Standard ECMA-328

6th Edition / December 2013

Determination of Chemical Emission Rates from Electronic Equipment

Standard

Rue du Rhône 114 CH-1204 Geneva T: +41 22 849 6000 F: +41 22 849 6001

Contents

Page

Introduction

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

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

In addition to stricter test procedures, the second edition uses 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's fast track procedure and published in September 2007.

In addition, the 4th edition fixes 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 the 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.

This 6th edition is aligned with the 2nd edition of ISO/IEC 28360:2011, and it adds 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 “Test method for the determination of emission from Hard Copy Devices” (RAL-UZ 122) has been replaced by “Test method for the determination of emission from Hard Copy Devices” (RAL-UZ 171) published in January 2013.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 this 6th edition.

This Ecma Standard has been adopted by the General Assembly of December 2013.

"COPYRIGHT NOTICE

© 2013 Ecma International

This document may be copied, published and distributed to others, and certain derivative works of it may be prepared, copied, published, and distributed, in whole or in part, provided that the above copyright notice and this Copyright License and Disclaimer are included on all such copies and derivative works. The only derivative works that are permissible under this Copyright License and Disclaimer are:

(i) works which incorporate all or portion of this document for the purpose of providing commentary or explanation (such as an annotated version of the document),

(ii) works which incorporate all or portion of this document for the purpose of incorporating features that provide accessibility,

(iii) translations of this document into languages other than English and into different formats and

(iv) works by making use of this specification in standard conformant products by implementing (e.g. by copy and paste wholly or partly) the functionality therein.

However, the content of this document itself may not be modified in any way, including by removing the copyright notice or references to Ecma International, except as required to translate it into languages other than English or into a different format.

The official version of an Ecma International document is the English language version on the Ecma International website. In the event of discrepancies between a translated version and the official version, the official version shall govern.

The limited permissions granted above are perpetual and will not be revoked by Ecma International or its successors or assigns.

This document and the information contained herein is provided on an "AS IS" basis and ECMA INTERNATIONAL DISCLAIMS ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO ANY WARRANTY THAT THE USE OF THE INFORMATION HEREIN WILL NOT INFRINGE ANY OWNERSHIP RIGHTS OR ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE."

Determination of Chemical Emission Rates from Electronic Equipment

1 Scope

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

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

This Standard includes specific methods for equipment using consumables, such as printers, and equipment not using consumables, such as monitors and PC's. Annex A specifies monochrome and colour print patterns for use in the operating phase of EUT using consumables (e.g. paper).

Examples of EUT that do not use consumables are:

- Monitors and TV sets (CRT, Plasma, LCD, Rear projector, Beamer).
- Video (VCR, DVD Player/Recorder, Camcorder).
- SAT Receiver (Set-Top Box).
- Audio units (CD Player/Recorder, Home theatre Systems, Audio Home Systems, Micro-/Mini, Midi Systems, Amplifier, Receiver).
- Portable Audio (CD Player, MP 3 Player, Radio recorder, Clock radio etc).
- Computer (desktop, tower, server), portable computers (Notebooks).

Emission rates from EUT using consumables may also be determined according to additional requirements identified by "RAL-UZ 171 Option".

Calculations use the generalised model and approximations thereof as developed in Annex C.

The emission rates determined with this method may be used to compare equipment in the same class.

Predictions of "real indoor" *concentrations* from the determined *emission rates* are outside the scope of this Standard.

2 Conformance

Determinations of emission rates and total number of emitted particles conform to this Standard 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.

For EUT using consumables, determinations according to additional requirements identified by “RAL-UZ 171 Option” herein conform to the RAL-UZ 171 Option.

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.

ECMA-74, *Measurement of Airborne Noise emitted by Information Technology and Telecommunications Equipment*

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

ISO 13655:1996, *Graphic technology – Spectral Measurements and colorimetric computation for graphic arts images*

ISO 16000-3:2001, *Indoor air – Part 3: Determination of formaldehyde and other carbonyl compounds – Active sampling method*

ISO 16000-6:2004, *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*

EN 55013:2001, *Sound and Television Broadcast Receivers and associated equipment – Radio disturbance characteristics – Limits and methods for measurement*

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 (Cp) over 31±3 seconds

4.2
Averaged ozone concentration time series
Simple Moving Average of ozone concentration (Co3) over 80±5 seconds

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

4.4
Aerosol Measuring System
AMS
device for measuring the total number concentration of aerosol particles within a size range at a certain frequency

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
AMS capable to measure the total particle number concentration

NOTE AMS consist of a flow meter, a particle counting device, a computer and suitable software. An AMS may also be equipped with a particle size classifier.

4.9
Consumables
toner, ink, paper and ribbon

4.10
Emission Test Chamber
ETC
enclosure with controlled operational parameters for testing analyte mass emitted from EUT

4.11
Equipment Under Test
EUT
functional and complete ICT or CE equipment from which chemical emission rates are determined

4.12
Fast AMS
AMS with integrated particle size classifier

4.13
Fine Particles
FP
particles with particle size / diameter range between 0.1 µm and 2.5 µm

4.14
Loading factor
ratio of the EUT volume to the volume of the unloaded ETC

4.15
Hard Copy Devices
class of EUT using Consumables that includes printers, (Photo)copiers and Multi Functional Devices (MFD)

4.16

Maximum usage time before testing

MUT

<EUT using consumables> ratio between the total number of prints carried out by the EUT and the printing speed of the EUT.

NOTE Maximum usage time is the maximum permitted time of operation before testing in order to consider the EUT as newly manufactured equipment for testing purposes.

4.17

Operating phase

phase in which the EUT is performing its intended functions

4.18

Particle

tiny piece of solid or liquid matter with defined physical boundaries suspended in a gas

4.19

Particle Emission Rate

PER

averaged emission rate, i.e. total number of particles in a specified particle size range emitted during the operating phase

4.20

Particle Emission Rate

PER(t)

time dependent emission rate of particles in a specified particle size range after the start of the operating phase

4.21

Particle loss-rate coefficient

β

coefficient describes the loss of particles in a specified particle size range in an ETC

4.22

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).

4.23

Particulate Matter

PM

quantity of particles measured by gravimetric methods

4.24

Pre-operating phase

phase in which the EUT is connected to an electrical supply before the EUT is able to enter the operating phase

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

4.25

Post-operating phase

phase following the operating phase

NOTE The post-operating can include energy saving modes.

4.26
Total Number of Emitted Particles
TP
calculated total number of particles emitted in a specified particle size range

4.27
Total Particle Number Concentration
C_p
particle number concentration in a specified particle size range

4.28
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

4.29
Ultrafine Particles
UFP
particles with particle diameter less or equal 0.1 µm

4.30
Unit specific emission rate
SER
mass, in micrograms, of a specific analyte emitted per hour

NOTE If more than one EUT is placed in the ETC, the determined SER is divided by the number of EUTs to obtain the unit specific emission rate SERu.

4.31
Volatile Organic Compounds
VOC
compounds that elute between n-hexane and n-hexadecane on an unpolar GC-column

5 Symbols and abbreviated terms

5.1 Abbreviated terms

AMS	Aerosol Measuring System
CE	Consumer Electronics
CPC	Condensation Particle Counter
DNPH	2,4-Dinitrophenylhydrazine
ETC	Emission Test Chamber
EUT	Equipment Under Test
FP	Fine Particles
FID	Flame Ionisation Detector
GC/MS	Gas chromatography/Mass spectrometry
ICT	Information and Communication Technology

MFD	Multi Functional Device
PTFE	Polytetrafluoroethene
PVC	Polyvinylchloride
rH	Relative humidity
SER	Unit Specific Emission Rate
PER	averaged Particle Emission Rate
PER(t)	time-dependent Particle Emission Rate
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-rate coefficient [h^{-1}]
C_s	Average mass concentration [µg m^{-3}]
C_{bg}	Background mass concentration [µg m^{-3}]
C_0	Initial mass concentration [µg m^{-3}]
C_{pre}	Average mass concentration during pre-operating phase [µg m^{-3}]
C_{ope}	Average mass concentration during operating phase and optionally during post-operating phase [µg m^{-3}]
C_p	Total particle number concentration [cm^{-3}]
$Cp_{,BG}$	Background particle number concentration [cm^{-3}]
Co3	Ozone concentration [mg/m3]
d	Equivalent Particle Diameter [nm]
C_{max} /2	
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_{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]
m_{pre}	Sampled mass [µg] during pre-operating phase
m_{ope}	Sampled mass [µg] during operating and optionally post-operating phase
n	Air exchange rate [h^{-1}]
p	Atmospheric pressure [Pa]
PER	Particle Emission Rate [h^{-1}]
R	gas constant [PaK-1], (for ozone: 339.8 [PaK-1])
SER_{bg}	Background SER [µg h^{-1}]
SER_{ope}	SER during operating and optionally post-operating phase [µg h^{-1}]
SER_{O3}	SER for ozone [µg min^{-1}]
SER_{pm}	SER for particulate matter [µg h^{-1}]
SER_{pre}	SER during pre-operating [µg h^{-1}]
SER_u	SER per unit [µg h^{-1} u^{-1}]
T	Ambient temperature [K]
TP	Total Number of Emitted Particles
t_{ope}	Operating phase duration [h]
t_G	Sampling time during operating and optionally post-operating phase [h]
t_{start}	point in time marking the start of operating phase
t_{stop}	point in time marking the end of particle emission
t_{pre}	Pre-operating phase duration [h]
Δt	Time-resolution of the UFP measurement [s]
u	Number of EUTs units
V	ETC volume [m^3]
V_s	Sampled air 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

