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Safety of machinery — Evaluation of the emission of airborne hazardous substances —

Part 4:
Tracer method for the measurement of the capture efficiency of an exhaust system

Sécurité des machines — Évaluation de l'émission de substances dangereuses véhiculées par l'air —

Partie 4: Méthode par traceur pour le mesurage de l'efficacité de captage d'un système d'échappement

Reference number
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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 29042-4 was prepared by Technical Committee ISO/TC 199, *Safety of machinery*.

ISO 29042 consists of the following parts, under the general title *Safety of machinery — Evaluation of the emission of airborne hazardous substances*:

— *Part 1: Selection of test methods*

— *Part 2: Tracer gas method for the measurement of the emission rate of a given pollutant*

— *Part 3: Test bench method for the measurement of the emission rate of a given pollutant*

— *Part 4: Tracer method for the measurement of the capture efficiency of an exhaust system*

The following parts are under preparation:

— *Part 5: Test bench method for the measurement of the separation efficiency by mass of air cleaning systems with unducted outlet*

— *Part 6: Test bench method for the measurement of the separation efficiency by mass of air cleaning systems with ducted outlet*

— *Part 7: Test bench method for the measurement of the pollutant concentration parameter*

A room method for the measurement of the pollutant concentration parameter and a decontamination index are to form the subjects of future parts 8 and 9.

Introduction

The structure of safety standards in the field of machinery is as follows:

a) type-A standards (basic safety standards) giving basic concepts, principles for design, and general aspects that can be applied to all machinery;

b) type-B standards (generic safety standards) dealing with one safety aspect or one type of safeguard that can be used across a wide range of machinery:

— type-B1 standards on particular safety aspects (e.g. safety distances, surface temperature, noise);

— type-B2 standards on safeguards (e.g. two-hand controls, interlocking devices, pressure-sensitive devices, guards);

c) type-C standards (machine safety standards) dealing with detailed safety requirements for a particular machine or group of machines.

This part of ISO 29042 is a type-B standard as stated in ISO 12100-1.

The requirements of this document can be supplemented or modified by a type-C standard.

For machines which are covered by the scope of a type-C standard and which have been designed and built according to the requirements of that standard, the requirements of that type-C standard take precedence.

ISO/TC 199 has a mandate in this area to produce type-A and type-B standards, which will allow verification of conformity with the essential safety requirements.

ISO 29042-4 is based on EN 1093-4:1996, amended by Amendment 1:2008, published by the European Committee for Standardization (CEN).

Safety of machinery — Evaluation of the emission of airborne hazardous substances —

Part 4:
Tracer method for the measurement of the capture efficiency of an exhaust system

1 Scope

This part of ISO 29042 specifies a method based on a tracer technique for measuring the capture efficiency of an exhaust system installed on a machine. It is applicable to all types of test environment — test bench, room or field (see ISO 29042-1) — but is only applicable if the tracer shows aerodynamic behaviour comparable to that of the real pollutant.

The measurement of the capture efficiency of an exhaust system can serve for

d) evaluation of the performance of a machine's exhaust system,

e) evaluation of the improvement of an exhaust system,

f) comparison of exhaust systems for machines of similar design,

g) ranking of exhaust systems according to their capture efficiency,

h) determination of the air flow rate of an exhaust system to achieve a given level of capture efficiency, and

i) determination of the state-of-the-art of machine exhaust systems with respect to capture efficiency.

2 Normative references

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

ISO 12100-1:2003, *Safety of machinery — Basic concepts, general principles for design — Part 1: Basic terminology, methodology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12100-1 and the following apply.

3.1
capture efficiency

η_C

ratio of the mass flow rate of a given pollutant directly collected by an exhaust system to the uncontrolled mass flow rate of this pollutant emitted from the machine

3.2
tracer technique
use of gaseous substances with an aerodynamic behaviour comparable with the hazardous substance under consideration and for which concentrations can be reliably measured

4 Principle

The principle of the measurement method consists of:

a) emitting a tracer simulating the aerodynamic behaviour of the real pollutant, with the tracer flow rate, q_E;

b) measuring the flow rate, q_C, of the tracer collected by the exhaust system.

