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Representation of results of particle size analysis —

Part 4:
Characterization of a classification process

Représentation de données obtenues par analyse granulométrique —

Partie 4: Caractérisation d'un processus de triage

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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.ch
Web www.iso.ch

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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 3.

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 part of ISO 9276 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 9276-4 was prepared by Technical Committee ISO/TC 24, *Sieves, sieving and other sizing methods*, Subcommittee SC 4, *Sizing by methods other than sieving*.

ISO 9276 consists of the following parts, under the general title *Representation of results of particle size analysis*:

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— *Part 1: Graphical representation*

— *Part 2: Calculation of average particle sizes/diameters and moments from particle size distributions*

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— *Part 3: Fitting of an experimental cumulative curve to a reference model*

— *Part 4: Characterization of a classification process*

— *Part 5: Validation of calculations relating to particle size analyses using the logarithmic normal probability distribution*

Annex A of this part of ISO 9276 is for information only.

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Introduction

In classification processes used in particle size analysis, such as occurring in impactors, sieves, etc., the mass of the supply or feed material, m_s, or its number, n_s, of particles, the particle size distribution of which is described by its density distribution, $q_{r,s}(x)$, is separated into at least one fine fraction of mass, m_f, or number, n_f, and of density distribution, $q_{r,f}(x)$ and a coarse fraction of mass, m_c, or number, n_c, and a density distribution, $q_{r,c}(x)$. The type of quantity chosen in the analysis is described by the subscript, r, the supply or feed material and the fine and coarse fractions by the additional subscripts: s; f and c respectively. See Figure 1.

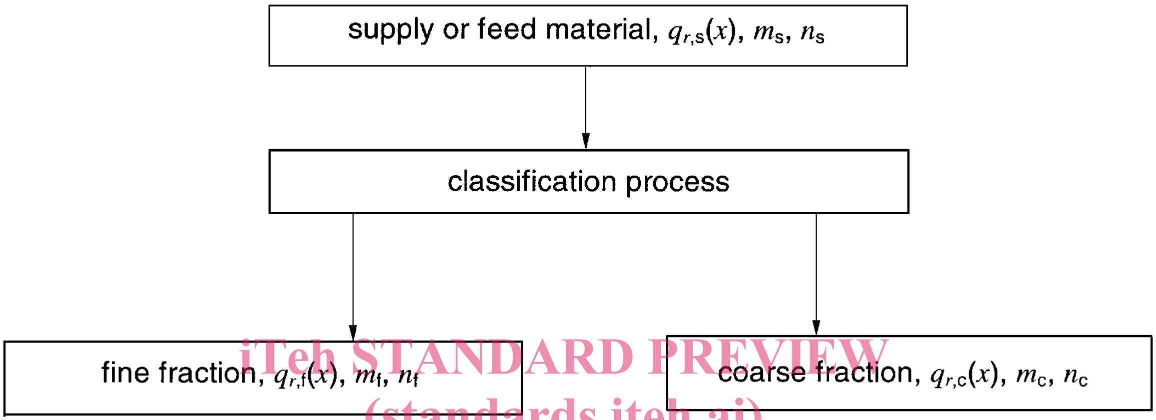

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Figure 1 — Fractions and distributions produced in a one step classification process

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For the characterization of processes with more than one coarse fraction, e.g. cascade impactors, s, f and c can be replaced by numbers 0, 1 and 2. In this case e.g. number 3 describes a second coarse fraction containing larger particles than fraction 2.

It is assumed that the size, x, of a particle is described by the diameter of a sphere. Depending on the problem, the particle size, x, may also represent an equivalent diameter of a particle of any other shape.

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Representation of results of particle size analysis —

Part 4:
Characterization of a classification process

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1 Scope

The main object of this part of ISO 9276 is to provide the mathematical background for the characterization of a classification process. This part of ISO 9276 is not limited to an application in particle size analysis, the same procedure may be used for the characterization of a technical classification process (e.g. air classification, centrifugal classification) or a separation process (e.g. gas or hydrocyclones).

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In clause 3 the characterization of a classification process is described under the presupposition that the density distribution curves describing the feed material and the fractions, as well as the overall mass balance, are free from errors. In clause 4 the influence of systematic errors on the efficiency of a classification process is described. The effect of stochastic errors in the characterization of a classification process is described in annex A.

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2 Symbols

2.1 Symbols for specific terms

See Table 1.