6 Method overview

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

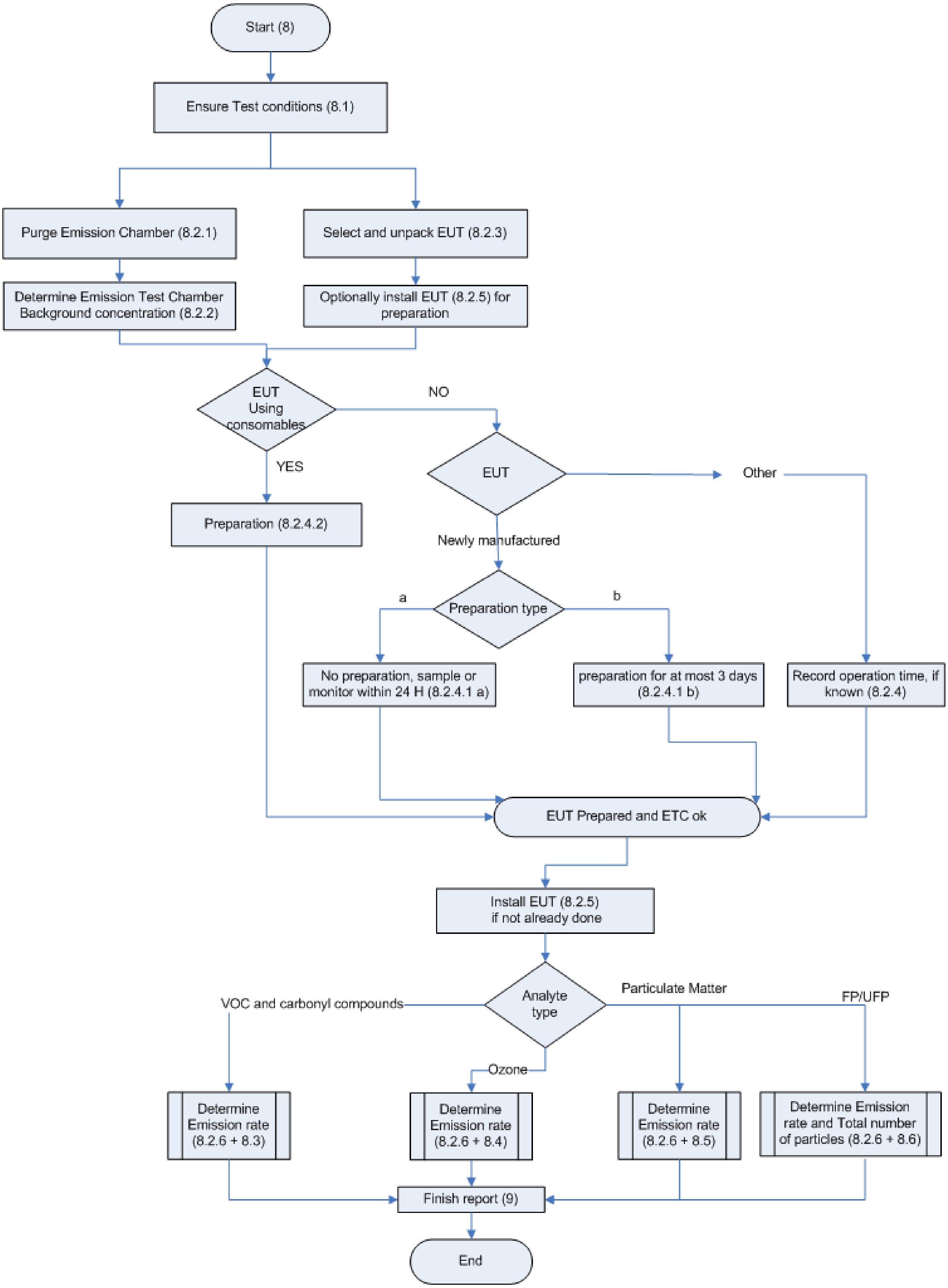


Figure 1 — Determination method overview

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

For the RAL-UZ 171 Option, tests should be executed within 10 working days after delivery of the EUT.

8.1 Test conditions

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.

8.1.1 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.

Consult 8.2.6.2 for special requirements on rH for EUT using consumables.

8.1.2 Air exchange rate (n)

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

8.1.3 Air velocity

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

8.1.4 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

EUT shall be selected from normal manufactured batches or shall be a prototype that is representative for EUT from such batches. For determinations using the RAL-UZ 171 Option, EUT shall be stored in an air-conditioned room (23 °C, 50% rH) in its original packaging.

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 1:100.

8.2.1 ETC purging

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

k' shall be less than 0,0693 [min^{-1}], which corresponds to an ozone half-life of greater than 10 minutes, when n = 1.

To determine k', 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.

8.2.2 Background concentrations (C_{bg})

Following purging, the C_{bg} of Analyte in the unloaded ETC shall be determined and recorded.

NOTE C_{bg} may stem from e.g. emissions from the ETC itself and sampling tubes or filters.

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

Table 1 — Background concentrations

Analyte	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_p = 2000 [cm^{-3}]

8.2.3 EUT unpacking

Emissions from packaging may influence measurements considerably; in addition 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 8.2.4).

NOTE After unpacking, installation (step 8.2.5) may precede the preparation step (8.2.4).

8.2.4 Preparation of the EUT before testing

8.2.4.1 EUT not using consumables

Newly manufactured equipment is known to emit higher levels in the first days of use, which is not representative for the normal emissions over the intended lifetime.

For newly manufactured equipment, one of the following preparatory operations shall be executed:

a) The EUT shall not be operated before testing; testing shall start within 24 hours after unpacking.

b) The EUT shall have been in operation for a maximum of three days or equivalent before the start of testing.

For other equipment, that may have been operated longer than three days, no preparation shall be executed; in this case, the number of days that the EUT has been in operation shall be recorded, if known, otherwise “not known” shall be reported.

NOTE Typical treatment conditions for types of EUT are:
PCs and ICT & CE equipment: 8 hours operation in idle mode for three days at 8 hours per day which is equivalent to 24 hours of continuous operation.

8.2.4.2 EUT using consumables

For EUT using paper consumables, a 60 g/m^2 to 80 g/m^2 A4 paper with water content between 3,8% and 5,6%, and printing the patterns as specified in Annex A.1 and A.2 are appropriate for the following preparatory operation. The maximum duration of the operating phase shall be determined. Thereafter, lightness (L*) and colour values (L*, a*, b*), as appropriate shall be determined from the printouts according to CIE 15:2004 and ISO 13655.

Before testing the EUT may be used up to the duration of the MUT. The MUT (as duration of the total operating cycles) is 120 minutes.

One to two 10-minutes operating cycles outside or inside the ETC shall be performed at least one day before the UFP test in order to determine the print speed, to ensure the proper operation and to avoid influence on emissions due to unstable UFP emission which sometimes may occur in operation after long-term disuse of the EUT.

For the RAL-UZ 171 option one or two 10-minute operating cycles or at most 1000 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.

Treatment conditions shall be recorded in the test report.

8.2.5 EUT installation

8.2.5.1 EUT not using consumables

The EUT shall be installed while executing its intended function(s) as specified in ECMA-74, using suitable test signals as specified in chapter 5.2 of EN 55013:2001 or another appropriate standard or specification.

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

8.2.5.2 EUT using consumables

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 water content from 3,8% to 5,6% 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 test as specified in 8.2.6, requires the EUT to be powered-on.

For the determination of FP and UFP specified in 8.6 and/or for the RAL-UZ 171 option 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 8.2.6, shall not begin within at least 3 air exchanges following installation.

8.2.6 EUT operation during test

The start of the operation of the EUT shall be recorded as the time t_0.

The start and duration of the operating phases shall be recorded.

8.2.6.1 EUT not using consumables

For this class of EUT, VOC and carbonyl compounds as specified in 8.3 shall be determined and ozone as specified in 8.4 should be determined while continuing to execute its intended functions as initiated during installation (see 8.2.5.1).

The used test standard or specification shall be reported, preferably by referring to a standard.

8.2.6.2 EUT using consumables

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.

For this class of EUT, VOC and carbonyl compounds as specified in 8.3; ozone as specified in 8.4; particulate matter as specified in 8.5 and FP and UFP as specified in 8.6 shall be determined while the EUT being controlled from outside the ETC.

8.2.6.2.1 Pre-operating phase

To enter the pre-operating phase, the EUT shall be powered-on and remain in this phase between 1 and 4 air exchanges. For the determination of FP and UFP as specified in 8.6, 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.

8.2.6.2.2 Operating phase

The Hard Copy Device class of EUT shall operate at nominal speed. Operating may include colour-, and/or dual sides printing. The monochrome and colour print patterns specified in Annex A.1 and A.2 respectively shall be used for EUT using paper consumables.

Enter the operating phase by starting 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.

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

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

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

Second priority: If 10 minutes duration is technically not feasible the operational phase shall be as long as possible. The number of printed pages should not fall below 150. The maximum duration possible and the number of printed pages have to be checked prior to testing and have to be documented in the test protocol.

8.2.6.2.3 Post-operating phase

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

8.3 VOC, carbonyl compounds

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

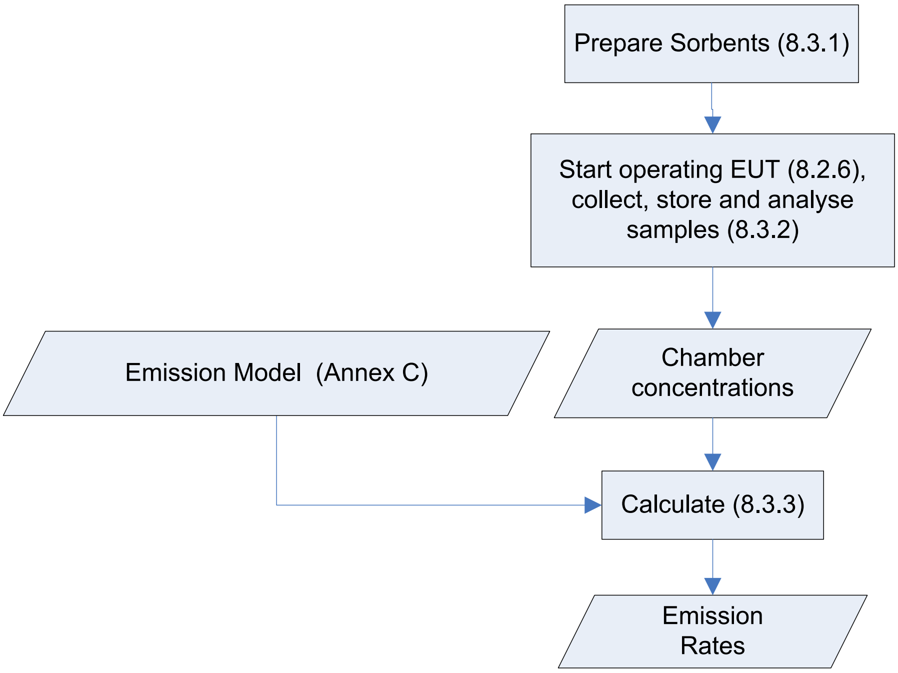


Figure 2 — Determination method for VOC, carbonyl compounds

8.3.1 Sorbents

VOC sampling and analysis shall be performed using the sorbents as specified in ISO 16017-1, with the exception of Chromosorb and Porapack 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 the RAL-UZ 171 Option, Tenax tubes shall be spiked with an internal standard such as cyclodecane or deuterated toluene.

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

8.3.2 Sample collection

For VOC, duplicate samples shall be taken, and for carbonyl compounds at least one sample shall be taken.

Individual VOCs, carbonyl compounds with a concentration ≥ 1,0 $\mu g/m^3$ and, under the RAL-UZ 171 Option, benzene with a concentration ≥ 0,25 $\mu g/m^3$, shall be detected.

8.3.2.1 Sample collection from EUT not using consumables

Sampling shall start at 3 and end no later than 4 air exchanges after t_0.

