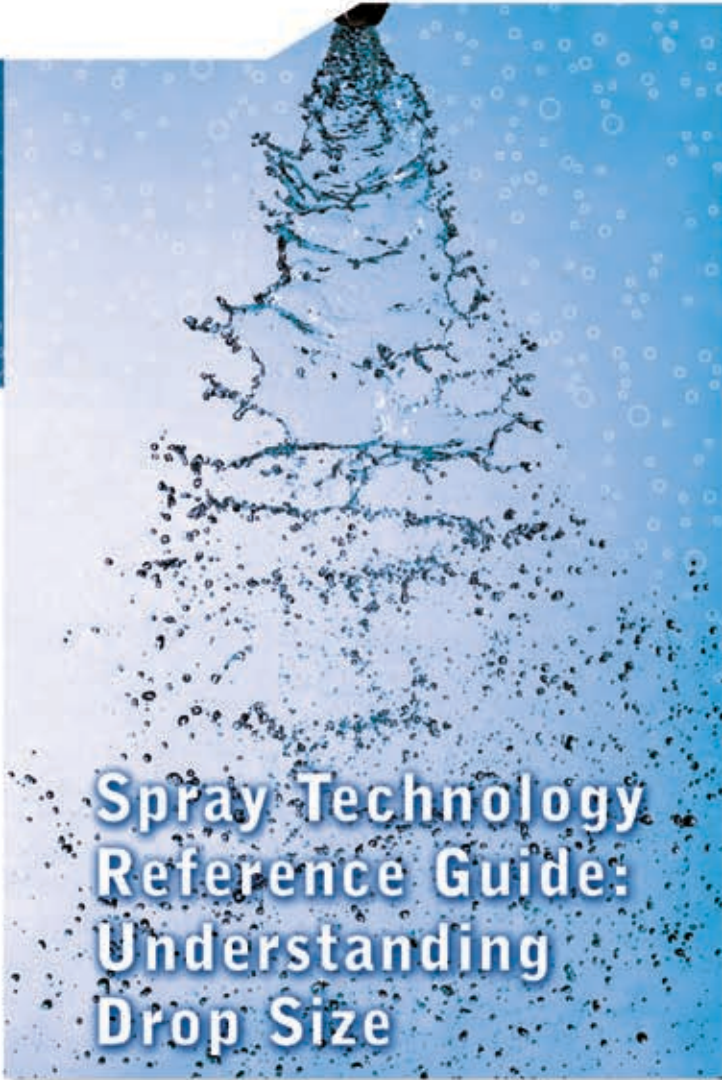




Spray Analysis
and Research Services
A Service of *Spraying Systems Co.*



Spray Technology Reference Guide: Understanding Drop Size

By *Rudolf J. Schick*
Spraying Systems Co.

Table of Contents

Preface	4
Section 1 — Introduction	5
What is atomization?	5
Understanding drop size	5
Section 2 — Sampling Techniques	6
Spatial technique.....	6
Flux technique.....	6
Section 3 — Drop Size Analyzers	8
Optical imaging analyzers.....	8
Laser diffraction analyzers	9
Optical array probes	10
Phase Doppler particle analyzers (PDPA)	11
Section 4 — Statistics	14
Rosin-Rammler distribution function	14
ASTM® Standard E799-03	14
Lognormal distribution.....	15
Section 5 — General Terminology	16
Section 6 — Terms Related to Drop Population	18
Section 7 — Factors Affecting Drop Size	19
Section 8 — Drop Size Data Forms	25
Section 9 — Practical Considerations for Drop Size Data Use	28
Section 10 — References	33
Organizations	34
Suggested reading	35

Preface

The importance of drop size information has increased considerably during the last decade. Many spray applications such as evaporative cooling, gas conditioning, fire suppression, spray drying and agricultural spraying rely on this information for effective use. It is increasingly important for engineers to understand the basic atomization process and how it is evaluated.

The science and technology of atomization has evolved dramatically as spray applications have become more sophisticated. Major advancements in spray analysis and spray characterization instrumentation have been made. Research and regulatory organizations such as ASTM®, Institute for Liquid Atomization and Spray Systems (ILASS) and ISO are dedicated to the advancement of atomization research and technology. These efforts have been well documented in the proceedings of many conferences and in the publication of drop size related standards.

This booklet is designed to provide engineers with a working knowledge of drop size and related issues. It begins with a brief introduction to atomization and is followed by sections on drop size sampling techniques (methods available for capturing data) and drop size analyzers (methods available for recording data). Sections 4, 5 and 6 discuss the statistics and terminology used in drop size data analysis. Several drop size distribution functions and drop size mean diameter terms are defined and discussed. Factors affecting drop size distribution are discussed in Section 7. Section 8 reviews several forms of drop size data such as graphical and tabular and how data is used.

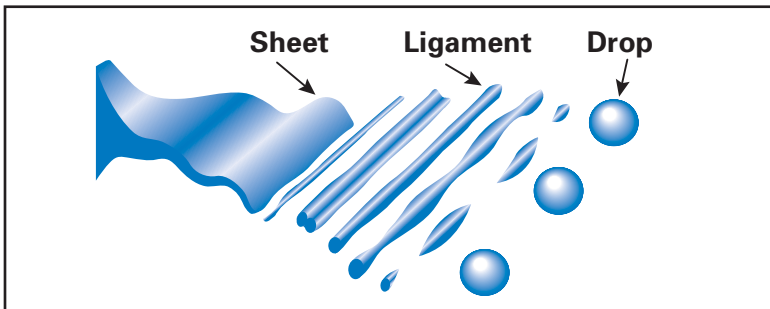
Section 9 addresses practical considerations to take into account when evaluating drop size data. This section examines various aspects of data interpretation to reduce confusion when reviewing reports. Lastly, Section 10 provides a list of reference materials, suggested reading and information on drop size related organizations.

Section 1 – Introduction

Accurate drop size information is an important factor in the overall effectiveness of spray nozzle operation. Drop size is especially of interest in applications such as gas cooling, gas conditioning, fire suppression, spray drying, tablet coating, agricultural spraying and others. Drop size is a by-product of atomization.

What is atomization?

The process of generating drops is called atomization. The process of atomization begins by forcing liquid through a nozzle. The potential energy of the liquid (measured as liquid pressure for hydraulic nozzles or liquid and air pressure for two-fluid nozzles) along with the geometry of the nozzle causes the liquid to emerge as small ligaments. These ligaments then break up further into very small “pieces”, which are usually called drops, droplets or liquid particles.



Each spray provides a range of drop sizes; this range is referred to as a drop size distribution. A simple explanation of this process is the breakup of a liquid as it emerges from an orifice. Various spray nozzles have different shaped orifices and produce various spray patterns such as hollow cone, full cone, flat spray and others. The drop size distribution will be dependent on the nozzle type and will vary significantly from one type to another.

Other factors such as the liquid properties, nozzle capacity, spraying pressure and spray angle can affect drop size too.

Understanding drop size

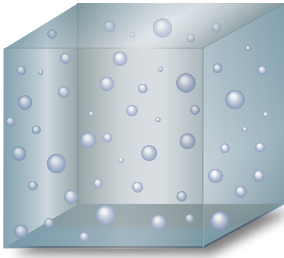
In order to accurately assess and understand drop size data, all of the key variables such as nozzle type, pressure, capacity, liquid properties and spray angle have to be taken into consideration. The drop size testing method should also be fully understood. The measurement techniques, type of drop size analyzer and data analysis and reporting methods all have a strong influence on the results.

