Standard ECMA-328-1

10th Edition / December 2020

Determination of Chemical Emission Rates from Electronic Equipment– Part 1 (using consumables)

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Introduction

Globally, governmental agencies, academic institutions, environmental organizations and manufacturers have started to develop methods to determine chemical emissions from electronic equipment. These attempts however, initially resulted in a range of tests from which the results were not necessarily comparable, either qualitatively or quantitatively.

Following the publications of the 1st edition of ECMA-328 in 2001 and the “Test method for the determination of emissions from Hard Copy Devices” (RAL-UZ 122), experts from BAM and Ecma have collaborated to harmonise methods to determine the chemical emission rates from ICT & CE equipment in the 2nd edition.

In addition to stricter test procedures, the 2nd edition used generalised emission formulae, and their derivations developed in Annex C, to calculate emission rates from concentrations of analytes that are measured in Emission Test Chambers.

The 3rd edition was fully aligned with the 1st edition of ISO/IEC 28360:2007 adopted under ISO/IEC JTC 1 fast track procedure and published in September 2007.

In addition, the 4th edition fixed a number of errata on ISO/IEC 28360:2007 that JTC 1/SC 28 identified.

Following the publications of the 4th edition of ECMA-328 and the “Test method for the determination of emissions from Hard Copy Devices” (RAL-UZ 122), experts from BAM, WKI, JBMIA and Ecma have collaborated to harmonise methods to determine the Fine Particle (FP) and Ultrafine Particle (UFP) emissions from hard copy devices in the 5th edition.

The 6th edition was aligned with the 2nd edition of ISO/IEC 28360:2012, and it added a new ozone calculation method. “Test method for the determination of emission from Hard Copy Devices” (RAL-UZ 122) has been replaced by “Test method for the determination of emission from Hard Copy Devices” (RAL-UZ 171) published in January 2013. Therefore, “RAL-UZ 122 option” is replaced with “RAL-UZ 171 option” in the 6th edition.

The 7th edition of ECMA-328 is fully aligned with ISO/IEC 28360:2015.

The 8th edition was divided into two parts, a part for electronic equipment using consumables and a part for electronic equipment not using consumables:

- Determination of Chemical Emission Rates from Electronic Equipment – Part 1 (using consumables)

- Determination of Chemical Emission Rates from Electronic Equipment – Part 2 (not using consumables)

The purpose of the split was to make the description of test procedures simpler (they included considerable differences between the two equipment categories) and to facilitate users’ understanding.

This 8th edition is fully aligned with “Test method for the determination of emission from Hard Copy Devices” (RAL-UZ 205).

The 9th edition is fully aligned with the third edition of ISO/IEC 28360:2018.

The 10th edition has been re-organised to incorporate RAL-UZ Options into the main text as one of the two methods for determining emission rates of VOC and carbonyl compounds.

One method (QEM), which is in harmony with DE-UZ 205[1], Test Method for the Determination of Emissions from Hardcopy Devices (Appendix S-M), originates from the former RAL-UZ 205 Options. The other method (CEM) employs the generalised constant emission model in the former editions. The two methods may yield slightly different emission rates, so the user is encouraged to select the one that satisfies their technical application.

Different elements of the two methods are described alongside each other in the main text. The models used to calculate emission rates in each method are explained in the informative Annexes C and D. Some requirements in the former RAL-UZ Options which appear too detailed and stringent as an international standard are now listed in the informative Annex E so that users can fully meet the requirements of DE-UZ 205[1] (Appendix S-M).

In this edition, it is deduced in the CEM that emission rates of VOC and carbonyl compounds during the operating phase (SER_{ope}) originate from the pre-operating phase (SER_{pre}) and printing (SER_{prp}) operations as well as in the QEM and the former RAL-UZ Options.

This part of the Standard is Part 1.

This Ecma Standard was developed by Technical Committee 38 and was adopted by the General Assembly of December 2020.

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[1] The German Blue Angel Environmental Label changed the naming convention of its award criteria from RAL-UZ 205 to DE-UZ 205 in 2019.

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Part 1

Determination of Chemical Emission Rates from Electronic Equipment (using consumables)

1 Scope

This Standard (all parts) specifies methods to determine chemical emission rates of analytes from ICT & CE equipment during intended operation in an Emission Test Chamber (ETC).

This Standard (all parts) includes specific methods for equipment using consumables, such as printers, and equipment not using consumables, such as monitors and PC's.

Part 1 specifies the methods to determine the emission rates of VOC and carbonyl compounds, ozone, particulate matter, fine particles (FP) and ultra-fine particles (UFP) from electronic equipment using consumables.

The methods comprise preparation, sampling (or monitoring) in a controlled ETC, storage and analysis, calculation and reporting of emission rates.

Part 1 has two different methods for the determination of emission rates of VOC and carbonyl compounds. The two methods use two different emission models, the quasi-equilibrium model (QEM) and the constant emission model (CEM) respectively, to determine the emission rates of VOC and carbonyl compounds during the pre-operating phase.

The quasi-equilibrium model method has been developed with hard copy devices for office or home use in mind whose energy-saving modes automatically activate during most intervals between operations. The calculation of emission rates during the pre-operating phase is based on the quasi-equilibrium assumption as shown in Annex C.

The emission rates determined with this method can be used to compare equipment in the same class since test procedures are specified more narrowly than the other method (CEM).

The constant emission model (CEM) has been developed for hard copy devices whose energy-saving modes have such a negligible effect on the determination of emission rates of VOC and carbonyl compounds that the generalised constant emission model shown in Annex D can be used for the determination of their emission rates during the pre-operating phase. This method presents more flexible test procedures than the QEM. Due to such features of this method, it may be used for hard copy devices whose idling mode usually lasts throughout intervals between operations, such as large hard copy devices used professionally. It may also be used for various equipment having different functions and structure for its intended use and the determination of carbonyl compounds requiring longer sampling duration due to a lack of sensitivity.

Annex A specifies monochrome and colour print patterns for use in the operating phase of EUT using consumables.

The operational readiness of AMS is confirmed according to Annex B.

Predictions of “real indoor” concentrations from the determined emission rates are outside the scope of this document.

2 Conformance

Determinations of emission rates and total number of emitted particles conform to this Standard (Part 1) when:

1. Executed using a Quality Assurance Project Plan, Quality Assurance and Quality Control as specified in ISO 16000-9;

2. Tested in a controlled ETC as specified in Clause 7;

3. Sampled/monitored and calculated as specified in Clause 8 and Annex B;

4. Reported as specified in Clause 9.

3 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.

ISO 554:1976, *Standard atmospheres for conditioning and/or testing – Specifications*

ISO 16000-3:2011, *Indoor air – Part 3: Determination of formaldehyde and other carbonyl compounds – Active sampling method*

ISO 16000-6:2011, *Indoor air – Part 6: Determination of volatile organic compounds in indoor and chamber air by active sampling on TENAX TA sorbent, thermal desorption and gas chromatography using MS/FID*

ISO 16000-9:2006, *Indoor air – Part 9: Determination of the emission of volatile organic compounds from building products and furnishing – Emission test chamber method*

ISO 16017-1:2000, *Indoor ambient and workplace air - Sampling and analysis of volatile organic compounds by sorbent tube / thermal desorption / capillary gas chromatography – Part 1: Pumped sampling*

CIE 15:2004, *Commission Internationale de l'Eclairage – Colorimetry, 3rd edition*

4 Terms and definitions

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

4.1
averaged concentration time series
simple moving average of total particle number concentration (C_p) over 31 ± 3 seconds

4.2
averaged ozone concentration time series
simple moving average of ozone concentration (Co_3) over 80 ± 5 seconds

4.3
aerosol
suspension of solid particles and/or liquid droplets in a gas

4.4
aerosol measuring system
AMS
device category for measuring the total particle number concentration of an aerosol within a size range at a certain frequency

NOTE CPC (4.8) and fast AMS (4.14) belong to AMS.

4.5
air exchange rate
n
ratio (n) of the volume of clean air brought into the ETC per hour [m^3/h] to the unloaded ETC volume [m^3]

4.6
air velocity
air speed [m/s] measured in the unloaded ETC

4.7
analyte
volatile organic compounds (VOC), carbonyl compounds, ozone, particulate matter, fine particles (FP) and ultrafine particles (UFP)

4.8
condensation particle counter
CPC
instrument that measures the particle number concentration of an aerosol

NOTE For the purpose of this standard a CPC is used as a standalone instrument which measures the total particle number concentration within a device dependent size range.

4.9
constant emission model method
CEM
method to determine emission rates of VOC and carbonyl compounds using the constant emission model, assuming that an emission rate is constant throughout the pre-operating phase

NOTE This method can apply to the pre-operating phase which consists of the warming-up and following idling and energy saving modes as far as constant emission during that phase can be assumed.

4.10
consumables
toner, ink, paper and ribbon

4.11
emission test chamber
ETC
enclosure with controlled operational parameters for testing analyte mass emitted from EUT

4.12
energy saving mode
mode in a lower power state than that of the idling mode which hard copy devices enter after a period of inactivity

4.13
equipment under test
EUT
electronic equipment from which chemical emission rates are determined

4.14
fast AMS
instrument with rapid time resolution and particle size classification

4.15
fine particles
FP
particles with particle size / diameter range between 0.1 μm and 2.5 μm

4.16
hard copy devices
class of EUT using Consumables that includes printers, (photo)copiers and Multi-Functional Devices (MFD)

4.17
idling mode
mode where hard copy devices are kept ready to perform its intended functions lasting from the end of warming-up mode or its operation to the start of an energy saving mode

4.18
loading factor
ratio of the EUT volume to the volume of the unloaded ETC

4.19
operating phase
phase in which the EUT is performing its intended functions

4.20
particle
solid or liquid matter with defined physical boundaries suspended in a gas

4.21
particle emission rate
PER
averaged time dependent particle emission rate between the points in time of the start (t_{start}) and end (t_{stop}) of particle emission

4.22
time dependent particle emission rate
PER(t)
time dependent emission rate of particles in a specified particle size range after the start of the operating phase

4.23
particle loss coefficient
$\boldsymbol{\beta}$
coefficient describes the loss of particles in a specified particle size range in an ETC

4.24
particle size / particle diameter
measurement category to describe the physical dimension of a particle

NOTE The term particle size is often used as a synonym for particle diameter. The particle diameter is used to assign a particle to a particle size class (e.g. UFP).

4.25
particulate matter
PM
quantity of particles measured by gravimetric methods

4.26
pre-operating phase
phase between the points in time at which the EUT is powered-on and the signal to start the operating phase is sent to the EUT

NOTE The pre-operating phase can include warming-up and energy saving modes.

4.27
post-operating phase
phase following the operating phase

NOTE The post-operating phase can include energy saving modes.

4.28
quasi-equilibrium model method
QEM
method to determine emission rates of VOC and carbonyl compounds using the quasi-equilibrium model characterized by the assumption that the concentration of an analyte in the ETC reaches a quasi-equilibrium much earlier than expected in theory due to the activation of energy saving modes

4.29
specific emission rate
SER
mass, in micrograms, of a specific analyte emitted per hour

4.30
stabilizing period
t_s
Suspension time between the pre-operating and operating phases, which starts when the air exchange rate is changed and ends when the operating-phase begins if the air exchange rates during the pre-operating and operating phases differ

NOTE A certain length of suspension time may exist for preparation for sampling, conditioning of humidity in the ETC, stabilization of the air exchange rate and the concentrations of VOC and carbonyl compounds before the start of the operating phase.

4.31
standard particle emission rate
PER_{10}
calculated number of particles emitted during a 10-minute operating phase in a specified particle size range

4.32
total number of emitted particles
TP
calculated total number of particles in a specified particle size range between the points in time of the start (t_{start}) and end (t_{stop}) of particle emission

4.33
total particle number concentration
$\mathbf{C_p}$
particle number concentration in a specified particle size range

4.34
total usage time before testing
TUT
ratio between the total number of prints carried out by the EUT and the printing speed of the EUT

NOTE Total usage time is equal to or shorter than 120 minutes to be tested as newly manufactured EUT.

4.35
total volatile organic compounds
TVOC
the sum of the concentrations of identified VOC and the concentrations of the converted areas of unidentified peaks using the toluene response factor

NOTE This definition of “total volatile organic compounds” differs from the definition in ISO 16000-6:2011.

4.36
ultrafine particles
UFP
particles with particle diameter less or equal to 0.1 µm

4.37
volatile organic compounds
VOC
compounds that elute between n-hexane and n-hexadecane (including these compounds) on a nonpolar GC-column

5 Symbols and Abbreviated terms

5.1 Abbreviated terms

AMS	Aerosol Measuring System
CEM	Constant Emission Model Method
CPC	Condensation Particle Counter
DNPH	2,4-Dinitrophenylhydrazine
ETC	Emission Test Chamber
EUT	Equipment Under Test
FID	Flame Ionisation Detector
FP	Fine Particles
GC/MS	Gas Chromatography/Mass Spectrometry
MFD	Multi Functional Device
PER	Averaged Particle Emission Rate
PER(t)	Time-dependent Particle Emission Rate
PER_{10}	Standard Particle Emission Rate
PTFE	Polytetrafluoroethene (Polytetrafluoroethylene)
PVC	Polyvinylchloride
QEM	Quasi-equilibrium Model Method
RH	Relative Humidity
SER	Unit Specific Emission Rate
TUT	Total Usage Time Before Testing
TVOC	Total Volatile Organic Compounds
UFP	Ultrafine Particles
VOC	Volatile Organic Compounds

5.2 Symbols

α	Factor in the exponential particle decay function [cm^{-3}]

β	Particle loss coefficient [h^{-1}]
C_{bg}	Background mass concentration [$\mu g\ m^{-3}$]
C_{max}	Maximum mass concentration in the operating phase [$\mu g\ m^{-3}$]
C_{ope}	Average mass concentration during sampling in the operating and post-operating phase [$\mu g\ m^{-3}$]
C_{o3}	Ozone concentration [mg/m3]
C_p	Total particle number concentration [cm^{-3}]
C_{pbg}	Background particle number concentration [cm^{-3}]
C_{pre}	Average mass concentration during sampling in the pre-operating phase [$\mu g\ m^{-3}$]
C_s	Average mass concentration [$\mu g\ m^{-3}$]
C_0	Initial mass concentration [$\mu g\ m^{-3}$]
d	Equivalent Particle Diameter [nm]
m_{after}	Sample filter mass [µg] after sampling
m_{before}	Sample filter mass [µg] before sampling
m_{bg}	Sampled mass for chamber background [µg]
m_{ope}	Sampled mass [µg] during operating and optionally post-operating phase
m_{pre}	Sampled mass [µg] during pre-operating phase
m_{pm}	Mass of particulate matter [µg] deposited on the filter
$m_{ref\text{-}after}$	Reference filter mass [µg] after sampling
$m_{ref\text{-}before}$	Reference filter mass [µg] before sampling
m_s	Sampled mass [µg]
n	Air exchange rate during operating and post-operating phase [h^{-1}]
n_{pre}	Air exchange rate during pre-operating phase
p	Atmospheric pressure [Pa]
R	Gas constant [PaK-1], (for ozone: 339.8 [PaK-1])
SER_{bg}	Background SER [$\mu g\ h^{-1}$]
SER_{O3}	SER for ozone [$\mu g\ min^{-1}$]
SER_{ope}	SER during operating phase [$\mu g\ h^{-1}$]
SER_{pm}	SER for particulate matter [$\mu g\ h^{-1}$]
SER_{pre}	SER during pre-operating phase [$\mu g\ h^{-1}$]

SER_{prp}	SER stemming from printing during the operating phase excluding emission at the rate of SER_{pre} which is lasting from the pre-operating phase [µg h^{-1}] $SER_{prp} = SER_{ope} - SER_{pre}$
T	Ambient temperature [K]
t_G	Sampling time during operating and optionally post-operating phase [h]
TP	Total Number of Emitted Particles
t_{ope}	Operating phase duration [h]
t_{pre}	Pre-operating phase duration [h]
t_s	Stabilizing period duration [h]
t_{start}	Point in time marking the start of particle emission
t_{stop}	Point in time marking the end of particle emission
Δt	Time-resolution of the UFP measurement [s]
V	ETC volume [m^3]
V_{bg}	Sampled air volume [m^3] for determination of C_{bg}
V_{pre}	Sampled air volume [m^3] in pre-operating phase
V_{ope}	Sampled air volume [m^3] in operating and optionally post-operating phase
V_s	Sampled air volume [m^3]

6 Method overview

The flowchart in Figure 1 illustrates the method; clause numbers are indicated in brackets.

