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INTERNATIONAL STANDARD

Printed electronics –
Part 302-2: Equipment – Inkjet – Imaging-based measurement of droplet volume

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PRINTED ELECTRONICS –

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International Standard IEC 62899-302-2 has been prepared by IEC technical committee 119: Printed Electronics.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
119/204/FDIS	119/216/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62899 series, published under the general title *Printed electronics*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
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PRINTED ELECTRONICS –

Part 302-2: Equipment – Inkjet – Imaging-based measurement of droplet volume

1 Scope

This part of IEC 62899 specifies the method for determining accurate inkjet droplet volume based on images obtained by drop-in-flight measurement systems. It does not apply to imaging systems using interference fringes, such as holography or phase doppler anemometry. This document is not limited to drop-on-demand inkjet systems, but might not be applicable to continuous inkjet or liquid dispensing systems. This document includes a description of the issues concerning such measurements and consideration of the limits to measurement accuracy.

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.

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- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
droplet volume
amount of jetted fluid from an inkjet print-head nozzle measured by single event imaging

Note 1 to entry: For a single event drive pulse designed to produce sub-drops that are intended to merge in-flight to form a larger droplet, for example to form a specific greyscale image value on deposition, droplet volume refers to the large merged droplet and not to smaller component sub-drops.

3.2
native drop volume
amount of fluid within the smallest sub-drop jetted from a greyscale inkjet print-head used to create images with droplets formed by multiple sub-drops within a single event

Note 1 to entry: Native drops (or threads or satellite drops) might be too small for accurate measurements by flash imaging, but satellite drops that have merged in-flight might be large enough for drop analysis systems. (See Figure 1 for a representation of the relative sizes for greyscale droplets in-flight.)

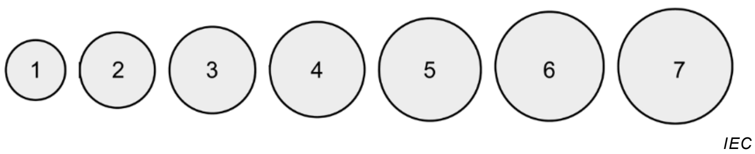

Figure 1 – Representation of greyscale drop size 1 (“native drop”) to size 7

4 Droplet volume measurement

4.1 General

4.1.1 Overview

This document concerns accurate determination of inkjet droplet volume from high speed flash images of inkjet droplets travelling in-flight from inkjet print-head nozzles. Accurate relative (rather than absolute) droplet volumes are useful for industrial inkjet-printed electronics applications. Short flash durations avoid significant motion blurring in droplet images. Two widely used scenarios, for flash imaging as applied to measurement of inkjet drop speed, are considered in this document because they produce slightly different information about droplet volumes. Images that contain superposed nominally identical and similarly placed droplets can provide an average size for volume measurements, whereas the single event images give measures of the size and variations of the size and centroid location produced during volume measurements. Clause A.1 gives further information about specific instrumentation limits.

Shadowgraph imaging can readily determine individual inkjet droplet sizes if the fluid bodies appear dark against a light background [1[1]]. However, droplets should be well-focused, and the optical images have a suitable pixel resolution and background intensity with low intensity variations, and image blur due to droplet motion during the flash should have minimal effect on droplet size determination. For liquid droplets, background intensity level, refraction and diffraction can alter apparent image size, and if the liquid is not opaque refraction often produces a bright central spot. As spherical droplet shapes are preferred for the most accurate and rapid online image analysis and conversion to volume, all in-flight measurements should be made only where any sub-drops (and satellites) from the same single event pulse have merged, and also any droplet shape oscillations have fully damped out. Droplet volume is then inferred from the diameter (pixels) or area (number of pixels covered) of the dark region by assuming spherical geometry and image symmetry about the focal plane and linear calibration of the optical system (in µm/pixel). Accurate fitting algorithms determine droplet size to sub-pixel levels, but also depend on an assumption about where the droplet boundary is located in an image. This can provide an absolute droplet volume if calibrated using a suitable traceable method. For example, the measured weight of a known number of drops of known density gives the average drop volume which may be compared with that deduced by the drop measurement system [2].