Section 2 – Sampling Techniques

There are two different types of drop size sampling techniques: spatial and flux (also known as temporal).

Spatial technique

The spatial technique (i.e., spatial distribution) is implied when a collection of drops occupying a given volume is sampled instantaneously. Generally, spatial measurements are collected with the aid of holographic means such as high-speed photography or light scattering instruments. This type of measurement is sensitive to the number density in each class size and the number of particles per unit volume.

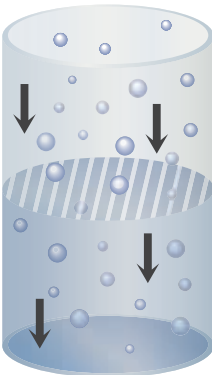


Measurement volume

- Averaged over a finite volume.
- Instantaneous sample.
- Sensitive to number density.

Flux technique

The flux technique (i.e., flux distribution) is when individual drops pass through the cross section of a sampling region and are examined during an interval of time. Flux measurements are generally collected by optical instruments that are capable of sensing individual drops. This type of measurement is sensitive to the particle flux.



Measurement cross-section

- Time averaged.
- Sensitive to particle flux.

The sampling technique is critical for understanding drop size data. Typically, nozzles measured using the spatial technique will report drops smaller on average than nozzles measured using the flux technique. When comparing data from different sources, identify the differences in sampling techniques. This should help resolve many data discrepancies.

The flux distribution may be transformed to a spatial distribution by dividing the number of samples in each class size by the average velocity of the drops in that size class. If all drops in a spray are moving at the same velocity, the flux and spatial distributions are identical. However, the spray will generally exhibit differences in drop velocities that vary from class size to class size. In addition, these differences depend on the type of nozzle, capacity and spraying pressure. The table below lists the Volume Median Diameter (VMD or $D_{v0.5}$) in micrometers (microns or μm) for a single nozzle at identical conditions using both flux and spatial samples.

Volume Median Diameter	
Flux	Spatial
650 μm	530 μm

The sampling technique used can also be application-driven. For example, gas conditioning, cooling or similar processes would be better served with a spatial sampling technique. In applications requiring accurate spray deposition such as painting and agricultural spraying, a flux sampling technique would be more appropriate. Flux methods are more sensitive to individual drop sizes and velocity and provide the additional detail required by some applications.

Section 3 — Drop Size Analyzers

There are many drop size analyzers available. Most of these use optical methods to characterize sprays. Optical methods fall into two main categories: imaging and non-imaging. Imaging includes photography and holography. Non-imaging methods can be subdivided into two classes, those that measure a large number of drops simultaneously (ensemble) and those that count and size individual drops one at a time (single particle counters). Optical analyzers are typically non-intrusive and do not influence the spray behavior during testing.

Since repeatable test results are essential in comparing drop size data, proper testing procedures must be followed. Testing variables must be factored into the results, including the analyzer's limitations.

The following is an overview of testing procedures and the most popular drop size analyzers.

Optical imaging analyzers

Optical imaging analyzers incorporate the spatial measurement technique. These analyzers consist of a light source (typically a strobe light or laser), video camera and computer. The light is used to illuminate the spray; which is recorded using the video camera. The image is then scanned and the drops are sized and separated into different classes. Sources of error early in the development of this device included blurring, depth of field variations and improper sample size. These error sources have been recognized and corrected.

This type of analyzer is still in use. Initially, availability of these instruments was limited and prevented researchers and other interested members of the drop size analysis community from verifying data from different sources and comparing performance from similar nozzle designs. However, the number of instruments now available has increased and validation of results is now possible. The measurement range of these instruments is 1 to unlimited μm with the system optics determining the upper range. A schematic of a typical optical imaging analyzer is shown in figure 1.

Optical imaging analyzer instrument manufacturers include:

- Oxford Laser, Inc., Didcot, United Kingdom (<http://www.oxfordlasers.com>)
- LaVision GmbH, Goettingen, Germany (<http://www.lavision.com>)

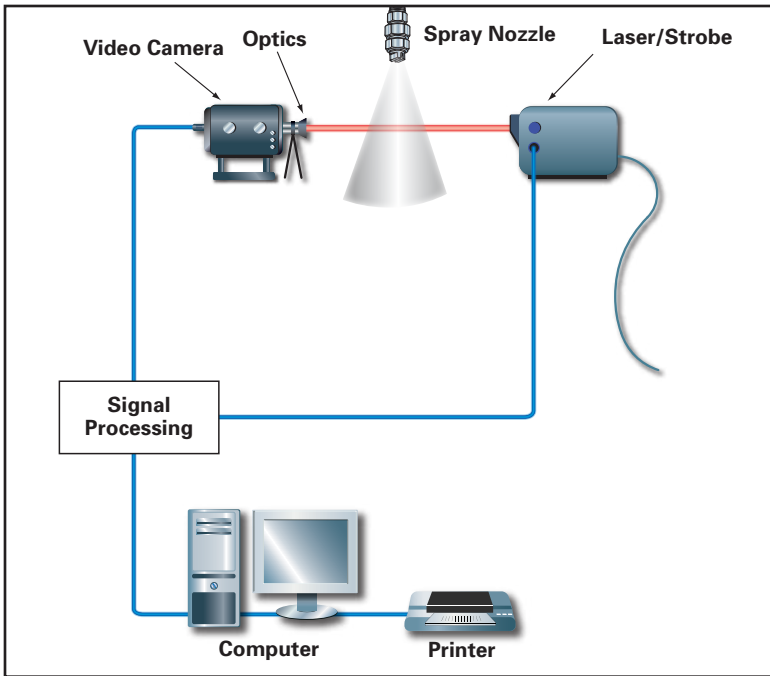


Figure 1. Optical imaging analyzer.

Laser diffraction analyzers

Laser diffraction analyzers are also spatial sampling devices but fall into the non-imaging (ensemble) category. These analyzers consist of a transmitter, receiver and computer. The technique is based on measuring the scattered light intensity caused by the drops as they pass through the analyzer sampling area.

The scattered light intensity is measured using a series of semicircular photo-diodes housed in the receiver unit. A curve-fitting program is used to convert the light intensity distribution into any of several empirical drop size distribution functions. The range of instruments using this technique is 1.2 to 1,800 μm , although recently some manufacturers have increased the measurement range up to 3,000 μm .

This instrument is best suited for measuring small capacity two-fluid, hydraulic and flat spray nozzles and is useful for comparisons and quick evaluation of prototype nozzles. The most serious limitation of this technique is known as multiple scattering. Multiple scattering occurs when spray densities are too high resulting in the light being scattered by multiple drops before reaching the detector. This introduces errors in computing the drop size distribution.

The most common laser diffraction instrument in use today is the Malvern analyzer. A schematic of the Malvern analyzer is shown in figure 2.

