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Determination of particle size distribution — Single particle light interaction methods —

Part 2: Light scattering liquid-borne particle counter

Détermination de la distribution granulométrique — Méthodes d'interaction lumineuse de particules uniques —

Partie 2: Compteur de particules en suspension dans un liquide en lumière dispersée

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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.

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

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

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

This document was prepared by Technical Committee ISO/TC 24., *Particle characterization including sieving*, Subcommittee SC 4, *Particle characterization*.

This second edition cancels and replaces the first edition (ISO 21501-2:2007), which has been technically revised. The main changes from the previous edition are as follows:

— Clause 4 for “Principle” and Clause 5 for “Basic configuration” have been added;

— “size calibration” and “verification of size setting” have been combined as “size setting error” in the requirements (Clause 6);

— “Test report” (3.11 in the previous edition) has been changed to 6.10 on “Reporting of test and calibration results”;

— information about uncertainties has been enriched and is now the subject of Annex D.

A list of all parts in the ISO 21501 series can be found on the ISO website.

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

Introduction

Monitoring particle contamination levels is required in various fields, e.g. in the electronic industry, in the pharmaceutical industry, in the manufacturing of precision machines and in medical operations. Particle counters are useful instruments for monitoring particle contamination in liquid. The purpose of this document is to provide a calibration procedure and verification method for particle counters, so as to minimize the inaccuracy in the measurement result by a counter, as well as the differences in the results measured by different instruments.

Determination of particle size distribution — Single particle light interaction methods —

Part 2: Light scattering liquid-borne particle counter

1 Scope

This document describes a calibration and verification method for a light scattering liquid-borne particle counter (LSLPC), which is used to measure the size and particle number concentration of particles suspended in liquid. The light scattering method described in this document is based on single particle measurements. The typical size range of particles measured by this method is between 0,1 µm and 10 µm in particle size.

The method is applicable to instruments used for the evaluation of the cleanliness of pure water and chemicals, as well as the measurement of number and size distribution of particles in various liquids. The measured particle size using the LSLPC depends on the refractive index of particles and medium; therefore, the measured particle size is equivalent to the calibration particles in pure water.

The following are within the scope of this document:

— size setting error;

— counting efficiency;

— size resolution;

— false count;

— maximum particle number concentration;

— sampling flow rate error;

— sampling time error;

— sampling volume error;

— calibration interval;

— reporting results from test and calibration.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
calibration particles
monodisperse spherical particles with a known mean particle size, e.g. polystyrene latex (PSL) particles, where the certified size is traceable to the International System of Units (SI), a relative standard uncertainty equal to or less than 2,5 %, and a refractive index that is approximately 1,59 at the wavelength of 589 nm (sodium D line)

Note 1 to entry: For spherical particles, the particle size is equal to the diameter.

3.2
counting efficiency
ratio of the number concentration measured by a *light scattering liquid-borne particle counter* (3.4) to that measured by a reference instrument for the same sample

3.3
false count
apparent count per unit volume of sample liquid when a sample liquid containing no measurable particles is measured by the *light scattering liquid-borne particle counter* (3.4)

3.4
LSLPC
light scattering liquid-borne particle counter
instrument that measures liquid-borne particle numbers by counting the pulses as the particles pass through the sensing volume, as well as particle size by scattered light intensity

Note 1 to entry: The optical particle size measured by the LSLPC is the light scattering equivalent particle size and not the geometrical size.

3.5
PHA
pulse height analyser
instrument that analyses the distribution of pulse heights

3.6
size resolution
measure of the ability of an instrument to distinguish between particles of different sizes

3.7
coincidence loss
reduction of particle count caused by multiple particles passing simultaneously through the sensing volume and/or by the finite processing time of the electronic system

3.8
MPE
maximum permissible error
limit of error
extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications for a given measurement, measuring instrument, or measuring system

Note 1 to entry: This document uses decimal numbers for the requirements to MPEs to avoid confusions that may arise when relative uncertainties of test results are reported in percent figures.