Table 1 — Symbols for specific terms

Symbol	Term
A	Parameters derived from cumulative distribution curves
E	Mass balance error, cumulative distributions
I	Imperfection
$K(x)$	Corrected cumulative distribution
m	Mass
n	Total number of size classes, number of particles
$q_r(x)$	Density distribution curve
$Q_r(x)$	Cumulative distribution curve
$\Delta Q_{r,i}$	Difference of two cumulative distribution values, relative amount in the ith particle size interval, Δx_i
s^2	Variance
t	Student's factor
T	Grade efficiency
T_o	Overall classification or separation efficiency
$T(x)$	Grade efficiency curve
x	Particle diameter, diameter of a sphere
x_a	Analytical cut size
x_e	Equiprobable cut size, median particle size of a grade efficiency curve
x_i	Upper particle size of the ith particle size interval
x_{i-1}	Lower particle size of the ith particle size interval
Δx_i	Width of the ith particle size interval
x_max	Particle size above which there are no particles in a given size distribution
x_min	Particle size below which there are no particles in a given size distribution
α	Angle of slope, weighted sum of variances
ε	Mass balance error, density distributions
$\eta_{r,i} = Q_{r,\mathrm{s},i} - Q_{r,\mathrm{c},i}$	Variable
κ	Sharpness of cut parameters formed with characteristic particle sizes
ν	Relative amount
$\xi_{r,i} = Q_{r,\mathrm{f},i} - Q_{r,\mathrm{c},i}$	Variable
τ	Amount of particles not participating in a classification process
ϕ	Variable

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2.2 Subscripts

See Table 2.

Table 2 — Subscripts

Symbol	Significance
c	Coarse fraction (second subscript after r)
f	Fine fraction (second subscript after r)
i	Number of the size class with upper particle size: x_i
r	Type of quantity of a density distribution [a] (general description)
s	Supply or feed material (second subscript after r)
0	Replaces s in case of more than one coarse fraction
1	Replaces f in case of more than one coarse fraction
2	Replaces c in case of more than one coarse fraction
[a] For example, $r = 3$ if type of quantity = volume or mass.	

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3 Characterization of a classification process based on error-free distribution curves and mass balances

3.1 Density distribution curves representing a classification process

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In a classification process a given supply or feed material (subscript s) is classified into at least two parts, which are called the fine (subscript f) and the coarse (subscript c) fractions. If an *ideal* classification were possible, the fine fraction would, as shown in Figure 2, contain particles below or equal to a certain size, x_e, the so-called cut size, and the coarse fraction would contain all particles above that size.

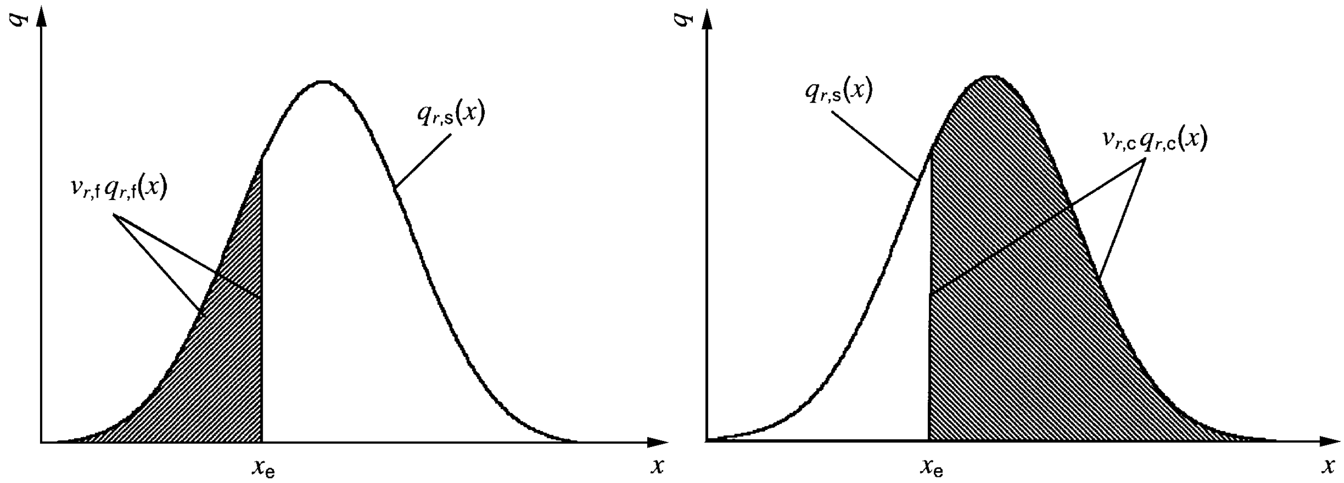

Figure 2 — Weighted density distributions of the feed material $q_{r,s}(x)$ and the fine and coarse fractions of an *ideal* classification process

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The shaded areas beneath the weighted density distributions of the fine and the coarse product represent the relative mass, $v_{3,f}$, or number, $v_{0,f}$, of the fine, $v_{r,f}$, and the coarse fraction, $v_{r,c}$, the sum which equals 100 % or unity.

