276-1, *Representation of results of particle size analysis — Part 1: Graphical representation*

ISO/TS 80004-1, *Nanotechnologies — Vocabulary — Part 1: Core terms*

ISO/TS 80004-2, *Nanotechnologies — Vocabulary — Part 2: Nano-objects*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TS 80004-1, ISO/TS 80004-2 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

### 3.1 General terms and definitions

**3.1.1**
**aerosol**
system of solid or liquid particles suspended in gas

[SOURCE: ISO 15900:2009, 2.1]

**3.1.2**
**nanoscale**
length range approximately from 1 nm to 100 nm

Note 1 to entry: Properties that are not extrapolations from a larger size are predominantly exhibited in this length range.

[SOURCE: ISO/TS 80004-1:2015, 2.1]

### 3.1.3
### nanoparticle

*nano-object* (3.1.4) with all external dimensions in the *nanoscale* (3.1.2) where the lengths of the longest and the shortest axes of the nano-object do not differ significantly

Note 1 to entry: If the dimensions differ significantly (typically by more than 3 times), terms such as nanofibre or nanoplate may be preferred to the term nanoparticle.

[SOURCE: ISO/TS 80004-2:2015, 4.4]

### 3.1.4
### nano-object

discrete piece of material with one, two or three external dimensions in the *nanoscale* (3.1.2)

Note 1 to entry: The second and third external dimensions are orthogonal to the first dimension and to each other.

[SOURCE: ISO/TS 80004-1:2015, 2.5]

### 3.1.5
### paint

pigmented coating material which, when applied to a substrate, forms an opaque dried film having protective, decorative or specific technical properties

[SOURCE: ISO 4618:2014, 2.184]

### 3.1.6
### equivalent spherical diameter

x

diameter of a sphere having the same physical properties as the particle in the measurement

Note 1 to entry: Physical properties are for instance the same settling velocity or electrolyte solution displacing volume or projection area under a microscope.

Note 2 to entry: The physical property to which the equivalent diameter refers shall be indicated using a suitable subscript, for example $x_S$ for equivalent surface area diameter or $x_V$ for equivalent volume diameter.

[SOURCE: ISO 26824:2013, 1.6]

### 3.1.7
### particle size distribution
### PSD

cumulative distribution of the fraction of material smaller (undersize) than given particle sizes, represented by equivalent spherical diameters or other linear dimensions or distribution density of the fraction of material in a size class, divided by the width of that class

Note 1 to entry: Particle size distributions are described in ISO 9276-1.

### 3.1.8
### condensation particle counter
### CPC

instrument that measures the particle number concentration of an *aerosol* (3.1.1)

Note 1 to entry: The sizes of particles detected is usually smaller than several hundred nanometres and larger than a few nanometres.

Note 2 to entry: A CPC is one possible detector for use with a DEMC.

Note 3 to entry: In some cases, a condensation particle counter may be called a condensation nucleus counter (CNC).

[SOURCE: ISO 15900:2009, 2.5]

### 3.1.9

**differential electrical mobility classifier**

**DEMC**

classifier that is able to select *aerosol* (3.1.1) particles according to their electrical mobility and pass them to its exit

Note 1 to entry: A DEMC classifies aerosol particle sizes by balancing the electrical force on each particle with its aerodynamic drag force in an electrical field. Classified particles are in a narrow range of electrical mobility determined by the operating conditions and physical dimensions of the DEMC, while they can have different sizes due to difference in the number of charges that they have.

[SOURCE: ISO 15900:2009, 2.7]

### 3.1.10

**differential mobility analysing system**

**DMAS**

system to measure the size distribution of submicrometre *aerosol* (3.1.1) particles consisting of a DEMC, flow metres, a particle detector, interconnecting plumbing, a computer and suitable software

[SOURCE: ISO 15900:2009, 2.8]

## 3.2 Specific terms and definitions

### 3.2.1

**particle release from paints, varnishes and plastics**

transfer of material from paints, varnishes and plastics to a liquid or gas as a consequence of mechanical stress

### 3.2.2

**particle number release**

$n$

total number of particles in a specified size range, released from a test specimen as a consequence of mechanical stress

### 3.2.3

**area-specific particle number release**

$n_\mathrm{A}$

*particle number release* (3.2.2), divided by the stressed surface area of the test specimen