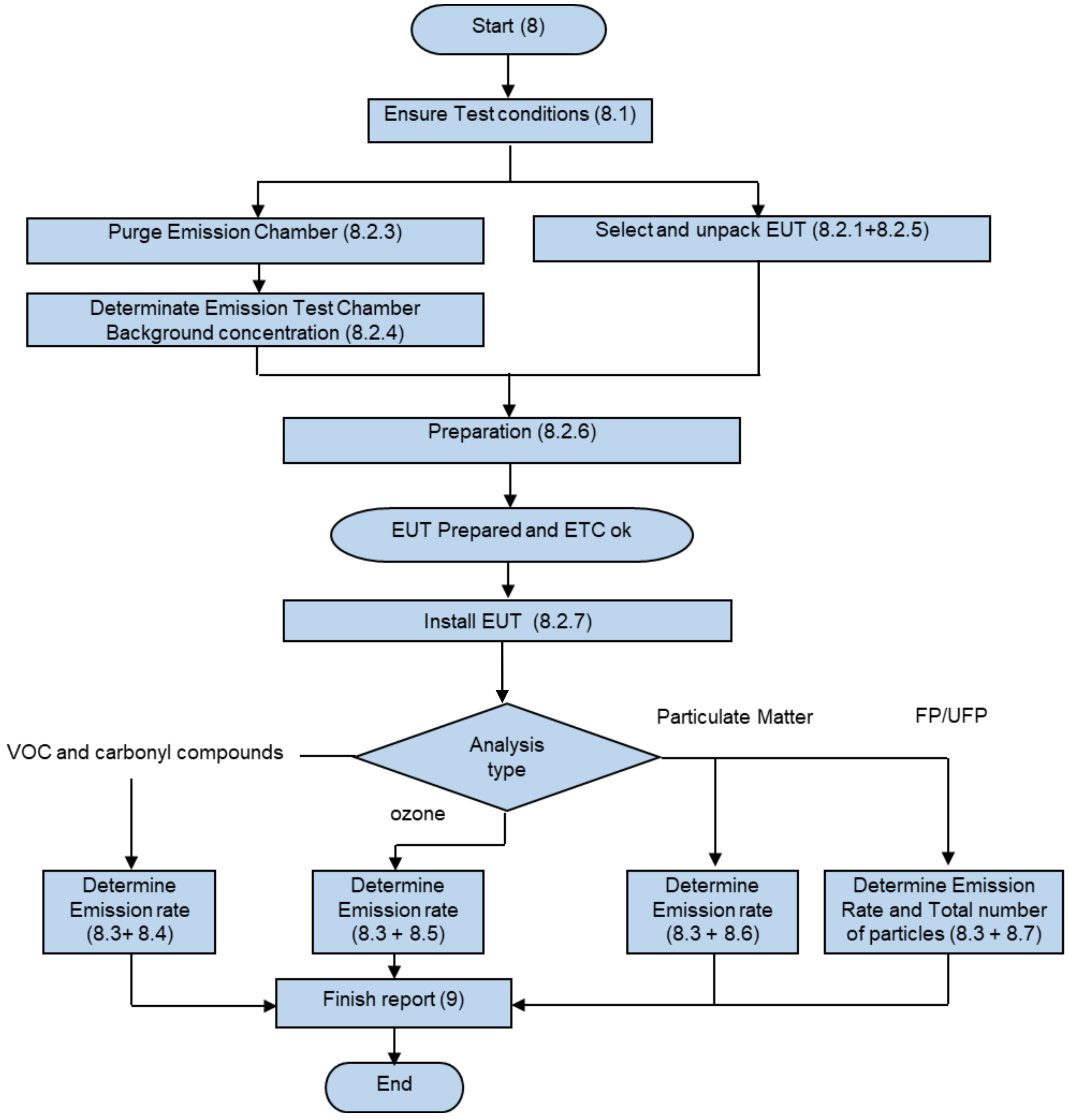

Figure 1 — Determination method overview

7 ETC requirements

7.1 Construction materials

ETC construction materials shall comply with ISO 16000-9.

7.2 Air tightness

The ETC air tightness shall be as specified in ISO 16000-9.

7.3 Air mixing efficiency

The air mixing efficiency in the ETC shall be as specified in ISO 16000-9.

8 Determination method

8.1 Test conditions

8.1.1 General

To meet the operational requirements specified herein, ETC parameters such as temperature, relative humidity and supply airflow shall be controlled and measured at regular intervals and recorded in accordance with ISO 16000-9 and shall be reported as specified in Clause 9.

8.1.2 Operating temperature and relative humidity (RH)

Tests shall be executed at (23 ± 2) °C and (50 ± 5) %RH according to ISO 554. For EUT used in alternative climatic conditions, higher operating temperature and humidity conditions may be used as specified in ISO 554.

NOTE To avoid condensation due to vaporisation of water from paper during the operating phase, incoming air with RH of at most 10% may be inserted in the ETC before the operating phase. In addition, the air exchange rate (n) may have to be increased to avoid such condensation. Increase of humidity during the operating phase also depends on the ETC volume. Condensation of water vapour (i.e. RH > 85%) on the ETC walls invalidates the test.

8.1.3 Air exchange rate (n)

For unloaded ETCs with a volume larger than 5 m^3, “n” shall be in the range from between 1,0 to 2,0. For unloaded ETC’s with a volume of 5 m^3 or smaller, “n” shall be in the range from between 1,0 to 5,0.

8.1.4 Air velocity

The air velocity in the unloaded ETC should be in the range from 0,1 to 0,3 m/s.

8.1.5 Sampled air flow

The sum of sampled airflow shall be less than 80% of the inlet airflow into the ETC.

8.2 Handling of EUT and ETC

8.2.1 Selection and storage of EUT

EUT shall be selected from normal manufactured batches or shall be a prototype that is representative for EUT from such batches. EUT shall be stored before the test in a room where EUT is not likely to be contaminated.

The amount of VOC emitted from electronic equipment generally changes with usage. Newly manufactured equipment usually emits the highest amount of VOC in its life. EUT belongs to the following two categories in this standard.

Newly manufactured EUT: The EUT of which the TUT is equal to or shorter than 120 minutes.

Used EUT: The EUT of which he TUT is longer than 120 minutes. TUT shall be reported in the test report, if known, otherwise “not known” shall be reported.

8.2.2 Loading Factor

To ensure detection of a minimum emission within a practicable time, the ETC with capabilities as specified in 7 shall be selected such that the loading factor is in the range of 1:4 to 1:400. For the ETC where the loading factor is in the range of 1:100 to 1:400, the air volume flow of the ETC shall be ≤ 5 m³/h.

8.2.3 ETC purging

The selected ETC shall be unloaded and its interior walls shall be cleaned as described in ISO 16000-9.

The ozone half-life, the period of time for the ozone concentration (C) to drop from C to C/2, shall be greater than 10 minutes, when n = 1.

To determine the ozone half-life, the ETC should be deactivated by exposure to an ozone concentration of 0,2 mg/m^3 to 0,4 mg/m^3 for at least ten minutes or until a stable concentration is reached.

Thereafter, the ETC shall be purged with 4 ETC volumes of clean air.

8.2.4 Background concentrations (C_{bg} and C_{pbg})

Following purging, the background concentrations of analytes in the unloaded ETC shall be determined and recorded. The background concentration values at n = 1, shall be below the limits shown in Table 1.

NOTE C_{bg} of VOC and carbonyl compounds may stem from the ETC itself, supplied air to the ETC and sorbents used for sampling.

For ETC materials, with SER = SER_{bg}, the background concentration has reached an equilibrium after purging:

$$C_{bg} = \frac{SER_{bg}}{n \cdot V}$$

For supplied air, the background concentration is influenced by supplied air quality and the performance of filters for the analyte

For sorbents, the background concentration is influenced by blank values of the sorbents and sampling duration.

The background concentration should be determined in conditions with equivalent air exchange rate, sampling duration and sampling date to the following tests so that influences of the sources above can be minimized.

The sampling date, sampling duration and air exchange rate for the ETC shall be recorded with the background concentration.

The C_{bg} values at n = 1, shall be below the limits shown in Table 1.

Table 1 — Background concentrations

Item	Limit
VOC and carbonyl compounds	2 [µg/m^3] for any analysed substance
TVOC	20 [µg/m^3]
Ozone	4 [µg/m^3]
PM	10 [µg/m^3]
FP and UFP	C_{pbg} = 2000 [cm^{-3}]

8.2.5 EUT unpacking

Emissions from packaging may influence measurements considerably, because packaging itself may emit VOCs that are not representative for EUTs in typical use. Therefore, the EUT to be tested shall be removed from the shipping containers and all protective shipping packaging such as spacers, film wrapping and any other shipping/packaging elements before preparation (as specified in 8.2.6).

NOTE After unpacking, installation (step 8.2.7) may precede the preparation step (8.2.6).

8.2.6 Preparation of the EUT before testing

Printing the patterns as specified in A.1 and A.2 are appropriate for the following preparatory operation below. The maximum duration of the operating phase shall be determined.

One or two 10-minute operating cycles should be performed for the purpose of EUT function testing and measurement of print speed. The TUT of the EUT shall not exceed 120 minutes when the EUT is tested as the newly manufactured EUT.

The one or two 10-minute operating cycles shall be performed at least one day before the UFP test to avoid influence on emissions due to unstable UFP emission which may occur in operation after long-term disuse of the EUT.

Treatment conditions shall be recorded in the test report.

8.2.7 EUT installation

Before installation, the EUT shall have sufficient consumables to complete the operations. In case of paper consumables, 60 g/m^2 to 80 g/m^2 A4 paper with normal water content (preferably from 3,8% to 5,6%) to avoid water condensation shall be used.

To avoid contamination, the powered-off EUT shall be installed in the middle of the ETC as fast as possible and all operators shall leave the ETC immediately thereafter.

The EUT shall remain powered-off until the emission tests require the EUT to be powered-on as specified in 8.3.1.

For the determination of FP and UFP specified in 8.7 the EUT shall be installed on the day before the emission test.

The ETC shall remain closed until all sampling and/or monitoring is completed.

The installation date and time shall be recorded.

Emission testing, as specified in 8.3, shall not begin within at least 3 air exchanges following installation.

8.3 EUT Operation during Test

8.3.1 General

EUT operation during test consists of the pre-operating phase, operating phase and post-operating phase. QEM and CEM have slightly different operation as shown in the clauses for each phase.

Emission rates of VOC and carbonyl compounds as specified in 8.4, ozone as specified in 8.5, particulate matter as specified in 8.6 and FP and UFP as specified in 8.7 shall be determined while the EUT is being controlled from outside the ETC.

NOTE Users can determine emission rates of VOC and carbonyl compounds according to QEM or CEM at their discretion after comparing their individual purposes of the test and the features of the two determination methods described in Clause 1.

8.3.2 Pre-operating phase

QEM

To enter the pre-operating phase, the EUT shall be powered-on in the ETC and remain on for an hour. n_{pre} shall be 1,0/h during this phase.

CEM

To enter the pre-operating phase, the EUT shall be powered-on in the ETC and remain on during this phase from between 1 to 4 air exchanges. For unloaded ETCs with a volume larger than 5 m^3, n_{pre} shall be in the range from between 1,0 to 2,0. For unloaded ETC's with a volume of 5 m^3 or smaller, n_{pre} shall be in the range from between 1,0 to 5,0.

NOTE For the determination of FP and UFP as specified in 8.7, particle counting shall be started from the start of the pre-operating phase because particle emission is observed for some EUTs soon after they are powered-on.

8.3.3 Operating phase

The operating phase follows the pre-operating phase. Enter the operating phase by beginning copying or printing. The output of the first printed page marks the start of the operating phase. It ends with the output of the last printed page.

The EUT shall operate at nominal speed. Operating may include monochrome, colour, single-sided (simplex) and/or double-sided (duplex) printing. The monochrome and colour print patterns specified in Annex A.1 and A.2, respectively, shall be used for EUT using paper consumables.

QEM

The duration of the operating phase shall be planned as follows:

First priority: The duration shall be at least 10 minutes.

Second priority: If a 10-minute duration is technically not feasible the operational phase shall be as long as possible. The duration shall not be below five minutes.

CEM

In conjunction with other parameters such as "n", ETC volume and the use of the post-operating phase, the duration of the operating and post-operating phase shall be such that quantitative analysis is ensured.

NOTE There may be a certain length of suspension time between the pre-operating and operating phases for various reasons. The suspension time is defined as the stabilizing period ($t_{s)}$ in this standard (See 4.30).

8.3.4 Post-operating phase

The post-operating phase starts when the operating phase ends, and may last up to four air exchanges.

8.3.5 Recording of EUT operation

The start and duration of the pre-operating, operating and post-operating phases shall be recorded.

8.4 VOC and carbonyl compounds

The flow chart in Figure 2 illustrates the determination method for VOC and carbonyl compounds.

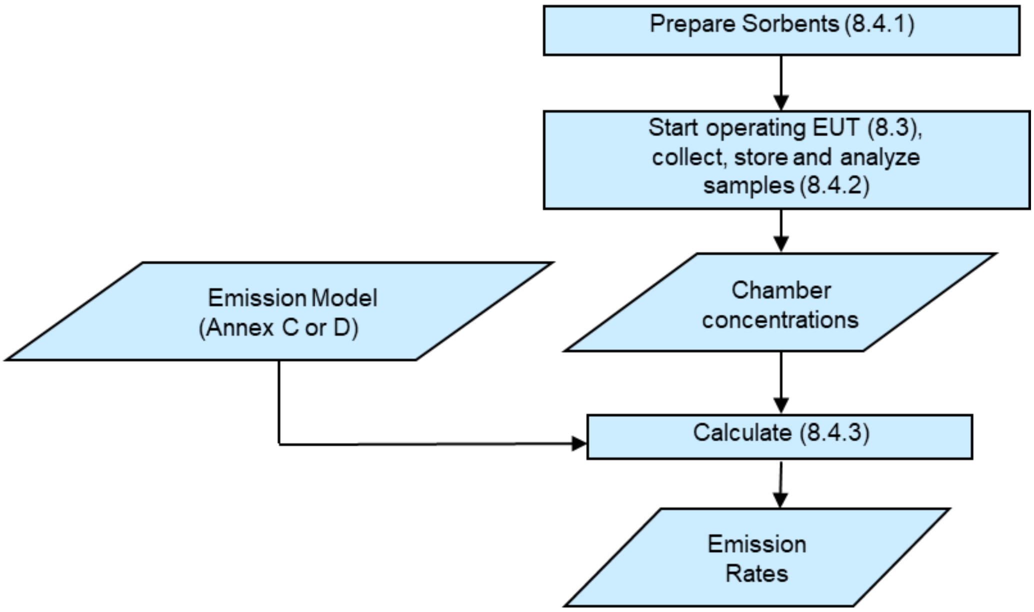

Figure 2 — Determination method for VOC and carbonyl compounds

8.4.1 Sorbents

VOC sampling and analysis shall be performed using the sorbents as specified in ISO 16017-1, with the exception of Chromosorb and PoraPak due to their high blank values. Tenax TA™ shall be conditioned and analysed according to ISO 16000-6 to minimise the production of artefacts, especially benzene.

For carbonyl compounds, DNPH cartridges shall be used as sorbent material.

8.4.2 Sample collection

8.4.2.1 General

For VOC, duplicate samples shall be taken.

Individual VOC and carbonyl compounds with a concentration ≥ 1,0 μg/m^3 shall be detected.

In addition, carbonyl compounds sampling shall be conducted as specified in ISO 16000-3.

8.4.2.2 Sampling

Sampling shall be performed during the following periods:

QEM

- The last twenty minutes of the pre-operating phase -- from 40 minutes after the start until the end of the pre-operating phase.

- The complete operating phase and the first one air exchange of the post-operating phase — from the beginning until the end of the operating phase and sampling shall continue for one air exchange in the post-operating phase.

CEM

- The complete pre-operating phase — from the beginning until the end of this phase

- The operating phase, starting at the beginning of this phase, sampling may continue into the post-operating phase.

8.4.2.3 Requirements after sampling

Loaded samples shall be stored and analysed as specified in ISO 16000-3 and ISO 16000-6.

Identified VOC shall be quantified using absolute response factors, determined by calibration. Unidentified VOC and those identified, response factors of which cannot be determined, shall be quantified as toluene equivalents using the toluene response factor.

When benzene is detected, this shall be verified and quantified by analysing a sample on alternate carbonaceous sorbent such as Carbotrap/Carbopack type materials.

When in doubt, positive findings of benzene are to be verified via a second independent sampling (e.g. using Carbotrap/Carbopack™ or activated carbon-type materials).

NOTE Relative response factors determined by calibration compared to an internal standard may be used instead of absolute response factors to eliminate variation in response factors.

8.4.3 Emission rate calculation

8.4.3.1 General

Sub-clause 8.4.3 specifies formulae to calculate emission rates in practical situations derived from the emission models as shown in Annexes C and D.