4 Principle

The measurement principle of the LSLPC is based on detection of light scattered by a particle when the particle passes through an incident light beam.

The particle size is determined from the intensity of the scattered light, and the number of particles from the number of light pulses scattered by individual particles.

More specifically, a sample liquid is drawn from the inlet of the LSLPC at a constant flow rate, and introduced to the sensing volume of the LSLPC where a light beam is irradiated. When a particle suspended in the sample liquid passes through the light beam, it scatters the light, emitting a light pulse. The light pulse is detected by a photo detector and converted to an electrical pulse. The electrical pulse height is proportional to the scattered light intensity, and depends on the optical system design, the electronic components used, and the light source. The intensity of the scattered light is dependent on the size, refractive index and shape of the particle. If the particle is spherical, the scattered light intensity is described by the Mie theory. In order to establish a relationship between the electrical pulse height and the particle size, calibration of each LSLPC with use of particles having a well-defined size, refractive index, and shape is required.

5 Basic configuration

An LSLPC is composed typically of a light source, a sample liquid supply/suction system, a sensing volume, a photoelectric conversion device, a pulse height analyser, and a display (see Figure 1). Some LSLPCs do not contain a sample liquid supply/suction system and/or a display.

To make the particle size calibration possible, the LSLPC should be constructed so that pulse height distributions for calibration particles can be measured.

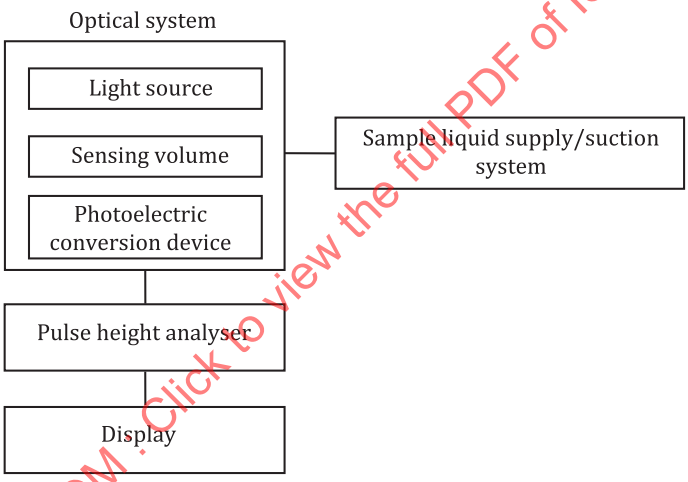


Figure 1 — Example of basic configuration of LSLPC

6 Requirements

6.1 Size setting error

The MPE for size setting in the minimum detectable particle size and other sizes specified by the manufacturer of an LSLPC is 0,15 (corresponding to 15 % of the specified size).

Size setting shall be conducted before the LSLPC is shipped from the manufacturer, and when the size setting error is found not fulfilled in a periodic calibration.

A recommended procedure for size setting is described in 7.1.2. If other methods are used, their uncertainty shall be evaluated and described.

6.2 Counting efficiency

The counting efficiency shall be within 0,20 to 0,80 [corresponding to (50 ± 30) %] for calibration particles with a size close to the minimum detectable size, and it shall be within 0,70 to 1,30 [(100 ± 30) %] for calibration particles with the particle size 1,5 to 3 times larger than the minimum detectable particle size.

When calibration particles with exactly the same size as the minimum detectable particle size are not available, particles whose size is within ±5 % of the minimum detectable particle size may be used and the diameter of the calibration particles shall be reported.

6.3 Size resolution

The size resolution shall be less than or equal to 0,10 (corresponding to 10 % of the specified particle size), when it is evaluated using calibration particles of a certified average size specified by the manufacturer.

A recommended procedure is described in 7.3. If other methods are used, their uncertainty shall be evaluated and described.

6.4 False count

The false count per volume in litre and its 95 % upper confidence limit (UCL) shall be determined according to 7.4. The 95 % UCL shall be less than or equal to the value specified and reported by the manufacturer of the LSLPC.