### 3.2.4

**mass-specific particle number release**

$n_\mathrm{m}$

*particle number release* (3.2.2), divided by the mass of removed material

### 3.2.5

**total volume flow rate**

$V_\mathrm{t}$

volume flow rate, which takes up all air-transported emissions at the particle source and transfers them

### 3.2.6

**particle number concentration**

$n_\mathrm{V}$

number of particles per volume of air

### 3.2.7

**process concentration**

*particle number concentration* (3.2.6), which results from the *total volume flow rate* (3.2.5) and the *particle number release* (3.2.2) as a consequence of mechanical stress on the test specimens

### 3.2.8
**measuring concentration**

*particle number concentration* (3.2.6), which is calibrated by defined dilution of the *process concentration* (3.2.7), in order to establish optimal conditions for the aerosol analysis

### 3.2.9
**model room concentration**

*particle number concentration* (3.2.6), which results from the *area-specific particle number release* (3.2.3) under optimal mixing conditions for a defined room height

Note 1 to entry: The model room concentration is independent of the selected test conditions and represents a reference concentration for real particle number concentrations (e.g. particle pollution in the laboratory) when the height of the model room has been selected carefully.

## 4 Symbols and abbreviated terms

For the purposes of this document, the following symbols (see Table 1) and abbreviated terms (see Table 2) apply.

**Table 1 — Symbols**

| Symbol | Dimension | SI unit |
|---|---|---|
| $n$ | particle number release | Without dimension |
| $n_V$ | particle number concentration | $m^{-3}$ |
| $n_A$ | area-specific particle number release | $m^{-2}$ |
| $n_m$ | mass-specific particle number release | $kg^{-1}$ |
| $V_t$ | total volume flow | $m^3 s^{-1}$ |

**Table 2 — Abbreviated terms**

| Abbreviation | Meaning |
|---|---|
| APS | aerodynamic particle sizer |
| CPC | condensation particle counter |
| DEMAS | differential electrical mobility analysing system |
| DEMC | differential electrical mobility classifier |
| EAD | electrical aerosol detector |
| EDX | energy dispersive X-ray spectroscopy |
| EEPS | engine exhaust particle sizer |
| ELPI | electrical low pressure impactor |
| ESP | electrostatic precipitator |
| FAPES | fast aerosol particle emission spectrometer |
| FMPS | fast mobility particle sizer |
| HEPA | high efficiency particulate air filter |
| ICP-MS | inductively coupled plasma mass spectrometry |
| ICP-OES | inductively coupled plasma optical emission spectrometry |
| LAS | laser aerosol spectrometer |
| NSAM | nanoparticle surface area monitor |
| OPC | optical particle counter |
| OPS | optical particle sizer |
| PM | particulate matter |
| PSD | particle size distribution |

**Table 2** *(continued)*

| Abbreviation | Meaning |
|---|---|
| SEM | scanning electron microscopy |
| SMPS | scanning mobility particle sizer |
| TEM | transmission electron microscopy |
| TP | thermal precipitator |
| WRAS | wide range aerosol sampler |

# 5 Methods of stress

## 5.1 Test specimens requirements

Coatings applied on respective substrates or solid materials are suitable test specimens. For good reproducibility the test specimens should be plane and a homogenous distribution of the pigments or extenders in the matrix material should be given.

For interpretation of the measuring results reference test specimens shall be prepared in addition to the actual test specimens. Unpigmented or unfilled test specimens can give information on the influence of these in regard to particle release. For analysing aged or weathered test specimens, unaged or unweathered equivalent test specimens shall be consulted for data interpretation.

An important aspect is the given condition of the test specimen. Detailed information on preparation of test specimens, used pigments and extenders, on pre-conditioning and treatment (ageing, exposure) shall be documented.

Contaminations of the test specimens during preparation, pre-conditioning, pre-treatment, transport, and storage shall be reduced to a minimum. Finished test specimens shall be analysed promptly in order to avoid changes of the physico-chemical properties (e.g. hardness, elasticity) of the test specimens due to impacts of external influences (e.g. temperature variation, UV radiation).

When transporting the test specimens, it shall be observed that the test specimens are not contaminated due to contact with the container used for transport or other test specimens. The duration of contact with ambient aerosol shall be minimized as far as possible.

## 5.2 Test apparatus requirements

### 5.2.1 General

The test apparatus shall cover the aspects of introduction of the test specimens, the stress application on the test specimens, and the sampling.