Concentrations shall be determined, using the following equations:

$$C_s = \frac{m_s}{V_s} \qquad C_{ope} = \frac{m_{ope}}{V_{ope}} \qquad C_{pre} = \frac{m_{pre}}{V_{pre}} \qquad C_{bg} = \frac{m_{bg}}{V_{bg}} \tag{1}$$

8.4.3.2 Emissions in the pre-operating phase

QEM

Assuming that a quasi-equilibrium in concentration is reached during the pre-operating phase, emission rates shall be calculated as follows:

$$SER_{pre} = C_{pre} \cdot n_{pre} \cdot V \tag{2}$$

CEM

Assuming constant emission rates during the pre-operating phase, emission rates shall be calculated as follows:

$$SER_{pre} = \frac{C_{pre} \cdot n_{pre}^{2} \cdot V \cdot t_{pre}}{n_{pre} \cdot t_{pre} + exp(-n_{pre} \cdot t_{pre}) - 1} \tag{3}$$

8.4.3.3 Emissions in the operating and post-operating phase

QEM

The following general formula shall be used for the calculation of SER_{prp}.

$$SER_{prp} = \frac{C_{ope} \cdot n^{2} \cdot V \cdot t_{G} - SER_{pre} \cdot \left[n \cdot t_{G} - \left(1 - \frac{n}{n_{pre}} \right) exp(-n \cdot t_{s}) \cdot (1 - exp(-n \cdot t_{G})) \right]}{exp(-n \cdot t_{G}) - exp\left(-n(t_{G} - t_{ope}) \right) + n \cdot t_{ope}} \tag{4}$$

If n_{pre} and “n” are almost the same or t_s is relatively long ($n*t_s \geq 3$), the general formula is reduced to:

$$SER_{prp} = \frac{C_{ope} \cdot n^{2} \cdot V \cdot t_{G} - SER_{pre} \cdot n \cdot t_{G}}{exp(-n \cdot t_{G}) - exp\left(-n(t_{G} - t_{ope}) \right) + n \cdot t_{ope}} \tag{5}$$

SER_{ope} is obtained as follows:

$$SER_{ope} = SER_{pre} + SER_{prp} \tag{6}$$

NOTE Formula (5) may be used instead of formula (4) when $n*t_s$ is equal to or larger than one air exchange (DE-UZ 205). Smaller $n*t_s$ than three may cause a small overestimation of SER_{ope}.

CEM

The following general formula shall be used for the calculation of SER_{prp}.

$$SER_{prp} = \frac{C_{ope} \cdot n^{2} \cdot V \cdot t_{G} - SER_{pre} \cdot \left[n \cdot t_{G} - \left(1 - \frac{n}{n_{pre}} \cdot \left(1 - exp(-n_{pre} \cdot t_{pre}) \right) \right) \cdot exp(-n \cdot t_{s}) \cdot (1 - exp(-n \cdot t_{G})) \right]}{exp(-n \cdot t_{G}) - exp\left(-n(t_{G} - t_{ope}) \right) + n \cdot t_{ope}} \tag{7}$$

If t_s is relatively long ($n*t_s \geq 3$), the general formula is reduced to:

$$SER_{prp} = \frac{C_{ope} \cdot n^{2} \cdot V \cdot t_{G} - SER_{pre} \cdot n \cdot t_{G}}{exp(-n \cdot t_{G}) - exp\left(-n(t_{G} - t_{ope}) \right) + n \cdot t_{ope}} \tag*{(5) reshown}$$

If n_{pre} and n are almost the same and there is no stabilizing period of time (t_S) between the two phases, the general formula is reduced to:

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot [n \cdot t_G - exp(-n \cdot t_{pre}) \cdot (1 - exp(-n \cdot t_G))]}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \qquad (8)$$

If t_{pre} in formula (8) is relatively long ($n*t_{pre} \geq 3$),

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot n \cdot t_G}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \qquad \text{(5) reshown}$$

SER_{ope} is obtained as follows:

$$SER_{ope} = SER_{pre} + SER_{prp} \qquad \text{(6) reshown}$$

NOTE Theoretically, SER_{prp} may be a negative value. Even though SER_{prp} is a negative value, SER_{ope} which is the sum of SER_{prp} and SER_{pre} will be a positive value or zero.

NOTE Inserting formula (8) in formula (6) yields:

$$\begin{aligned} & SER_{ope} \\ & = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot \left[n \cdot t_G - exp\left(-n \cdot t_{pre}\right) \cdot \left(1 - exp(-n \cdot t_G)\right)\right]}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \\ & + \frac{SER_{pre} \cdot \left[exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}\right]}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \\ & = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot \left[exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot \left(t_G - t_{ope}\right) - 1 + \left(1 - exp\left(-n \cdot t_{pre}\right)\right) \cdot \left(1 - exp(-n \cdot t_G)\right)\right]}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \end{aligned}$$

This is the general case fomula where $C_{bg} = 0$ shown in the main text of the former editions.

8.4.4 Total VOC emission rate

The total VOC emission rate should be calculated as the sum of all identified and unidentified substances.

NOTE While this part of ECMA-328 Part 1 (Sub-clause 8.4) specifies the determination method for individual VOC or carbonyl compounds, not only one substance emission rate but also the total VOC emission rate is important to characterize chemical emissions from hard copy devices. The determination of emission rates of quantifiable VOC according to this standard allows the total VOC emission rate, which is the sum of the emission rates determined, to comply with this Standard.

8.5 Ozone

The flowchart in Figure 3 illustrates the determination method for ozone.

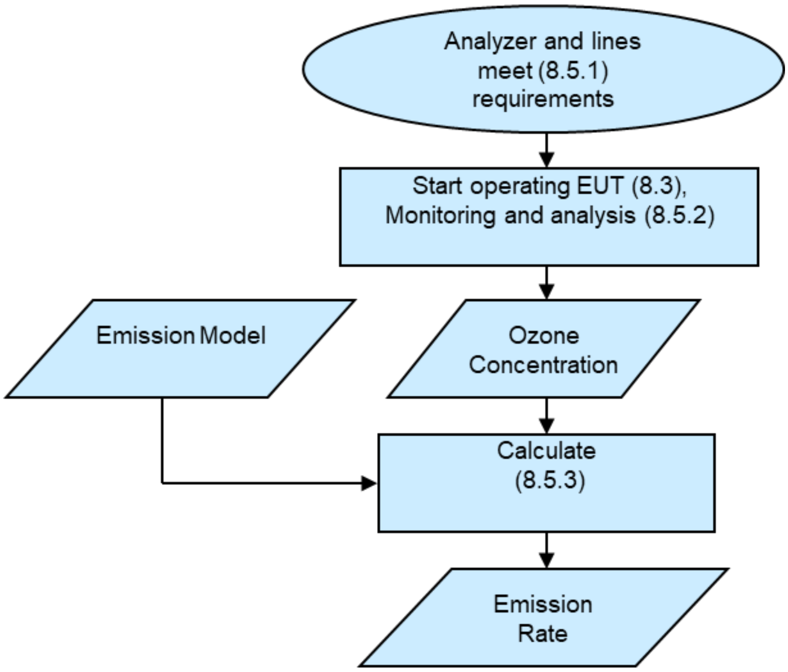

Figure 3 — Determination method for ozone

8.5.1 Analyser and sampling line requirements

Ozone analysers shall at least fulfil the following requirements:

- The capability to detect concentrations between 4 µg/m^3 and 1mg /m^3;
- A precision of 2 µg/m^3;
- A sampling rate (may be important for small ETCs) of ≤ 2 l/min.

Ozone concentrations of the data points used to determine the maximum ΔCo_3 shall not be rounded to the nearest whole ppb (1 ppb = 1.963 µg/m^3) by data processing of the analyser because rounding may cause errors in the determination of the ΔCo_3.

To prevent loss of ozone in the sampling line, it shall be of minimum length, not exceeding 4 m, and made of a flexible inert material such as PTFE.

8.5.2 Monitoring

Since ozone is an unstable molecule, it shall be monitored and analysed instantaneously at least every 30 seconds, preferably every 15 seconds during the operating phase to determine the maximum ΔCo_3 as specified in 8.5.3. In addition, some data points before and/or after the operating phase shall be recorded so that the averaged ozone concentration time series can be calculated as specified in 8.5.3.

8.5.3 Emission rate calculation

The ozone emission rate is derived from the increase in ozone concentration during the early part of the operating phase. In this part of the operating phase ozone loss by chemical reactions with air constituents and by discharge due to air exchange is comparatively small. Therefore, the increase of ozone concentration with time is approximated as linear.

By taking formula (9) in the operating phase

$$\frac{\Delta m}{\Delta t} = \frac{\Delta c_{O3} * V}{\Delta t} \tag{9}$$

Δm: emitted ozone mass [mg]

ΔCo_3: change of ozone concentration [mg/m³]
Δt: time interval [min]

the emission rate of ozone shall be calculated by formula (10):

$$\mathrm{SER}_{\mathrm{O3}} = \frac{\Delta c_{O3} * V * p * 60}{\Delta t * T * R} \tag{10}$$

A time interval *Δt* of two minutes and the maximum ΔCo_3 shall be applied in formula (10). This is the case when the averaged ozone concentration time series exhibits the greatest slope for the two-minute time interval ($Co_3(t+2) - Co_3(t)$ = maximum). The averaged ozone concentration time series is created with the simple moving average over 80 ± 5 seconds.

NOTE Theoretically, a time interval of the data points at the start of the operating phase gives the maximum Δm/Δt corresponding to the true emission rate. However, deviations of measured ozone concentration curves from the theoretical curve occur due to fluctuations of ozone data caused by incompleteness of air mixing in the chamber and effects of electric noises of ozone analysers, especially in larger chambers. The deviations make it difficult to determine an ozone emission rate according to the theory. Effects of electric noises can be reduced significantly by using the averaged ozone concentration time series. In addition, Δt of 2 minutes is selected and the determination of the maximum ΔCo_3 is conducted to minimize the effects of remaining fluctuations.

For analysers indicating values that are converted for the Standard Ambient Temperature and Pressure (SATP) of (273 + 25 = 298) K and 101 325 Pa (i.e. 1 atmosphere), SER_{O3} shall be calculated using the actual ETC pressure (p in Pa), the actual ETC temperature (T in K) and the gas conversion constant (R = 339,8 Pa/K), otherwise p/TR = 1 shall be used.

NOTE If the temperature and pressure in the ETC equal the SATP, p/TR is 1.

8.6 Particulate matter

The flowchart in Figure 4 illustrates the gravimetric determination method for particulate matter emitted from EUT using consumables.

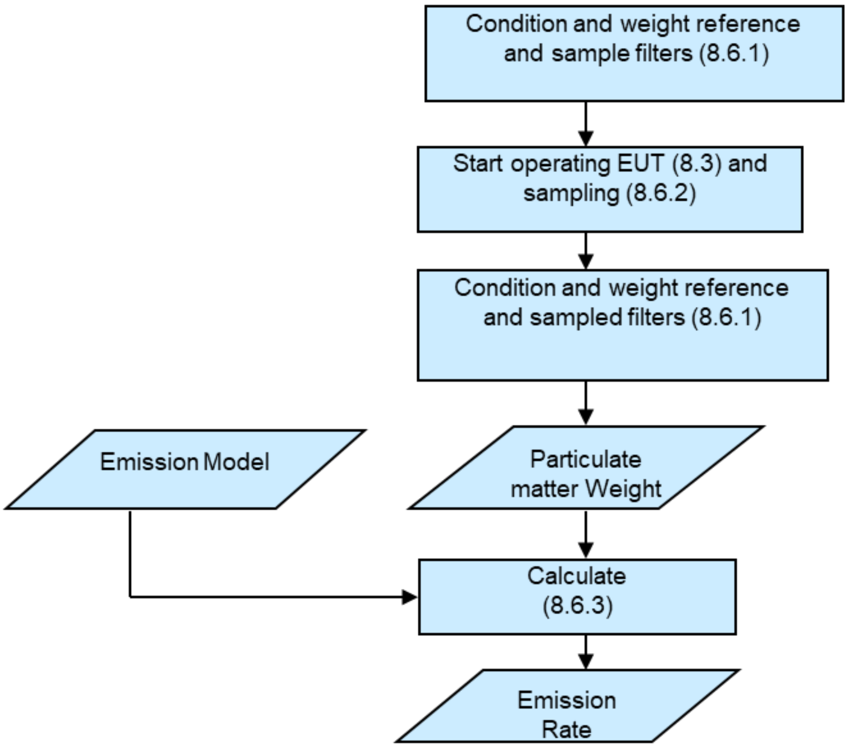

Figure 4 — Determination method for particulate matter

8.6.1 Weighing and Filter conditioning

The analytical balance, with a weighing precision of 1µg or better, shall be located in a temperature and humidity-controlled room (weighing room) as specified in 8.1.2.

Glass fibre filters with 0,7 µm pore size, or equivalent e.g. 0,8 µm pore size PVC filters, shall be used.

The filters shall be conditioned (remain in the weighing room) for at least 48 hours or to constant mass in the weighing room. Since even the smallest inevitable fluctuations in the relative humidity in the weighing room affect the weight of the glass fibre filter, at least one unloaded reference filter is weighed at the same time as the sampling filter before and after particulate matter sampling to minimise the influence of climate on the filter material by a climate correction. The unloaded reference filter and the sampling filters shall be weighed before sampling giving $m_{ref\text{-}before}$ and m_{before}.

During particulate matter sampling, air is drawn through the test filter. As the relative humidity of this air may differ from that in the weighing room, the sampling filter must be conditioned again after particulate matter sampling for at least 48 hours or to a constant weight in the controlled room.

The reference filter is left in the weighing room constantly.

8.6.2 Sampling

Particulate matter shall be sampled during the operating and post-operating phases of the EUT. Sampling duration shall ensure the detection of at least 5 µg/m3 of particulate matter.

8.6.3 Emission rate calculation

The unused reference filter and the sampling filters shall be weighted after sampling giving $m_{ref\text{-}after}$ and m_{after}.

The particulate matter mass shall be corrected with the reference filter mass difference:

$$m_{pm} = (m_{after} – m_{before}) - (m_{ref\text{-}after} - m_{ref\text{-}before}). \quad (11)$$

With $C_{ope} = m_{pm} / V_{ope}$, the SER_{pm} shall be calculated using the following formula:

$$SER_{pm} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G}{\exp(-n \cdot t_G) - \exp[-n \cdot (t_G - t_{ope})] + n \cdot t_{ope}} \quad (12)$$

The following approximate formula may be used when the operating and post-operating phase is relatively long ($n*t_G \geq 3$):

$$SER_{pm} = \frac{C_{ope} \cdot n \cdot V \cdot t_G}{t_{ope}} \quad (13)$$

8.7 Fine and Ultrafine Particles (FP and UFP)

The flow chart in Figure 5 illustrates the determination method for FP and UFP. FP and UFP determination does not substitute for the gravimetric determination of particulate matter (8.6). It is an additional test to be performed in parallel.

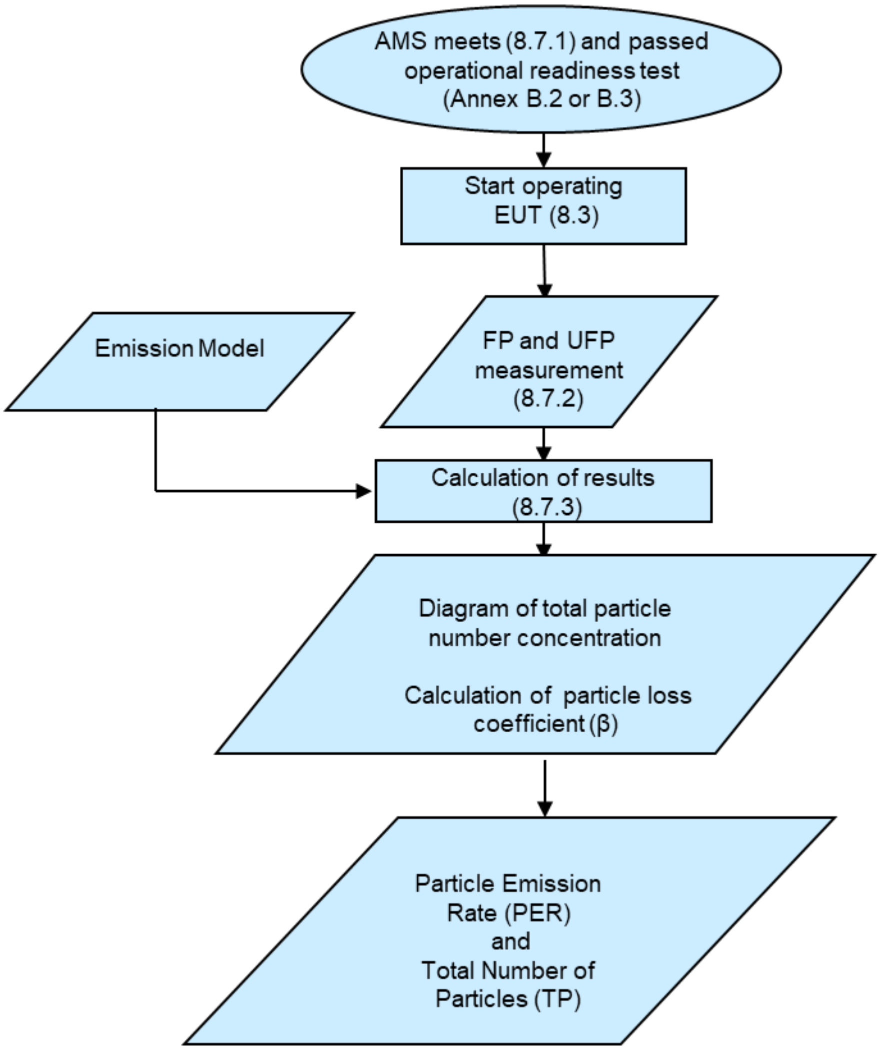

Figure 5 — Determination method for FP and UFP emissions

8.7.1 General Requirements for Aerosol Measuring Systems (AMS)

8.7.1.1 General

An AMS shall be capable to measure the time dependent total particle number concentration with particle size range as specified in 8.7.1.2, particle number concentration range as specified in 8.7.1.3 and time resolution as specified in 8.7.1.4.