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

8.3.2.2 Sample collection from EUT using consumables

Sampling shall be performed during:

i. The pre-operating phase, starting at the beginning of this phase, or, under the RAL-UZ-171 Option, with a sample flow of 100 to 200 ml/min, from 20 minutes before the end until the end of the one-hour pre-operating phase; and

ii. The operating phase, starting at beginning of this phase, and may continue into the post-operating phase. Under the RAL-UZ 171 Option, sampling shall continue for one air exchange in the post-operating phase, with a sample flow of 100 to 200 ml/min.

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

Identified VOCs shall be quantified using absolute response factors, determined by calibration. Unidentified VOCs shall be quantified using the toluene equivalents as a relative 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).

8.3.3 Emission rate calculation

This Clause specifies formulae that apply to practical situations that are special cases of the general case (as developed in Annex C).

Concentrations shall be determined, using the following equations:

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

8.3.3.1 EUT not using consumables

The SER for EUT not using consumables is:

$$SER_u = \frac{(C - C_{bg}) \cdot n \cdot V}{u} \tag{2}$$

8.3.3.2 EUT using consumables

The Background emission rates are:

$$SER_{bg} = C_{bg} \cdot n \cdot V \tag{3}$$

a) Emissions in the pre-operating phase

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

1. If a sample is taken from the beginning of this phase:

$$SER_{pre} = \frac{\left(C_{pre} - C_{bg}\right) \cdot n^2 \cdot V \cdot t_{pre}}{\exp(-n \cdot t_{pre}) - 1 + n \cdot t_{pre}} \tag{4}$$

2. RAL-UZ 171 Option

$$SER_{pre} = C_{pre} \cdot n \cdot V \tag{5}$$

b) Emissions in the operating and post-operating phase

1. General case

Emission rates in these phases shall be determined using the following general formula:

$$SER_{ope} = \frac{\left(C_{ope} - C_{bg}\right) \cdot n^2 \cdot V \cdot t_G - SER_{pre}\ [\exp(-n \cdot (t_G - t_{ope})) + n \cdot (t_G - t_{ope}) - 1 + (1 - \exp(-n \cdot t_{pre})) \cdot (1 - \exp(-n \cdot t_G))\ ]}{\exp(-n \cdot t_G) - \exp[-n \cdot (t_G - t_{ope})] + n \cdot t_{ope}} \tag{6}$$

2. Special cases

Consult Annex C for more detail on special cases.
If there is no post-operating phase ($t_G = t_{ope}$), then:

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

If the post-operating phase is relatively long ($n \cdot t_G \geq 3$):

$$SER_{ope} = \frac{\left(C_{ope} - C_{bg}\right) \cdot n^2 \cdot V \cdot t_G - SER_{pre}\, [n \cdot t_G - \exp(-n \cdot t_{pre}))]}{n \cdot t_{ope}} \tag{8}$$

3. RAL-UZ 171 Option

For the RAL-UZ 171 Option the post-operating phase shall last one air exchange and the following approximate formula shall be used for the calculation of SER_{ope} (i.e. (B.28) as derived in Annex C.9):

$$SER_{ope} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot n \cdot t_G}{\exp(-n \cdot t_G) - \exp[-n \cdot (t_G - t_{ope})] + n \cdot t_{ope}} \tag{9}$$

8.3.3.3 TVOC (RAL-UZ 171 Option)

The TVOC value shall be calculated as the sum of the concentrations of all identified and unidentified substances, eluting between n-hexane and n-hexadecane and resulting in emission rates above the following values:

- For measurements in ETCs ≤ 5 m^3: $SER_{pre} \geq 0{,}005$ mg/h and $SER_{opr} \geq 0{,}05$ mg/h;
- For measurements in ETCs > 5 m^3: $SER_{pre} \geq 0{,}02$ mg/h and $SER_{opr} \geq 0{,}2$ mg/h.

8.4 Ozone

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

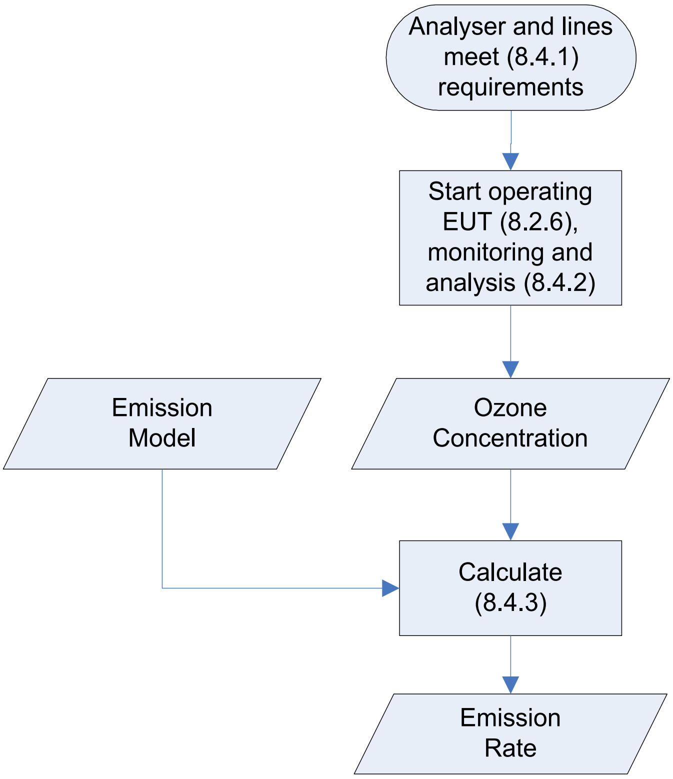


Figure 3 — Determination method for ozone

8.4.1 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 `ΔCo3` shall not be rounded to the nearest whole ppb (1.963 `µg/m`^{3}) by data processing of the analyser because rounding may cause errors in the determination of the `ΔCo3`.

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.

8.4.2 Monitoring

Since ozone is an unstable molecule, it shall be monitored and analysed instantaneously at least each 20 seconds for at least the first 6 minutes of the operating phase to determine the maximum ΔCo3 as specified in 8.4.3. In addition, data points before and/or after the first 6 minutes of the operating phase shall be sampled so that the averaged ozone concentration time series can be calculated as specified in 8.4.3.

8.4.3 Emission rate calculation

The ozone emission rate is derived from the increase in ozone concentration during the first ~~in~~ 6 minutes 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 10 in this part of the operating phase

$$\frac{\Delta m}{\Delta t} = \frac{\Delta c_{O3} * V}{\Delta t} \tag{10}$$

Δm: emitted ozone mass [mg]
$\Delta Co3$: change of ozone concentration [mg/m^3]
Δt: time interval [min]

the emission rate of ozone shall be calculated by formula 11:

$$\mathrm{SER}_{\mathrm{O3}} = \frac{\Delta c_{O3} * V * p * 60}{\Delta t * T * R} \tag{11}$$

A time interval Δt of two minutes and the maximum $\Delta Co3$ shall be applied in formula 11. The data points recorded in 6 minutes from the start of the operating phase shall be used to determine the maximum $\Delta Co3$. This is the case when the averaged ozone concentration time series exhibits the greatest slope for the two minute time interval (Co3(t+2) – Co3(t) = maximum). The Averaged ozone concentration time series is created with the Simple Moving Average over 80 ±5seconds.

NOTE Theoretically, a time interval of the data points at the start of the operating phase gives the maximum Δm/Δt leading 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 ΔCo3 for 6 minutes 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.

8.5 Particulate matter

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

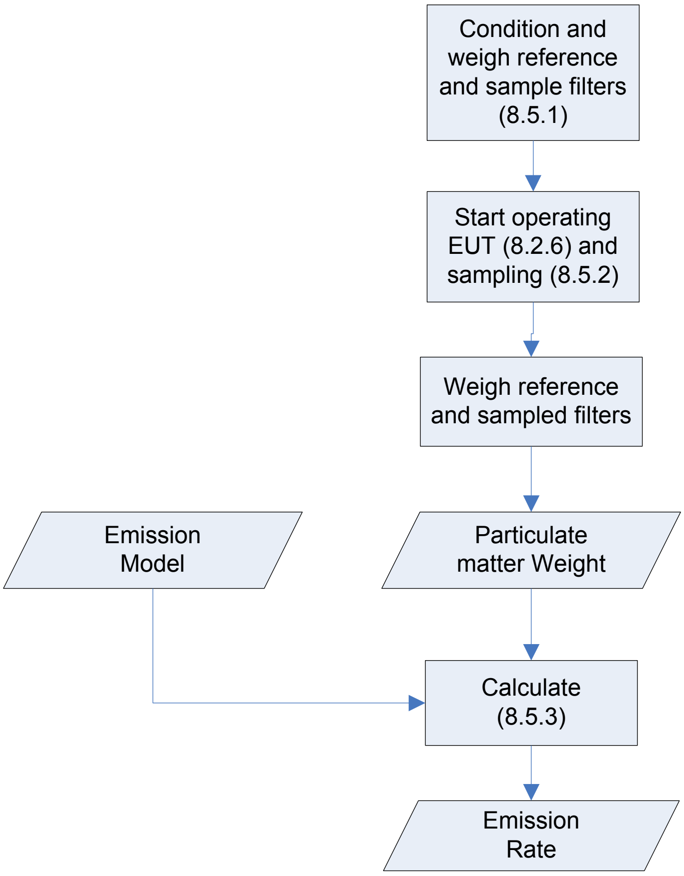


Figure 4 — Determination method for particulate matter

8.5.1 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 as specified in 8.1.1.

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 remain in the controlled room for 48 hours. The unused reference filter and the sampling filters shall be weighed before sampling giving $m_{\text{ref-before}}$ and m_{before}.

8.5.2 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/m^3 of particulate matter.

For the RAL-UZ 171 Option sampling shall start at the beginning of the operating phase and continue during the full post-operating phase that lasts 4 air exchanges.

8.5.3 Emission rate calculation

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

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

$$m_{pm} = (m_{\text{after}} - m_{\text{before}}) - (m_{\text{ref-after}} - m_{\text{ref-before}}). \qquad (12)$$

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

$$SER_{pm} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G}{\exp(-n \cdot t_G) - \exp[-n \cdot (t_G - t_{ope})] + n \cdot t_{ope}} \tag{13}$$

For the RAL-UZ 171 Option the following approximate formula shall be used:

$$SER_{pm} = \frac{C_{ope} \cdot n \cdot V \cdot t_G}{t_{ope}} \tag{14}$$

8.6 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 the gravimetric determination of particulate matter (8.5). It is an additional test to be performed in parallel.