More commonly, reference objects of known dimension(s) placed in the drop measurement system are imaged and analysed using the same optical conditions as for the inkjet droplets. Relative volume comparisons can be made between droplets without an absolute calibration.

4.1.2 Volume measurement and droplet shape equalization processes

In principle, once droplets have been ejected from an inkjet print-head nozzle, their volume does not change if evaporation losses or drop merging are negligible. However the resultant droplet shapes can alter markedly from their jetted shapes until they relax towards their final shapes (see Figure A.5). Accurate in-flight measurements always analyse spherical shapes, avoiding long thin jet shapes [1] (or spinning non-spherical blobs of liquid) that might not actually lie symmetrically in the (2D) image focal plane and hence might not be convertible into volume. Some inkjet fluids used in printed electronics and other applications do not always form fully smooth or spherical droplets under all jetting conditions [3] and in such cases the drop analysis system provides less accurate (or even misleading) results. Examples are highly shear-thinning high viscosity fluids, gels and fluids with large particles. Accurate droplet volume measurement systems using multiple event imaging also require very stable jetting by the inkjet print-head and avoidance of first droplet and burst printing effects in inkjet printing [4, 5].

1 Numbers in square brackets refer to the Bibliography.

4.1.3 Imaging optics

Drop-on-demand inkjet drops move at 5 m/s to 10 m/s and typically need sub-microsecond high power flash illumination and also high resolution digital cameras with 10X magnification (or more) for in-flight measurement of droplet volume using shadowgraph imaging. Tele-centric optical designs and high power LED flash can deliver (background) illumination and imaging conditions with a depth of focus sufficient for accurate inkjet droplet volume measurements using drop analysis systems. Appropriate flash delay times can locate droplets near the centre of the optical field of view for accurate droplet volume determination. Optical field of view is determined by the magnification and camera sensor area and spans typically a few hundred micrometers. Multiple-event imaging increases the background image level where the single event flash intensity is limited, at the cost of achievable droplet volume accuracy. Background intensity levels, expressed as a greyscale intensity level, are ideally specified for the drop analysis system, as is apparent from recent studies of image analysis errors [6]. Proper focusing of drop analysis systems can reduce unwanted blurring of droplet images, which can otherwise cause inaccurate analysis of the droplet shape, size and volume.

4.1.4 Image shape processing

One or more regions of interest, within the total field of view of the drop imaging system, may be set (by a user or automatically) to contain the particular droplet images for analysis. This assists automatic identification of droplets and speeds up the analysis and presentation of results. Either axial or spherical symmetry of droplet images should be assumed by the drop analysis system so that droplet volumes can be computed from individual shadowgraph images. The image shape processing used by the drop analysis system may involve thresholding, edge detection, boundary location, circles, ellipses, equivalent circular diameters, maximum lengths and widths, area, sliced drums or cones, or even evolving shapes [6, 7, 8, 9]. Accurate determination of droplet volume requires sub-pixel techniques, as shown in Clause A.1.

4.1.5 Calibration

The linear calibration of the optical field of view should be established with grids, lines or objects of suitable known size and spacing under similar light conditions and flash duration; the threshold value used for such calibrations should equal that used for drop measurements. Calibration factors of 1,00 µm/pixel or less are typical for drop analysis systems accurately measuring drop-on-demand inkjet droplet volumes, using camera pixel sizes of 10 µm or less. An approximate (~1 %) calibration factor can be conveniently found for some measurements by imaging several inkjet nozzles or emerging jets within the same field of view (i.e. > 100 µm) and comparing the (nominal) nozzle pitch with the apparent pixel separation. However this is often not feasible for industrial inkjet print-heads because they have a shielded nozzle plane.