The operational readiness test for AMS shall be passed prior to testing as specified in Annex B.

8.7.1.2 Particle size range

The following instrument settings should be regarded as minimum requirements: The AMS shall be capable to count particles within a size range from at least 7 nm to at least 300 nm.

The detection efficiency at the lower size limit (7 nm) must be equal or higher than 50%.

NOTE Consult the AMS instruction manual for specific details.

8.7.1.3 Particle number concentration range

The below instrument criteria should be fulfilled without the application of an aerosol dilution system between the ETC sampling port and the inlet of the AMS.

CPC:

The required lower particle number concentration level shall be 1 cm^{-3} within the above specified size range.

The required upper particle number concentration level within the above specified size range shall be at least $10^7 cm^{-3}$. It may be necessary to use a calibrated aerosol dilution stage with a specified dilution factor.

Fast AMS:

The required lower concentration level in the size channel nearest to the lower particle size limit of 7 nm shall be equal or lower than 5,000 cm^{-3}.

The required upper concentration level in the size channel nearest to the upper particle size limit of 300 nm shall be equal or higher than 10^6 cm^{-3}.

NOTE 1 These requirements refer to concentration values normalized to size channels widths and a time resolution of 1 s.

NOTE 2 Refer to Annex B.1 for further information.

8.7.1.4 Time resolution

Particle number concentration values shall be recorded at a rate of at least 0.5 Hz.

8.7.1.5 Working fluids for CPC

CPCs shall be operated with the working fluids butanol or isopropanol.

NOTE CPCs which use water as a working fluid give much different C_p's from those determined with other compliant CPCs for the purpose of this Standard.

8.7.1.6 Connection of AMS to ETC

The tubing between the ETC sampling port and the aerosol inlet of the AMS shall consist of electrically conductive material (e.g. conductive silicon rubber) and shall not exceed 3 m in length. Sharp bends in the tubing shall be avoided. The connecting hose should protrude at least 10 cm deep into the ETC.

8.7.1.7 Quality Assurance

AMS shall have the following capabilities:

- device-side controlled flow rates
- automatic display of malfunctions during measurement
- export of measurement data for evaluation
- display of the individual device settings to be selected by the user
- ability to adjust or synchronise time and date

- measurement of electrometer noise levels for fast AMS

- a detailed description of cleaning and maintenance procedures must be available.

8.7.2 Measurement

FP and UFP shall be measured during the pre-operating, operating and post-operating phases of the EUT. The result of FP and UFP measurement are presented as a diagram of C_p versus time comprising the period from 5 min before start of the operating phase to at least 30 min after its end.

8.7.3 Calculation

8.7.3.1 General

The AMS manufacturer's software data display feature should be used in order to check the quality of measured data as described below.

- The particle number concentration time series should not reveal sudden discontinuities or steps during or after the operating phase. Occurring steps should not exceed a maximum acceptable step height of approximately 15,000 cm^{-3}.

- If this criterion cannot be met even after repeated measurement, dilution of the aerosol between the ETC sampling port and the inlet of the AMS is acceptable in order to operate a CPC in the Single Counting Mode.

Technical note on steps in measured data from CPC: At low concentrations CPCs operate in the Single Counting Mode (SCM). With increasing particle number concentration, the CPC switches to Photometric Mode (PM). Refer to the manufacturer's manual for the respective concentration range. For many CPCs it is typically between 10,000 and 50,000 cm^{-3}. In this range steps or discontinuities may occur.[1]

The AMS manufacturer's software should be used to export the total particle number concentration time series from the measuring file to an editable file. The data should be corrected accordingly if aerosol dilution was applied.

The averaged concentration time series, i.e. the Simple Moving Average over 31 ± 3 seconds, shall be used to calculate the Particle loss coefficient β, the Particle Emission Rate PER and the Total number of emitted Particles TP.

8.7.3.2 Calculation of Particle loss coefficient β

It is recommended to use consistent data formats and unit for time data points throughout the calculations.

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[1] GILHAM R.J.J., QUINCEY P.G., *Measurement and mitigation of response discontinuities of a widely used condensation particle counter*, J Aerosol Sci, Volume 40, Issue 7, July 2009, p 633-637)

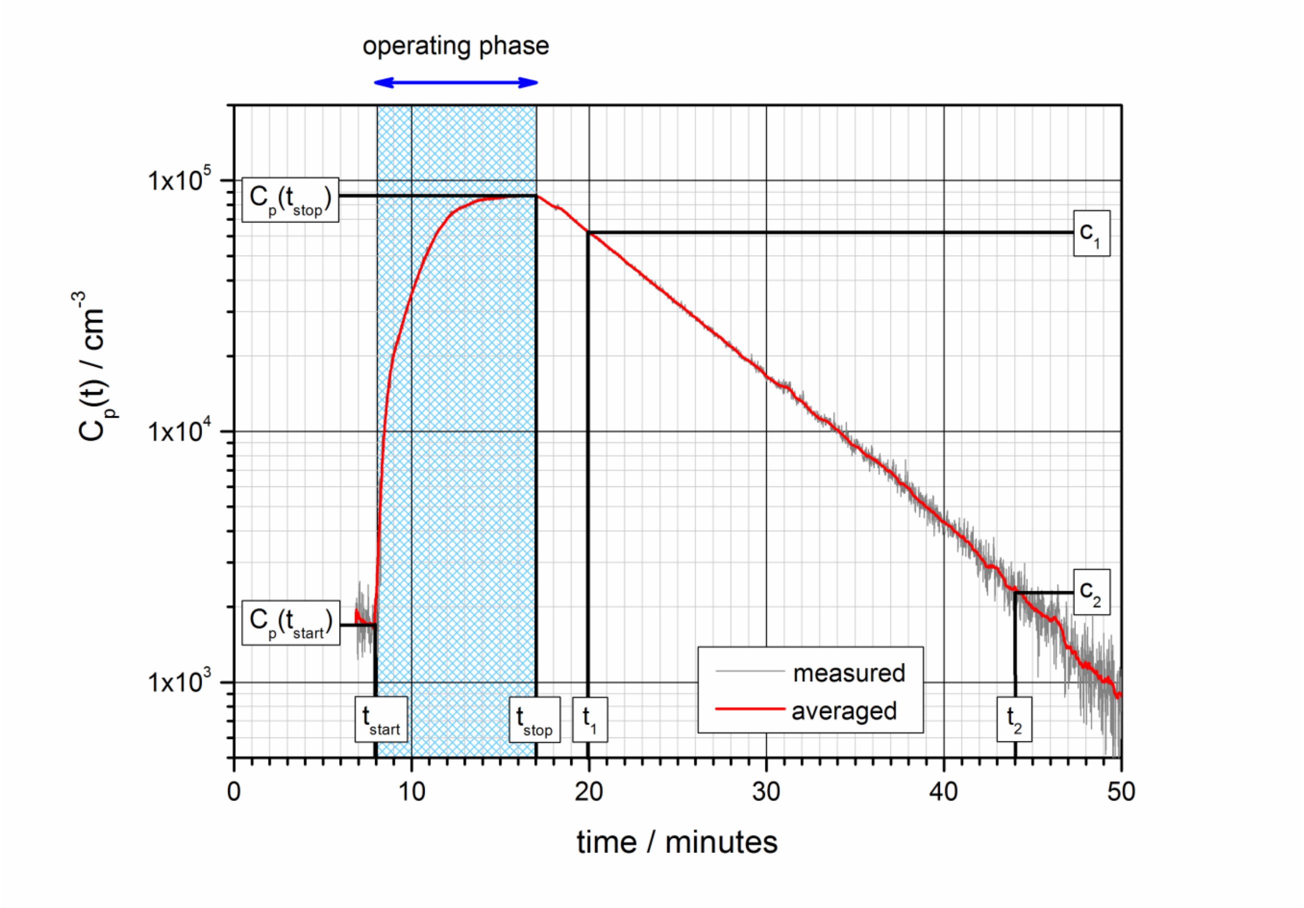


Figure 6 — Diagram of a total particle number concentration time series (example)

a) Plot the averaged concentration time series as shown in Figure 6 for about 5 minutes before the operating phase, during the operating phase and at least for 30 minutes thereafter (optionally the concentration time series may be added to the diagram).

b) As indicated in Figure 6, the value pairs c_1, t_1 and c_2, t_2 should be read from the smoothed time-dependent curve of particle number concentration as accurately as possible or determined by means of a cursor. On a logarithmic scale, t_1 should be chosen within the linear descending range at least 5 minutes after the end of the operating phase and t_2 at least 25 minutes after t_1.

c) Calculate β using the following formula:

$$\beta = \frac{\ln\left(\frac{c_1}{c_2}\right)}{t_2 - t_1} \qquad (14)$$

NOTE Time difference $t_2 - t_1$ must be calculated in the unit [s].

Alternatively, β may be determined by fitting the total particle number concentration decay after the end of particle emission to a single-exponential decay function:

$$C_p = \alpha \cdot \exp(-\beta \cdot t) \qquad (15)$$

The correlation coefficient shall be larger than 0.98 to ensure the quality of the following calculations.

8.7.3.3 Calculation of PER and TP

a) The values t_{start} and $C_p(t_{start})$ should be read from the smoothed time-dependent curve of particle number concentration (cf. Figure 6) as accurately as possible or determined by means of a cursor.

b) The time difference Δt between two successive data points of the particle number concentration $C_p(t)$ is given in the manufacturer’s manual.

NOTE Δt must be given in the unit [s] and is generally set to 1 s

c) PER(t) [s^{-1}] will be calculated using Δt, β and the data set of the smoothed particle number concentration.

$$PER(t) = V\left(\frac{C_p(t) - C_p(t - \Delta t)\exp(-\beta \cdot \Delta t)}{\Delta t \exp(-\beta \cdot \Delta t)}\right) \tag{16}$$

$C_p(t)$: smoothed curve of particle number concentration [cm^{-3}]

V: ETC volume [cm^3]

Δt: time difference between two successive data points [s]

β: particle loss coefficient [s^{-1}]

NOTE $C_p(t)$ is usually in the unit [cm^{-3}]. The chamber volume V_C must be accordingly converted into the unit [cm^3]. Δt must be substituted in the unit [s].

PER(t) and the smoothed $C_p(t)$ curve will be plotted according to the example in Figure 7. The abscissa (time-axis) should be given in units of [min] or [s].

d) Plot PER(t) as shown in Figure 7.

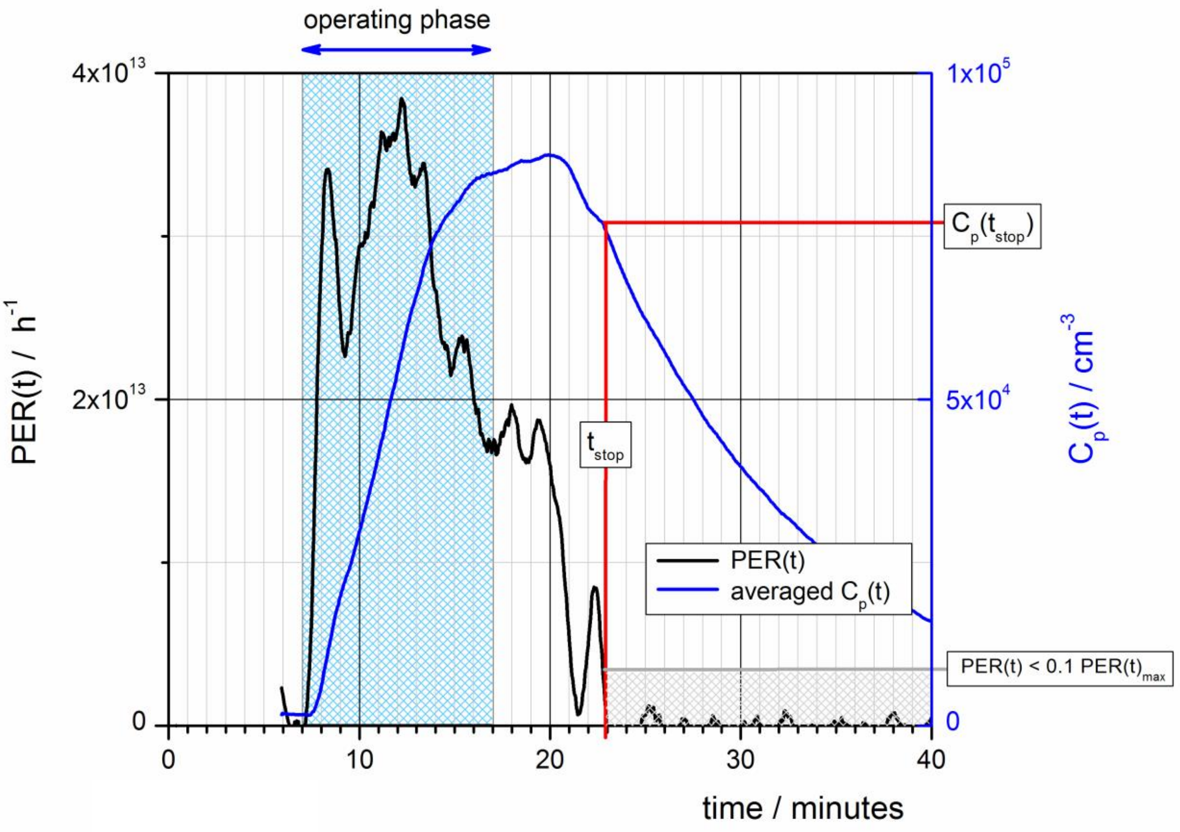


Figure 7 — Diagram of PER(t) and $C_p(t)$

e) The values t_{stop} and $C_p(t_{stop})$ shall be read with high accuracy from the averaged concentration time series curve in Figure 7 as indicated. t_{stop} marks the point on the time axis, from which on PER(t) remains below 10% of its maximum.

NOTE In some cases the particle emission rate curve may partially fall below the zero baselines due to particle concentration reduction effects in the ETC, not considered in the calculations. Before and after the particle emission the PER(t) values shall be near to the zero baseline, i.e. they shall deviate by less than ± 5% of the PER(t)-maximum from zero.

f) Proceed with final steps in 8.7.3.4.

8.7.3.4 Calculation of PER and TP, final steps

a) The difference of total particle number concentrations (ΔC_p) shall be calculated as follows:

$$\Delta C_p = C_p\left(t_{stop}\right) - C_p\left(t_{start}\right) \tag{17}$$

b) The arithmetic mean of measured concentration values between t_{start} and t_{stop} shall be calculated:

$$C_{av} = \frac{\sum_{i=1}^{n} C_{p,i}}{n} \tag{18}$$

with n: number of measured concentration values between t_{start} and t_{stop}.

c) PER shall be calculated using the following formula:

$$PER = V\left(\frac{\Delta C_p}{t_{stop} - t_{start}} + \beta \cdot C_{av}\right) \tag{19}$$

Assume 25% as relative error of PER [h^{-1}]

NOTE ΔC_p and C_{av} have the unit [cm^{-3}]. ß is defined in the unit [s^{-1}]. For the correct application of the formula, the chamber volume V must be substituted in the unit [cm^3] and the emission time $t_{stop} - t_{start}$ in the unit [s].

d) TP shall be calculated using the following formula:

$$TP = PER \cdot \left(t_{stop} - t_{start}\right) \tag{20}$$

Assume 25% as relative error of TP.

The calculation of PER and TP is not reliable if:

$$\Delta C_p \leq 1000\, cm^{-3}$$

In this case, the numeric results (β, PER, TP) shall be specified in the protocol as “non-quantifiable”.