In *reality*, however, in a certain range of sizes $x_{min,c} < x < x_{max,f}$ particles of the same size, x, are present in both the fine and the coarse fractions. The density distribution curves of the fine and the coarse fractions overlap and intersect each other in this size range, The point of intersection as shown in Figure 3 corresponds to a cut size, which is called the equiprobable cut size, x_e(see 3.3.2).

The particles below the cut size, x_e, in the coarse or above x_e in the fine fraction have been incorrectly classified.

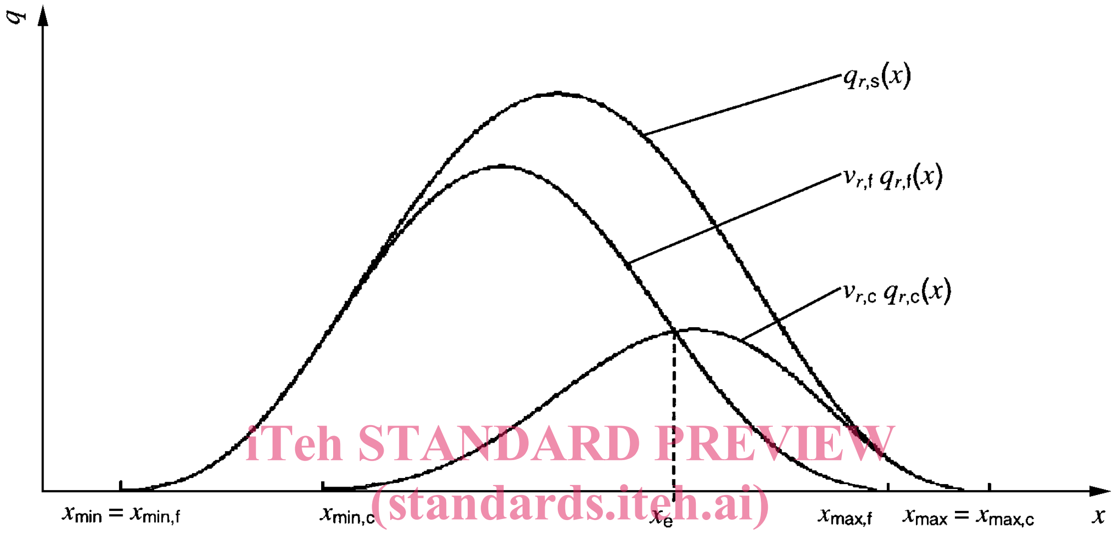

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Figure 3 — Weighted density distributions of feed material, $q_{r,s}(x)$, and the fine, $v_{r,f}\ q_{r,f}(x)$, and the coarse fraction, $v_{r,c}\ q_{r,c}(x)$, of an *real* classification process

3.2 Mass and number balances

3.2.1 Mass and number balance in the size range from x_{min} to x_{max}

Due to the classification process, the mass, m_s, or number, n_s, of the feed material, is split into the mass, m_f, or number, n_f, of the fine material and the mass, m_c, or number, n_c, of the coarse material. One obtains:

$$m_s = m_f + m_c \quad \text{or} \quad n_s = n_f + n_c \tag{1}$$

and

$$1 = \frac{m_f}{m_s} + \frac{m_c}{m_s} \quad \text{or} \quad 1 = \frac{n_f}{n_s} + \frac{n_c}{n_s} \tag{2}$$

$$1 = v_{3,f} + v_{3,c} \quad \text{or} \quad 1 = v_{0,f} + v_{0,c} \tag{3}$$

$v_{r,f}$ represents the relative amount of the fine fraction, $v_{r,c}$ the relative amount of the coarse fraction.

In Figures 2 and 3, $v_{r,f}$ and $v_{r,c}$ are represented by the areas beneath the weighted density distribution curves of the fine, $v_{r,f}\ q_{r,f}(x)$, and the coarse, $v_{r,c}\ q_{r,c}(x)$, fractions. The area beneath the density distribution curve of the feed material, $q_{r,s}(x)$, equals unity.