For the verification of systematic analysis, i.e. for obtaining reproducible results, the test specimens shall be introduced so that the stress is applied only once in order to avoid interferences of repeating applications of energy and constant changes of the stress intensity of the test specimen under test.

Particle number release quantification requires a test apparatus for the simulation of mechanical stress. The intensity of mechanical should be adjustable to the physico-chemical properties of the test specimen. The test apparatus should be described carefully, and appropriate test parameter should be identified before testing. For testing, the test parameter shall be adjusted, checked, and documented.

In order to enable quantification of particle number release, all of the particles released as consequence of mechanical stress shall be measured as close as possible to the location of their formation.

NOTE Mechanical stress application on test specimens can lead to thermal particle generation, which could lead to an overestimation of the particle number release.

### 5.2.2 Stress processes — Process parameters and characteristics

The process parameters to be applied for testing and the derivable process characteristics shall be selected in correspondence to the materials to be stressed, see Table 3.

NOTE See also Annex A.

**Table 3 — Process parameters and characteristics of selected stress application processes**

| **Process** (example) | **Process parameter** | **Process characteristics** |
|---|---|---|
| **Overflow**<br>Wind erosion on buildings, Stress of flow on moving vehicles | — Total volume flow rate<br>— Nozzle diameter<br>— Speed, feed of test specimen | — Speed, flow<br>— Suction performance |
| **Friction**<br>Skin contact on coatings | — Total volume flow rate<br>— Normal force<br>— Contact surface<br>— Friction path<br>— Material combination<br>— Speed, feed of test specimen | — Support pressure<br>— Friction force<br>— Friction performance |
| **Abrasion stress**<br>Processing of materials during manufacturing of products, reworking of damaged surfaces | — Total volume flow rate<br>— Normal force<br>— Contact surface<br>— Abrasion surface<br>— Rotational speed/revolution<br>— Speed, feed of test specimen<br>— Abrasive paper | — Support pressure<br>— Tangential force<br>— Cutting force ratio - Cutting performance - Speed ratio (see Reference [1]) |

## 6 Measuring methods

### 6.1 Measurands

The quantification of the particle release requires the analysis of three higher-ranking measurements:

- particle concentration;
- particle size;
- particle material.

The particle size as well as the concentration can be determined for aerosols in different quantity types (e.g.: particle number concentration, aerosol length concentration, mass concentration). The number represents the most sensitive quantity type in regard to air-transported nanoparticles and shall be consulted preferably for aerosol characterization (particle number concentration, number-weighted particle size distribution) because of the availability of commercially available measuring devices.

NOTE See Annex B.

At present, only a quantification of all particle emissions is possible by means of aerosol measuring methods. A material-selective quantification of the release of pigment or extender nanoparticles embedded in the paint or pigmented plastics is only possible limitedly by separate direct (e.g. EDX, ICP-MS, ICP-OES) and indirect measuring methods (e.g. morphological analysis via SEM, TEM).

For the reproducibility and transferability of the analysis results or for the process characterization further suitable measurements shall be obtained depending on the objective:

- mass abrasion during material-removing stress application;
- ambient conditions (temperature, humidity);
- aerosol charge state.

## 6.2 Aerosol measuring methods

For the characterization of aerosols numerous measuring methods are commercially available. In accordance with References [2], [7] and [9], aerosol measuring and collecting methods can be assigned to the following four categories:

- size resolved and time resolved measuring methods (e.g. FMPS, EEPS, FAPES, ELPI, OPS);
- size resolved and time integrated measuring methods (e.g. cascade impactor, WRAS);
- size integrated and time resolved measuring methods (e.g. CPC);
- size integrated and time integrated measuring methods (e.g. ESP, TP, filter).

The selection of the methods to be used for measuring aerosols depends on the type of exposure and the resulting aerosol, i.e. on the particle size distribution and the run of the particle number concentration. For processes with short-term aerosol generation ($<60$ s) or with heavy changes of the particle number concentration high-resolution measuring methods ($\leq 1$ s) in regard to time shall be used (e.g. CPC, FMPS, EEPS, FAPES). Due to the functional principle of the presently available aerosol measuring methods of category a) for the nanometre range respective minimum measuring concentrations ($>100$ cm$^{-3}$) shall be given in order to detect usable signals.