9 Test report

The test report shall include the following, if applicable and available:

Test laboratory

- Reference to ISO/IEC 28360.
- Name and address of test laboratory.
- Name of the responsible person.
- Unique identification number of the test report.

EUT description

- Manufacturer.
- Type, brand name and serial number of EUT, and if tabletop or floor-mounted.
- Print or copying speed according to manufacturer’s information.
- Identification number (model number) and lot number of consumables used.
- History of the EUT and of the consumables (date of production, date of arrival to the test laboratory, date and time of unpacking, storage time, environmental storing conditions before test).
- Newly manufactured EUT or used EUT (Refer to 8.2.1).
- Type of packaging.
- External dimensions.

- Number of prints which has been made with the equipment before the test.

Test conditions and methods

- Date of test.
- Method used to determine emission rates of VOC and carbonyl compounds, QEM or CEM.
- Description of the test apparatus and methods used (ETC, clean air system, environmental control system, sample collection, analytical instrumentation, standard generation and calibration).
- Description of AMS:
  - Manufacturer, model, type and serial number of AMS
  - Name and version of the AMS software
  - Date of last calibration and /or maintenance
  - AMS settings used for measurement
  - Particle size range (or Fast AMS: Particle size range and number of channels within this range)
  - Result of the mandatory operational readiness test (see Annex B).
- Statement on the compliance to Quality Assurance items.
- Name and storage location of the raw data measurement files.
- Name and storage location of the ASCII-export data files.
- ETC test conditions (T, RH, n).
- Background concentrations (C_{bg}).
- Loading factor.
- Sampling methods used (sorbent(s) used, volume sampled, sampling start time and duration).
- Start and duration of pre-operating, operating and post-operating phases.
- Test specification for intended functions.
- Print speed during test and number of printed sides.
- Print mode used for testing (monochrome or colour; simplex or duplex).
- Ozone half-life of the unloaded ETC.
- Detection limits of VOC, carbonyl compounds, ozone and particulate matter.
- Disturbances of - and deviations from test methods.

Emission rate determination and total number of particles determination

- Identification of the formulae used to determine specific emission rates from measured ETC concentrations.
- Identification of the calculation method used to determine PER and TP.

Results

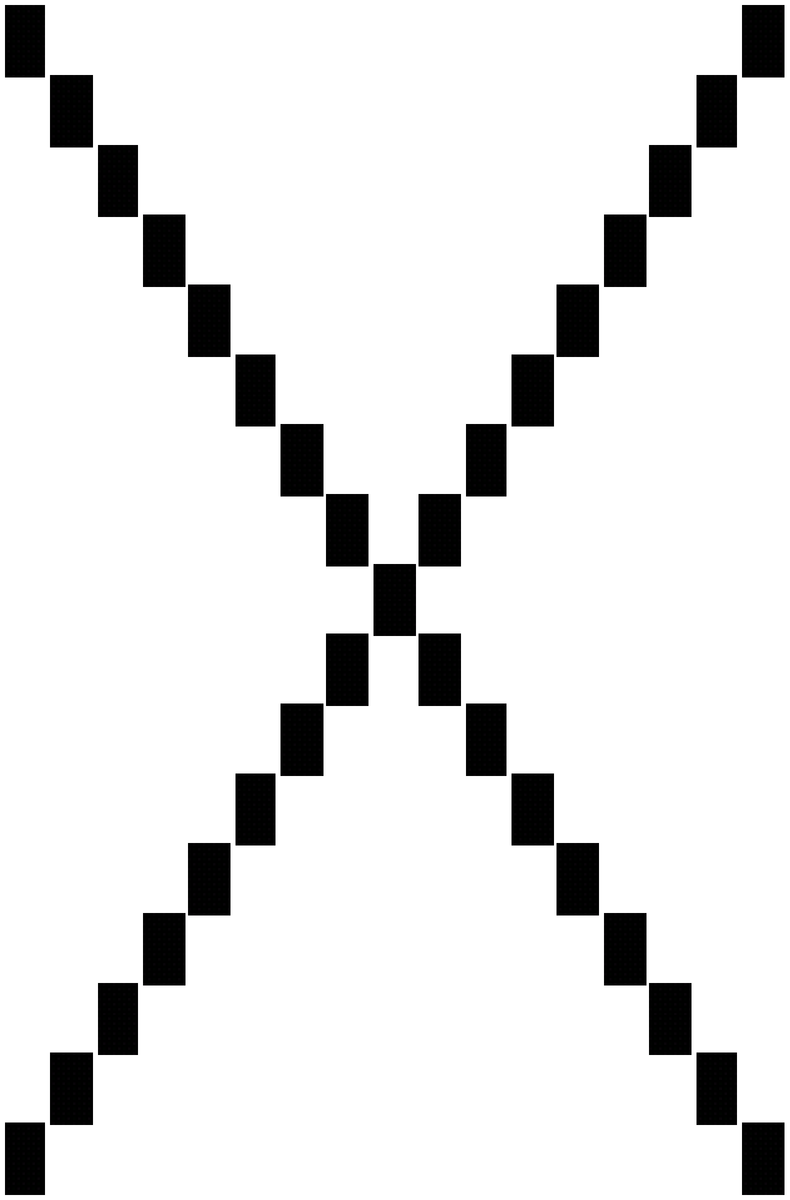
- Name, CAS-number and concentration of identified VOCs, formaldehyde and other carbonyl compounds in pre-operating phase and operating phase and calculated emission rates.
- Concentration of unidentified VOCs in pre-operating phase and operating phase and calculated emission rates.
- Total VOC emission rate as the sum of the identified and unidentified compounds during pre-operating phase and operating phase as well as calculated emission rates of individual compounds.
- Maximum change of ozone concentration for 2 minutes and calculated ozone emission rate.
- Mass of sampled particulate matter (m_{pm}) and calculated emission rate (SER_{pm}).
- Diagram of particle number concentration time series as specified.
- Dilution factor if aerosol dilution was applied.
- Calculated Particle loss coefficient β.
- Particle emission rate PER.
- Total number of emitted particles TP.

Annex A
(normative)

Print Patterns

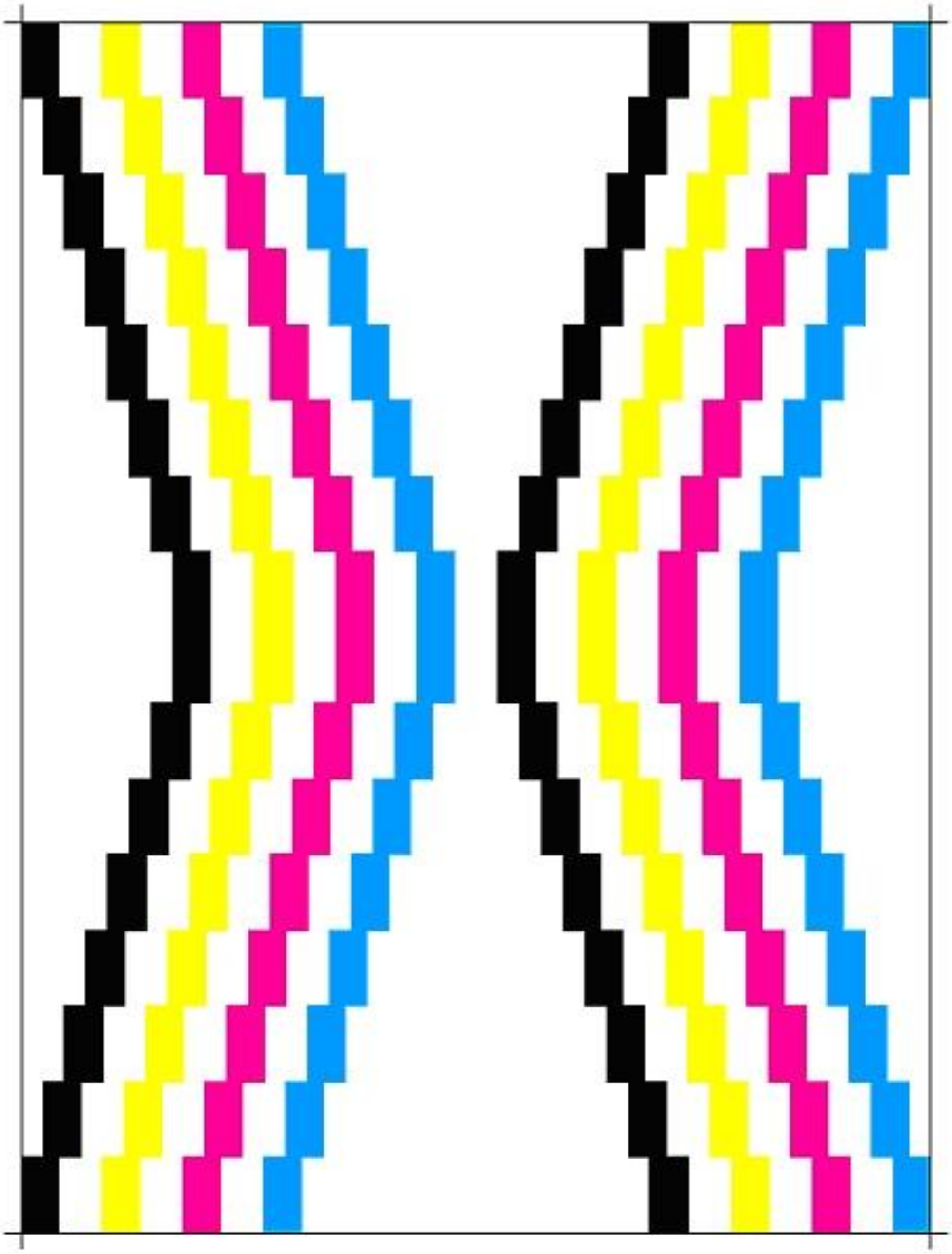
A.1 Monochrome print pattern, 5% coverage

This Annex illustrates the monochrome pattern with 5% black coverage; tests of EUT using paper consumables as specified in this Standard shall be executed using the pattern at http://www.ecma-international.org/publications/standards/Ecma-328.htm.



A.2 Colour print pattern, 20% coverage

This Annex illustrates the colour pattern with 20% colour coverage (5% needed for each colour [black, magenta, cyan, yellow]), tests of EUT using paper consumables as specified in this Standard shall be executed using the pattern at http://www.ecma-international.org/publications/standards/Ecma-328.htm.



Annex B
(normative)

Preparatory AMS Test Procedures

B.1 Procedures for operational readiness of AMS

This Annex specifies procedures for testing the operational readiness of AMS. These steps are additional requirements to periodical instrument maintenance.

B.1.1 Particle size concentration range measurements

The lower particle size limit is the smallest diameter at which the counting efficiency of a specific AMS is 50%.

The upper particle size limit is the largest diameter at which the counting efficiency of a specific AMS is 50%.

B.1.2 Particle number concentration range measurements

The lower particle number concentration level is the concentration that can be distinguished with a statistical certainty of 95% from the reported concentration background value due to the instrument's false count rate. The false count rate is the reported count rate which is not caused by particles.

For Fast AMS based on the measurement of electric currents the lower particle number concentration level decrease with increasing particle size while the upper particle number concentration level decreases with increasing particle size. Both limits are much higher compared to other AMS, such as CPCs.

The size dependent number concentration of Fast AMS may be presented as absolute concentration C_P, or as concentration normalized to the width of the respective size class $dc_i/dlogd_i$, where index i corresponds to the size class.

B.2 Procedures for operational readiness test of Fast AMS

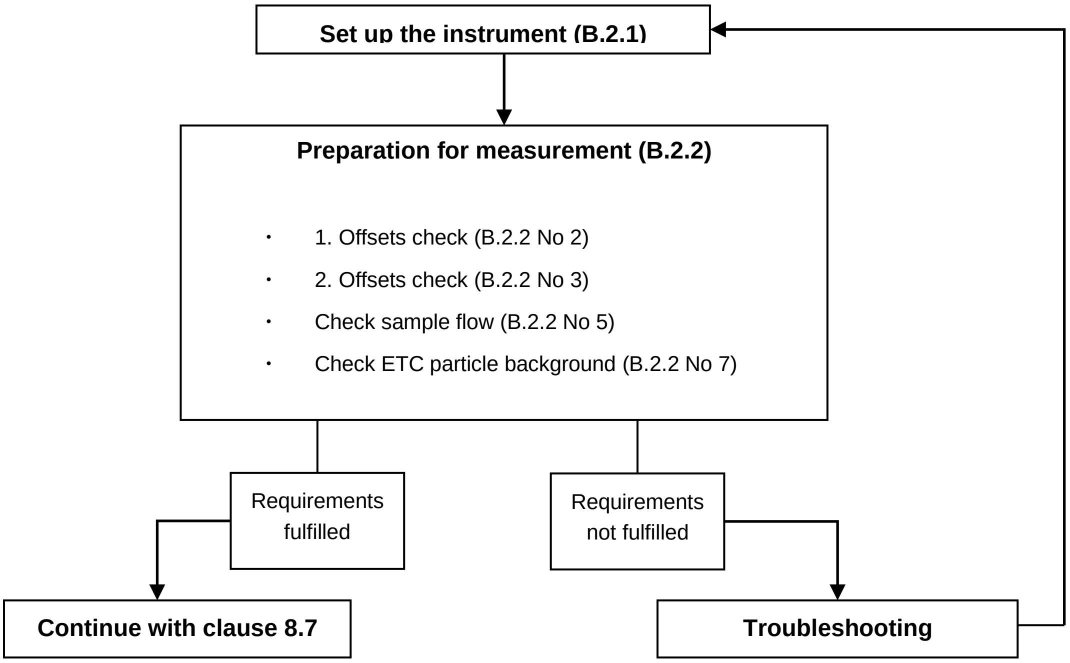


Figure B.1 — Scheme for the operational readiness test for Fast AMS

B.2.1 Set up of instrument

1. Check for proper cleanliness of the instrument and tubing.

2. Set up the Fast AMS for the purpose of enabling a straight connection between the sampling port of the ETC and the aerosol inlet of the AMS with a maximum length of 3 m.

3. Check date and time settings of AMS and/or AMS software and laboratory clock and synchronize if date is different and/or if time differs by more than 1 s.

B.2.2 Preparation for measurement

The following steps should be executed in sequence:

1. All operating parameters (air temperature, voltage, internal pressure and flow rates) are checked.

2. A reset (zeroing) is performed according to the manufacturer's instructions after instrument warmup (first check). Electrometer current offsets and RMS values will be recorded and checked for compliance with manufacturer’s specifications.

3. After another period of 30 minutes, step 2 is repeated (second check). Electrometer offsets from first and second check may not differ by more than ± 10 fA. Compliance with this requirement is mandatory and must be stated in the test protocol. Instruments which do not pass this test need maintenance and may not be used for test purposes.

4. The HEPA filter is removed from the aerosol inlet of the AMS.

5. The sampling flow rate of the AMS is checked. An internal flow meter should preferably be used for this. Otherwise, an externally calibrated flow meter must be used. The measured flow rate of the AMS must not deviate by more than ± 10% of the specified set point in the calibration certificate.

6. The AMS is connected to the sampling port of the ETC.

7. The particle background concentration is measured in the ETC. The background concentration level should correspond to the value given in 8.2.4, Table 1.

B.3 Procedures for operational readiness test of CPC

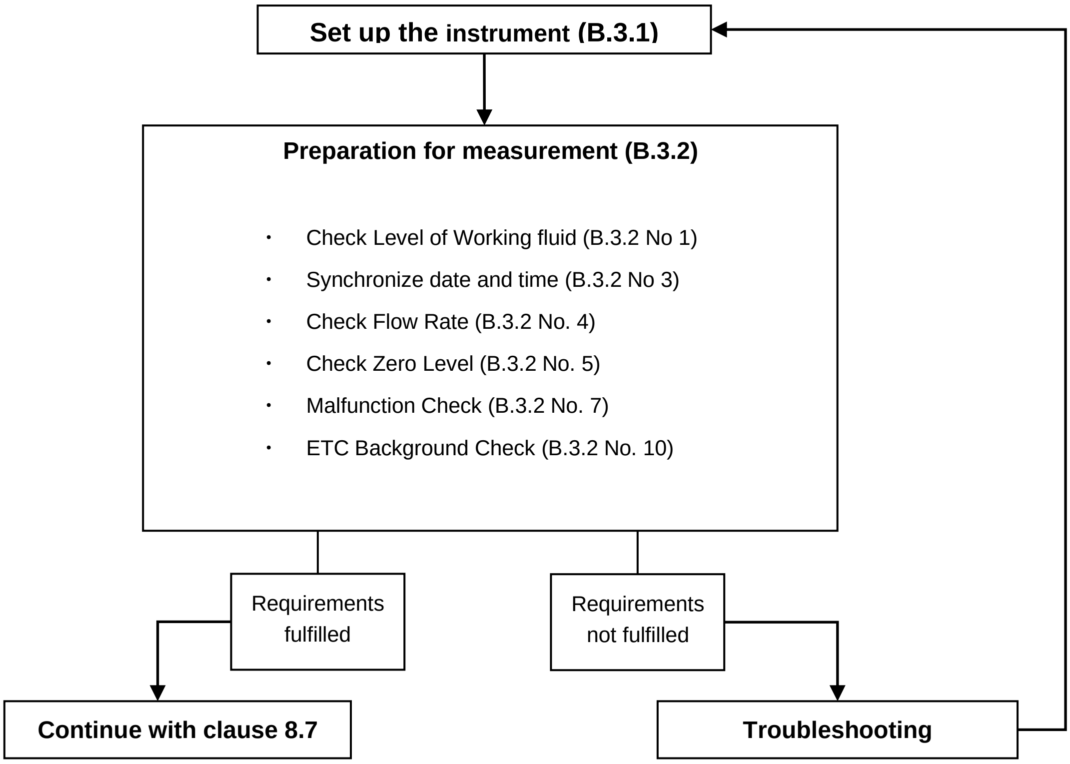


Figure B.2 — Preparation scheme for CPC

B.3.1 Set up the instrument

For the measurement of total particle number concentration, only those CPCs are used which use isopropanol or butanol as a working fluid. Check for proper cleanliness of the instrument and tubing.