6.5 Maximum particle number concentration

The maximum measurable particle number concentration shall be specified by the manufacturer. The coincidence loss at the maximum particle number concentration of an LSLPC shall be less than or equal to 0,1 (corresponding to 10 %).

NOTE The probability of occurrence of coincidence loss increases with increasing particle number concentration.

6.6 Sampling flow rate error

The MPE of the sampling flow rate shall be specified by the manufacturer. The user shall check that the sampling flow rate is within the range specified by the manufacturer.

6.7 Sampling time error

The MPE in the duration of sampling time shall be 0,01 (corresponding to 1 %) of the preset value.

If the LSLPC does not have a sampling time control system, this subclause does not apply.

6.8 Sampling volume error

The MPE of sampling volume shall be 0,05 (corresponding to 5 %) of the preset value.

This subclause does not apply when the LSLPC is not equipped with a sampling system.

6.9 Calibration interval

The calibration of the LSLPC should be conducted at an interval equal to or shorter than one year. The requirements should be met during the calibration interval.

6.10 Reporting of test and calibration results

The report shall contain at least the following information:

a) date of test/calibration;

b) test/calibration particles used;

c) results for the parameters:

1) size setting error;

2) counting efficiency;

3) sampling flow rate error;

4) size resolution (with the particle size used);

d) threshold voltage values or channel of the built-in PHA corresponding to the size settings;

e) reference of the test/calibration method used (i.e. ISO 21501-2).

f) report/certificate identification, test/calibration location, title and identification of test/calibration provider including signature and date;

g) identification of customer and device under test, including how output was obtained for counting efficiency (e.g. analogue, display or digital output).

A calibration certificate shall furthermore include:

h) identification and — if possible — statement of metrological traceability of all reference equipment and calibration particles used;

i) relevant environmental conditions (e.g. temperature, air pressure and humidity) under which the calibration was performed;

j) a stated uncertainty for each result for the parameters 1 to 2 with reference to the calculation method (e.g. ISO/IEC Guide 98-3) — Annex D gives a recommended procedure for evaluating the uncertainty of the results of the performance tests.

k) a stated false count at a 95 % confidence limit (see Annex C).

NOTE Calibration certificates issued by ISO/IEC 17025 accredited laboratories and covering all results for the parameters 1 to 2 are considered to comply with the requirements above.

7 Test and calibration procedures

7.1 Size setting

7.1.1 Evaluation of size setting error

Calculate the size setting error, ε, according to Formula (1).

$$\varepsilon = \frac{x_i' - x_i}{x_i} \tag{1}$$

where

x_i is the size setting specified for the LSLPC;

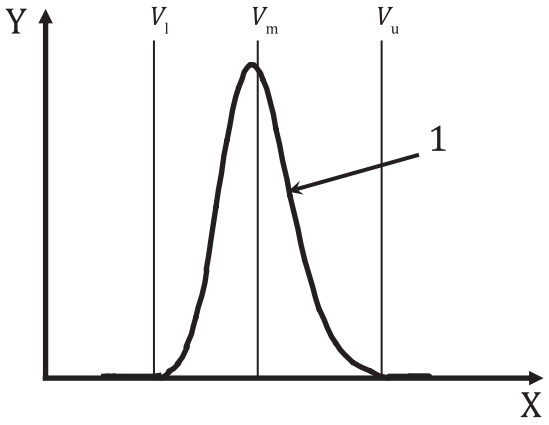
x_i' is the actual size setting corresponding to V_{ti} (see 7.1.2 for the meaning of V_{ti}).

7.1.2 Procedure of size setting

By use of a PHA connected to the output terminal for signal pulses of the LSLPC, or by use of a built-in PHA if one is contained as a part of the LSLPC, obtain a pulse height distribution for a sample liquid in which calibration particles are suspended. Let V_l and V_u denote the lower and upper voltage limits, respectively, of the range of pulse heights for the calibration particles (see Figure 2). The median voltage

V_m of the pulse height distribution in the range from V_l to V_u, shall be calculated, and is assigned to the certified size of the calibration particles, x_c.

