Designation: E799 – 03 (Reapproved 2020)$^{\varepsilon 1}$

Standard Practice for Determining Data Criteria and Processing for Liquid Drop Size Analysis[1]

This standard is issued under the fixed designation E799; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Keywords were added editorially in April 2020.

1. Scope

1.1 This practice gives procedures for determining appropriate sample size, size class widths, characteristic drop sizes, and dispersion measure of drop size distribution. The accuracy of and correction procedures for measurements of drops using particular equipment are not part of this practice. Attention is drawn to the types of sampling (spatial, flux-sensitive, or neither) with a note on conversion required (methods not specified). The data are assumed to be counts by drop size. The drop size is assumed to be the diameter of a sphere of equivalent volume.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 The analysis applies to all liquid drop distributions except where specific restrictions are stated.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1296 Terminology for Liquid Particle Statistics (Withdrawn 1997)[3]

2.2 *ISO Standards:*[4]

ISO 13320–1 Particle Size Analysis-Laser Diffraction Methods

ISO 9276–1 Representation of Results of Particle Size Analysis-Graphical Representation

ISO 9272–2 Calculation of Average Particle Sizes/Diameters and Moments from Particle Size Distribution

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *flux-sensitive, adj*—describes the observation of measurement of the traffic of drops through a fixed area during intervals of time. Examples of flux-sensitive sampling are the collection for a period of time on a stationary slide or in a sampling cell, or the measurement of drops passing through a plane (gate) with a shadowing on photodiodes or by using capacitance changes. An example that may be characterized as neither flux-sensitive nor spatial is a collection on a slide moving so that there is measurable settling of drops on the slide in addition to the collection by the motion of the slide through the swept volume. Optical scattering devices sensing continuously may be difficult to identify as flux-sensitive, spatial, or neither due to instantaneous sampling of the sensors and the measurable accumulation and relaxation time of the sensors. For widely spaced particles sampling may resemble temporal and for closely spaced particles it may resemble spatial. A flux-sensitive set of data is proportional to flux density: number per (unit area × unit time).

3.1.2 *local, adj*—indicates observations of a very small part (volume or area) of a larger region of concern.

3.1.3 *representative, adj*—indicates that sufficient data have been obtained to make the effect of random fluctuations acceptably small. For temporal observations this requires sufficient time duration or sufficient total of time durations. For spatial observations this requires a sufficient number of observations. A spatial sample of one flash photograph is usually not

[1] This practice is under the jurisdiction of ASTM Committee E29 on Particle and Spray Characterization and is the direct responsibility of Subcommittee E29.02 on Non-Sieving Methods.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

representative since the drop population distribution fluctuates with time. 1000 such photographs exhibiting no correlation with the fluctuations would most probably be representative. A temporal sample observed over a total of periods of time that is long compared to the time lapse between extreme fluctuations would most probably be representative.

3.1.4 *spatial, adj*—describes the observation or measurement of drops contained in a volume of space during such short intervals of time that the contents of the volume observed do not change during any single observation. Examples of spatial sampling are single flash photography or laser holography. Any sum of such photographs would also constitute spatial sampling. A spatial set of data is proportional to concentration: number per unit volume.

3.2 *Symbols—Representative Diameters:*

3.2.1 ($\bar{D}_{pq}$) is defined to be such that:[5]

$$\bar{D}_{pq}^{(p-q)} = \frac{\sum_i D_i^p}{\sum_i D_i^q} \quad (1)$$

where:

$\bar{D}$ = the overbar in $\bar{D}$ designates an averaging process,
$(p - q)$ $p > q$ = the algebraic power of $\bar{D}_{pq}$,
p and q = the integers 1, 2, 3 or 4,
D_i = the diameter of the ith drop, and
$\sum_i$ = the summation of D_i^p or D_i^q, representing all drops in the sample.
$0 = p$ and q = values 0, 1, 2, 3, or 4.

$\sum_i D_i^0$ is the total number of drops in the sample, and some of the more common representative diameters are:

$\bar{D}_{10}$ = linear (arithmetic) mean diameter,
$\bar{D}_{20}$ = surface area mean diameter,
$\bar{D}_{30}$ = volume mean diameter,
$\bar{D}_{32}$ = volume/surface mean diameter (Sauter), and
$\bar{D}_{43}$ = mean diameter over volume (De Broukere or Herdan).

See Table 1 for numerical examples.

3.2.2 D_{Nf}, D_{Lf}, D_{Af}, and D_{Vf} are diameters such that the fraction, f, of the total number, length of diameters, surface area, and volume of drops, respectively, contain precisely all of the drops of smaller diameter. Some examples are:

$D_{N0.5}$ = number median diameter,
$D_{L0.5}$ = length median diameter,

[5] This notation follows: Mugele, R.A., and Evans, H.D., "Droplet Size Distribution in Sprays," *Industrial and Engineering Chemistry*, Vol 43, No. 6, 1951, pp. 1317–1324.