Laser diffraction instrument manufacturers include:

- Malvern Instruments Ltd., Worcestershire, United Kingdom (<http://www.malvern.co.uk>)
- Sympatec GmbH, Clausthal-Zellerfeld, Germany (<http://www.sympatec.com>)

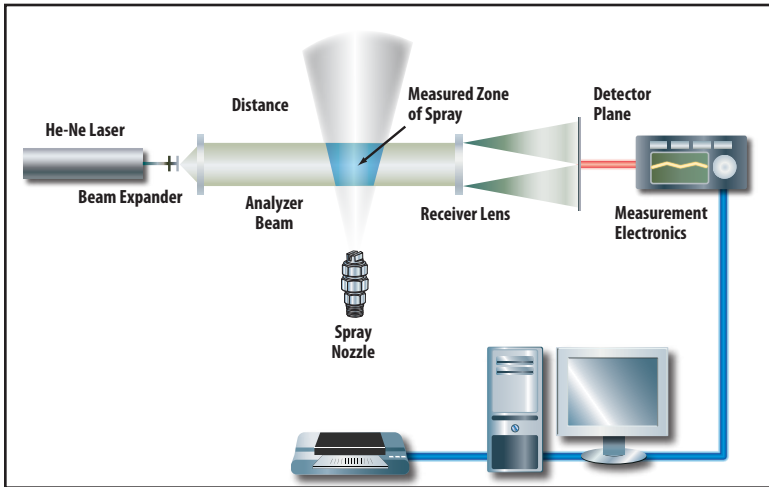


Figure 2. Laser diffraction analyzer.

Optical array probes

Optical array probes are flux sampling instruments and fall into the non-imaging (single particle counter) category. They consist of a light source (low-power laser beam), photo-diode array and computer. As the drops pass through the sampling plane, they are sized and counted, providing information that can be used to determine velocity. The data collection is based on measuring the amount of laser light shadowed by the drops passing through the sampling region.

A data analysis routine is needed to convert the raw drop count into a meaningful drop size distribution. The typical measurement range for these probes can vary from 100 to 12,400 μm . These instruments are best suited for large capacity nozzles. A schematic of the PMS-OAP probe is shown in figure 3.

The most common optical array probe in use is the PMS-OAP:

- Particle Measuring Systems, Boulder, CO (<http://www.particlemeasuringsystems.com>)

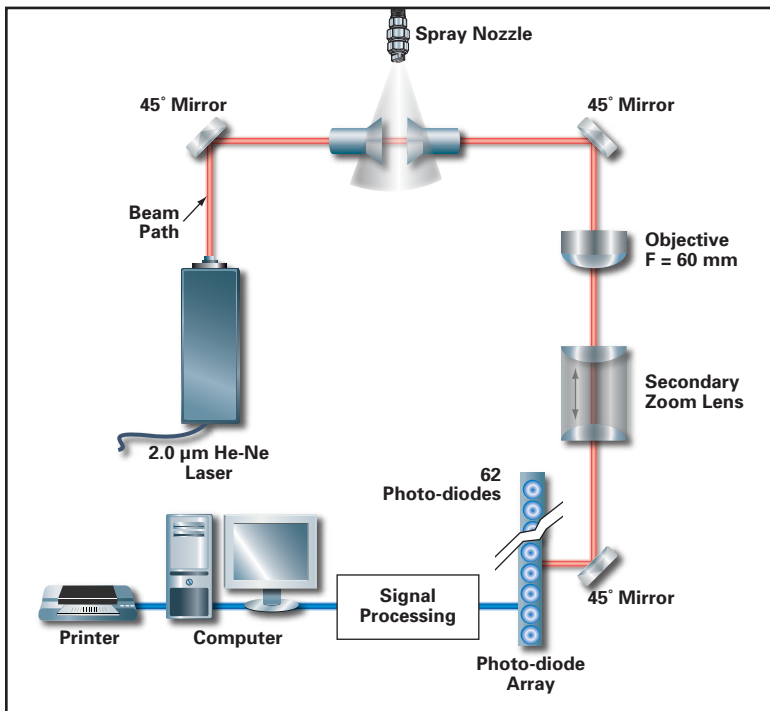


Figure 3. Optical array probe.

Phase Doppler particle analyzers (PDPA)

PDPA are flux sampling instruments and fall into the non-imaging (single particle counter) category. These analyzers consist of a transmitter, receiver, signal processor and computer. The PDPA uses a low-power laser that is split into two beams or four beams for a 2-dimensional system. By utilizing a beam splitter and frequency module; these laser beams intersect again at a point referred to as the probe volume. When a drop passes through the probe volume, the scattered light forms an interference fringe pattern.

The scattered interference sweeps past the receiver unit at the Doppler difference frequency, which is proportional to the drop velocity. The spatial frequency of the fringe pattern is inversely proportional to the drop diameter. A data analysis routine is used to convert the raw drop count into a meaningful drop size distribution. The PDPA measures sizes in the 0.5 to 10,000 μm range using various optical configurations.

The PDPA is best suited for two-fluid, hydraulic and flat spray nozzles in every capacity. It is ideal for complete spray evaluation and where drop velocities are required. A schematic of the PDPA is shown in figure 4.

There are several manufacturers of Phase Doppler analyzers:

- Artium Technologies, Inc., Sunnyvale, CA (<http://www.artium.com>)
- Dantec Dynamics A/S, Skovlunde, Denmark (<http://www.dantecdynamics.com>)
- TSI Incorporated, Shoreview, MN (<http://www.tsi.com>)

Each analyzer is best suited for specific types of testing. Some overlap in measurement range may be present between these instruments. However, it is virtually impossible to compare data from these different

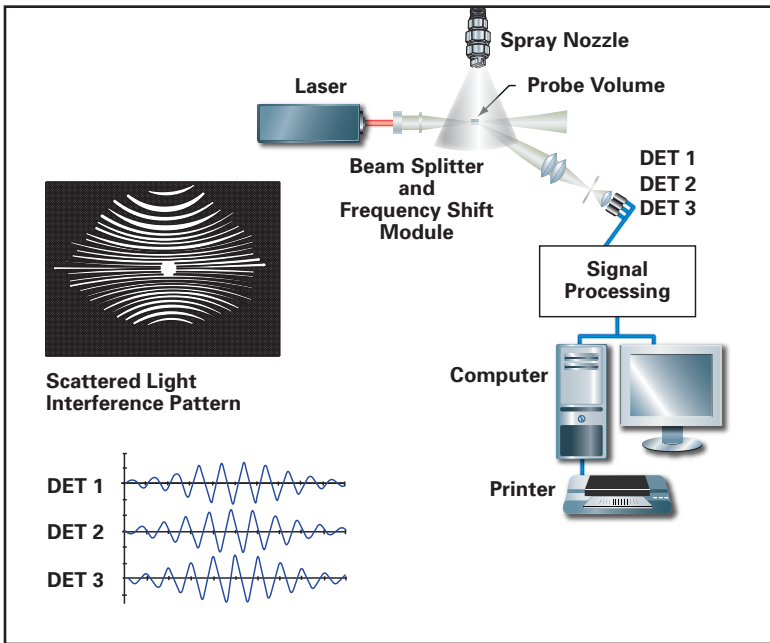


Figure 4. Phase Doppler analyzer.

instruments without a clear understanding of the test conditions and methodology.

Similarly, it is very difficult to compare data from various nozzle manufacturers even when the same type of instrument was used, because optical configuration and data sampling methods might differ.

In addition, improper calibration and maintenance may impact results. Properly scheduled calibration tests are important, particularly in laboratories where many researchers use the equipment.

Section 4 – Statistics

Drop size analyzers collect and record data that is typically in the form of number count per class size. The data is arranged into a mathematical representation referred to as a *drop size distribution*. The mathematical representation is most often dependent on the analyzer used. Recently, however, some analyzer manufacturers have allowed the user to select from a list of distribution functions rather than a default drop size distribution function.

Some of the most common drop size distribution functions used in industry are the Rosin-Rammler⁽¹⁾ distribution function and the ASTM[®] Standard E799-03⁽²⁾ analysis and Lognormal distribution.