When a built-in PHA is used, the abscissa of the pulse height distribution may be given in channel number instead of voltage. In this case, the term "voltage" above and in relevant descriptions below should be interpreted as channel number of the PHA.

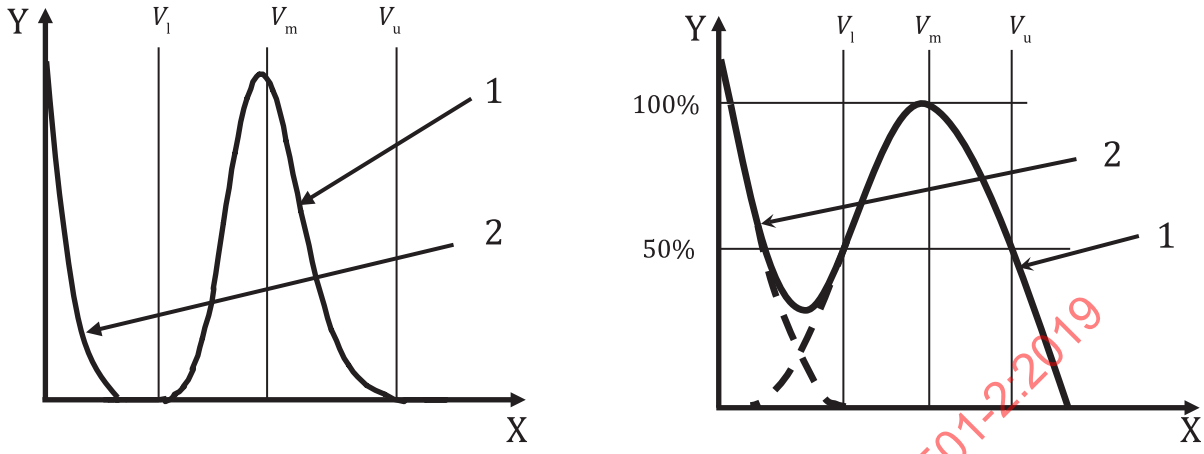


Key

X pulse height voltage
Y frequency
1 pulse height distribution
V_l lower voltage limit
V_m median voltage
V_u upper voltage limit

Figure 2 — Pulse height distribution for the sample liquid

If a noise distribution is observed in the pulse height distribution, and if it is separated distinctly from the main peak corresponding to the calibration particles, the voltages V_l and V_u shall be chosen so that the range (V_l, V_u) encompasses only the main peak [see Figure 3 a)]. If the noise distribution overlaps with the main peak, V_l and V_u shall be chosen so that the range (V_l, V_u) corresponds to the full width at half maximum of the main peak [see Figure 3 b)]. The latter way of determining V_l and V_u is allowed only when the height of the valley between the noise distribution and the main peak is at most half the main peak height.



Key

X pulse height voltage
Y frequency
1 pulse height distribution for calibration particles
2 noise distribution (false particles, small particles and/or optical or electrical noises)
V_l lower voltage limit
V_m median voltage
V_u upper voltage limit

Figure 3 — Pulse height distribution for the sample liquid when noise exists

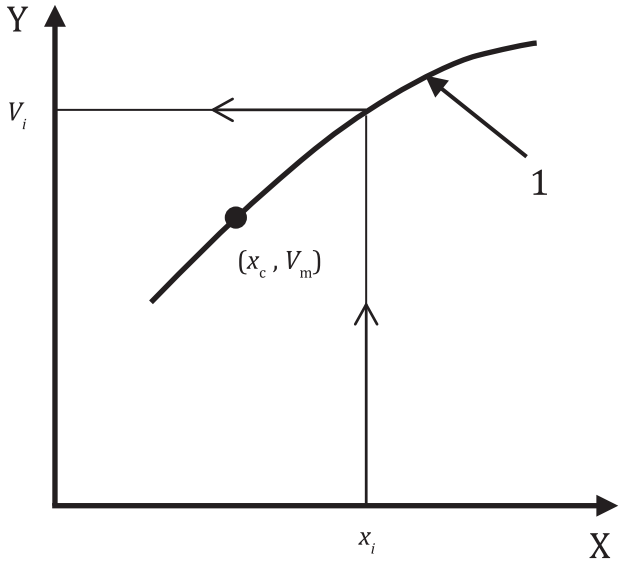
By use of the data pair (x_c, V_m) obtained in this way, or multiple data pairs (x_{cj}, V_{mj}) (j = 1, 2, ...) obtained similarly for multiple calibration particles, determine the voltage values V_i (i = 1, 2, ...) that correspond to the size settings (or threshold sizes) x_i given as specifications of the LSLPC (see Figure 4). In this determination, a theoretical response curve based on Mie theory may be used to calculate V_i from experimentally observed V_m.