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3.2.2 Mass and number balance in the size range from x to $x + \mathrm{d}x$

Particles of a certain size, x, present in the feed material, are either transferred in the classification process to the fine or to the coarse fractions. The amount of these particles in the feed material, $\mathrm{d}Q_{r,\mathrm{s}}(x)$, is therefore split into two fractions: $v_{r,\mathrm{f}}\,\mathrm{d}Q_{r,\mathrm{f}}(x)$ and $v_{r,\mathrm{c}}\,\mathrm{d}Q_{r,\mathrm{c}}(x)$.

$$\mathrm{d}Q_{r,\mathrm{s}}(x) = v_{r,\mathrm{f}}\,\mathrm{d}Q_{r,\mathrm{f}}(x) + v_{r,\mathrm{c}}\,\mathrm{d}Q_{r,\mathrm{c}}(x) \tag{4}$$

Replacing $\mathrm{d}Q_r(x)$ by equation 5:

$$\mathrm{d}Q_r(x) = q_r(x)\,\mathrm{d}x \tag{5}$$

one obtains:

$$q_{r,\mathrm{s}}(x) = v_{r,\mathrm{f}}\,q_{r,\mathrm{f}}(x) + v_{r,\mathrm{c}}\,q_{r,\mathrm{c}}(x) \tag{6}$$

Equation 6 must be used to construct the set of density distribution curves of Figure 3. It should be realized that in plotting Figure 3 only three of the variables of equation 6 can be chosen arbitrarily. If, two density distributions and the relative amount of the fine or the coarse material, e.g., $q_{r,\mathrm{s}}(x)$, $q_{r,\mathrm{f}}(x)$ and $v_{r,\mathrm{f}}$ are given, $q_{r,\mathrm{c}}(x)$, and $v_{r,\mathrm{c}}$ are fixed.

3.2.3 Mass and number balance in the size range from x_{min} to x

Integrating equation 6 between x_{min} and x yields:

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$$Q_{r,\mathrm{s}}(x) = v_{r,\mathrm{f}}\,Q_{r,\mathrm{f}}(x) + v_{r,\mathrm{c}}\,Q_{r,\mathrm{c}}(x) \tag{7}$$

3.2.4 The indirect evaluation of $v_{r,\mathrm{f}}$ and $v_{r,\mathrm{c}}$

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In many cases of practical application $v_{r,\mathrm{f}}$ and $v_{r,\mathrm{c}}$ cannot be calculated from the relevant masses or mass flow rates, due to the fact that these are not available or difficult to measure, etc. If however, representative samples of the feed material and the fine and the coarse fraction have been measured equations 3 and 6 or 7 may be used to calculate $v_{r,\mathrm{f}}$ or $v_{r,\mathrm{c}}$. Introducing equation 3 into equations 6 and 7 and solving with respect to $v_{r,\mathrm{f}}$ yields:

$$v_{r,\mathrm{f}} = 1 - v_{r,\mathrm{c}} = \frac{Q_{r,\mathrm{s}}(x) - Q_{r,\mathrm{c}}(x)}{Q_{r,\mathrm{f}}(x) - Q_{r,\mathrm{c}}(x)} = \frac{q_{r,\mathrm{s}}(x) - q_{r,\mathrm{c}}(x)}{q_{r,\mathrm{f}}(x) - q_{r,\mathrm{c}}(x)} \tag{8}$$

If the cumulative distributions $Q_{r,\mathrm{s}}(x)$, $Q_{r,\mathrm{f}}(x)$ and $Q_{r,\mathrm{c}}(x)$ are free from errors, i.e. the mass balance according to equations 6 or 7 leave no remainder, $v_{r,\mathrm{f}}$ or $v_{r,\mathrm{c}}$ will be constant and independent of size x.

3.3 Definitions of cut size, x_{e}

3.3.1 General

In principle, any value of x between $x_{\mathrm{min\ c}}$ and $x_{\mathrm{max\ f}}$, i.e. the size range in which the density distributions of the fine and the coarse fractions overlap, can be used as cut size.

Two definitions are commonly used as described in 3.3.2 and 3.3.3.

3.3.2 The equiprobable cut size, x_{e}, the median of the grade efficiency curve

In Figure 3 the weighted density distribution curves of the fine and the coarse fraction intersect at a certain size x_{e}. This particle size, which represents the median of the grade efficiency curve, $T(x)$, as defined in 3.4, is the equiprobable cut size, x_{e}:

$$x_{\mathrm{e}} = x\,(T = 0{,}5) \tag{9}$$

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