TABLE 1 Sample Data Calculation Table

Size Class Bounds (Diameter in Micrometres)	Class Width	No. of Drops in Class	Sum of D_i^r in Each Size Class[A]				Vol. % in Class[B]	Cum. % by Vol.
			D_i	D_i^2	D_i^3	D_i^4		
240–360	120	65	19.5×10^3	5.9×10^6	1.8×10^9	$1. \times 10^{12}$	0.005	0.005
360–450	90	119	48.2	19.6	8.0	3	0.021	0.026
450–562.5	112.5	232	117.4	59.7	30.5	16	0.081	0.107
562.5–703	140.5	410	259.4	164.8	105.2	67	0.280	0.387
703–878	175	629	497.2	394.7	314.5	252	0.837	1.224
878–1097	219	849	838.4	831.3	827.6	827	2.202	3.426
1097–1371	274	990	1221.7	1513.7	1883.2	2352	5.010	8.436
1371–1713	342	981	1512.7	2342.1	3641.1	5683	9.687	18.123
1713–2141	428	825	1589.8	3076.1	5976.2	11657	15.900	34.023
2141–2676	535	579	1394.5	3372.5	8189.2	19965	21.788	55.811
2676–3345	669	297	894.1	2702.8	8203.5	24999	21.826	77.637
3345–4181	836	111	417.7	1578.2	5987.6	22807	15.930	93.567
4181–5226	1045	21	98.8	466.5	2212.1	10532	5.885	99.453
5226–6532	1306	1	5.9	34.7	348.5	1534	0.547	100.000
Totals of D_i^r in $\sum\kappa$ entire sample		= 6109 $D_{N0.5} = 1300$	8915.3×10^3 $\bar{D}_{10} = 1460$	16562.6×10^6 $\bar{D}_{21} = 1860$ $\bar{D}_{20} = 1650$	37729.0×10^9 $\bar{D}_{32} = 2280$ $\bar{D}_{31} = 2060$ $\bar{D}_{30} = 1830$ $D_{V0.5} = 2540$	100695×10^{12} $\bar{D}_{43} = 2670$		

Worst case class width

$\frac{348.5}{37729} = 0.009$ Relative Span $= (D_{V0.9} - D_{V0.5})/D_{V0.5} = (3900 - 14200)/2530 = 0.98$

$\frac{669}{2676+3345} \times 0.21826 = 0.024$

Less than 1 %, adequate sample size

Adequate class sizes

[A] The individual entries are the values for each κ as used in 5.2.1 (Eq 1) for summing by size class.
[B] SUM D_i^3 in size class divided by SUM D_i^3 in entire sample.

$D_{A0.5}$ = surface area median diameter,
$D_{V0.5}$ = volume median diameter, and
$D_{V0.9}$ = drop diameter such that 90 % of the total liquid volume is in drops of smaller diameter.

See Table 2 for numerical examples.

3.2.3

$$\log\left(\bar{D}_{gm}\right) = \sum_i \log(D_i)/n \qquad (2)$$

where:

n = number of drops,
$\bar{D}_{gm}$ = the geometric mean diameter

3.2.4

$$D_{RR} = D_{VF} \qquad (3)$$

where:

f = $1 - 1/e \approx 0.6321$, and
D_{RR} = Rosin-Rammler Diameter fitting the Rosin-Rammler distribution factor (see Terminology E1296).

3.2.5 D_{kub} = upper-boundary diameter of drops in the kth size class.

3.2.6 D_{klb} = lower-boundary diameter of drops in the kth size class.

TABLE 2 Example of Log Normal Curve with Upper Bound

Data Collected May 2, 1979			Computer Analysis May 2, 1979
Upper Bound Diameter (µm)	Normal Curve, %	Adjusted Data, %	Data, %
360.00	0.006	0.005	0.005
450.00	0.027	0.027	0.026
562.50	0.109	0.108	0.107
703.00	0.389	0.387	0.387
878.00	1.227	1.224	1.224
1097.00	3.421	3.426	3.426
1371.00	8.407	8.437	8.436
1713.00	18.109	18.124	18.123
2141.00	34.080	34.024	34.023
2676.00	55.551	55.811	55.811
3345.00	77.828	77.637	77.637
4181.00	93.648	93.568	93.567
5226.00	99.481	99.453	99.453
6532.00	100.000	100.000	100.000

For Computing Curve Averages

Largest drop diameter	=	6532.00 µm
Smallest drop diameter	=	240.00 µm
Fraction of normal curve	=	0.999995

Normal Curve		Simple Calculation
	(Gaussian Limits—4.55457 to 4.53257)	
D_{10}	= 1464.91	1459.37 µm (length mean diameter)
D_{20}	= 1646.44	1646.57 µm (surface mean diameter)
D_{30}	= 1824.85	1832.39 µm (volume mean diameter)
D_{21}	= 1850.45	1857.79 µm (surface/length mean diameter)
D_{31}	= 2036.73	2053.27 µm (volume/length mean diameter)
D_{32}	= 2241.75	2269.32 µm (sauter mean diameter)
D_{43}	= 2615.67	2670.75 µm (mean diameter over volume)
$D_{V0.5}$	= 2534.53	2533.31 µm (volume median diameter)
$D_{N0.5}$	= 1303.62	1304.71 µm (number median diameter)

Average of Absolute Relative Deviation from $D_{V0.5}$ by Volume = 0.311
Relative Span = $(D_{V0.900} - D_{V0.100})/ D_{V0.5}$ $(D_{V0.9} - D_{V0.1})/D_{V0.5}$
= (3913.74 − 1437.21)/2534.53
= 0.977

$$\text{Normal curve \% } F(D) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{DEL \ln\left(\frac{AD}{XM-D}\right)} e^{-z^2}\, dz$$

where:
A = 1.8941,
DEL = 1.17206, and
XM = 7335.30.

F(D) = accumulative fraction of liquid volume in drops having diameter less than D.