Let V_{ti} denote the adjustable threshold voltage corresponding to x_i. For all the size settings x_i, adjust the value of V_{ti} to V_i.

NOTE 1 The response curve can be calculated according to the Mie theory when the parameter set defining the optical system of the LSLPC is available. If the parameter set of the optical system is not available, the response curve in the vicinity of x_i can still be empirically determined by fitting a simple function, e.g. a quadratic or cubic polynomial, to multiple data pairs (x_{cj}, V_{mj}) obtained for x_{cj} on either side of x_i.

NOTE 2 The detailed procedure for determining V_i can vary depending on the model of the LSLPC.

NOTE 3 V_{ti} can be the set voltage of an electric comparator used in the LSLPC, or if a built-in PHA is used, it can be the threshold channel of the built-in PHA which is intended to be assigned to x_i. For the sake of simplicity in description, it is assumed that electric comparators are employed in the LSLPC, unless otherwise stated.



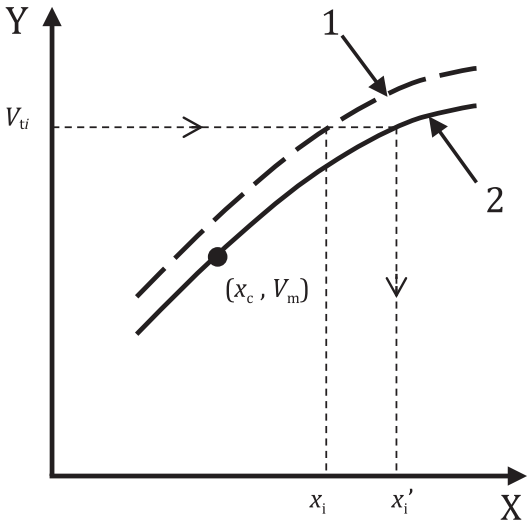
Key

X particle size
Y pulse height voltage
1 response curve
x_c certified size of the calibration particles
V_m median voltage corresponding to x_c
x_i size setting specified for the LSLPC
V_i voltage corresponding to x_i

Figure 4 — Size calibration

Read out the value of V_{ti} set for the electric comparator of the LSLPC. Ideally V_{ti} corresponds to x_i, but in reality, V_{ti} corresponds to a particle size x_i' which may be different from x_i owing, for example, to a change of the response curve over time. Determine the actual response curve according to the procedure as described above or to another method which is scientifically documented and determine x_i' using this curve (see Figure 5). Calculate the size setting error ε according to Formula (1).

NOTE 4 The expected response curve in Figure 5 is a hypothetical curve on which the threshold voltages of the electric comparator, V_{ti}, would correspond exactly to the specified size thresholds x_i.



Key

X particle size
Y pulse height voltage
1 expected response curve
2 actual response curve
x_c certified size of the calibration particles
V_m median voltage corresponding to x_c
x_i size setting specified for the LSLPC
x_i' actual size setting corresponding to V_{ti}
V_{ti} voltage read out from the electric comparator

Figure 5 — Evaluation of size setting error

7.2 Evaluation of counting efficiency

To evaluate the counting efficiency of the LSLPC, use two populations of calibration particles; one that has a size close to the minimum detectable particle size, and another that has a size 1,5 to 3 times larger than the minimum detectable particle size.