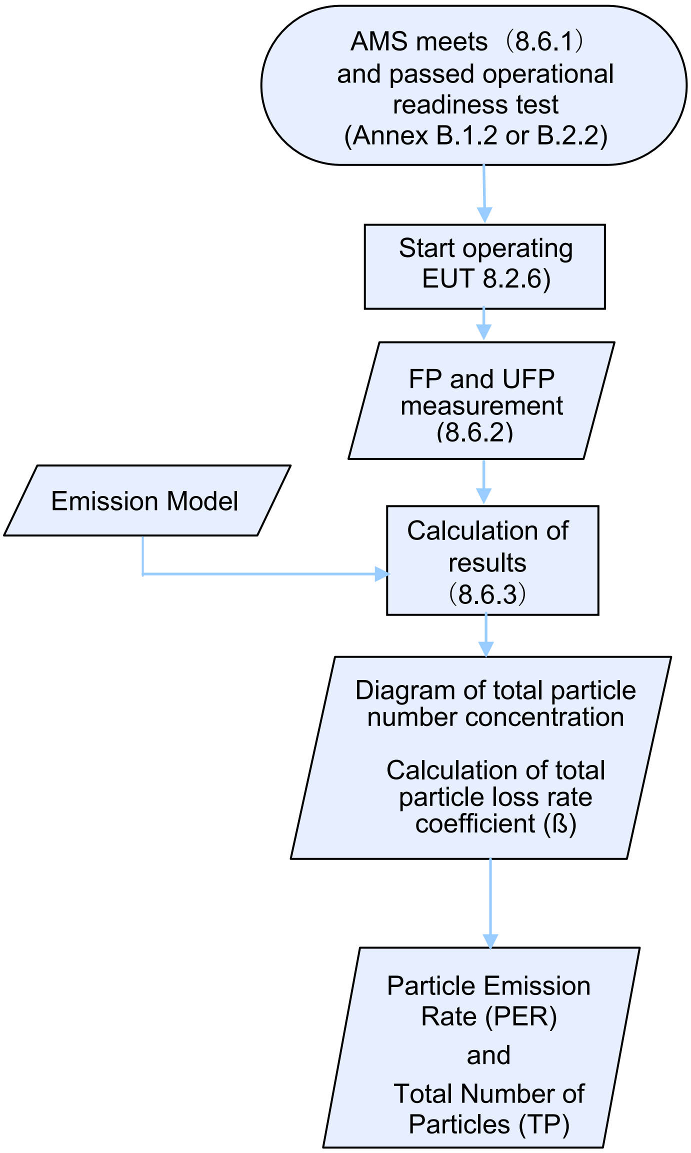


Figure 5 — Determination method for FP and UFP emissions

8.6.1 General Requirements for Aerosol Measuring Systems (AMS)

An AMS shall be capable to measure the time dependent total particle number concentration with particle size range as specified in 8.6.1.1, particle number concentration range as specified in 8.6.1.2 and time resolution as specified in 8.6.1.3.

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

8.6.1.1 For the RAL-UZ 171 Option each individual AMS used must be qualified and approved as specified therein.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.

8.6.1.2 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:

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

Required upper particle number concentration level within the above specified size range shall exceed 10^7 cm^3.

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 5000 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.

8.6.1.3 Time resolution

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

8.6.1.4 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.

8.6.1.5 Quality Assurance

AMS shall have the following capabilities:

- calibration of air flux
- Report and display of malfunctions during measurements automatically
- Procedures for cleaning and maintenance
- Export of ASCII data
- report of settings
- Time and date setting/synchronization
- Measurement of electrometer noise levels for Fast AMS.

8.6.2 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.

8.6.3 Calculation

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 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 1/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-rate coefficient β, the Particle Emission Rate PER and the Total number of emitted Particles TP.

8.6.3.1 Calculation of Particle loss rate coefficient β

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

---

[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)

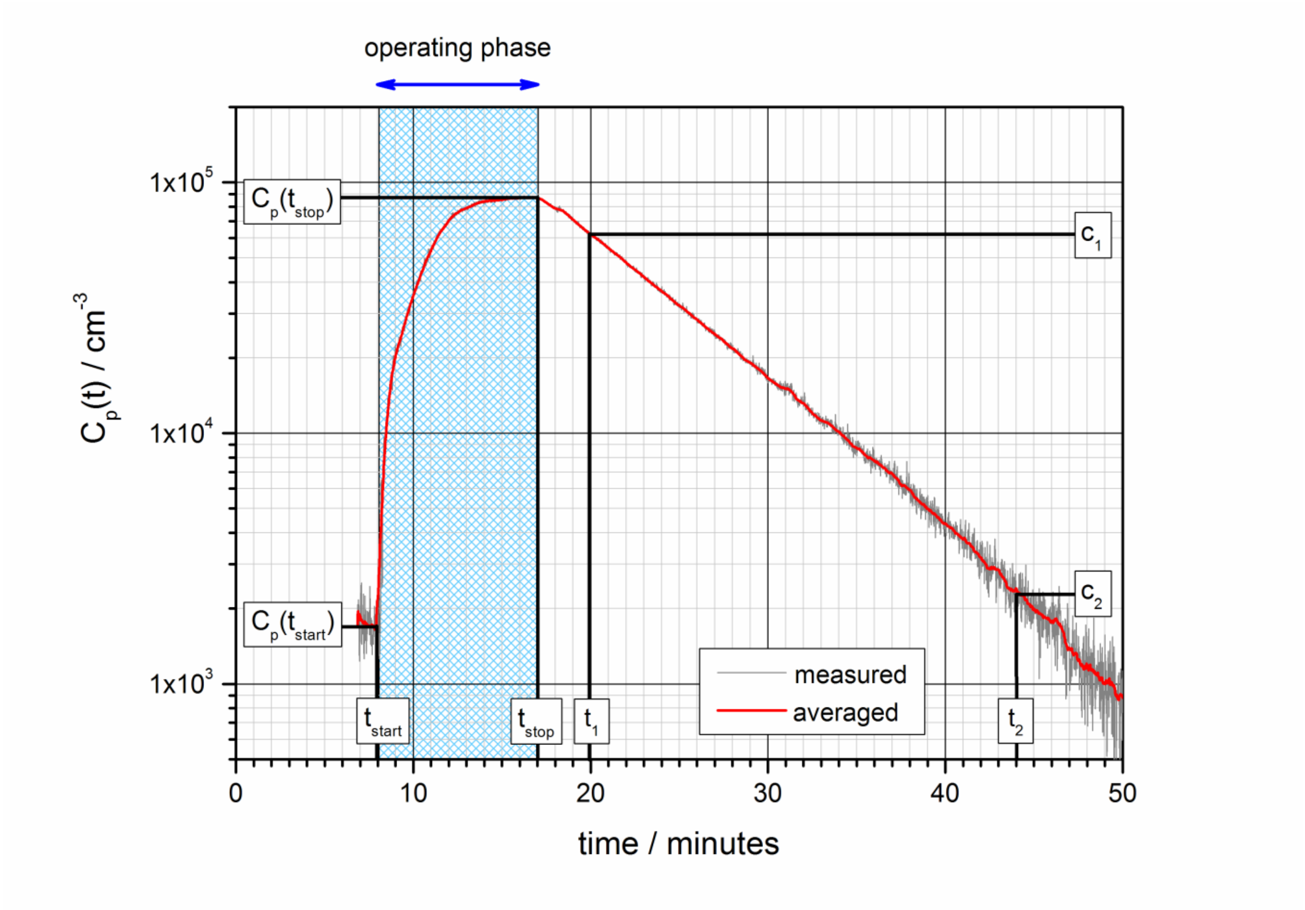


Figure 6 — Diagram of a total particle number concentration time series (example)

1. Plot the <u>averaged</u> concentration time series as shown in Figure 6 (optionally the concentration time series may be added to the diagram).
2. Read the values c_1, t_1 and c_2, t_2 as indicated in Figure 6 with high accuracy from the averaged concentration time series. Make sure that the values c_1, t_1 are read at least 5 minutes after the maximum of the particle number concentration. It is essential that no particle release occurs after t_1 (see Fig. 7) Make sure that the values c_2, t_2 are read at some distance – at least 25 min – after t_1.
3. Calculate β using the following formula:

$$\beta = \frac{\ln\left(c_1/c_2\right)}{t_2 - t_1} \tag{15}$$

NOTE 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:

$$C_p = \alpha \cdot \exp(-\beta \cdot t) \tag{16}$$

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

8.6.3.2 Calculation of PER and TP

Distinction of cases for the calculation:

Case a) if $C_p(t)$ is continuously <u>decreasing</u> after end of operating phase the steps described in 8.6.3.2.1 shall be applied.

Case b) if $C_p(t)$ is <u>increasing</u> after end of operating phase the steps described in 8.6.3.2.2 shall be applied.

8.6.3.2.1 Case a)

1. Read the values t_{start} and $C_p(t_{start})$ as indicated in Figure 6 with high accuracy from the averaged concentration time series.

2. Read the values t_{stop} and $C_p(t_{stop})$ as indicated in Figure 6 with high accuracy from the averaged concentration time series.

3. Proceed with final steps in 8.6.3.2.3.

8.6.3.2.2 Case b) (Calculation of PER(t))

1. Read the values t_{start} and $C_p(t_{start})$ as indicated in Figure 6 with high accuracy from the averaged concentration time series.