Scanning mobility particle sizers (SMPS, DEMAS: DEMC+CPC) have the highest sensitivity and precision for the characterization of aerosols in the range of sizes of about 5 nm to 1 000 nm, however, when discontinuities in the particle number concentration occur they lead to errors in the particle size distribution (e.g. concentration increase during the measuring cycle in the SMPS at continuous or gradual increase of the scanning voltage leads to a rougher PSD than actually exists).

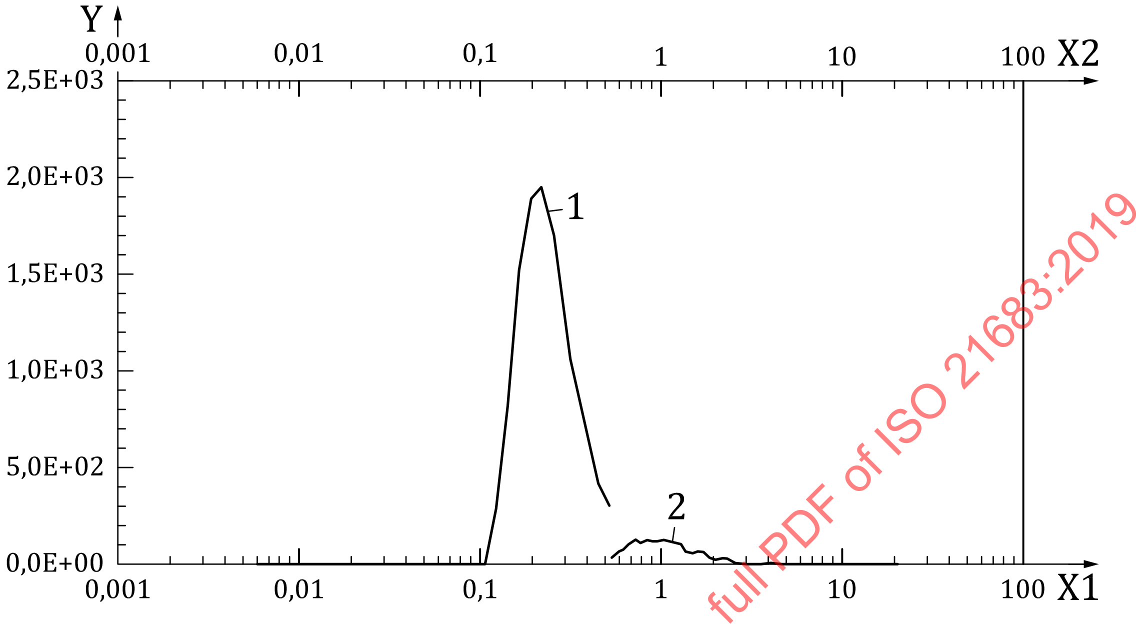
For high particle number concentrations, technical measures for the defined reduction can be taken while concentrating is more difficult in order to reach an optimal measuring concentration. According to their physical functional principles, aerosol measuring methods can only cover a limited particle size range, which requires a combination of several measuring methods for a quantitative characterization of the process aerosol. In this case, however, the operation conditions specified by the manufacturer shall be observed.

Numerous methods for measuring aerosols are intended for aerosol analyses under atmospheric pressure, only slight changes of the pressure level (high or low pressure) can strongly bias the measuring results.

The majority of commercially available methods for measuring aerosols has a separator for large particles (e.g. aero-cyclone, impactor) on the aerosol feed, which primarily changes the aerosol composition at the margins of the measuring range during aerosol measurements due to a non-ideal separating function.

Depending on the measuring principle respective equivalent particle diameters result, or different types of quantities, that shall be responded to during interpretation of the measuring data.

For optical aerosol measuring methods, the lower and upper range limit are defined as 50 % counting probability. The upper range limit, physically conditioned, results from sedimentation of large particles in the line system, while the lower range limit, technically conditioned, depends on the signal yet to be detected. Due to the decrease of the counting efficiency with decreasing particle size a decrease of the PSD can occur (see APS curve in Figure 2), which often leads to incorrect interpretation of the measuring results. Consequently, for the selection of methods for measuring aerosols, the size range should overlap over several size classes.