Tests with other particle sizes may be added, if it is requested by a user of the LSLPC.

Use either a calibrated LSLPC as a reference instrument or a microscopic method. The counting efficiency of the reference instrument shall have a metrological traceability to a national or international standard or the International System of Units (SI).

Measure the number concentrations of sample liquid suspending each of the two kinds of calibration particles with the LSLPC under test and with the reference instrument (see Annex A). Determine the counting efficiency according to Formula (2):

$$\eta = \frac{C_1}{C_0} \tag{2}$$

where

η is the counting efficiency;

C_0 is the particle number concentration measured by reference particle counter or by microscopic method;

C_1 is the particle number concentration measured by particle counter under test.

For these measurements, the particle number concentration of the test sample should be equal to or less than 25 % of the maximum particle number concentration of both the LSLPC under test and the reference instrument.

NOTE When the particle concentration measured by an LSLPC is, as usually is the case, not corrected for the coincidence loss, the counting efficiency of the LSLPC depends on the particle number concentration stemming from the coincidence loss. If the maximum particle number concentration is so determined that the coincidence loss at this concentration is 0,1 (10 %) (see 6.5), and the counting efficiency η is evaluated at 0,25 (25 %) of this concentration, then the obtained value of η is smaller than the value that would be obtained in the limit of zero concentration by approximately 0,026 (2,6 %).

7.3 Evaluation of size resolution

Calculate the size resolution of the LSLPC, R, by Formula (3) (see also Annex B).

$$R = \frac{\sqrt{\sigma^2 - {\sigma_c}^2}}{x_c} \tag{3}$$

where

R is the size resolution;

σ is the apparent standard deviation of the size distribution of the calibration particles observed by the LSLPC;

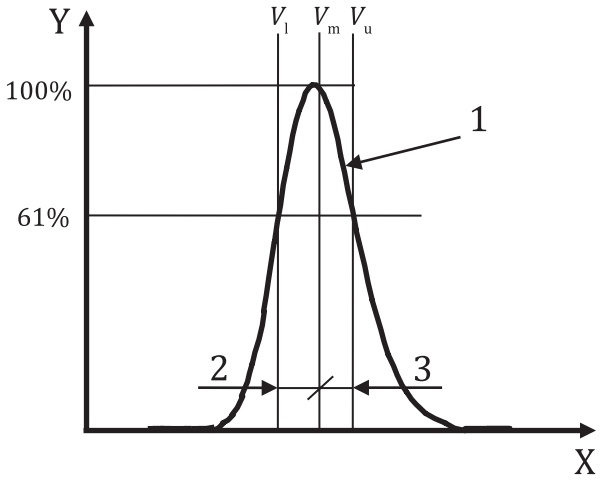
σ_c is the standard deviation of the size distribution of the calibration particles provided by the manufacturer of the calibration particles;

x_c is the certified average size of the calibration particles.

NOTE Due to the uncertainties in determining σ and σ_c, σ^2 can, in some cases, be smaller than σ_c^2. In such cases, the value of R is regarded as 0.

The particle size recommended by the manufacturer of the LSLPC should be used for this test. The standard deviation of the calibration particles, σ_c, should be known. It is recommended to determine the median voltage (or channel) V_m of the pulse height distribution for the calibration particles, as shown in Figure 6, in accordance with the method given in 7.1.2.

Determine the lower and upper voltage limits, V_l and V_u, which correspond to 61 % of the peak height in the pulse height distribution. Using the calibration curve, determine the particle sizes x_l and x_u corresponding respectively to V_l and V_u. Calculate the absolute value of the differences, $|x_l - x_c|$ and $|x_u - x_c|$, where x_c is the certified size of the calibration particles. Let the apparent standard deviation, σ, be equal to the larger one of $|x_l - x_c|$ and $|x_u - x_c|$.