2. Calculate the time difference between two consecutive time data points, Δt in seconds,

3. PER(t) in particles/second shall be calculated using Δt

$$PER(t) = \frac{V}{u}\left(\frac{C_p(t) - C_p(t-\Delta t)\exp(-\beta\cdot\Delta t)}{\Delta t\ \exp(-\beta\cdot\Delta t)}\right) \tag{17}$$

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

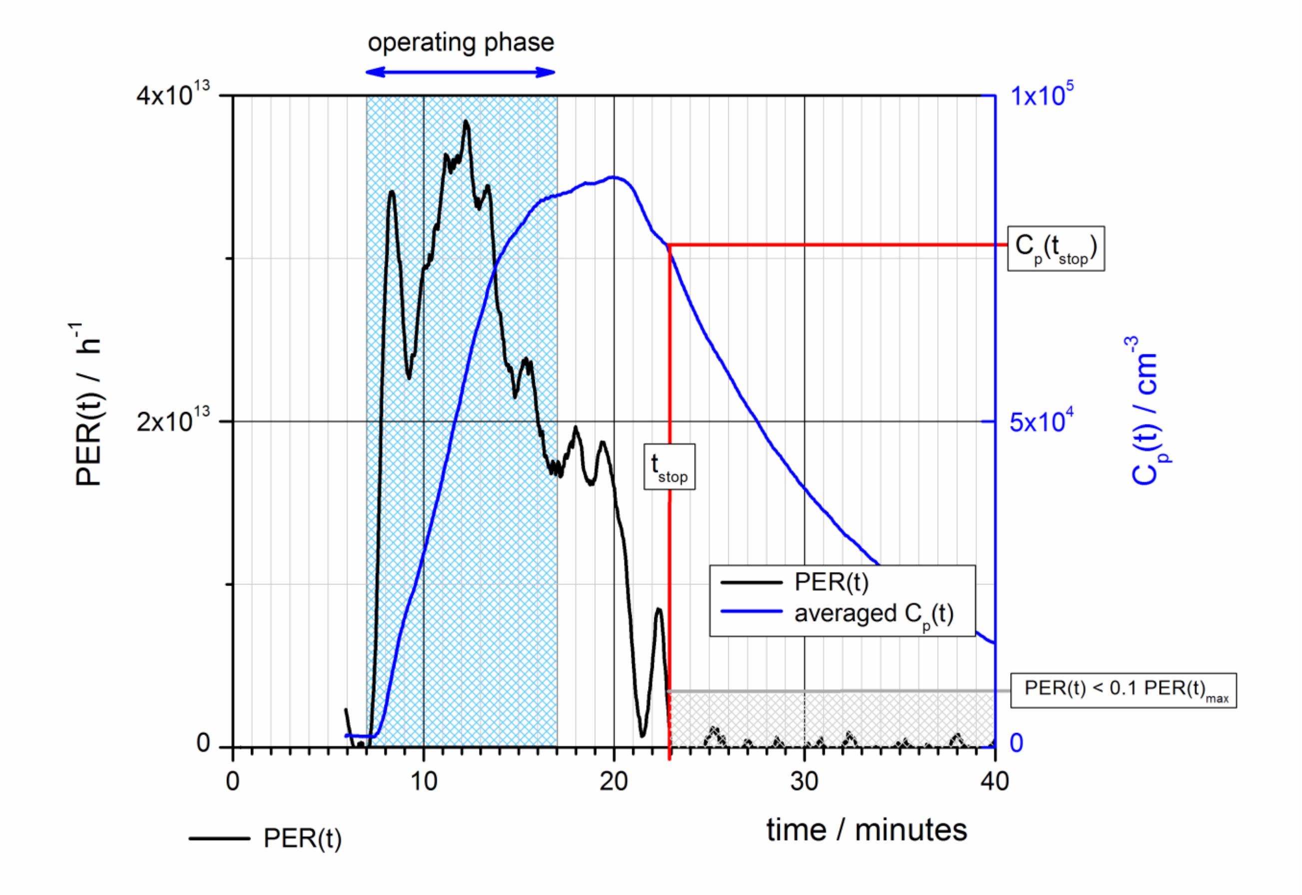


Figure 7 — Diagram of PER(t) and C_p(t)

5. 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.

6. Proceed with final steps in 8.6.3.2.3.

8.6.3.2.3 Calculation of PER and TP, final steps

1. The difference of total particle number concentrations (Δc_p) shall be calculated as follows:

$$\Delta C_p = C_p\left(t_{stop}\right) - C_p\left(t_{start}\right) \tag{18}$$

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

$$C_{av} = \frac{\sum_{i=1}^{n} C_{p,i}}{n} \tag{19}$$

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

3. PER shall be calculated using the following formula:

$$PER = \frac{V}{u}\left(\frac{\Delta C_p}{t_{stop} - t_{start}} + \beta \cdot C_{av}\right) \tag{20}$$

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

4. TP shall be calculated using the following formula:

$$TP = PER \cdot \left(t_{stop} - t_{start}\right) \tag{21}$$

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 “not 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 for EUT using consumables: if tabletop or floor-mounted.
- Print or copying time 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).
- Types of packaging.
- External dimensions.
- Number of hours the equipment has been used while energised during manufacture and testing.

Test conditions and methods

- Date of test.
- 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.
- Type, start time and duration of preparation for newly manufactured equipment; for other equipment, the number of days in operation before test, if known; “not known” otherwise.
- 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.
- Printing speed during test and number of printed pages.
- Print mode used for testing (monochrome or colour).
- Lightness and/or colour values (L*, a*, b*) from printout.
- 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

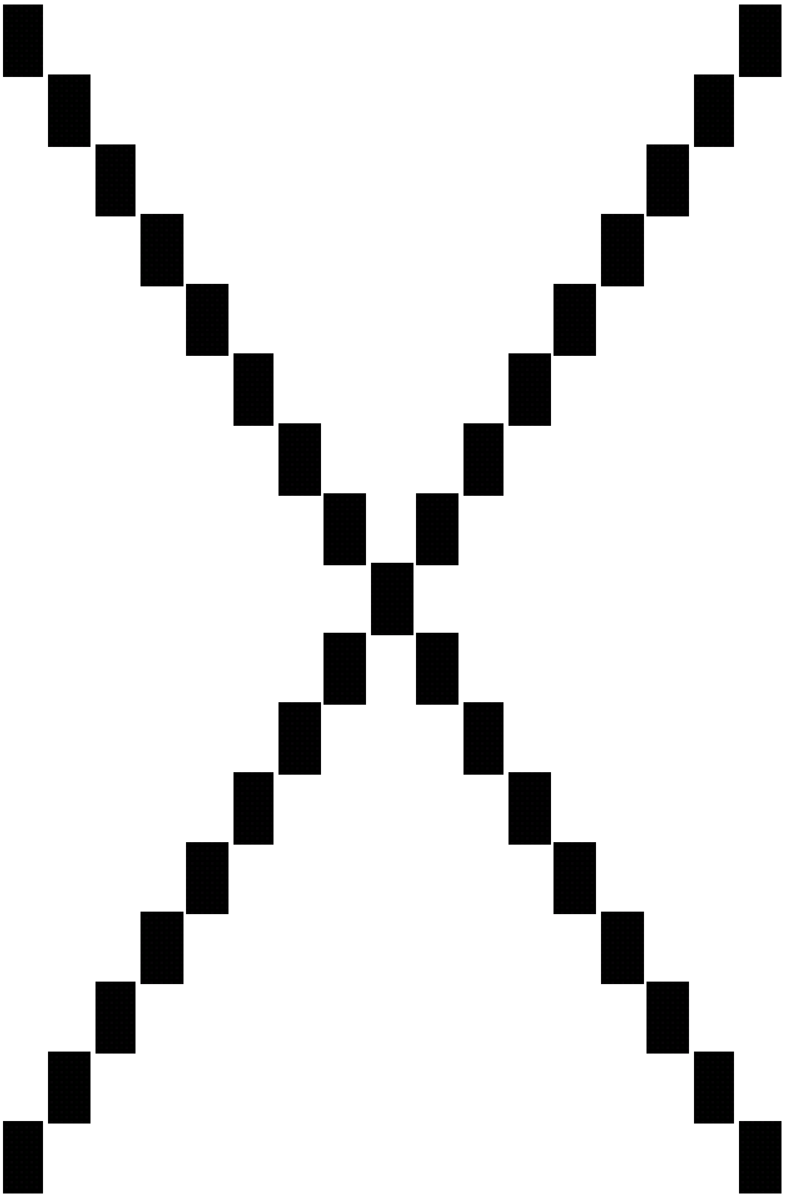
- Name, CAS-number and concentration of identified VOCs, formaldehyde and other carbonyl compounds in pre-operating phase and operating phase and calculated emission rates.
- Concentration of unidentified VOCs in pre-operating phase and operating phase and calculated emission rates.
- TVOC value calculated based on the response factor of toluene as specified in ISO 16000-6, for the RAL-UZ 171 Option.
- 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 rate coefficient β.
- Particle emission rate PER.
- Total number of emitted particles TP.

Annex A
(normative)

Print Patterns

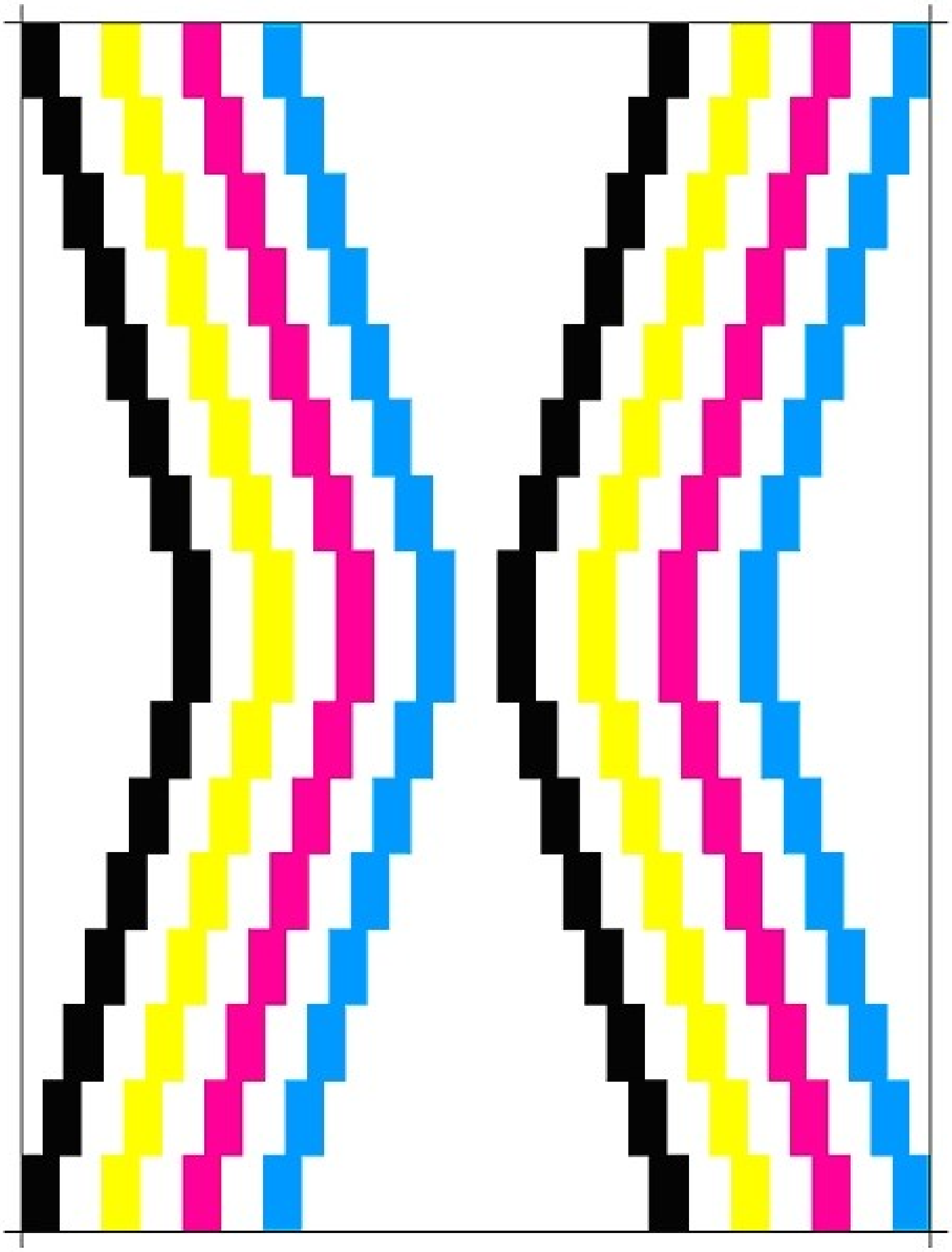
A.1 Monochrome print pattern 5% coverage

Annex A.1 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%.