4.1.6 Uncertainties

Imaging-based measurements of droplet volume depend on the cube of the linear calibration factor, so that droplet volume uncertainty is three times that of the calibration factor uncertainty. Thus the minimum uncertainty in accurate droplet volume measurements is ± 3 % for a linear calibration factor known to ± 1 %. As a typical example, the calibration factor of 1,00 µm/pixel in 4.1.5 has no error shown, so that the minimum assumed linear uncertainty is ± 0,01 µm, i.e. ≥ ± 1 %, and therefore the minimum assumed absolute volume uncertainty is ≥ ±3 %. Traceable standards should normally have an absolute uncertainty more than ten times lower than this. Uncertainties in droplet volumes appropriate to relative comparisons of images recorded with a drop analysis system are given in Clause A.2.

4.2 Processes for measurement of inkjet droplet volume

4.2.1 General

Inkjet droplet volume shall be measured by using one of the two following methods, unless there is an alternative user and supplier agreement. These two methods principally differ in the use of single- or multiple-event-mode images to determine droplet diameter, but may also differ in calibration procedures: single-event mode is appropriate for highest accuracy and absolute measurements while multiple-event mode provides smeared “droplet size” measures often used for relative comparisons.

4.2.2 Process for measurement of inkjet droplet volume – Method 1

This process describes the in-flight method for inkjet droplet volume measurements using the single-event mode: individual droplet images are recorded for analysis without any superposition of other droplets.

1) Commence inkjet printing with the desired specifications (frequency, ink selection, waveform, etc). It is recommended to record jetting conditions, including these specifications and other relevant details, as described in Clause A.3.
2) Ensure that the desired jets and merged droplets are “in focus” at the focal plane of the imaging optics, adjusting the delay time of the single event light flash such that fully merged and equalized droplet shapes are located in the analysis region of interest. This process may be performed automatically or manually, and it may be combined with a measurement of instantaneous droplet speed using double flash, as described by IEC 62899-302-1 (analysis method 4) [13]. The duration of the flash should not be greater than a few hundred nanoseconds to avoid image blur of the droplet. The (double) flash intensity should be sufficient to allow discrimination between the drop edge and the background, without saturating the image.
3) Extract the single event mode droplet diameter D (pixel) by suitable analysis of the recorded image. The average and statistical variance of repeated single-event-mode droplet diameters are used to represent the average droplet diameter with a standard error free from smearing by any velocity and timing variations. This process may be performed automatically or manually, and it is recommended that this and the number of drops used in the average also be recorded, as described in Clause A.3.
4) The calibration factor F (µm/pixel) should be determined at the optical magnification used by the drop analysis system to determine droplet volume (picolitre). This calibration is preferably made using traceable standards placed in the focal plane, or using the average pitch of inkjet nozzles in array print-heads. It is recommended that all details of the calibrations used be recorded, as described in Clause A.3.

4.2.3 Process for measurement of inkjet droplet volume – Method 2

This process describes the in-flight method for inkjet droplet volume measurements using the multiple-event mode: different droplets are recorded as a single image and analysed as if they were a single droplet.

1) Commence inkjet printing with the desired specifications (frequency, ink selection, waveform, etc). It is recommended to record jetting conditions, including these specifications and other relevant details, as described in Clause A.3.
2) Ensure that the desired jets and merged droplets are “in focus” at the focal plane of the imaging optics, adjusting the delay time of the single event light flash such that fully merged and equalized droplet shapes are located in the analysis region of interest. This process may be performed automatically or manually, and it may be combined with a measurement of drop speed, as described in IEC 62899-302-1 (methods 1 to 3) [13]. The duration of the flash should not be greater than a few hundred nanoseconds to avoid image blur of the droplet. The flash intensity should be sufficient to allow discrimination between the drop edge and the background, without saturating the superposed image.

3) Extract the multiple-event-mode droplet diameter (pixel) by suitable analysis of the recorded image. This gives an average droplet diameter (potentially) smeared by any velocity and timing variations. This process may be performed automatically or manually, and it is recommended that this and the number of drops used in the average is also recorded, as described in Clause A.3.

4) The calibration factor F (µm/pixel) should be determined at the optical magnification used by the drop analysis system to determine droplet volume (picolitre). This calibration is preferably made using traceable standards placed in the focal plane, or using the average pitch of inkjet nozzles in array print-heads. It is recommended that all details of the calibrations used be recorded, as described in Clause A.3.