Rosin-Rammler distribution function

$$F(D) = 1 - \exp \left[- \left(\frac{D}{\bar{X}} \right)^N \right]$$

The Rosin-Rammler distribution function is the default function for the Malvern analyzer. The (\bar{X} and N) parameters obtained from the measurement are used in this equation to calculate the distribution and the characteristic or mean diameters.

$$d_{pq}^{(p-q)} = \left[\frac{\sum N_i d_i^p}{\sum N_i d_i^q} \right]$$

ASTM Standard E799-03

The ASTM Standard E799-03 is best suited for use with analyzers that are classified as single particle counters such as the PMS-OAP and PDPA. This standard is used to classify the drop counts/diameters and also to calculate the distribution and the characteristic or mean diameters.

There are many other drop size distributions that are often used in industry. See Suggested reading for more information.

Lognormal distribution

A variable X is lognormally distributed if $Y = \text{LN}(X)$ is normally distributed with “LN” denoting the natural logarithm. The general formula for the probability density function of the lognormal distribution is where θ is the shape parameter, σ is the location parameter and m is the scale parameter. The case where $\theta = 0$ and $m = 1$ is called the standard lognormal distribution. The case where $\theta = 0$ is called the 2-parameter lognormal distribution.

$$f(\chi) = \frac{e^{-((\ln((\chi-\theta)/m))^2/(2\sigma^2))}}{(\chi - \theta) \sigma \sqrt{2\pi}} \quad \chi \geq \theta; m, \sigma > 0$$

The equation for the standard lognormal distribution is:

$$f(\chi) = \frac{e^{-((\ln \chi)^2/2\sigma^2)}}{\chi \sigma \sqrt{2\pi}} \quad \chi \geq 0; \sigma > 0$$

Regardless of what drop size distribution function is used, they all essentially perform the same task. The result is a mathematical drop size distribution from which a collection of characteristic or mean diameters can be extracted. These diameters are single values that express the various mean sizes in the spray. Drop diameters are usually expressed in micrometers (microns or μm). One micrometer equals 1/25,400 inch (0.001 mm).

Section 5 – General Terminology

Terminology is often the major source of discrepancy and confusion in understanding drop size. The mean and characteristic diameters are the diameters extracted from the drop size distribution (see figure 5). To compare the drop size from one nozzle to another, the same diameters have to be used as the source of comparison. For example, one cannot compare the $D_{V0.5}$ from one nozzle to the D_{32} from another nozzle. The following lists the most popular mean and characteristic diameters, definitions and most appropriate use. Drop size terminology can be found in ASTM® standard E1620-97^(1,3).

$D_{V0.5}$: Volume Median Diameter (also known as VMD or MVD). A means of expressing drop size in terms of the volume of liquid sprayed. The VMD is a value where 50% of the total volume (or mass) of liquid sprayed is made up of drops with diameters larger than the median value and 50% smaller than the median value. This is best used for comparing the average drop size from various analyzers.

$D_{V0.1}$: A value where 10% of the total volume (or mass) of liquid sprayed is made up of drops with diameters smaller or equal to this value. This diameter is best suited to evaluate drift potential of individual drops.

D_{min} : The minimum drop size by volume (or mass) present in the spray. This diameter is also used to evaluate the drift potential of individual drops.

$D_{V0.9}$: A value where 90% of the total volume (or mass) of liquid sprayed is made up of drops with diameters smaller or equal to this value. This measurement is best suited when complete evaporation of the spray is required.

D_{max} : The maximum drop size by volume (or mass) present in the spray. This diameter is also used when complete evaporation of the spray is required.

D_{32} : Sauter Mean Diameter (also known as SMD) is a means of expressing the fineness of a spray in terms of the surface area produced by the spray. SMD is the diameter of a drop having the same volume to surface area ratio as the total volume of all the drops to the total surface area of all the drops. This diameter is best suited to calculate the efficiency and mass transfer rates in chemical reactions.

D_{10} : Arithmetic mean diameter. This diameter is best suited for calculating evaporation rates.

D_{20} : Surface mean diameter. This diameter is best suited for surface controlling applications such as absorption.

D₃₀: Volume mean diameter. This diameter is best suited for volume controlling applications such as hydrology.

D₂₁: Surface mean diameter. This diameter is best suited for absorption studies.

D₃₁: Mean evaporative diameter. This diameter is best suited for evaporation and molecular diffusion studies.

D₄₃: Herdan diameter. This diameter is best suited for combustion studies.

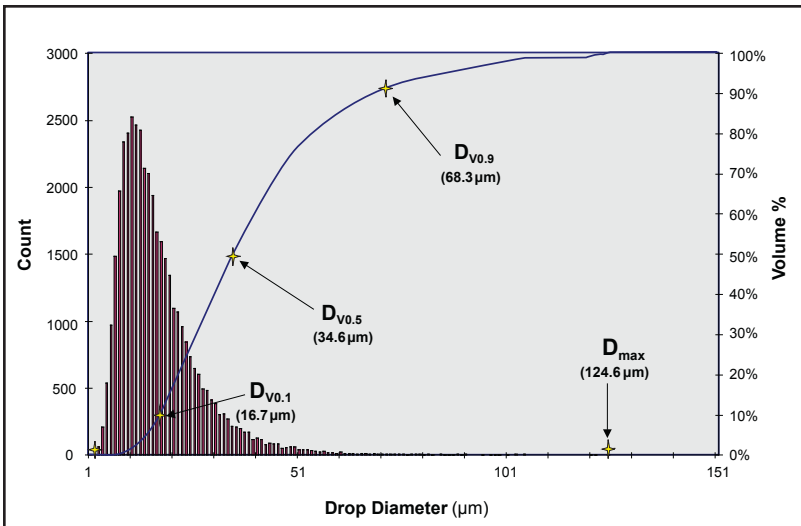


Figure 5. Typical drop size distribution.

Section 6 – Terms Related to Drop Population

Drop size distribution: The size distribution of drops present in a spray sample. This distribution is typically expressed by the size vs. the cumulative volume percent.

Flux: The number of drops flowing through a given plane area per unit time.

Flux-sensitive: A sampling process where the magnitude measured responds to the traffic of drops through the sampling region.

Flux/temporal size distribution: The size distribution of drops passing through a planar sampling zone during a given interval of time, wherein individual drops are counted and sized.

Global: Indicates measurements or observations of a total dispersion of drops (e.g., a sample representative of an entire liquid spray).

Local: Indicates measurements or observations of a small part of a larger region of interest.

Number density: The number of drops contained in a specified volume of space at a given instant.

Relative Span Factor (RSF): A dimensionless parameter indicative of the uniformity of the drop size distribution. RSF is defined as:

$$\frac{D_{V0.9} - D_{V0.1}}{D_{V0.5}}$$

Representative sample: A sample containing enough measured elements that the effect of random fluctuations is acceptably small.

Spatial averaging: The combination of drop size distributions for regions or locations within a liquid dispersion into a distribution representative of a larger sampling region.

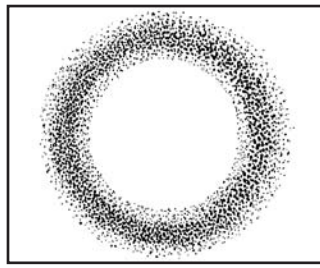
Spatial resolution: The size and physical separation of drop samples relative to the total region of interest, taking into account the magnitude of drop size variations within the region.

Section 7 – Factors Affecting Drop Size

Drop size and drop size uniformity will vary based on several factors: characteristics of the solution; the solution viscosity; the spray nozzle design; the flow through the spray nozzle and the air pressure if two-fluid nozzles are being used.