5 Simplified expression of the capture efficiency

The capture efficiency, η_c, expressed as a percentage, is given by Equation (1):

$$\eta_c = \frac{q_C}{q_E} \times 100 \qquad (1)$$

The tracer flow rate, q_E, is determined by emitting the tracer at constant flow rate directly into the exhaust duct and by measuring the average tracer concentration in a cross-section of the duct, then using Equation (2):

$$q_E = Q(C_2 - C_1) \qquad (2)$$

where

Q is the average air flow rate in the duct during the measurement period of q_E;

C_1 is the average ambient concentration of the tracer before the measurements (background level);

C_2 is the average concentration of the tracer in the duct (emission of tracer in the duct).

The tracer flow rate, q_C, is determined by emitting the tracer at a constant flow rate, q_E, at a characteristic point or zone of the emission of the real pollutant (e.g. at the locations in the emission zone furthest from the exhaust system) and by measuring the average concentration of tracer in the same points of the duct, then using Equation (3):

$$q_C = Q'(C_3 - C'_1) \qquad (3)$$

where

Q' is the average air flow rate in the duct during the measurement period of q_C;

C'_1 is the average ambient concentration of the tracer after the background level is stabilized;

C_3 is the average concentration of the tracer in the duct (emission at a selected location).

The capture efficiency is expressed as a percentage using Equation (4):

$$\eta_c = \frac{q_C}{q_E} \times 100 = \frac{Q'(C_3 - C'_1)}{Q(C_2 - C_1)} \times 100 \qquad (4)$$

If the exhaust flow rate can be considered as being constant, then $Q = Q'$, and the expression can be simplified as Equation (5):

$$\eta_c = \frac{C_3 - C_1'}{C_2 - C_1} \times 100 \tag{5}$$

The capture efficiency is then determined by measuring only concentrations in the exhaust duct.

6 Test method

6.1 General procedure

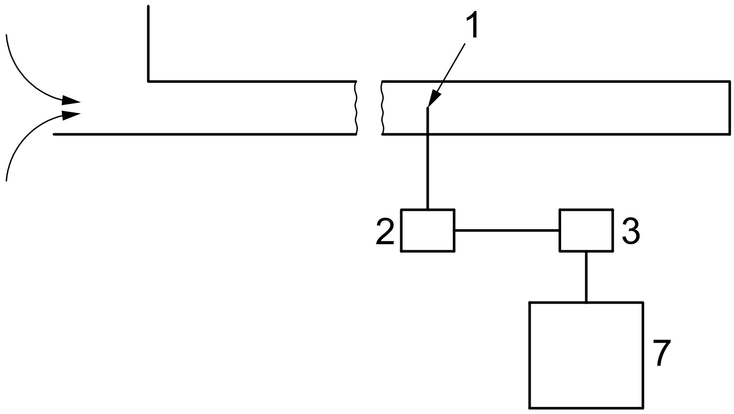
The measurement procedure is shown in Figure 1, while Figure 2 shows a typical test recording.

In order to be able to measure the concentration by sampling the air in the duct, it is assumed that the tracer is well mixed with the air.[1)]

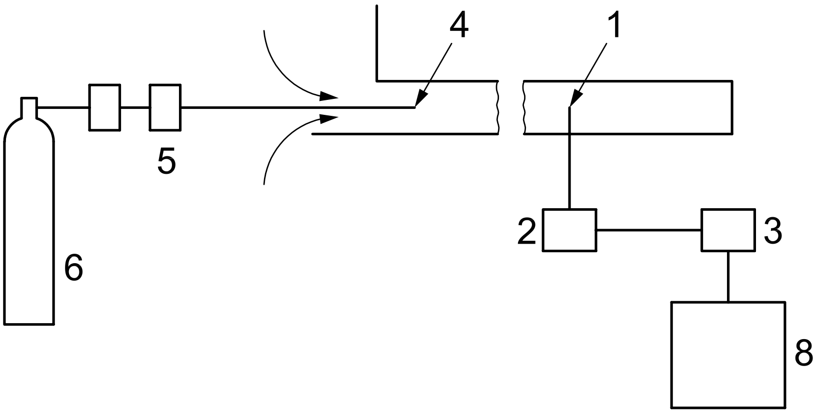
NOTE Devices can be added to the duct to reduce the mixing length.

At least three tests shall be performed.