Key

X pulse height voltage (or channel)
Y frequency
1 pulse height distribution for the calibration particles
2 lower side resolution
3 upper side resolution
V_l lower voltage limit
V_m median voltage
V_u upper voltage limit

Figure 6 — Verification of size resolution

7.4 Evaluation of false count

Obtain the particle count at the size channel corresponding to the minimum detectable particle size for a certain volume of particle free liquid to the LSLPC under test. The 95 % UCL of the false count can be calculated according to the procedure given in Annex C. Determine the false count and its 95 % UCL by dividing them by the volume of the sample liquid.

7.5 Estimation of coincidence loss at the maximum particle number concentration

The coincidence loss is determined by the flow rate, the time required for particles to pass through the sensing volume and the electrical signal processing time. These values are determined by the design of the LSLPC. Coincidence loss is calculated as in Formula (4).

$$L = 1 - \exp\left(-q \cdot t_{total} \cdot C_{max}\right) \tag{4}$$

where

L is the coincidence loss at the maximum particle number concentration;

q is the flow rate;

t_{total} is the sum of the time for a particle to pass through the sensing volume and electrical processing time;

C_{max} is the maximum particle number concentration.

7.6 Evaluation of sampling flow rate error

Obtain a flow rate by the sampling volume (see 7.8) and the sampling time (see 7.7), or use a calibrated flow meter. Calculate the error in the sampling flow rate, ε_q, by Formula (5).

$$\varepsilon_q = \frac{q_m - q_s}{q_s} \tag{5}$$

where

ε_q is the sampling flow rate error;

q_s is the sampling flow rate specified by the manufacturer;

q_m is the measured sampling flow rate.

If the LSLPC does not have a sampling function, this subclause does not apply.

7.7 Evaluation of sampling time error

Sampling time is the time during which the LSLPC measures a sample (from the beginning of counting to the end of counting). Calculate the error in the sampling time, ε_t, by Formula (6).

$$\varepsilon_t = \frac{t_m - t_0}{t_0} \tag{6}$$

where

ε_t is the sampling time error;

t_0 is the sampling time preset to the LSLPC;

t_m is the measured sampling time.

Calibrated instruments should be used for sampling time measurement.

7.8 Evaluation of sampling volume error

Measure the sampling volume by weighing the pure water with the balance and converting to volume, or measure the volume by means of a calibrated graduated cylinder.

If the LSLPC does not have a sampling function, this subclause does not apply.

Annex A
(informative)

Counting efficiency

Figure A.1 shows the test system for counting efficiency. The sample contains calibration particles in pure water. The counting efficiency of the reference particle counter at the minimum detectable particle size of the particle counter under test shall be 100 %.

The counting efficiency is obtained by calculating the ratio of the particle number concentration measured by the particle counter under test and the particle number concentration measured by the reference particle counter. The particle number concentration of the sample should be less than 25 % of the maximum particle number concentration of both the reference particle counter and the particle counter under test. The counting efficiency of the reference particle counter shall be established by a method of known uncertainty, such as the microscopic method (see method described in JIS B 9925[2]).

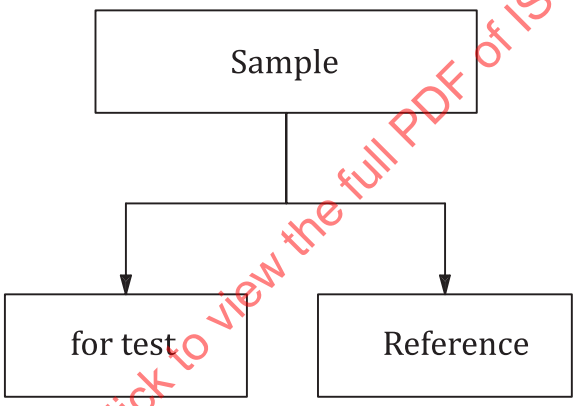


Figure A.1 — Example of a counting efficiency test system

Annex B
(informative)

Size resolution

Size resolution denotes one standard deviation of the measured size distribution of monodisperse calibration particles expressed as the mean size of the monodisperse calibration particles.