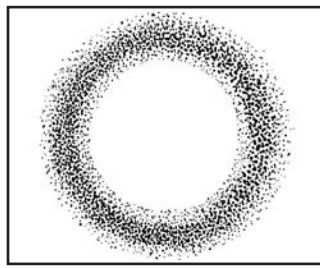
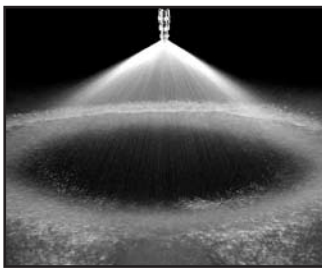
Nozzle type: Typically, full cone nozzles have the largest drop size followed by flat spray and hollow cone nozzles. This trend applies equally to hydraulic and air assisted nozzles, however, air assisted nozzles provide very fine drops that are smaller in size than traditional hydraulic nozzles.

Hollow cone nozzle (whirlchamber-type)



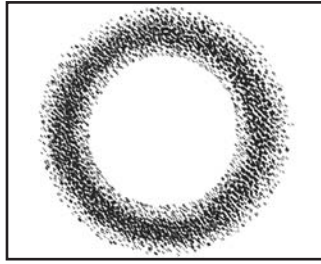
Extensive range of capacities and drop sizes makes the hollow cone nozzle useful for a variety of applications where a combination of small drop size and capacity is required.

Hollow cone nozzle (deflected-type)



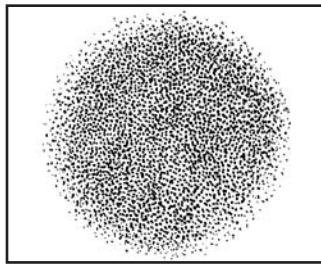
Hollow cone pattern with small drops.

Hollow cone nozzle (spiral-type)



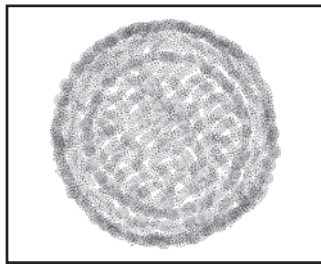
Hollow cone pattern with slightly coarser drops.

Full cone nozzle



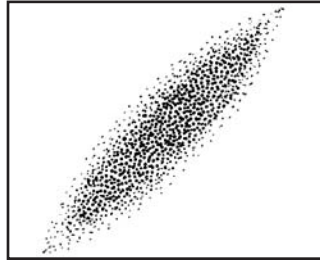
Uniform, round and full spray pattern with medium-to-large sized drops.

Full cone nozzle (spiral-type)



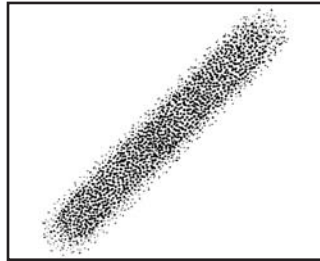
Full cone pattern with relatively coarser drops.

Flat spray nozzle (tapered)



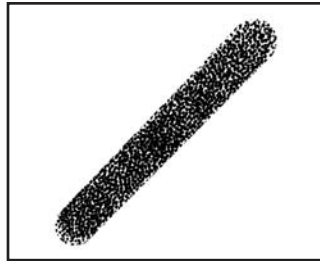
Tapered edge flat spray pattern with medium-sized drops.

Flat spray nozzle (even)



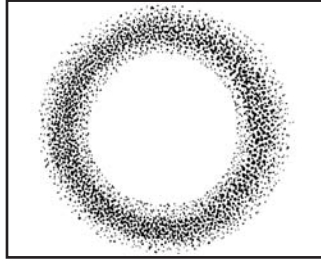
Thin rectangular pattern produces medium-sized drops.

Flat spray nozzle (deflected-type)



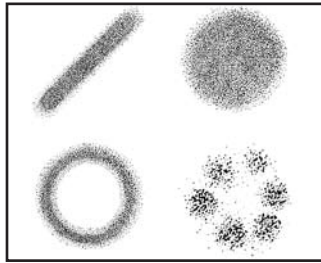
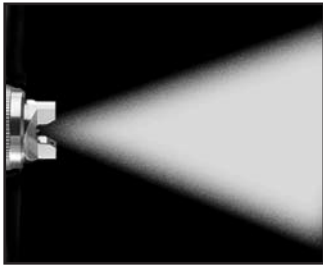
Large free passage design reduces clogging and produces medium-sized drops.

Hydraulic atomizing nozzle (fine mist)



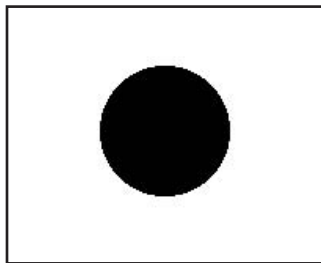
Low capacity spray producing small drops in a hollow cone pattern.

Two-fluid and air assisted nozzles



Atomization produces small drop sizes using a combination of air and liquid pressures.

Solid stream nozzle



*A solid jet of liquid. No atomization occurs.
(For illustrative purposes only.)*

Flow rate: Flow rate has a direct relation to drop size. An increase in flow rate will increase the drop size; similarly a decrease in flow rate will decrease drop size.

Example: A 250 gpm (946 l/min) hollow cone nozzle at 10 psi (0.7 bar) has a *larger* drop size than a 225 gpm (852 l/min) hollow cone at 10 psi (0.7 bar), similarly a 120 gpm (454 l/min) full cone nozzle at 7 psi (0.5 bar) has a *smaller* drop size than a 160 gpm (606 l/min) full cone nozzle at the same pressure.

Pressure: Pressure has an inverse relationship effect on drop size. An increase in pressure will reduce the drop size. A reduction in pressure will increase the drop size.

Example: A 0.5 gpm (1.9 l/min) flat spray nozzle has a *larger* drop size at 20 psi (1.4 bar) than at 50 psi (3.5 bar), similarly a 250 gpm (946 l/min) spiral nozzle has a *smaller* drop size at 15 psi (1.0 bar) than at 10 psi (0.7 bar).

Spray angle: Spray angle has an inverse relationship effect on drop size. An increase in spray angle will reduce the drop size. A reduction in spray angle will increase the drop size.

Example: A 1 gpm (3.8 l/min) flat spray nozzle with a 50° spray angle has a *larger* drop size than a 1 gpm (3.8 l/min) flat spray nozzle with a 110° spray angle.

Liquid properties: Viscosity and surface tension increase the amount of energy required to atomize the spray. An increase in any of these properties will typically increase the drop size.

Viscosity: The property of a liquid that presents resistance to flow due to the existence of internal friction within the fluid.

An increase in viscosity:

- Decreases flow rate.
- Creates heavy edges.
- Requires a higher minimum pressure to maintain adequate spray angle/coverage.
- Increases capacity.
- Increases drop size.

Surface tension: The property of a liquid by virtue of which the surface molecules exhibit a strong inward attraction, thus forming an elastic skin which tends to contract to the minimum area.

An increase in surface tension:

- Increases the minimum operating pressure.
- Decreases spray angle.
- Increases drop size.

Specific gravity: A liquid's density relative to the density of water — typically measured at 60°F (16°C) where its density is 64.4 lb/ft³ (0.9991 g/cm³). Higher specific gravity means lower capacity and lower specific gravity allows higher capacity.