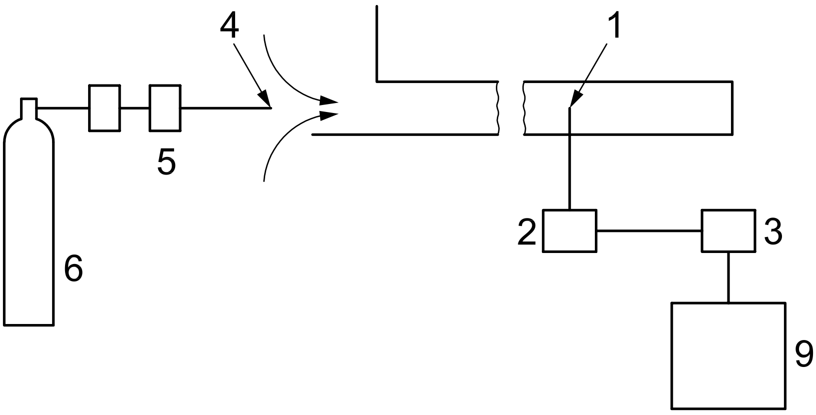
1) In EN 1093-4:1996, on which this part of ISO 29042 is based, a recommendation was given for the use of the procedures for straight ducts described in ISO 4053-1:1977. ISO 4053-1 has since been withdrawn and is no longer publicly available; at the time of publication of this part of ISO 29042, it had not been replaced by another International Standard.



Test phases one and four: measurement without tracer emission



Test phase two: measurement with tracer emission in the duct

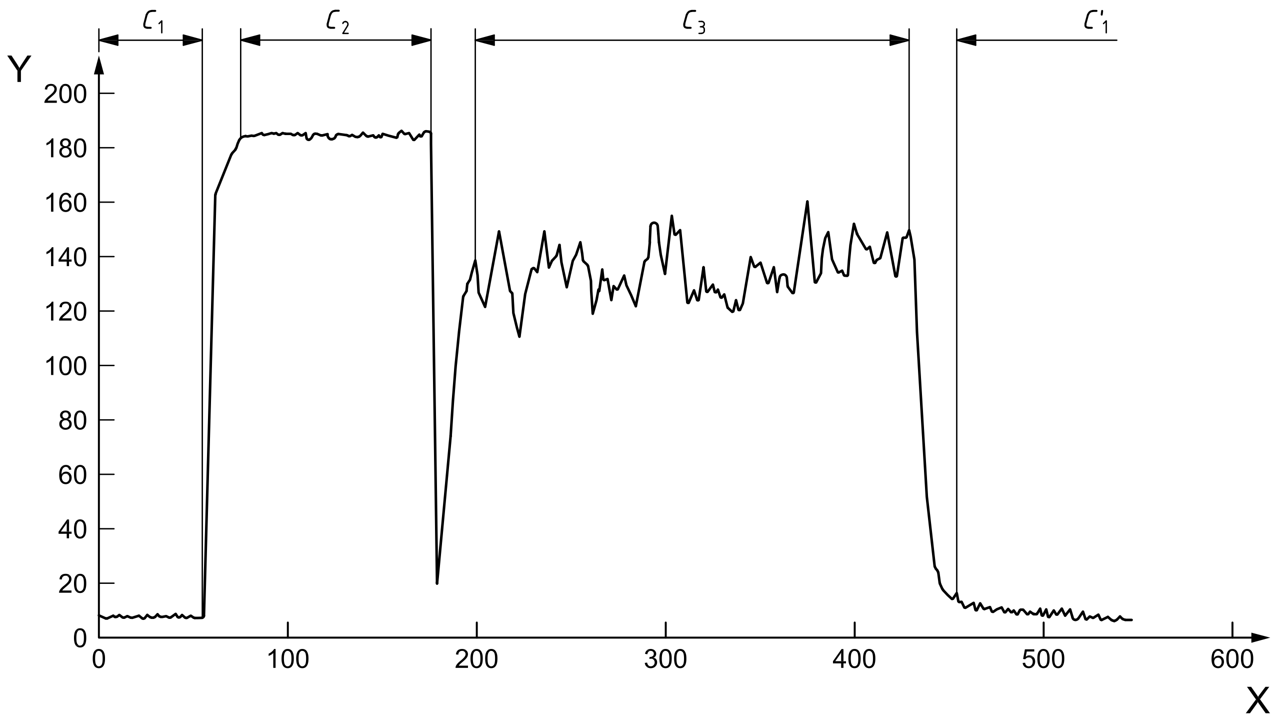


Test phase three: measurement with tracer emission simulating the real pollutant

Key

1 sampling
2 pump
3 analyser
4 injection
5 tracer gas flow meter
6 tracer gas cylinder (pure or diluted tracer gas)
7 ambient concentration, C_1 or C'_1
8 concentration, C_2
9 concentration, C_3

Figure 1 — Measurement procedure for simple exhaust system using tracer gas



Key

X time, s

Y tracer concentration

Figure 2 — Typical test recording

6.2 Measurement of concentration, C_3

Considering an emitter whose flow rate changes suddenly from 0 to q_E, concentration C_3 rises progressively as a function of time. The curve of variation of C_3 roughly shows two time constants:

— the first, relatively small, corresponds to the accumulation of tracer in the volume directly under the influence of the exhaust system;

— the second, which is larger, corresponds to the accumulation of tracer in the rest of the room — a part of the tracer, escaping from the zone of direct influence of the exhaust system, is secondarily and indirectly collected over a longer period of time.