Set up the CPC for the purpose of enabling a straight connection between the sampling port of the ETC and the aerosol inlet of the CPC with a maximum length of 3 m.

B.3.2 Preparation for measurement

The following steps should be executed in sequence:

1. The work fluid reservoir of the CPC will be filled. If there is one - the excess reservoir of the CPC should be checked and emptied in order to avoid malfunctions during the measurements.

2. The CPC will be switched on and runs through warm-up according to the manufacturer's instructions.

3. Time and date of the CPC will be synchronized with a maximum deviation of 1 second to the laboratory timer.

4. CPC function test: The sampling flow rate of the CPC is checked. An internal flow meter should preferably be used for this. Otherwise, an externally calibrated flow meter must be used. The measured flow rate of the CPC must not deviate by more than ± 10% of the set point specified in the calibration certificate.

5. The inlet of the CPC will be connected to a HEPA filter (filter efficiency ≥ 99.99%). If particle number concentrations > 1 cm-3 are indicated over a period of 1 min - after any leaks between the HEPA filter and aerosol inlet were eliminated - there is a malfunction in the CPC.

6. The HEPA filter is removed from the aerosol inlet of the CPC.

7. The particle number concentration in ambient air outside the ETC is measured. Readings should exceed 1 cm-3. Aerosol sources with sufficiently high output may be used for this test. A zero readout indicates a malfunction of the CPC.

8. The correct function of the CPC will be reported.

9. The CPC is connected to the sampling port of the ETC via a conductive material (e.g. conductive silicone tube, stainless steel) with a maximum length of 3 m.

10. The measured particle background concentration in the ETC must not exceed the specified values specified in 8.2.4, Table 1.

Annex C
(informative)

Model for QEM

C.1 Objectives

This Annex develops a generalised formula to calculate emission rates from VOC and carbonyl compound mass concentrations determined by sampling in an ETC. This model can apply in general cases where energy-saving modes are enacted within an hour in the pre-operating phase, and as a result, the emission rates are not constant during this phase.

C.2 Approach

The following is assumed:

- Emission rates decrease after the activation of energy-saving modes in the pre-operating phase, resulting in reaching a quasi-equilibrium in concentration earlier than expected in theory;
- The quasi-equilibrium continues during the operating and post-operating phases;
- The emission rates which originate from EUT are constant during the operating phase.

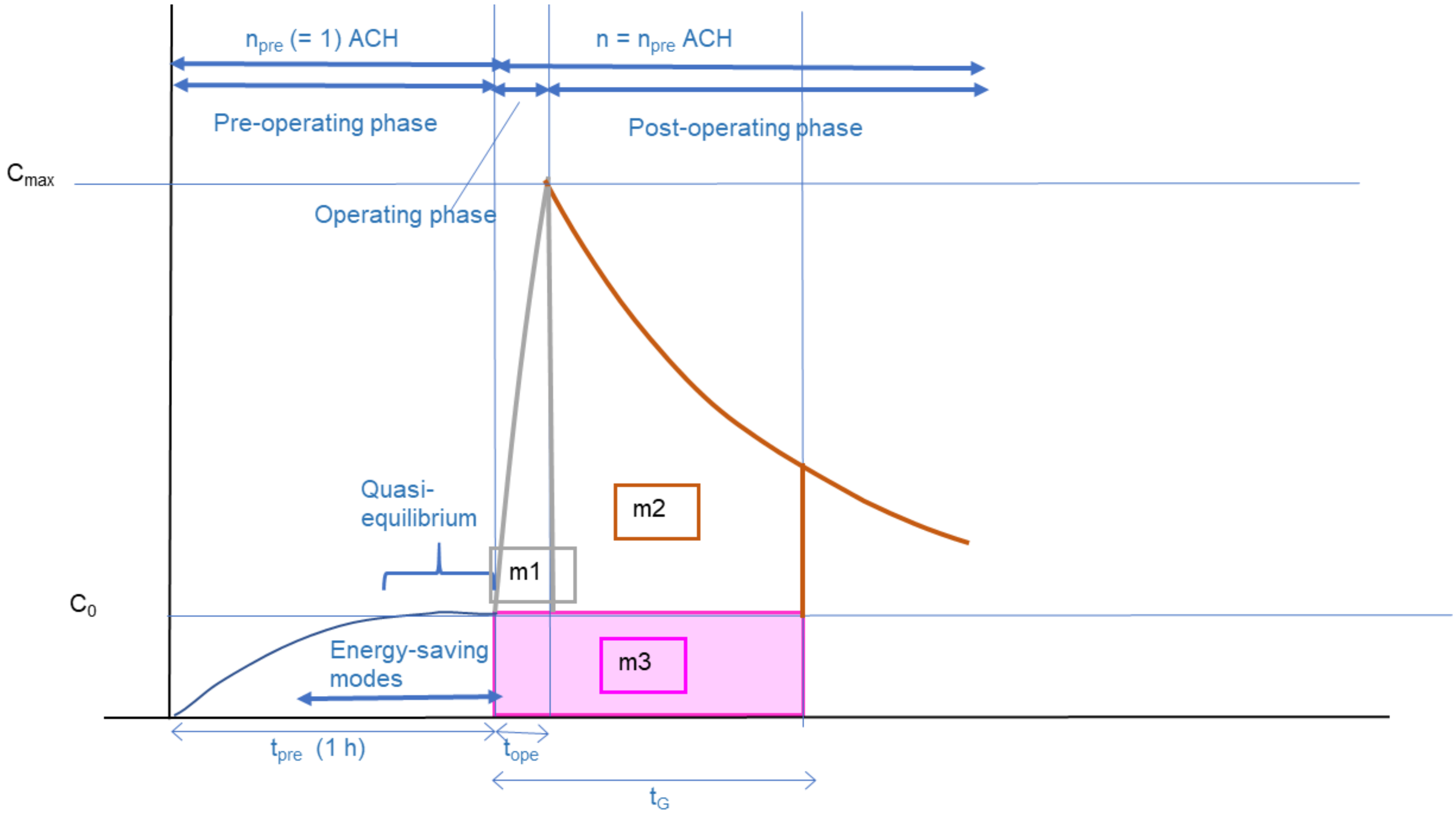
Average concentrations are acquired by sampling over a period of time and emission rates must be calculated from those concentrations.

Figure C.1 shows in (a), (b) and (c) that the concentration increase lessens after the activation of energy-saving modes during the pre-operating phases. As a result, the concentration changes are very gradual during the last 20 minutes of the pre-operating phases. By assuming that these gradual changes represent a quasi-equilibrium, the emission rate (SER_{pre}) is determined.

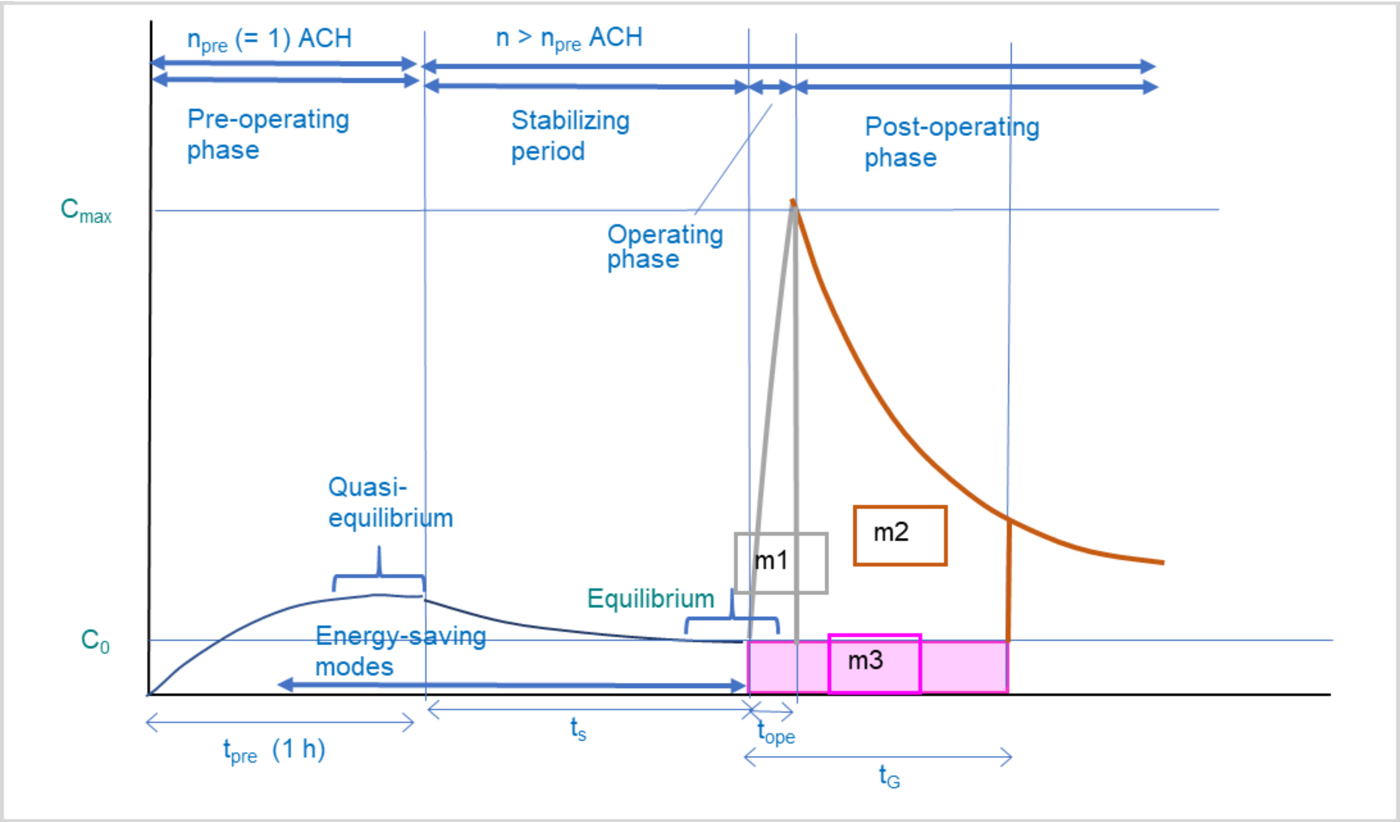
The areas of concentration regions during the operating and post-operating phases in Figure C.1 (a), (b) and (c) must be calculated to determine the emission rate during the operating-phase (SER_{ope}).

Three concentration regions from m1 to m3 during the operating and post-operating phases are shown in Figure C.1 (a) and (b). m1 is shaped by the concentration build-up curve resulting from printing, excluding the continued pre-operating phase emission, and the time period of the operating phase. m2 is shaped by the concentration decay curve from C_{max}, excluding the continued pre-operating phase emission, and the time period of the post-operating phase. m3 is shaped by the equilibrium concentration line reached before the operating phase and time period of the operating and post-operating phases. In Figure C.1 (c), four regions, m1, m2, m4 and m5 shaped between the concentration curves (dashed lines) and time periods overlap one another since it is difficult to depict them separately. m3 in Figure C.1 (a) and (b) is divided into m4 and m5 overlapping each other as an equilibrium is not reached during the stabilizing phase. m4 is shaped between the concentration build-up curve resulting from the continued pre-operating phase emission and the time period of the operating and post-operating phases. m5 is shaped between the decay curve from the initial concentration (Co) and the time period of the operating and post-operating phases. m1 and m2 respectively, overlapping m4 and m5, are the same as those in Figure C.1 (a) and (b).

(a) without stabilizing period (“n” = n_{pre})



(b) with stabilizing period (“n” > n_{pre}, $n*t_s \geq 3$)



(c) with stabilizing period (“n” > n_{pre}, $n*t_s < 3$)

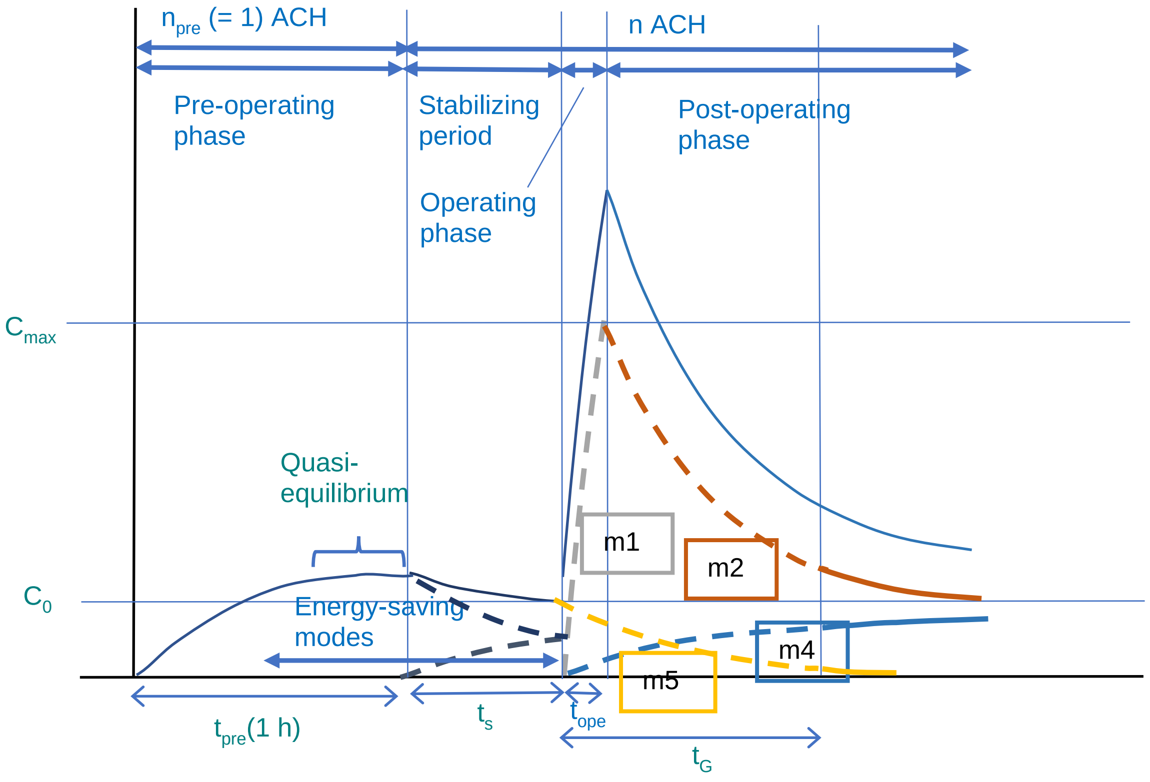


Figure C.1 — Model for QEM

C.3 General mass balance and concentration equations

The following mass balance is valid for an ETC containing an emission source with an *SER*:

$$\frac{dC}{dt} = \frac{SER}{V} - n \cdot C \tag{C.1}$$

Integrating (C.1) to obtain C:

$$C = \frac{SER}{n \cdot V}[1 - exp(-n \cdot t)] + C_0 exp(-n \cdot t) \tag{C.2}$$

C.4 Background Concentration

To simplify, assuming that C_{bg} is constant throughout the whole measurement process, subtract the C_{bg} determined in (8.2.4) from the concentrations acquired in this annex so that the effect of background concentration can be removed.