Section 8 — Drop Size Data Forms

Drop size data is published or reported in many forms. The most common forms are characteristic diameter (VMD/SMD) reports and graphs and drop size distributions (graphical and tabular). Depending on the intended use of the drop size, some data forms could be more useful than others. The following is a guide for the suggested use of each data form.

VMD/SMD report: A tabular representation of the requested drop size information. These reports will often list the VMD or SMD of specific nozzles at specific pressures or flow rate conditions. This data is best used to compare the drop size from one nozzle to another at specific operating conditions.

VMD / SMD Report			
Nozzle ID	Pressure (psi) Water Air	Flow Rate (gpm)	Volume Median Diameter (μm)
Hollow Cone Nozzle	60 (4.1 bar)	0.84 (3.2 l/min)	490
Two-fluid Nozzle	40 (2.8 bar)	0.47 (1.8 l/min)	120
Two-fluid Nozzle	40 (2.8 bar)	0.84 (3.2 l/min)	170

VMD/SMD graphs: A graphical representation of the requested drop size information. This will often contain several nozzles on the same graph. The representation is VMD or SMD plotted against requested pressure or flow rate range. See figures 6 and 7 on the following page. This type of data is best used to illustrate the effect of increased pressure or flow rate on drop size.

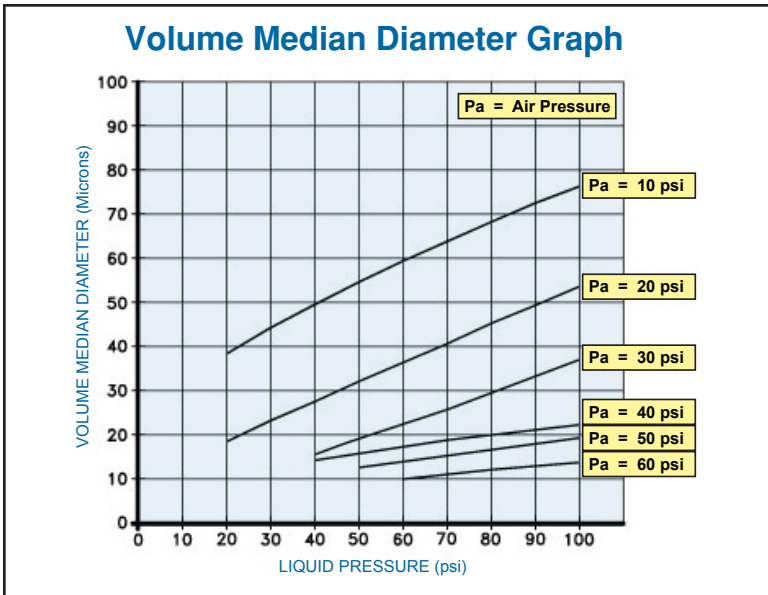


Figure 6. Pressure expressed in psi.

Drop size distributions: A tabular or graphical representation of the

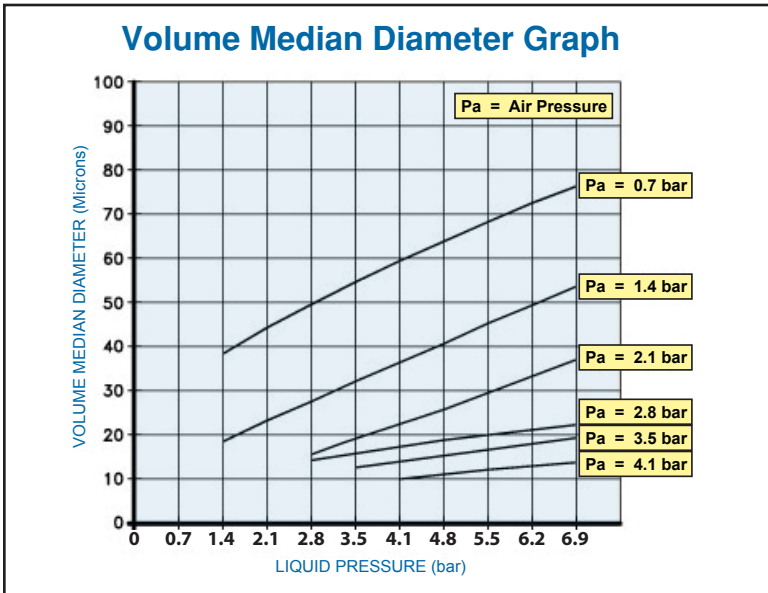


Figure 7. Pressure expressed in bar.

drop size distribution of a particular nozzle at a specific operating condition. The tabular data form will typically list the analyzer used, sampling method and data processing criteria⁽⁴⁾. Also included are the cumulative volume distribution, the percent count for each size class and the characteristic diameters. The graphical data form will typically include all the information included on the tabular form, however, the cumulative volume percent vs. drop size is represented with a graph. This type of data is best used to study the complete drop size distribution of a spray. See figure 8.

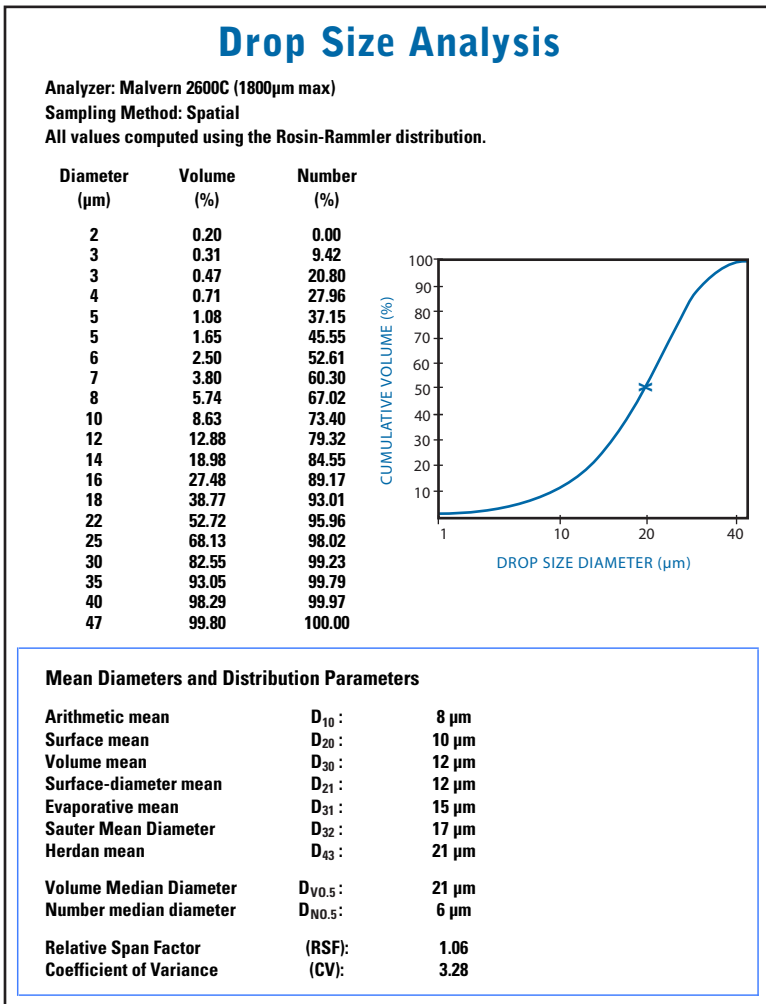


Figure 8.

Section 9 — Practical Considerations for Drop Size Data Use

Drop size data not only depends on many variables but is subject to interpretation as well. The following are some suggested guidelines to facilitate understanding drop size data and use it effectively.