If the distribution of calibration particles is assumed to be the Gaussian distribution,

$$f(x)=\frac{1}{\sqrt{2\pi}\sigma}\exp\left\{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right\} \quad \text{(B.1)}$$

where

$f(x)$ is the Gaussian function;

x is the particle size;

μ is the mean value;

σ is the standard deviation.

when $(x-\mu)=\pm\sigma$, the ratio of density to the maximum density is $\exp\left(-\frac{1}{2}\right)\approx 0{,}61$. This is the basis for the use of 61 % in the determination of size resolution.

Annex C
(informative)

False count rate

The probability of appearance of false counts is assumed to be defined by the Poisson distribution. The Poisson distribution is defined by Formula (C.1):

$$P(X;\lambda)=\frac{e^{-\lambda}\lambda^{X}}{X!} \tag{C.1}$$

where

X is the number of false counts;

λ is the mean value of the population;

$P(X;\lambda)$ is the probability of observing value X from a population having a mean value of λ.

The upper confidence limit, λ_u, is defined by Formula (C.2):

$$\sum_{x=0}^{X} P(x;\lambda_u)=\varepsilon \tag{C.2}$$

where ε is the significant level.

When the confidence limit is 95 %, ε is 0,05.

Table C.1 shows the observed count and the calculated upper and lower 95 % confidence limits. When the observed count is zero, it is possible to have up to three counts with a probability of 5 %. For example, if zero counts are observed in one minute at a sampling flow rate of 100 l/min, the false count rate is three counts in the volume sampled in one minute with a 95 % confidence limit, i.e. the false count is 30 counts per litre.

Table C.1 — Observed count and 95 % confidence limit

Observed count	Upper confidence limit λ_u
0	3
1	4,7
2	6,3
3	7,8
4	9,2
5	10,5
6	11,8
7	13,1
8	14,4
9	15,7
10	17,0

Annex D
(informative)

Procedure for evaluating the uncertainties of the results of the performance tests

D.1 Basics on measurement uncertainty

In this annex, a recommended procedure is described for evaluating the uncertainties of the results of the tests specified in 7.1 and 7.2 (see Note 1). This procedure follows ISO/IEC Guide 98-3, which is briefly summarized as follows.

Step 1) Identify the relationship between the measurand, y, and the input quantities, x_i (i = 1, 2, ..., N):

$$y = f(x_1, x_2, \cdots, x_N) \tag{D.1}$$

This functional relationship is called the mathematical model of measurement (see Notes 2, 3).

Step 2) Evaluate the standard uncertainty $u(x_i)$ of the input quantity x_i either by Type A or Type B evaluation of uncertainty (see Notes 4, 5).

Step 3) Combine the standard uncertainties of all x_i values to obtain the combined standard uncertainty of the measurement result, $u_c(y)$, according to the following 'law of propagation of uncertainty, (see Notes 6, 7).

$$u_c(y) = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} u(x_i) \right)^2} \tag{D.2}$$

Step 4) When necessary, the expanded uncertainty U is calculated according to Formula (D.3):

$$U = k \times u_c(y) \tag{D.3}$$

where k is the coverage factor. In this standard, k = 2 is consistently used for simplicity (see Note 8).

NOTE 1 The uncertainty components considered in this annex are those relevant to the tests specified in the main body of this document. These components are considered to cover major factors that can affect measurements of particles in the real environment, but are not intended to cover all of them. Additional factors that are not considered in this annex include the difference in optical properties between test particles and particles in the real environment, and the uncertainty associated with the determination of theoretical response functions.

NOTE 2 Input quantity is a quantity whose value is used to determine the result of measurement, or a quantity that can otherwise affect a measurement result.

NOTE 3 Although the quantities, Y and X_i, and their estimates, y and x_i, are represented by different symbols in ISO/IEC Guide 98-3, the same symbols are used here, as far as there is no risk of confusion.

NOTE 4 If the estimate of a quantity x_i is obtained from $x_i = \overline{q}$, where $\overline{q}$ is the mean of a series of observations, q_k(k = 1, 2, ..., n), then the standard uncertainty of x_i is evaluated as

$$u(x_i) = \frac{s}{\sqrt{n}} \tag{D.4}$$