Since the efficiency of a system is based on the direct collection of the pollutant, the efficiency is defined on the basis of the determination of the value of C_3 corresponding to the first time constant.

In practice, and except for very small rooms, the time constant of the room is much larger than the time constant of the collection system, so that the measurement may be facilitated by averaging the value of the efficiency over a time interval of a few minutes after obtaining the first quasi-equilibrium state. In small rooms, an increase in the ambient concentration can impair the quality of the measurement. For this reason, the measurement should only be accepted if the ratio

$$\frac{C_1 - C'_1}{C_2 - C_1}$$

is lower than 0,05. Concentration C'_1 should be measured 1 min after dosing of the tracer is stopped. Because of the fluctuations in the response, as can be observed in Figure 2, concentration C_3 should be established as an average over a reasonable period of time. For a given measurement, the effective averaging period can be calculated as the time constant for the measuring system multiplied by the number of samples taken. To allow statistical analyses of the signal, leading to results such as minimum capture efficiency or relative standard deviation, the time constant of the measuring system should be adjusted to a defined value. This adjustment can be achieved by use of a buffer volume on the sampling line or by use of a digital filter. The time constant should be adjusted to 10 s. The interval between successive samples should be greater than or equal to the time constant for the measuring system in use.

Statistical analysis of the signal C_3 can determine the concentration of C_3 (95 %). This is the value of C_3 which is exceeded for 95 % of the specified measurement time. This value leads to the minimum capture efficiency, the calculation of which is given by Equation (6):

$$\eta_{\mathrm{c}}(95\ \%) = \frac{C_3(95\%) - C_1'}{C_2 - C_1} \tag{6}$$

Assuming the distribution of C_3 is Gaussian, C_3 (95 %) can be derived from the mean value and the standard deviation of C_3 using Equation (7):

$$C_3(95\ \%) = C_3 - 1{,}64 \times \sigma(C_3) \tag{7}$$

The measurement result shall always be stated together with the uncertainty of the result. The uncertainty may be calculated according to Annex A. A typical percentage is 95 %, but other values above 75 % may be used.

It is also possible to describe the performance of the exhaust system by the relative standard deviation, calculated as the ratio of the estimated value of the standard deviation of C_3 to the mean value of C_3.

6.3 Application to a specific group of machines

Each new type-C standard based on this part of ISO 29042 dealing with a given group of machines shall supply additional information about more specific test conditions, particularly concerning the conditions of tracer generation and sampling, test duration and the operating conditions of the machine.

7 Control parameters and influencing factors

7.1 General

This clause deals with the control parameters which can be adjusted to simulate the actual pollutant emission accurately and the parameters that influence the measurement and characterize the situation during the measurement period.

7.2 Control parameters

7.2.1 Type of tracer

a) **Gaseous pollutant**

Since the turbulent diffusion coefficient of a gas, measured on site, is much higher than its molecular diffusion coefficient, it can be considered that the overall behaviour of all gases is practically identical from the standpoint of total mass transfer. In these conditions, a tracer gas shall be selected in accordance with the following criteria:

1) nil or very low toxicity;

2) chemical stability at the intended process temperature;

3) non-interference with pollutants present in the room;

4) low background level.

Since the capture efficiency may depend on the density of the tracer, one should check that emission conditions get close to the real ones.

NOTE In some cases, the tracer gas has to be diluted before emission. The choice of the tracer gas and associated analyser depends, in particular, on the desired accuracy, the measurement range, and the cost. The gases normally used are helium, sulfur hexafluoride and nitrous oxide.

b) **Aerosol pollutant**

On the basis of identical considerations about the diffusion coefficients, it may be considered that fine aerosols, particularly significant in industrial hygiene, can be simulated by tracer gas. Above 3 μm to 4 μm, the difference observed in transfer can increase progressively with particle size. However, up to 10 μm, the difference still remains lower than that due to other measurement uncertainties: the use of aerosol tracer techniques may be applied in certain cases.