Data collection repeatability and accuracy: A drop size test is said to be repeatable if the data from individual tests does not deviate by more than $\pm 6\%$. This figure could be larger for nozzles with a non-uniform surface finish such as silicone carbide or ceramics. In other words, if a test result indicates a VMD of $100\ \mu\text{m}$; another test with results ranging from 94 to $106\ \mu\text{m}$ can be considered identical.

Instrumentation and reporting bias: While instrumentation and reporting bias have been discussed, its importance to those responsible for evaluating nozzle performance and making recommendations is significant. When evaluating data, particularly from different sources, it is extremely important to know the type of instrument and range used, the sampling technique and the percent volume for each size class in order to make valid data comparisons.

Relative Span Factor (RSF): Comparing drop size distributions from alternate nozzles can be confusing. RSF reduces the distribution to a single number. This parameter is indicative of the uniformity of the drop size distribution. The closer this number is to 1, the more uniform the spray will be, i.e., tightest distribution, smallest variance from D_{max} to D_{min} . RSF provides a practical means for comparing various drop size distributions and should be used when possible.

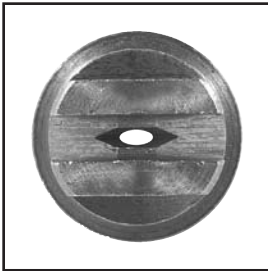
Consider the application: Select the drop size mean diameter of interest that is best suited for the application. If the objective is to simply compare the drop size of alternate nozzles, then the VMD/SMD report should suffice. More elaborate information such as D_{max} , D_{min} and others should be used when more information on drop evaporation is required.

Liquid properties: Generally drop size data supplied from nozzle manufacturers is based on spraying water under laboratory conditions. The effect of liquid properties should be understood and accounted for when selecting a nozzle for a process that is drop size sensitive.

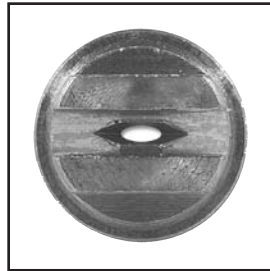
Nozzle wear: Nozzle wear has an effect on nozzle performance. Typically, the spray appearance deteriorates and flow rate and drop

size increase. There will be a difference in drop size between a new nozzle and one that has been in service, so watch for these symptoms:

Flow rate changes: In all nozzles, the flow rate will increase as the surfaces of the orifice and/or internal vane or core begins to deteriorate. Increased flow rates or lower spraying pressures may also result in larger drop sizes. However, nozzle tips will show little visible indication of wear so be sure to monitor flow rate to detect changes.






New spray tip.

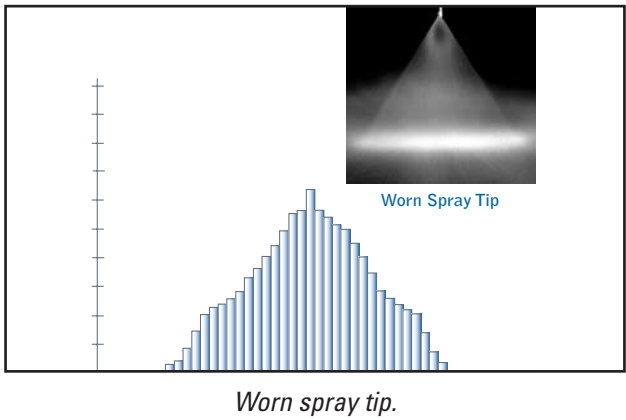
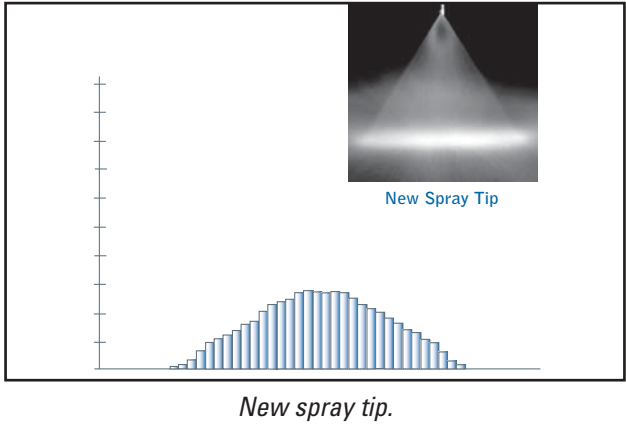


Worn spray tip. This tip sprays 30% over capacity.

Increase in drop size: Nozzle orifice wear causes the liquid flow to increase or the spraying pressure to decrease. Larger drops result and total liquid surface area is reduced.

Actual Drop Sizes			
One inch = 25,400 μm			
One millimeter = 1,000 μm	500 μm	1,200 μm	5,500 μm
μm = micrometers			

Deterioration of spray pattern quality: In some cases, spray nozzle wear can be detected since the spray pattern will become streaky or heavy edges/areas appear. However, in other cases, the spray pattern looks fine. The charts below show the difference using spray collection tubes. The worn tip is spraying 30% over capacity.



Lowered spray impact: Spray impact is lowered since worn nozzles operate at lower pressures.

The following equation can be used to calculate total theoretical spray impact.

$$I = K \times Q \times \sqrt{P}$$

where

I: Total Theoretical spray impact

K: Constant

Q: Flow rate

P: Liquid pressure

I	pounds	kilograms
K	0.0526	0.024
Q	gpm	l/min
P	psi	kg/cm ²

Erosion and wear: Gradual removal of the nozzle material causes the orifice and internal flow passages to enlarge or become distorted. The spray pattern may become irregular and the drops larger.



New



Excessive wear

Corrosion: Nozzle material may break down due to the chemical action of the liquid being sprayed or environment. Even small amounts of wear will negatively impact drop size and uniformity.



New



Corroded

Caking or bearding: Liquid evaporation can cause material to build up on the inside or outer edges of the nozzle orifice. The layer of dried solids obstructs the orifice or internal flow passage and compromises drop size and spray performance.



New



Caked

Clogging: Unwanted solid particles can block the inside of the orifice. Flow is restricted and spray pattern uniformity disturbed.



Clean nozzle



Clogged nozzle

Maintaining spray integrity (or maintaining spray performance):

Though spray nozzle wear and the related performance changes are inevitable, they can be effectively managed. Frequent observation and testing of spray nozzle performance is often necessary in spray applications where drop size is critical. Manual pressure and flow adjustments can often be made to keep nozzles operating as desired even after initial wear is detected. For more information on establishing a proactive nozzle maintenance plan, see Spraying Systems Co.'s Technical Manual 410, *Optimizing Your Spray System*.

It's also possible to monitor spray system performance and maintain spray integrity automatically. Spray controllers programmed with special algorithms are available to automatically adjust spray pressure and flow as needed to maintain drop size requirements as nozzle wear occurs. These controllers can help keep your system operating at peak efficiency and can significantly extend the useful life of your spray nozzles without compromising your product or process quality.