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

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/ D log d_i, where index i corresponds to the size class.

B.2 Procedures for Operational readiness test of Fast AMS

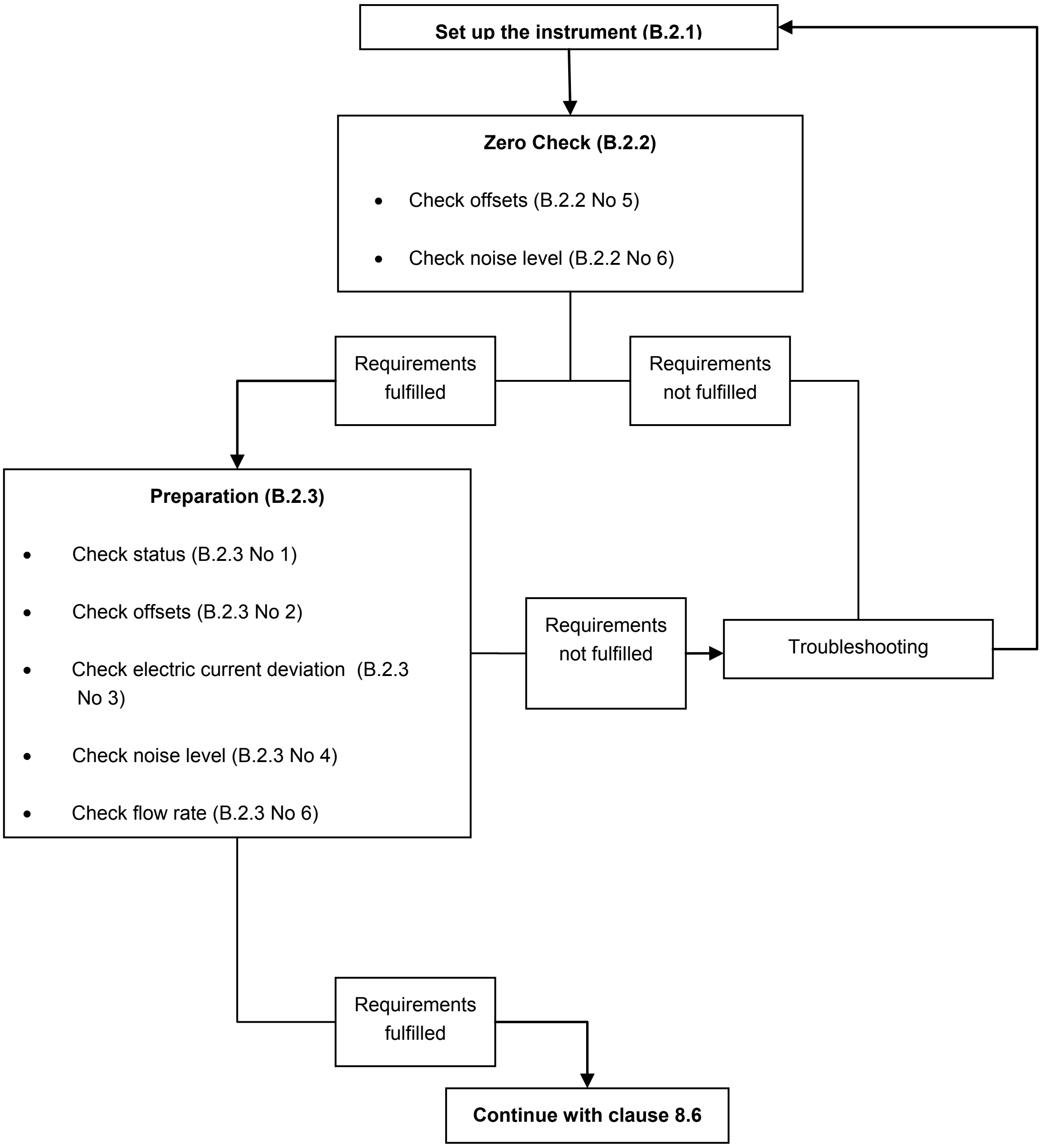


Figure B.1 — Scheme for the operational readiness test for Fast AMS

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 Zero Check

To ensure stability of the Fast AMS it should not be switched off between zero check and EUT test procedure.

1. Attach a HEPA filter (with at least 99.99% filter efficiency) to the aerosol inlet of the Fast AMS.

2. Switch on the Fast AMS and warm up for at least 20 minutes.

3. Ensure that all operating parameters (air temperature, voltages, internal pressure and different flows such as sample, sheath, extraction and charger flow) are correct.

4. Perform a zeroing procedure according to the manufacturer's manual and ensure correct electrometer offsets and RMS values.

5. Start the measurement with the HEPA filter attached in the particle number concentration mode with 1 s time resolution. Leave the measurement running for at least 2 hours. Check the recorded spectra for any malfunction records and artefacts.

6. The observed particle concentrations [dN] in each size channel should not exceed the respective lower concentration values – as specified by the manufacturer – by more than 500 cm^{-3}. The spectra shall be free of sudden changes of the concentrations (i.e. increasing/decreasing of concentration values by more than a factor two within less than 10 seconds).

B.2.3 Preparation for measurement

These steps shall be executed consecutively.

1. Ensure that all operating parameters (air temperature, voltages, internal pressure and different flows such as sample, sheath, extraction and charger flow) are correct.

2. Perform a zeroing procedure according to the manufacturer's manual and ensure correct electric current offsets and RMS values of electrometers.

3. Leave the instrument running for 30 minutes, repeat step 2 and ensure that the electric current offsets do not deviate more than +/- 10 fA.

4. The observed particle concentrations [dN] in each size channel should not exceed the respective lower concentration values – as specified by the manufacturer – by more than 500 cm^{-3}.

5. Remove the HEPA-filter from the aerosol inlet of the Fast AMS.

6. Measure the sample flow rate. If an internal flow meter allows the determination of the flow rate, refer to this value. Otherwise use a flow meter traceable to a calibration certificate. The measured flow of the AMS shall be **within ± 10%** of the value recorded in its calibration certificate.

7. Connect the AMS to the ETC. Avoid sharp bends of the tubing.

8. Measure the particle background concentration in the ETC. The background concentration level should correspond to the value given in 8.2.2, Table 1.

B.3 Procedures for Operational readiness test of CPC

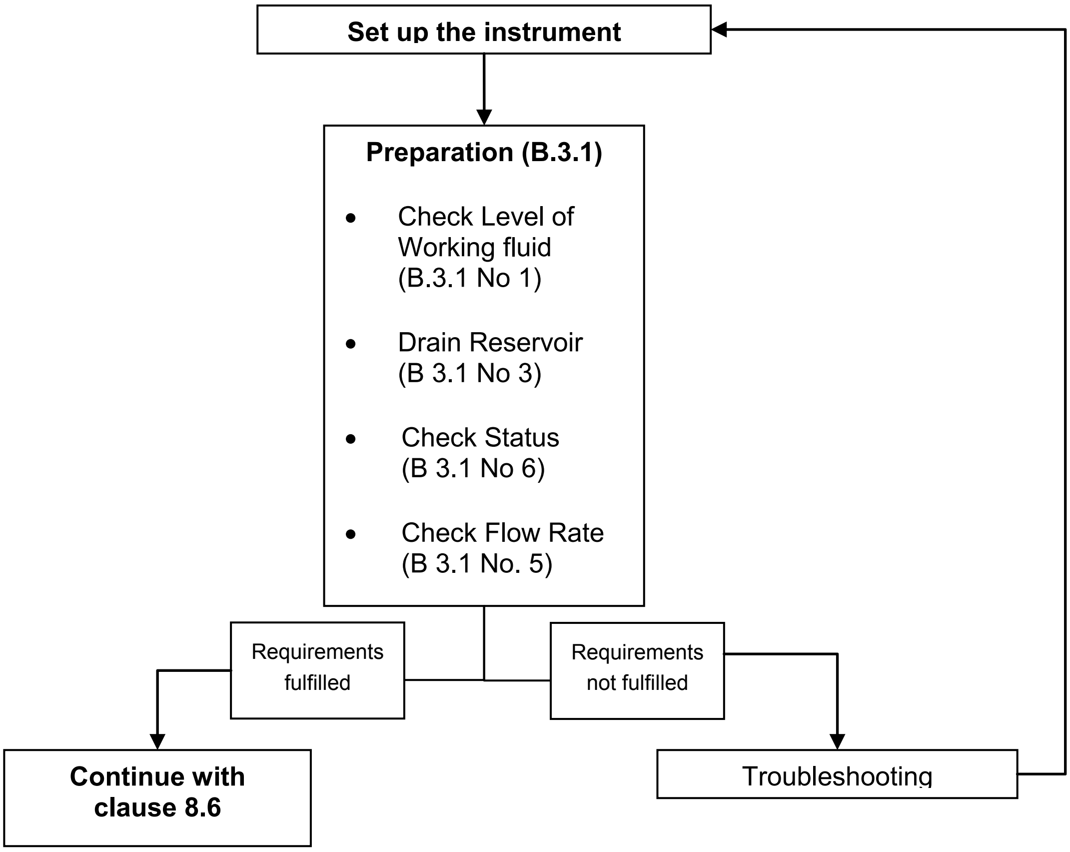


Figure B.2 — Preparation scheme for CPC

B.3.1 Preparation

1. Switch on the CPC and fill reservoir with working fluid to the specified level (observe manufacturer's precautions regarding moving the unit when reservoir is full).

2. If the CPC has been dried for shipment or storage follow the manual provided by the manufacturer on how to set the instrument in operating condition. After successful priming of the wick proceed with the next point.

3. Drain the CPC before testing if necessary.

4. Allow the saturator, condenser and optics to reach their specified temperatures.

5. Measure the sample flow rate. If an internal flow meter allows the determination of the flow rate, refer to this value. Otherwise use a flow meter traceable to a calibration certificate. The measured flow of the CPC shall be **within ± 10%** of the value recorded in its calibration certificate.

6. Check that the working fluid wick in the CPC is saturated. This can, for example, be done by sampling room air. The number concentration measured by the CPC should be higher than 1000 cm^{-3} because room air particle number concentration is typically higher than this value. Aerosols from other sources with sufficiently high number concentrations may also be used for this test.