C.5 Emission rate calculation

C.5.1 Emission during pre-operating phase

As shown in the emission model in Figure C.1, a quasi-equilibrium is reached during the last twenty minutes of the one-hour pre-operating phase,

Inserting SER_{pre} for SER and n_{pre} for n in (C.2) yields:

$$C = \frac{SER_{pre}}{n_{pre} \cdot V}\left[1 - exp\left(-n_{pre} \cdot t\right)\right] + C_o \, exp\left(-n_{pre} \cdot t\right) \qquad \text{(C.3)}$$

As background concentrations are subtracted from concentrations acquired, C_0 is considered zero. Assuming a quasi-equilibrium is reached during sampling (t → ∞). (C.3) becomes:

$$C_{pre} = \frac{SER_{pre}}{n_{pre} \cdot V} \qquad \text{(C.4)}$$

Rearrange (C.4) for SER_{pre}:

$$SER_{pre} = C_{pre} \cdot n_{pre} \cdot V \qquad \text{(C.5)}$$

C.5.2 Emission during operating phase

During the operating phase the concentration build-up originates from EUT operation. Inserting SER_{ope} for SER in (C.2) yields:

$$C = \frac{SER_{ope}}{n \cdot V}\left[1 - exp(-n \cdot t)\right] + C_o \, exp(-n \cdot t) \qquad \text{(C.6)}$$

Two emission sources are considered during the operating phase. One source continues to emit the same mass of VOC and/or carbonyl compounds as emitted during the pre-operating phase and the other source emerges due to printing. Therefore, SER_{ope} consists of the following two emission rates:

$$SER_{ope} = SER_{pre} + SER_{prp} \qquad \text{(C.7)}$$

Inserting SER_{ope} in (C.7) in (C.6) yields:

$$C = \frac{SER_{prp}}{n \cdot V}\left[1 - exp(-n \cdot t)\right] + \frac{SER_{pre}}{n \cdot V}\left[1 - exp(-n \cdot t)\right] + C_o \, exp(-n \cdot t) \qquad \text{(C.8)}$$

When the operating phase ends, SER_{prp} becomes zero. As a result, the concentration build-up which originates from this source stops and the concentration (C_{max}) starts to decay with air exchange in the ETC. During the post-operating phase, (C.8) becomes:

$$C = C_{max} exp\left(-n \cdot \left(t - t_{ope}\right)\right) + \frac{SER_{pre}}{n \cdot V}\left[1 - exp(-n \cdot t)\right] + C_o \, exp(-n \cdot t) \qquad \text{(C.9)}$$

In (C.8) and (C.9) C_0 is the initial concentration in the operating phase.

In (C.9) C_{max} is equal to the concentration at the end of the operating phase determined by substituting t_{ope} for t in the first term of (C.8):

$$C_{max} = \frac{SER_{prp}}{n \cdot V}\left[1 - exp\left(-n \cdot t_{ope}\right)\right] \qquad \text{(C.10)}$$

In Figure C.1 (a) and (b), the terms m1 and m2 denote the regions and their areas shaped between the build-up and decaying concentration curves which stem from printing and the time period of the operating and post-operating phases. The term m3 denotes the region and its area shaped between a concentration line which stems from the pre-operating phase emission after a quasi-equilibrium is reached and the time period of the operating and post-operating phases. In Figure C.1 (a), “n” is equal to n_{pre} and the operating phase starts soon after the end of the pre-operating phase. In Figure C.1 (b), n_{pre} and "n” differ and there is a stabilizing period between the pre-operating and operating phases which is equal to three air exchanges or more.

m1: Area between the build-up concentration curve which originates from printing and the time period of the operating phase

m2: Area between the concentration curve decaying from C_{max} with air exchange and the time period of the post-operating phase

m3: Area between the straight concentration line which reached a quasi-equilibrium and the time period of the operating and post-operating phases.

Integrating the first term of (C.8) over time from 0 to t_{ope} yields:

$$m1 = \int_0^{t_{ope}} \frac{SER_{prp}}{n \cdot V}\left(1 - exp(-n \cdot t)\right) dt = \frac{SER_{prp}}{n^2 \cdot V}\left(n \cdot t_{ope} + exp\left(-n \cdot t_{ope}\right) - 1\right) \qquad \text{(C.11)}$$

m2 is obtained by integrating the first term of (C.9) over time from t_{ope} to t_G:

$$m2 = \int_{t_{ope}}^{t_G} C_{max} exp\left(-n\left(t - t_{ope}\right)\right) dt = \frac{C_{max}}{n}\left(1 - exp\left(-n\left(t_G - t_{ope}\right)\right)\right) \qquad \text{(C.12)}$$

Inserting C_{max} in (C.10) in (C.12) yields:

$$m2 = \frac{SER_{prp}}{n^2 \cdot V}\left(1 - exp\left(-n \cdot t_{ope}\right)\right) \cdot \left(1 - exp\left(-n\left(t_G - t_{ope}\right)\right)\right) \qquad \text{(C.13)}$$

m3 can be found by the calculation of the rectangular area.

$$m3 = C_0 \cdot t_G \qquad \text{(C.14)}$$

A quasi-equilibrium concentration is reached in the ETC with the pre-operating phase emission and the air exchange rate of “n”. C_0 is:

$$C_0 = \frac{SER_{pre}}{n \cdot V} \qquad \text{(C.15)}$$

Insert (C.15) in (C.14):

$$m3 = \frac{SER_{pre}}{n \cdot V} \cdot t_G \qquad \text{(C.16)}$$

The average concentration (C_{ope}) during sampling in the operating and post-operating phase is:

$$C_{ope} = \frac{m1 + m2 + m3}{t_G} = \frac{m_{ope}}{V_{ope}} \qquad \text{(C.17)}$$

Inserting m1, m2 and m3 in (C.11), (C.13) and (C.16) in (C.17) and rearrange:

$$C_{ope} \cdot t_G = \frac{SER_{prp}}{n^2 \cdot V} \cdot \left[exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right) + n \cdot t_{ope}\right)\right] + \frac{SER_{pre}}{n \cdot V} \cdot t_G \qquad \text{(C.18)}$$

Rearrange (C.18) for SER_{prp}:

$$SER_{prp} = \frac{C_{ope}\cdot n^2\cdot V\cdot t_G - SER_{pre}\cdot n\cdot t_G}{exp(-n\cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n\cdot t_{ope}} \qquad \text{(C.19)}$$

In the case of Figure C.1 (c). “n” and n_{pre} differ and the stabilizing period t_s, which is shorter than three air exchanges, exists. In Figure C.1(c), the terms m1, m2, m4 and m5 denote the regions and their areas shaped between build-up and decaying concentration curves which stem from each source, and the time periods of the phases under consideration.

m1: Area between the building up concentration curve which originates from printing and the time period of the operating phase

m2: Area between the concentration curve decaying from C_{max} with air exchange and the time period of the post-operating phase

m4: Area between the building up concentration curve which originates from the source emitting the same mass as emitted during the pre-operating phase and the time period of the operating and post-operating phases

m5: Area between the concentration curve decaying from C_0 with air exchange and the time period of the operating and post-operating phases

$$m1 = \int_0^{t_{ope}} \frac{SER_{prp}}{n\cdot V}\left(1 - exp(-n\cdot t)\right)dt = \frac{SER_{prp}}{n^2\cdot V}\left(n\cdot t_{ope} + exp\left(-n\cdot t_{ope}\right) - 1\right) \qquad \text{(C.11) reshown}$$

$$m2 = \frac{SER_{prp}}{n^2\cdot V}\left(1 - exp\left(-n\cdot t_{ope}\right)\right)\cdot\left(1 - exp\left(-n\left(t_G - t_{ope}\right)\right)\right) \qquad \text{(C.13) reshown}$$

Integrating the second term of (C.8) and (C.9) over time from 0 to t_G yields:

$$m4 = \int_0^{t_G} \frac{SER_{pre}}{n\cdot V}\left(1 - exp(-n\cdot t)\right)dt = \frac{SER_{pre}}{n^2\cdot V}\left(n\cdot t_G + exp(-n\cdot t_G) - 1\right) \qquad \text{(C.20)}$$

m5 is obtained by integrating the third term of (C.8) and (C.9) over time from 0 to t_G:

$$m5 = \int_0^{t_G} C_0 exp(-n\cdot t)dt = \frac{C_0}{n}\left(1 - exp(-n\cdot t_G)\right) \qquad \text{(C.21)}$$

The average concentration (C_{ope}) during sampling in the operating and post-operating phase is:

$$C_{ope} = \frac{m1 + m2 + m4 + m5}{t_G} = \frac{m_{ope}}{V_{ope}} \qquad \text{(C.22)}$$

Inserting m1, m2, m4 and m5 in (C.11), (C.13), (C.20) and (C.21) in (C.22) and rearrange:

$$C_{ope}\cdot t_G = \frac{SER_{prp}}{n^2\cdot V}\left[exp(-n\cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right) + n\cdot t_{ope}\right)\right]$$

$$+ \frac{SER_{pre}}{n^2\cdot V}\left[exp(-n\cdot t_G) + n\cdot t_G - 1\right] + \frac{C_0}{n}\left[1 - exp(-n\cdot t_G)\right] \qquad \text{(C.23)}$$

Rearrange (C.23) for SER_{prp}:

$$SER_{prp} = \frac{C_{ope}\cdot n^2\cdot V\cdot t_G - SER_{pre}[exp(-n\cdot t_G) + n\cdot t_G - 1] - C_0\cdot n\cdot V[1 - exp(-n\cdot t_G)]}{exp(-n\cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n\cdot t_{ope}} \qquad \text{(C.24)}$$

In this case, C_0 in Figure C.1 (c) is obtained as the sum of the two concentrations, one of which decays from C_{pre} with the air exchange of “n” while the other builds up with the continuing emission during that period of time (t_s):

$$C_0 = C_{pre} exp(-n \cdot t_s) + \frac{SER_{pre}}{n \cdot V} \cdot [1 - exp(-n \cdot t_s)] \qquad \text{(C.25)}$$

Insert C_{pre} in (C.4) in (C.26):

$$C_0 = \frac{SER_{pre}}{n_{pre} \cdot V} exp(-n \cdot t_s) + \frac{SER_{pre}}{n \cdot V} \cdot [1 - exp(-n \cdot t_s)] \qquad \text{(C.26)}$$

Insert C_0 in (C.27) in (C.22) and rearrange for SER_{prp}:

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}\left[n \cdot t_G - \left(1 - \frac{n}{n_{pre}}\right) exp(-n \cdot t_s) \cdot (1 - exp(-n \cdot t_G))\right]}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \qquad \text{(C.27)}$$

SER_{ope} is obtained as follows:

$$SER_{ope} = SER_{pre} + SER_{prp} \qquad \text{(C.7) reshown}$$

Annex D
(informative)

Model for CEM

D.1 Objectives

This Annex develops a generalised formula to calculate emission rates from VOC and carbonyl compound mass concentrations determined by sampling in an ETC.

D.2 Approach

The following is assumed:

- Emission rates are constant during the pre-operating, operating and post-operating phases;
- Emission rates during pre- and post-operating phases are equal.

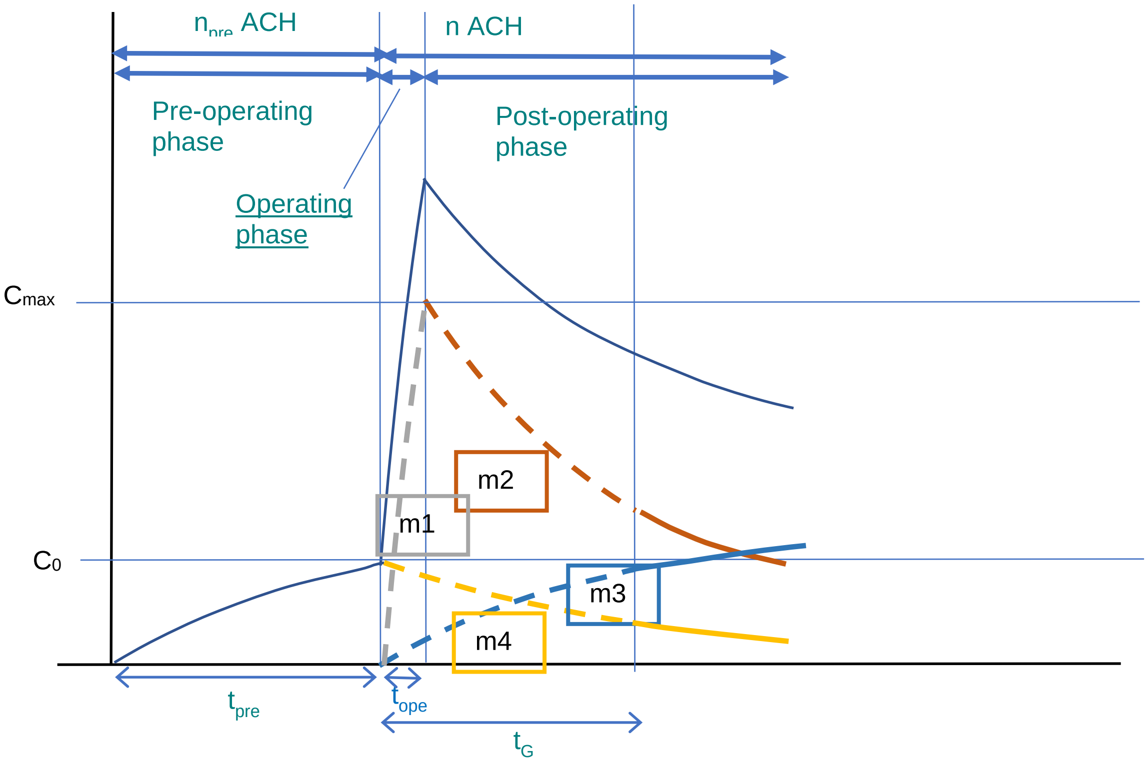
Cases, where the above assumptions do not apply, are outside the scope of this Annex.

Average concentrations are acquired by sampling over a period of time and emission rates must be calculated from those concentrations.

The areas of concentration regions during the operating and post-operating phases in Figure C.1 (a) and (b) must be calculated to determine the emission rate during the operating-phase ($\mathrm{SER}_{\mathrm{ope}}$).

Four concentration regions from m1 to m4 shaped between the concentration curves (dashed lines) and time periods during the operating and post-operating phases are shown in Figure D.1 (a) and (b). These concentration regions overlap one another. m1 is shaped between the concentration build-up curve resulting from printing, excluding the continued pre-operating phase emission, and the time period of the operating phase. m2 is shaped between the concentration decay curve from C_{max}, excluding the continued pre-operating phase emission, and the time period of the post-operating phase. m3 is shaped between the concentration build-up curve resulting from the continued pre-operating phase emission and the time period of the operating and post-operating phases. m4 is shaped by the decay curve from the initial concentration (Co) and the time period of the operating and post-operating phases.

(a) without stabilizing period (“n” = n_{pre})



(b) with stabilizing period (“n” > n_{pre})

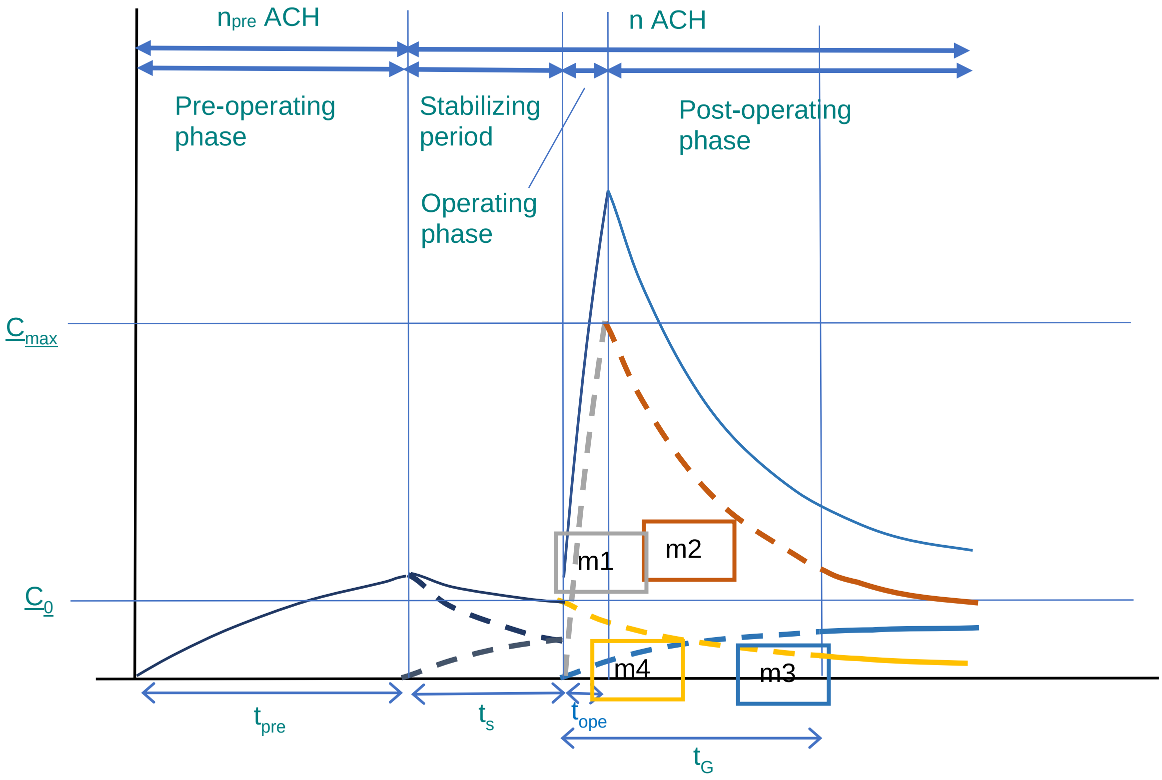


Figure D.1 — Model for CEM (a) without, and (b) with stabilizing period

D.3 General mass balance and concentration equations

The following mass balance is valid for an ETC containing an emission source with an SER:

$$\frac{dC}{dt} = \frac{SER}{V} - n \cdot C \tag{D.1}$$

Integrating (D.1) to obtain C:

$$C = \frac{SER}{n \cdot V}[1 - exp(-n \cdot t)] + C_0 exp(-n \cdot t) \tag{D.2}$$

D.4 Background concentrations

To simplify, assuming that C_{bg} is constant throughout the whole measurement process, subtract the C_{bg} determined (8.2.4) from the concentrations acquired in this annex so that the effect of background concentration can be removed.