**Key**

| | |
|---|---|
| X1 | electrical mobility diameter, in micrometres |
| X2 | aerodynamic particle diameter, in micrometres |
| Y | $q_0^* = \mathrm{d}c_\mathrm{n}/\mathrm{dlog}x$, in reciprocal cubic centimetres [cm$^{-3}$] |
| 1 | engine exhaust particle sizer (EEPS) |
| 2 | aerodynamic particle sizer (APS) |

**Figure 2 — Transformed particle size distribution density of the particle number concentration of an aerosol generated by an abrasion process, analysed with EEPS and APS**

## 6.3 Test preparation

### 6.3.1 General

For the test preparation, the individual basic operations (i.e. the aerosol generation), the conditioning of the aerosol (defined optimization of the aerosol properties to metrological conditions), and the aerosol analysis (coupling with selected measuring technology) shall be combined with each other in order to enable quantitative emission characterization.

### 6.3.2 Aerosol background

As far as possible, particle release tests should be carried out in a particle-free background atmosphere in order to exclude foreign-particle contaminations and to increase sensitivity for low quantities of released particles. Before and after the test procedure the particle background concentration shall be measured.

### 6.3.3 Aerosol sampling line

Depending on the present aerosol charge state and duration of stress application a suitable material should be used. Principally, the use of electrically conductive lines is recommended. In the case of a bipolar aerosol charge state, electrically conductive lines lead to a minimization of particle losses. In the case of a unipolar aerosol charge state, electrically non-conductive lines are suitable in order to reduce particle loss, however, the inner surface of the line system has to charge first – which causes problems when the duration of the stress application is short. Consequently, for short-term stress application an electrically conductive line system should be used as well.

Material, length and inner diameter of the transport line shall be documented and reported.

Diffusion, gravity, and inertia cause particle losses in line systems, which should be kept as short as possible for this reason. Since measuring devices operate at different volume flow rates, particle losses can be different despite of equal line length.

Particle number concentrations in line systems should be lower than 1 000 000 $\text{cm}^{-3}$ in order to avoid changes of the particle number concentration and the particle size distribution due to coagulation.

### 6.3.4 Aerosol conditioning

In order to avoid systematic errors, the aerosols generated by the respective process shall be conditioned in regard to their aerosol charge state and the concentration level to counteract coagulation or particle losses. This also includes the use of suitable connecting elements between test apparatus and measuring devices (e.g. electrically conductive tube or pipe system):

- aerosol charge state;
- neutralization (bipolar charge reversal);
- reduction of concentration (not size-selective).

## 7 Procedure

For carrying out tests of nano-object release from nanoscale pigments and extenders, the following pre-test steps are recommendable:

a) testing of the measuring methods,

   1) by means of a particle-free test aerosol using an absolute filter (HEPA, high efficiency particulate air filter) for the determination of the error count rate,

   2) by means of artificially generated test aerosols for the characterization and verification of the counting efficiency of the applied measuring methods;

b) testing of the test arrangement,

   1) when operating all of the components integrated in the test arrangement (measuring devices, stress modules, auxiliary components) without contact of stress application element and test specimen (reference measurement), in order to identify possible secondary sources of emission (e.g. ventilator of the measuring device, etc.),

   2) by supplying a test aerosol (e.g. 100 nm) for the characterization of particle losses and verification of detection capability.

The release analysis should be carried out in accordance with the following procedure:

1) cleaning of all of the components of the test arrangement (sampling unit, line system, separator for large particles), in order to avoid contaminations;

2) carrying out secondary tests on the test specimen to be analysed immediately prior to stress application (e.g.: gravimetric analysis for material-removing processes);

3) affixing the test specimen to be tested in the test apparatus;

4) air-flushing the test arrangement with particle-free air to adequate background concentration (e.g. ≤ 0,01 $\text{cm}^{-3}$);

5) procedure of stress application and measuring

   i) for short-term stress application processes metrological assessment of particle concentration and size with defined time interval prior to and after the actual stress application;

   ii) for reproducible long-term stress application metrological assessment of particle concentration and size after necessary running-in period during a stress-induced concentration plateau;

6) removal of the test specimens;

7) carrying out secondary tests on the stressed test specimen (gravimetric analysis for material-removing processes).

## 8 Calculation

As a result of the analyses, raw data occur in the form of particle concentrations and particle size distributions. Primarily, it shall be observed that raw data are available in the same quantity type (e.g. number). In consequence of the stress application a process aerosol with a process concentration is generated. This process concentration depends on the process itself but also on the analysis conditions. Depending on the volumetric flow rate during sampling and existing background aerosol (particle-free background or natural aerosol background) a more or less considerable dilution results. Consequently, the expression of the mere concentration values is only meaningful if the specified analysis conditions are indicated and the generated aerosol is available in a time-constant manner. Disregarding this, it is sometimes necessary to reduce the generated particle concentration by technical means in order to establish optimal measuring concentrations for the analysis of aerosols. For a quantification of the nano-object release, all concentration-changing measures shall be included in the evaluation.