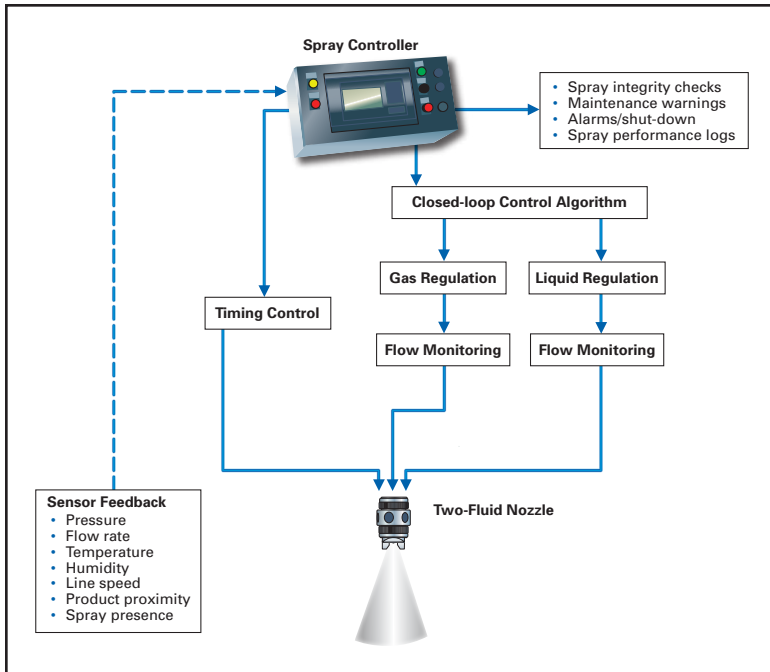


Figure 9. Dedicated spray controllers automate and improve spray operations using closed-loop control algorithms and advanced timing control.

Section 10 – References

1. Marshall, W.R. Atomization and Spray Drying; University of Wisconsin Madison, Department of Chemical Engineering. June 1954: 50-56.
2. E799-03: Standard Practice for Determining Data Criteria and Processing for Liquid Drop Size Analysis. 1996 Annual Book of ASTM® Standards, General Methods and Instrumentation, Volume 14.02: 535-539.
3. E1620-97: Standard Terminology relating to liquid particle statistics. 1996 Annual Book of ASTM Standards, General Methods and Instrumentation, Volume 14.02: 810-812.
4. Jerry Ferrazza, Wes Bartell and Rudolf Schick, Spraying Systems Co. Spray nozzle drop size: How to evaluate measurement techniques and interpret data and reporting procedures. Bulletin 336, (1992).

Organizations

Institute for Liquid Atomization and Spray Systems (ILASS):

ILASS-Americas is an organization of industrialists, researchers, academics and students engaged in professional activities connected with the spraying of liquids. It was established as an outgrowth of the International Conference on Liquid Atomization and Spray Systems (ICLASS). To date ICLASS conferences have been held in Japan (1978, 1988, 2003 and 2006), U.S.A. (1982, 1991 and 2000), Europe (1985 and 1994) and South Korea (1997). The purpose of ILASS is to foster interactions between scientists and engineers in the diverse fields that utilize atomization and spray processes. ILASS-Americas' membership is limited to residents of countries that are part of the American continents.

ILASS-Americas is interdisciplinary but focuses on four topic areas:

1. Transfer processes in which liquids are used, such as spray combustion, pesticide application, spray reactors, dryers, humidifiers, spray coating and spray cooling.
2. Fluid mechanics of sprays, theory and implementation of spray modeling.
3. Instrumentation for the measurement of drop size, velocity, concentration and patternation.
4. The design and operation of liquid atomizers and spray systems.

In addition to providing liaison with the International ILASS organization, a primary activity of ILASS-Americas is its annual conference at which current research on both practical applications and fundamental topics is reported. Extended abstracts of each presentation are compiled in a volume CD that is distributed at the conference and subsequently available to the membership.

Inquiries about ILASS activities may be addressed to:

ILASS-Americas Secretariat
Department of Mechanical Engineering
University of California
Irvine, CA 92717
<http://www.ilass.org>

ASTM® E29.04 Subcommittee:

ASTM Committee E29 on Particle and Spray Characterization was formed in 1969. E29 meets once each year in October with approximately 15 members attending over two days of technical meetings. The Committee, with membership of approximately 70, currently has jurisdiction of about 20 standards published in the Annual Book of ASTM Standards, Volume 14.02. Standard Specification E11

for Wire-Cloth Sieves for Testing Purposes is one of the most widely referenced documents within ASTM.

ASTM®
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
Tel: (610) 832-9585; Fax: (610) 832-9555
<http://www.ASTM.org>

Suggested reading

Atomization and Sprays: Journal of the International Institutes for Liquid Atomization and Spray Systems

While the application and utilization of sprays is not new, there is an increasing scientific interest in atomization — the need to understand the physical structure of liquids under conditions of higher shear rates and interaction with gaseous flow. *Atomization and Sprays*, is an international journal addressing this need through the presentation of high quality research, applications and review papers.

Inquiries about the journal may be sent to:

Atomization and Sprays
Professor Norman Chigier; Editor
Department of Mechanical Engineering
Carnegie Mellon University
5000 Forbes Ave.
Pittsburgh, PA 15213-3815
<http://www.begellhouse.com>

Atomization and Sprays

Arthur H. Lefebvre; West Lafayette, Indiana

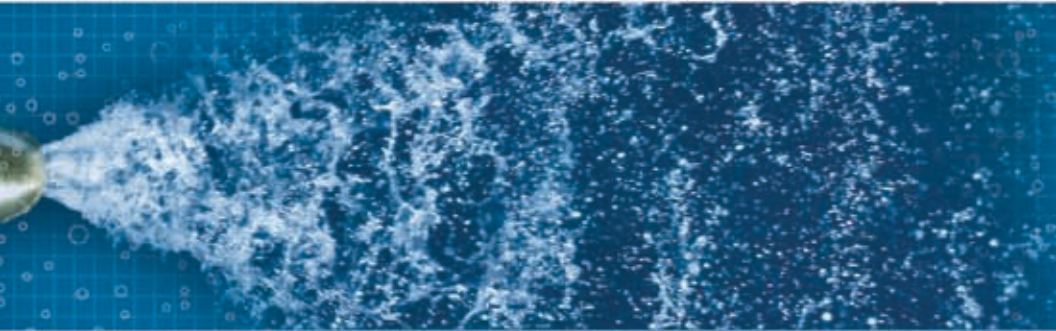
To special order a copy contact Macmillan Publishers New Zealand at <http://www.macmillan.co.nz>

Science and Engineering of Droplets

Huimin Lui; William Andrew Publishing, LLC
Norwich, NY

Fluid Dynamics and Transport of Droplets and Sprays

William A. Sirignano
University of California, Irvine
Cambridge University Press



About the Author

Rudolf J. Schick is Vice President of Spray Analysis and Research Services, a Service of Spraying Systems Co. He is responsible for consulting, testing and research services for industrial applications. In this capacity he oversees the company's spray characterization studies and worldwide drop size laboratories. Mr. Schick is also active in the American Society of Testing and Materials (ASTM) Subcommittee E29 on Particle Size Measurement and serves on the Board of Directors for the Institute of Liquid Atomization and Spray Systems (ILASS). With more than 15 years of experience in the area of spray characterization and research, he is a frequent speaker at technical conferences and an invited lecturer at courses on atomization and sprays. He has also authored numerous white papers and articles on spray characterization.



Spray Analysis and Research Services

P.O. Box 7900, Wheaton, IL 60189-7900 USA

Tel: 1.800.95.SPRAY Intl. Tel: 1.630.665.5000

Fax: 1.888.95.SPRAY Intl. Fax: 1.630.260.7593

www.SprayConsultants.com

A Service of



Spraying Systems Co.[®]
Experts in Spray Technology



Spray
Nozzles



Spray
Control



Spray
Analysis



Spray
Fabrication



Bulletin No. 459B Printed in the U.S.A. ©Spraying Systems Co. 2006