7. Check that zero concentration is reported when a HEPA filter (> 99,99% efficiency) is attached to the inlet of the CPC. If concentrations higher than 1 cm-3 are reported, check for, and correct, any leaks in the connection between the HEPA filter and the CPC. The CPC requires attention from the manufacturer if a particle concentration greater than 1 cm-3 is counted within an observation period of 1 minute after any leaks are eliminated.

8. Connect the CPC to the sampling port of the emission test chamber with conductive tubing of device specific diameter.

9. Measure the particle background concentration in the ETC. The background concentration level should correspond to the value given in 8.2.2, Table 1.

Annex C
(informative)

Emission rate model for EUT using consumables

C.1 Objective

This Annex develops a generalised formula to calculate emission rates from VOC, carbonyl compounds and particulate matter concentrations sampled in an ETC.

NOTE This Annex has been developed with Hard Copy Devices in mind therefore “printing phase” denotes the operating phase.

C.2 Approach

By sampling over a period of time averaged concentrations are acquired.

Emission rates must be calculated from these average concentrations. The average concentrations during printing can be described by 4 different regions as shown in Figure C.1. During printing, there are two regions: m1 for printing, and m2 for the decay of the initial concentration (*Co*) built up during the pre-operating phase. m3 represents the concentration decay from C_{max} during the post-operating phase, and m4 is the concentration build-up during the post-operating phase from pre-operating and background emission.

The following is assumed:

- The emission rates are constant;
- The emission rates during pre- and post-operating phases are equal;
- No energy saving modes apply during the pre- and post-operating phase.

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

C.3 General mass balance and concentration equations

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

$$\frac{dC}{dt} = \frac{SER}{V} - nC \qquad \text{(C.1)}$$

Integrate (B.1) to obtain C:

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

C.4 Background SER

With SER = SER_{bg} and Co = 0 in (C.2), the background concentration is:

$$C_{bg} = \frac{SER_{bg}}{n\cdot V}[1-\exp(-n\cdot t)] \tag{C.3}$$

For $n\cdot t \geq 3$, (C.3) reduces to (equilibrium): $SER_{bg} = C_{bg}\cdot n\cdot V$ (C.4)

To simplify, SER_{bg} may be substituted by $C_{bg}\cdot n\cdot V$ (from C.4) in derived formulae below, as has been applied for the formulae in Clause 8.

C.5 Emission during pre-operating phase

Assume the emission model as shown in Figure C.1. During the pre-operating phase, there are two constant emission sources; one originates from the background of the ETC, and the other originates from the EUT in the pre-operating phase.

SER = SER_{bg} + SER_{pre} in (B.1) yields:

$$\frac{dC}{dt} = \frac{SER_{bg}+SER_{pre}}{V} - nC \tag{C.5}$$

$$C_{pre} = \frac{SER_{bg}+SER_{pre}}{n\cdot V}\left[1-\exp(-n\cdot t)\right] + C_o\exp(-n\cdot t) \tag{C.6}$$

Because the concentration at the beginning of the pre-operating phase (Co) equals the background concentration C_{bg}, (C.6) becomes:

$$C_{pre} = \frac{SER_{pre}}{n\cdot V}\left[1-\exp(-n\cdot t)\right] + \frac{SER_{bg}}{n\cdot V} \tag{C.7}$$

The total measure for 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 (C.7) from $t=0$ to $t=t_{pre}$:

$$C_{pre}\cdot t_{pre} = \int_0^{t_{pre}} \left\{\frac{SER_{pre}}{n\cdot V}\left[1-\exp(-n\cdot t_{pre})\right] + \frac{SER_{bg}}{n\cdot V}\right\} dt = \frac{SER_{pre}}{n^2\cdot V}[n\cdot t_{pre} + \exp(-n\cdot t_{pre}) - 1] + \frac{SER_{bg}}{n\cdot V} t_{pre} \tag{C.8}$$

Rearrange (C.8) for SER_{pre}:

$$SER_{pre} = \frac{C_{pre}\cdot n^2\cdot V\cdot t_{pre} - SER_{bg}\cdot n\cdot t_{pre}}{n\cdot t_{pre} + \exp(-n\cdot t_{pre}) - 1} = \frac{(C_{pre} - C_{bg})\cdot n^2\cdot V\cdot t_{pre}}{n\cdot t_{pre} + \exp(-n\cdot t_{pre}) - 1} \tag{C.9}$$

C.6 Emission during operating phase

During the operating phase the concentration build-up originates from EUT operation and the background concentration only. C_{ope}. Integration of (C.1) with SER = SER_{bg} + SER_{ope} yields:

$$C_{ope} = \frac{SER_{ope} + SER_{bg}}{n \cdot V}\left[1 - \exp(-n \cdot t)\right] + C_o \exp(-n \cdot t)\big]$$

$$C_{ope} = \frac{SER_{ope} + SER_{bg}}{n \cdot V}\left[1 - \exp\left(-n \cdot t\right)\right] + C_o \exp\left(-n \cdot t\right) \tag{C.10}$$

NOTE In (C.10) Co is equal to the concentration at the end of the pre-operating phase (C_{pre}) determined in (B.7).

In Figure C.1, the terms from m1 to m4 denote the product of average concentration, stemming from a source, and the time period of the phase under consideration. Integrating equation (C.10) over time from zero to the end of printing (t_{ope}), yields m1 and m2.

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

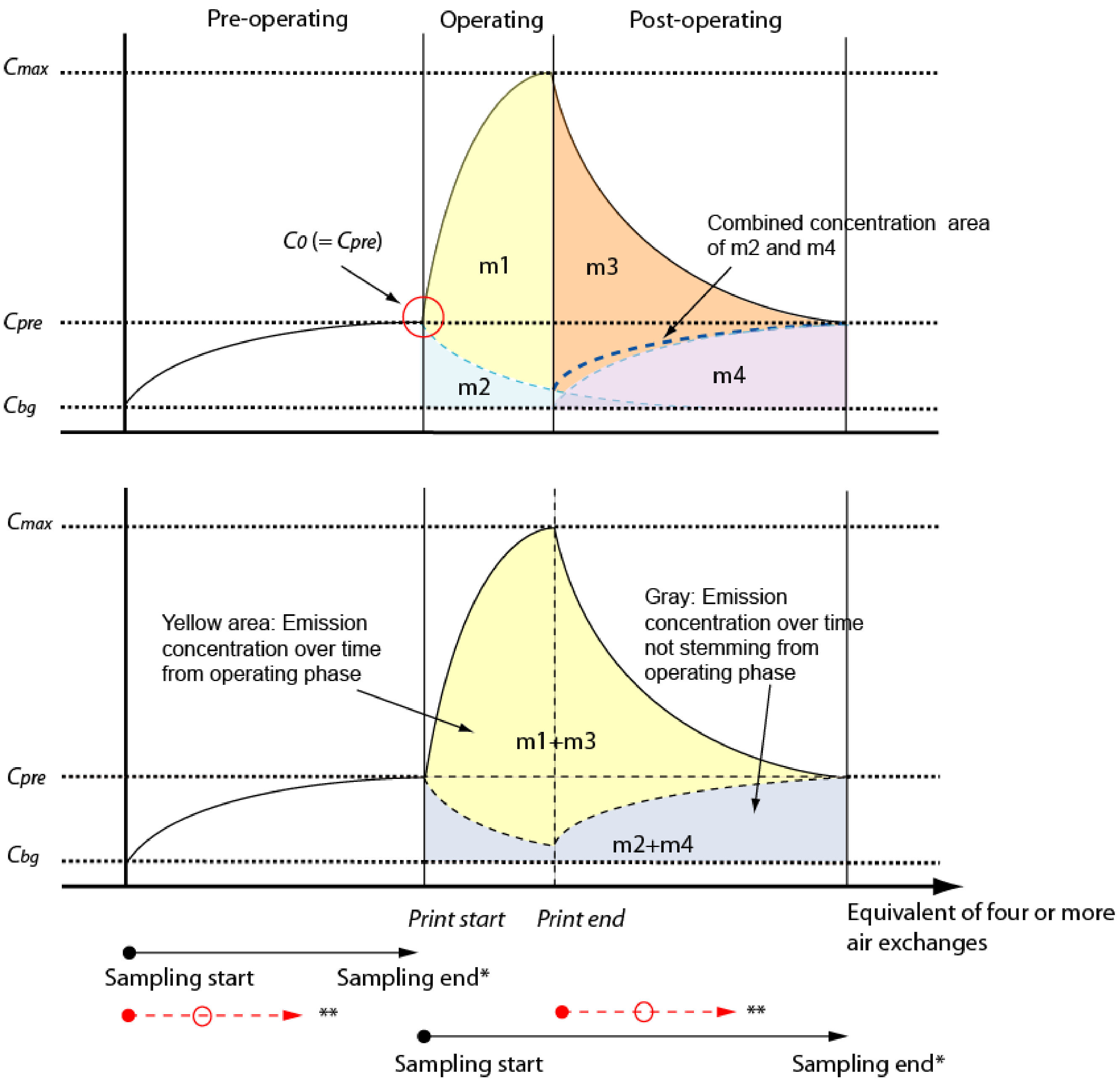
$$m2 = \int_0^{t_{ope}} \left[Co \cdot \exp(-n \cdot t)\right] dt = \frac{Co \cdot n \cdot V\,[1 - \exp(-n \cdot t_{ope})]}{n^2 \cdot V} \tag{C.12}$$

m1: Concentration area over time during printing

m2: Concentration area over time which decays from *Co* due to air exchange

m3: Concentration area over time which decays from C_{max} to the equilibrium concentration of pre-operating and background concentration

m4: Concentration area over time during post-operating phase.