For the characterization of the nano-object release, size-specific numbers of released particles are obtained by combining particle size distributions in accordance with ISO 9276-1 and particle number concentrations[3][5]. The particle number $n_{x,t}$ of a defined size fraction $x_i - x_j$ released in a time interval $t_1 - t_2$ can be calculated with regard to the total volume flow rate $V_t$ and the used dilution ratio $\varphi$ in accordance with Formula (1):

$$n_{x,t} = V_t \cdot \phi \cdot \int_{t_1}^{t_2} \int_{x_i}^{x_j} q_0(\xi,\tau) c_{n,tot}(\tau) d\xi d\tau \tag{1}$$

The measured particle number concentrations of the individual size classes $c_n(\xi,\tau)$ are available as discrete data sets. Since the particle number concentrations in the individual size classes as well as the chronology are already mean values, additional steps for the numeric integration of the data sets can often be neglected. Consequently, for obtaining the size-specific particle number release $n_{x,t}$ Formula (2):

$$n_{x,t} \approx V_t \cdot \phi \cdot \Delta t \cdot \sum_{i=a}^{b} \left( \sum_{k=c}^{d} c_{n,k,i} \right) \tag{2}$$

where

$\Delta t$ is the time span between two succeeding measurements;

$k$ is the running index of the size class;

$i$ is the running index of the elapsed time.

In order to be able to carry out a cross-process comparison of the particle release, the obtained size-specific particle numbers $n_x$, shall be referred to the respective stressed area[4],[5]. The size-specific and area-specific particle release number $n_{x,A}$ is defined as the quotient of the size-specific particle number $n_x$ and the actual stressed area $A_S$, see Formula (3):

$$n_{x,A} = \frac{n_x}{A_S} \tag{3}$$

NOTE 1 Beside the area, the abrasive mass is also suitable as reference characteristic value for material-removing stress application scenarios.

For the transferability of the results to real scenarios the obtained measuring data shall be transferred into a model room concentration or model concentration. The model concentration can be obtained from the size-specific and area-specific particle release number in accordance with Formula (4):

$$c_{n,m} = \frac{n_{x,A} \cdot A_m}{V_m} = \frac{n_{x,A} \cdot A_m}{A_m \cdot h_m} = \frac{n_{x,A}}{h_m} \tag{4}$$

where

$A_m$ is the base area;

$V_m$ is the volume of the model room.

The volume of the model room is defined as the product of the base area $A_m$ and height of the model room $h_m$, so that the base area is cancelled and the model room concentration only depends on the height of the room or on the situational operating distance.

NOTE 2 For the model room concentration an ideal aeration under neglect of particle losses and coagulation is presumed.

## 9 Test report

The test report shall contain at least the following information:

a) a reference to this document, i.e. ISO 21683:2019;

b) test specimens, including

  1) identification of test specimens,

  2) condition of test specimens (pigmentation, pre-treatment of test specimens),

  3) date of the preparation of the test specimens,

  4) time interval between preparation of the test specimen and measurement;

c) stress application, including

  1) type of stress,

  2) characteristic process parameters;

d) test arrangement configuration, including

  1) measuring and conditioning equipment (identification, manufacturer),

  2) flow chart of the test arrangement including operating parameters,

  3) figure of the experimental set up of the test preparation;

e) results, including

  1) particle size distributions in accordance with ISO 9276-1,

   2) area specific particle release numbers in selected size categories (e.g. $x \leq 100$ nm, $100 \text{ nm} < x < 1\,000$ nm, $x > 1\,000$ nm),

   3) information on morphology and species of particles,

   4) image of the surface of the tested material after the treatment;

f) any unusual features (anomalies) observed during the test;

g) the date of the test.

# Annex A
(informative)

## Examples of parameter specification of stress application methods

In the example shown in Figure A.1, the test specimens are supplied beneath a vertically movable sanding tool and where aerosol sampling is realized by a containment of the abrasion zone.