7.2.2 Emitter shape and position

Whenever possible, the shape of the emitter shall resemble the shape of the real pollutant source. A distinction is generally drawn between

- point sources,
- plane sources, and
- volumetric sources

Point sources may be simulated by opened tubes producing jets of variable aerodynamic characteristics or by sintered materials diffusing the tracer at a low initial velocity.

NOTE A typical emitter can consist of sintered bronze with maximum dimensions of 20 mm × 20 mm × 20 mm.

Plane and volumetric sources may be simulated by a network of point sources or perforated tubes which are suitably distributed. If this is not practicable, several efficiencies are determined with different locations of emitters corresponding to characteristic points of the pollutant emission, especially at the furthest locations from the capture system.

If many sources and capture devices are present, a compromise shall be found taking into account the main pollutant emission points on the machine under test.

7.2.3 Aerodynamic characteristics of emission

The aerodynamic characteristics of the tracer emission (velocity, flow rate) shall simulate those of the source.

The tracer emission intensity (initial velocity, flow rate) and direction shall be monitored. Directional sources and hot sources may be simulated by jets at a specified emission velocity.

The capture efficiency is relatively unaffected by

- small changes in the direction of the tracer jet,
- small changes in the tracer emission flow rate.

The emission duration shall be limited to avoid a significant increase of the tracer concentration in the surroundings that would be incompatible with the quality of measurement and with occupational exposure limits.

7.3 Influencing factors on capture efficiency

The performance of the exhaust system is influenced by the ambient environment. Whenever possible, the following factors shall be measured or evaluated during the measurements:

— direction and velocity of the cross draughts;

— characteristics of the air inlet and general exhaust systems (e.g. flow rate, jet velocity, positions of systems and characteristics of the heating systems).

In addition, during field tests, some factors concerning the other machines and their associated exhaust systems could exert a significant effect on the air flow rate of the tested exhaust system; therefore, these parameters should be kept as constant as possible and should be recorded.

8 Test report

The test report shall include at least the following information:

a) reference to this part of ISO 29042 (“ISO 29042-4:2009”) and any associated type-C standards;

b) description of the machine tested or exhaust device (manufacturer, model, type, version, design, size, year of manufacture, serial number, etc.) — for the machine itself and for each additional piece of equipment);

c) operational data during tests, including tools used with the machine and material processed on the machine;

d) description of the exhaust system tested (manufacturer, model, type, version, design, size, year of manufacture, serial number, operational data, etc.) and of the general ventilation system;

e) description of measurement procedures, in particular:

   — type, flow rate, direction and injection velocity of the tracer and the reason for selecting the tracer used;

   — geometric characteristics of the emitter;

   — location of the emission and sampling points;

   — measurement duration;

f) measuring instruments used and their most recent calibration dates;

g) test results of three determinations, average values, minimum efficiency and coefficient of variation;

h) test laboratory;

i) number of tests performed;

j) environmental data (temperature, humidity, atmospheric pressure);

k) description of procedures used (e.g. list of standards) for concentration and flow rate measurements;

l) name of the test person responsible;

m) date of testing;

n) comments on deviations from any relevant standard;

o) any additional comments.

Annex A
(informative)

Simplified calculation of random component of uncertainty on C_3 (95 %)

The uncertainty on the minimum capture efficiency, η_c (95 %), depends on a number of parameters, including the random component of the uncertainty on C_3 (95 %).

This random component in turn depends on the number of uncorrelated results obtained during the measurement of C_3. It may be estimated assuming again that the C_3 concentration follows a Gaussian distribution.

The fractile coming from the population C_3, σ, is asymptotically normal to

$$C_3 - t\sigma, \frac{\sqrt{2\pi\, q\,(1-q)}}{\mathrm{e}^{-\frac{t^2}{2}}} \times \frac{\sigma}{\sqrt{n}}$$

where

q is the fractile under consideration;

t is the course from a table of the reduced normal distribution such as the probability $\{x < t\}$ equals q.

EXAMPLE Application to q = 0,95, then t = 1,64 and the fractile 95 % follows the normal distribution:

$$\left(C_3 - 1{,}64\sigma, 2{,}11 \frac{\sigma}{\sqrt{n}} \right)$$

Bibliography

[1] ISO 4053-1, *Measurement of gas flow in conduits — Tracer methods — Part 1: General*

[2] ISO 29042-1, *Safety of machinery — Evaluation of the emission of airborne hazardous substances — Part 1: Selection of test methods*

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