D.5 Emission rate calculation

D.5.1 Emission during pre-operating phase

Assume the emission model as shown in Figure D.1. During the pre-operating phase, there is a constant emission source that originates from the EUT in the pre-operating phase.

Substituting SER_{pre} for SER in (D.1) and (D.2) yields:

$$\frac{dC}{dt} = \frac{SER_{pre}}{V} - n_{pre} \cdot C \tag{D.3}$$

$$C = \frac{SER_{pre}}{n_{pre} \cdot V}\left[1 - exp\left(-n_{pre} \cdot t\right)\right] + C_o\, exp\left(-n_{pre} \cdot t\right) \tag{D.4}$$

As background concentrations are subtracted from the concentrations acquired, C_0 is considered zero.

(D.4) is reduced to:

$$C = \frac{SER_{pre}}{n_{pre} \cdot V}\left[1 - exp\left(-n_{pre} \cdot t\right)\right] \tag{D.5}$$

The total measure for the mass of sampled VOCs is equal to the product of the averaged concentration and sampling time ($C_{pre}*t_{pre}$), and can be obtained by integrating (D.5) over time from $t=0$ to $t=t_{pre}$:

$$C_{pre} \cdot t_{pre} = \int_0^{t_{pre}} \frac{SER_{pre}}{n_{pre} \cdot V}\left[1 - exp(-n_{pre} \cdot t)\right]dt$$

$$= \frac{SER_{pre}}{n_{pre}^2 \cdot V}[n_{pre} \cdot t_{pre} + exp(-n_{pre} \cdot t_{pre}) - 1] \qquad (D.6)$$

Rearrange (D.6) for *SER_{pre}*:

$$SER_{pre} = \frac{C_{pre} \cdot n_{pre}^2 \cdot V \cdot t_{pre}}{n_{pre} \cdot t_{pre} + exp(-n_{pre} \cdot t_{pre}) - 1} \qquad (D.7)$$

D.5.2 Emission during operating and post-operating phase

During the operating phase the concentration build-up originates from EUT operation. Integration of (D.1) with SER = SER_{ope} yields:

$$C = \frac{SER_{ope}}{n \cdot V}[1 - exp(-n \cdot t)] + C_o\, exp(-n \cdot t) \qquad (D.8)$$

Two emission sources are considered during the operating phase. One source continues to emit the same mass of VOC and/or carbonyl compounds as emitted during the pre-operating phase and the other source newly emerges due to EUT operation (making prints). Therefore, SER_{ope} consists of two emission rates as follows:

$$SER_{ope} = SER_{pre} + SER_{prp} \qquad (D.9)$$

Inserting (D.9) in (D.8) yields:

$$C = \frac{SER_{prp}}{n \cdot V}[1 - exp(-n \cdot t)] + \frac{SER_{pre}}{n \cdot V}[1 - exp(-n \cdot t)] + C_o\, exp(-n \cdot t) \qquad (D.10)$$

When the operating phase ends, SER_{prp} becomes zero. As a result, the concentration build-up which originates from this source stops and the concentration (C_{max}) starts to decay with air exchange in the ETC. During the post-operating phase, (D.10) becomes:

$$C = C_{max} exp\left(-n \cdot \left(t - t_{ope}\right)\right) + \frac{SER_{pre}}{n \cdot V}[1 - exp(-n \cdot t)] + C_o\, exp(-n \cdot t) \qquad (D.11)$$

In (D.10) and (D.11) C_0 is the initial concentration in the operating phase.

In (D.11) C_{max} is equal to the concentration at the end of the operating phase (C_{pre}) determined by solving the first term of (D.10):

$$C_{max} = \frac{SER_{prp}}{n \cdot V}\left[1 - exp\left(-n \cdot t_{ope}\right)\right] \qquad (D.12)$$

In Figure C.1, the terms from m1 to m4 denote the regions and their areas shaped between the build-up and decaying concentration curves which stem from each source, and the time periods of the phases under consideration.

m1: Area between the build-up concentration curve which originates from printing and the time period of the operating phase

m2: Area between the concentration curve decaying from C_{max} with air exchange and the time period of the post-operating phase.

m3: Area between the build-up concentration curve which originates from the source emitting the same mass as emitted during the pre-operating phase and the time period of the operating and post-operating phases

m4: Area between the concentration curve decaying from C_0 with air exchange and the time period of the operating and post-operating phases

Integrating the first term of (D.10) over time from 0 to t_{ope} yields:

$$m1 = \int_0^{t_{ope}} \frac{SER_{prp}}{n \cdot V}\left(1 - exp(-n \cdot t)\right) dt = \frac{SER_{prp}}{n^2 \cdot V}\left(n \cdot t_{ope} + exp\left(-n \cdot t_{ope}\right) - 1\right) \qquad \text{(D.13)}$$

Integrating the second term of (D.10) and (D.11) over time from 0 to t_G:

$$m2 = \int_{t_{ope}}^{t_G} C_{max} exp\left(-n\left(t - t_{ope}\right)\right) dt = \frac{C_{max}}{n}\left(1 - exp\left(-n\left(t_G - t_{ope}\right)\right)\right) \qquad \text{(D.14)}$$

Inserting C_{max} in (D.12) in (D.14) yields:

$$m2 = \frac{SER_{prp}}{n^2 \cdot V}\left(1 - exp\left(-n \cdot t_{ope}\right)\right) \cdot \left(1 - exp\left(-n\left(t_G - t_{ope}\right)\right)\right) \qquad \text{(D.15)}$$

m3 is obtained by integrating the second term of (D.10) and (D.11) over time from 0 to t_G:

$$m3 = \int_0^{t_G} \frac{SER_{pre}}{n \cdot V}\left(1 - exp(-n \cdot t)\right) dt = \frac{SER_{pre}}{n^2 \cdot V}\left(n \cdot t_G + exp(-n \cdot t_G) - 1\right) \qquad \text{(D.16)}$$

M4 can be found by integrating the third term of (D 10).over time from 0 to t_G:

$$m4 = \int_0^{t_G} C_0 exp(-n \cdot t) dt = \frac{C_0}{n}\left(1 - exp(-n \cdot t_G)\right) \qquad \text{(D.17)}$$

The average mass concentration (C_{ope}) is:

$$C_{ope} = \frac{m1 + m2 + m3 + m4}{t_G} = \frac{m_{ope}}{V_{ope}} \qquad \text{(D.18)}$$

Insert m1, m2, m3 and m4 in (D.13), (D.15), (D.16) and (D.17) in (D.18) and rearrange:

$$C_{ope} \cdot t_G = \frac{SER_{prp}}{n^2 \cdot V}\left[exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right) + n \cdot t_{ope}\right)\right]$$

$$+ \frac{SER_{pre}}{n^2 \cdot V}\left[exp(-n \cdot t_G) + n \cdot t_G - 1\right] + \frac{C_0}{n}\left[1 - exp(-n \cdot t_G)\right] \qquad \text{(D.19)}$$

Rearrange (D.19) for SER_{prp}:

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}[exp(-n \cdot t_G) + n \cdot t_G - 1] - C_0 \cdot n \cdot V[1 - exp(-n \cdot t_G)]}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}}$$

(D.20)

When the operating phase starts soon after the end of the pre-operating phase, C_0 in (D.20) is equal to the concentration at the end of the pre-operating phase which can be determined by the emission during the pre-operating phase.

Substitute C_0 for C and t_{pre} for t in (D.5):

$$C_0 = \frac{SER_{pre}}{n_{pre} \cdot V}\left[1 - exp\left(-n_{pre} \cdot t_{pre}\right)\right] \tag{D.21}$$

Insert C_0 in (D.21) in (D.20):

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}\left[n \cdot t_G + exp(-n \cdot t_G) - 1 + \frac{n}{n_{pre}}\left(1 - exp\left(-n_{pre} \cdot t_{pre}\right)\right) \cdot \left(1 - exp(-n \cdot t_G)\right)\right]}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \tag{D.22}$$

If n_{pre} and “n” are the same, (D.22) is reduced to:

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}\left[n \cdot t_G - exp\left(-n \cdot t_{pre}\right) \cdot \left(1 - exp\left(-n \cdot t_G\right)\right)\right]}{exp\,(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \tag{D.23}$$

If t_{pre} is relatively long ($n{*}t_{pre} \geq 3$), (D.23) is reduced to:

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot n \cdot t_G}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \tag{D.24}$$

If the post-operating phase is relatively long ($n{*}(t_G - t_{ope}) \geq 3$), (D.22) is reduced to:

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}\left[n \cdot t_G - 1 + \frac{n}{n_{pre}}\left(1 - exp\left(-n_{pre} \cdot t_{pre}\right)\right)\right]}{n \cdot t_{ope}} \tag{D.25}$$

In the case n_{pre} and n differ and a stabilizing period exists, C_0 changes during that period of time (t_s).

In such cases, C_0 is obtained as the sum of the two concentrations, one of which decays from the concentration at the end of the pre-operating phase with air exchange while the other builds up with the continuing emission during that period of time (ts):

$$\begin{aligned} C_0 &= \frac{SER_{pre}}{n_{pre} \cdot V}\left[1 - exp\left(-n_{pre} \cdot t_{pre}\right)\right] exp(-n \cdot t_s) + \frac{SER_{pre}}{n \cdot V}\left[1 - exp(-n \cdot t_s)\right] \\ &= \frac{SER_{pre}}{n_{pre} \cdot n \cdot V}\left[n\left(1 - exp\left(-n_{pre} \cdot t_{pre}\right)\right) exp(-n \cdot t_s) + n_{pre}\left(1 - exp(-n \cdot t_s)\right)\right] \end{aligned} \tag{D.26}$$

Inserting (D.26) in (D.20) yields:

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}\left[n \cdot t_G - \left(1 - \frac{n}{n_{pre}}\left(1 - exp\left(-n_{pre} \cdot t_{pre}\right)\right)\right) exp(-n \cdot t_s) \cdot \left(1 - exp(-n \cdot t_G)\right)\right]}{exp\,(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \tag{D.27}$$

If the post-operating phase is relatively long ($n{*}(t_G - t_{ope}) \geq 3$), (D.27) is reduced to:

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}\left[n \cdot t_G - \left(1 - \frac{n}{n_{pre}}\left(1 - exp\left(-n_{pre} \cdot t_{pre}\right)\right)\right) exp(-n \cdot t_s)\right]}{n \cdot t_{ope}} \tag{D.28}$$

If the stabilizing period (t_s) is relatively long ($n*ts \geq 3$), (D.26) is reduced to:

$$SER_{prp} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot n \cdot t_G}{exp(-n \cdot t_G) - exp\left(-n\left(t_G - t_{ope}\right)\right) + n \cdot t_{ope}} \qquad \text{(D.24) reshown}$$

SER_{ope} is obtained as follows:

$$SER_{ope} = SER_{pre} + SER_{prp} \qquad \text{(D.9) reshown}$$

Annex E
(Informative)

DE-UZ 205 Options

DE-UZ 205 was developed as award criteria for the German Blue Angel Environmental Label. Its Appendix S-M, Test Method for the Determination of Emissions from Hard Copy Devices, was developed based on ECMA-328 as a test method for the criteria for substance emissions. Appendix S-M has also adopted the quasi-equilibrium model method (QEM) and is in harmony with ECMA-328. However, it has some additional and stricter requirements for comparing different equipment in the same class in order to equitably determine if the EUT meets the criteria for the Environmental Label. In this annex, the additional and stricter requirements are shown as DE-UZ 205 Options in the table below. Users may follow these requirements depending on their purposes.

NOTE The Appendix S-M is in harmony with QEM in 8.3.2, 8.3.3, 8.4.2.2, 8.4.3.2 and 8.4.3.3.

Sub-clause Number	Additional requirements under DE-UZ 205 Appendix S-M
8.2.1 Selection and storage of EUT	EUT shall be stored in its original packaging in a standard normal climate (23 °C, 50% RH) and tests should be executed within 10 working days after delivery of the EUT.
8.2.6 Preparation of the EUT before testing	One or two 10-minute operating cycles or at most 1200 printed pages are acceptable for the purpose of EUT function testing and measuring of print speed and no further preparation and/or usage shall be executed unless required due to malfunction of the EUT. NOTE The TUT of the EUT shall not exceed 20 minutes or the time corresponding to 1200-page printing meaning that the EUT selected is brand new.
8.2.7 EUT installation	In case of paper consumables, 60 g/m^2 to 80 g/m^2 A4 paper with water content from 3,8% to 5,6% shall be used. The EUT shall be installed on the day before the emission test.
8.3 EUT operation during test	A device shall be tested with a configuration that allows a 10-minute printing time in simplex mode (single sided pages). For devices which cannot achieve a printing time of at least 5 minutes and cannot be equipped with large paper output trays due to design, the test shall be carried out in duplex mode (double sided printing). The devices shall be tested with default setting (standard print quality).
8.4.1 Sorbents	Tenax tubes shall be spiked with an internal standard such as cyclodecane or deuterated toluene.
8.4.2 Sample collection (VOC, carbonyl compounds)	VOC shall be sampled with a sample air flow of 100 to 200 ml/min.
8.4.2.3 Requirements after sampling	If possible, all substances should be identified and individually quantified by the relative response factors determined for the internal standard from the calibration. If substances are not identifiable or the relative response factors cannot be determined, the quantification is carried out assuming the response factor for toluene or a toluene

	equivalent from the identified substance class respectively. It is permissible to use NIST- or Wiley- mass spectra data bases, if the analytes are not available as analytical standards. A match quality of at least 85% is sufficient. For a quantitative analysis the respective standard should be purchased.
8.4.3 Total VOC emission rate calculation	The total VOC emission rate shall be calculated as the sum of all identified and unidentified substances with calculated emission rates equal to or larger than the following values: • For measurements in ETCs ≤ 5 m3: SER_{pre} ≥ 0,005 mg/h and SER_{ope} ≥ 0,05 mg/h; • For measurements in ETCs > 5 m3: SER_{pre} ≥ 0,010 mg/h and SER_{ope} ≥ 0,10 mg/h. Emission rates should - according to DIN 1333:1992-02 - be rounded to 3 or 2 decimal places for the pre-operating phase and the operating phase respectively.
8.4.3.3 Emissions in the operating and post-operating phase	Formula (5) shall be used in the cases that not only n_{pre} and n are the same but also n_{pre} and n differ and $n*t_s$ is equal to or larger than one air exchange.
8.6.2 Sampling (Particulate matter)	The approximate formula (13) shall be used to calculate a particulate matter (dust) emission rate. Particulate matter (dust) sampling can be finalized after two air exchange periods of the post-operating phase.
8.7.1.1 General	Each individual AMS used must be qualified and approved as specified in the DE-UZ 205.
8.7.3.4 Calculation of PER and TP, final steps	The standard particle emission rate PER_{10} for an operating phase of 10 minutes (i.e. 600 seconds) shall be calculated using the following formula. $PER_{10} = TP \cdot \frac{600}{t_{ope}}$ (21) The length of the operating phase t_{ope} must be substituted in the unit [s]
9 Test report	The following should be included in the test report: Lightness and/or colour values (L*, a*, b*) from printout Standard particle emission rate PER_{10}.

Bibliography

[1] DE-UZ 205, Test method for the determination of emissions from Hard Copy Devices according to DE-UZ 205 (Appendix S-M).