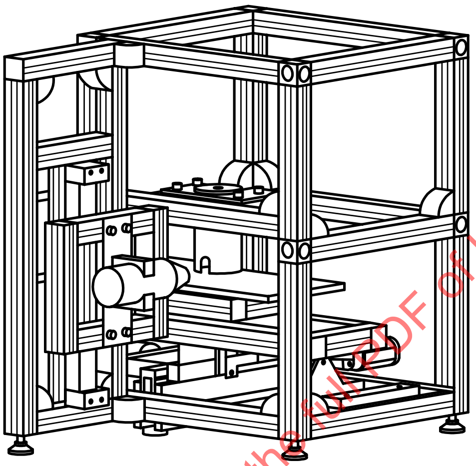
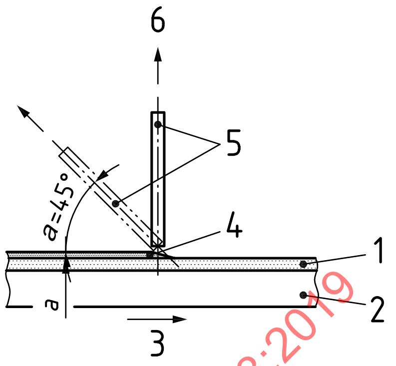
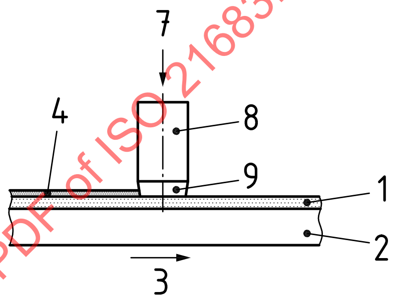
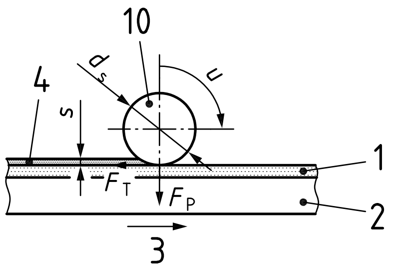


**Figure A.1 — Example of a test apparatus for the simulation of mechanical stress due to sanding[4]**

The examples on the variability of process parameters shown in Table A.1 are based on the test apparatus described and used in References [4] and [5] for particle number release quantification from paints, varnishes and plastics for the simulation of different stress situations.

### Table A.1 — Examples on the variability of process parameters

| | Process parameter | Unit | Operating range | Schematic diagram |
|---|---|---|---|---|
| **Overflow** | Volume flow rate (nozzle) | l·min$^{-1}$ | 1 – 20 |  |
| | Inner nozzle diameter | mm | 1 – 5 | |
| | Sample feed rate | mm·s$^{-1}$ | 0,05 – 5,0 | |
| | Air flow velocity | m·s$^{-1}$ | 1,5 – 100,0 | |
| | Stressed area | cm$^2$ | 1 – 5 | |
| **Dynamic friction** | Normal force | N | 5 – 15 |  |
| | Volume flow rate | l·min$^{-1}$ | 1 – 20 | |
| | Contact area | cm$^2$ | 0,8 – 1,5 | |
| | Sample feed rate | mm·s$^{-1}$ | 0,05 – 5,0 | |
| | Contact pressure | kPa | 30 – 170 | |
| | Force of dynamic friction | N | 5 – 11 | |
| **Abrasion process** | Normal force | N | 0,5 – 10,0 |  |
| | Volume flow rate | l·min$^{-1}$ | 10 – 30 | |
| | Sample feed rate | mm·s$^{-1}$ | 0,05 – 5,00 | |
| | Rotational frequency | min$^{-1}$ | 50 – 2 000 or<br>5 000 – 33 000 | |
| | Abrasive paper | – | P60 – P2000 | |
| | Rotational speed | m·s$^{-1}$ | 0,02 – 24,0 | |
| | Tangential force | N | 0,7 – 14,0 | |
| | Stressed area | cm$^2$ | 1 – 15 | |

**Key**

| | |
|---|---|
| 1 | coating |
| 2 | substrate |
| 3 | direction of motion |
| 4 | degenerated coating |
| 5 | suction nozzle |
| 6 | aerosol |
| 7 | normal force |
| 8 | friction piston |
| 9 | friction element |
| 10 | abrasive wheel |
| $a$ | thickness of the degenerated coating |
| $s$ | thickness of the degenerated coating |
| $d_\mathrm{s}$ | diameter of the abrasive wheel |
| $u$ | rotational speed |
| $F_\mathrm{T}$ | normal force |
| $F_\mathrm{p}$ | tangential force |