*: Sampling can be stopped at any time during the each phase

**: Error can be minimized if pre ope- and post-operating sampling time is equal.

Figure C.1 — Representation of concentration change during printing and post operating phase

C.7 Emission during post-operating phase

The concentration built-up from the operating phase (C_{max}) decreases with the air exchange in the post-operating phase. But emissions from background level to the level at the end of the pre-operating phase increase. Obtain C_{max} in Figure C.1 from (C.10) for $t = t_{ope}$:

$$C_{\max} = \frac{(SER_{ope} + SER_{bg})}{n \cdot V}[1 - \exp(-n \cdot t_{ope})] + Co\exp(-n \cdot t_{ope}) \tag{C.13}$$

Similar to (B.2), the concentration during the post-operating can be written as:

$$C_{post} = \underbrace{\frac{(SER_{pre} + SER_{bg})}{n \cdot V}[1 - \exp(-n \cdot (t - t_{ope}))]}_{\text{Term due to emissions in post operating phase}} + \underbrace{C_{\max}\exp[-n \cdot (t - t_{ope})]}_{\text{Concentration reached at } C_{max} \text{ decreased by air exchange}} \tag{C.14}$$

m3 in Figure C.1 is obtained by integrating the second term of (C.14) over time from t_{ope} to $t_{G:}$

$$m3 = \int_{t_{ope}}^{t_G} \left\{ \frac{(SER_{ope} + SER_{bg})}{n \cdot V}[1 - \exp(-n \cdot t_{ope})] + Co\exp(-n \cdot t_{ope}) \right\} \cdot \exp\left(-n \cdot \left(t - t_{ope}\right)\right) dt$$

$$= [\exp(-n(t_G - t_{ope})) - 1] \cdot \left\{ \frac{SER_{ope} + SER_{bg}}{n^2 \cdot V}[\exp(-n \cdot t_{ope}) - 1] - \frac{Co}{n}\exp(-n \cdot t_{ope}) \right\} \tag{C.15}$$

Similarly, m4 can be found by integrating the first term of (C.14):

$$m4 = \int_{t_{ope}}^{t_G} \frac{(SER_{pre} + SER_{bg})}{n \cdot V}[1 - \exp(-n \cdot (t - t_{ope}))]\, dt$$

$$= \frac{(SER_{pre} + SER_{bg})}{n^2 \cdot V}[n(t_G - t_{ope}) + \exp(-n(t_G - t_{ope})) - 1] \tag{C.16}$$

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

$$C_{ope} = \frac{m1 + m2 + m3 + m4}{t_G} = \frac{m_{ope}}{V_{ope}} \tag{C.17}$$

Insert m1, m2, m3 and m4 in (C.11), (C.12), (C.15), and (C.16) to obtain C_{ope} and rearrange for SER_{ope}:

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

$$- \frac{SER_{bg}[\exp(-nt_G) + nt_G - 1] + Co \cdot n \cdot V[1 - \exp(-n \cdot t_G)]}{\exp(-nt_G) - \exp[-n(t_G - t_{ope})] + nt_{ope}} \tag{C.18}$$

The initial concentration C_o can be determined from the emission during the pre-operating phase:

$$C_0 = \frac{SER_{pre}}{n \cdot V}\left[1 - \exp(-n \cdot t_{pre})\right] + \frac{SER_{bg}}{n \cdot V} \qquad (C.19)$$

If the air exchange rates in the pre-operating and operating phase differ, n can be replaced by n_{pre}:

$$C_0 = \frac{SER_{pre}}{n_{pre} \cdot V}\left[1 - \exp(-n_{pre} \cdot t_{pre})\right] + \frac{SER_{bg}}{n_{pre} \cdot V} \qquad (C.20)$$

(C.18) can be simplified using (C.19), where n is equal in the pre-, post- and operating phases:

$$SER_{ope} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}[\exp(-n(t_G - t_{ope})) + n(t_G - t_{ope}) - 1 + (1 - \exp(-n \cdot t_{pre})) \cdot (1 - \exp(-n \cdot t_G))] - SER_{bg} \cdot n \cdot t_G}{\exp(-nt_G) - \exp[-n(t_G - t_{ope})] + nt_{ope}}$$

(C.21)

(C.21) is the general case formula used in the main text.

NOTE It is advised to use the same sampling time during pre-operating (t_{pre}) and post-operating (t_G-t_{ope}) if the emission behaviour of the EUT is unknown (one or more energy modes in addition to save energy mode). In that case, (C.21) can be reduced to:

$$SER_{ope} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}[n(t_G - t_{ope}) - \exp(-nt_G) + \exp(-n \cdot (2t_G - t_{ope}))] - SER_{bg} \cdot n \cdot t_G}{\exp(-nt_G) - \exp[-n(t_G - t_{ope})] + nt_{ope}} \qquad (C.22)$$

C.8 Special cases

Case 1 Pre-operating phase is relatively long ($nt_{pre} \geq 3$), and post-operating phase relatively long ($nt_G \geq 3$), (C.21) can be reduced to:

$$SER_{ope} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot [n(t_G - t_{ope}) - \exp(-n \cdot t_{pre})] - SER_{bg} \cdot n \cdot t_G}{nt_{ope}} \qquad (C.23)$$

and if $nt_{pre} \geq 3$, (C.23) can be reduced to:

$$SER_{ope} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot [n(t_G - t_{ope})] - SER_{bg} \cdot n \cdot t_G}{nt_{ope}} \qquad (C.24)$$

and if background concentration is neglected, (C.24) can be reduced to:

$$SER_{ope} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot [n \cdot (t_G - t_{ope})]}{nt_{ope}} \qquad (C.25)$$

Case 2 Pre-operating phase is relatively long ($nt_{pre} \geq 3$), and the air exchange rate during the pre-operating and operating phases are equal ($n_{pre}=n$), (C.21) can be reduced to:

$$SER_{ope} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre}\left[\exp(-n(t_G - t_{ope})) + n(t_G - t_{ope}) - \exp(-n \cdot t_G)\right] - SER_{bg} \cdot n \cdot t_G}{\exp(-nt_G) - \exp[-n(t_G - t_{ope})] + nt_{ope}} \tag{C.26}$$

C.9 Model for RAL-UZ 171 Option

The model developed in earlier chapters of this Annex, and the model for the RAL-UZ 171 Option only differ by the definition of the emission rate during the operating phase.

The emission rate during the operating phase can be thought to be composed of SER_{ope} and SER_{pre}, as described in the following model.

Figure C.2a presents the situation where equilibrium has been reached in the pre-operating phase. In Figure C.2b no equilibrium has been reached in the pre-operating phase, but it is assumed that the EUT enters a energy save mode during the pre-operating phase, so that a quasi-equilibrium is attained at the end of the pre-operating phase.

Emission is defined as: the area under the concentration curve, expressed by m1’+m3’ in Figure C.2, which can be seen as the increase in concentration due to printing.

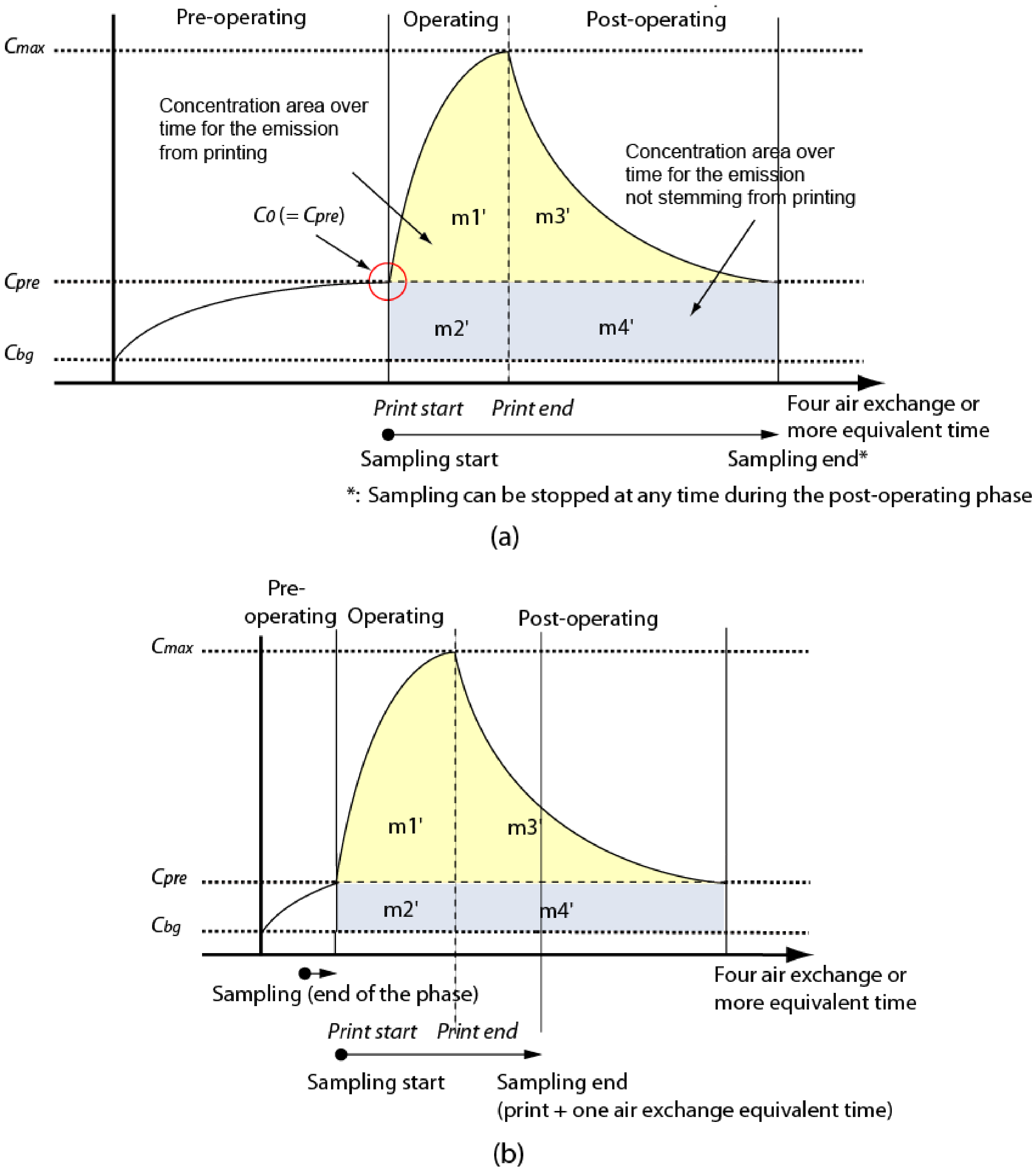


Figure C.2 — Model for equilibrium and constant Co (a) and (b) RAL-UZ 171 Option model

The SER_{ope} is:

$$SER_{ope} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - (SER_{pre} + SER_{bg}) \cdot [\exp(-nt_G) + nt_G - 1] - Co \cdot n \cdot V[1 - \exp(-n \cdot t_G)]}{\exp(-nt_G) - \exp[-n(t_G - t_{ope})] + nt_{ope}} \tag{C.27}$$

The initial concentration (*Co*) is the same as in equation (C.19) or (C.20).

If the initial concentration is equal to the pre-operating equilibrium concentration ($Co=SER_{pre}/(n*V)$) and n is equal in the pre-, post and operating phases (i.e. (C.19) holds), then (C.27) can be reduced to:

$$SER_{ope} = \frac{C_{ope} \cdot n^2 \cdot V \cdot t_G - SER_{pre} \cdot nt_G - SER_{bg} \cdot n \cdot t_G}{\exp(-nt_G) - \exp[-n(t_G - t_{ope})] + nt_{ope}} \tag{C.28}$$

Bibliography

[1] RAL-UZ 171, Test method for the determination of emissions from Hard Copy Devices according to RAL-UZ 171 (Annex 2)