SOME USES OF SPRAY NOZZLES

It is important that the nozzle you select is appropriate for your particular application. Liquid sprays are used in a seemingly endless variety of applications. Some of the more common uses are:

- Surface coating
- Washing
- Product mixing
- Heat transfer
- Humidification
- Chemical reactions
- Product cooling
- Combustion

Each of these broad application areas requires spray nozzles that are specifically designed to achieve the desired results. Parameters such as flow rate, spray angle, spray velocity, and materials of construction are all important elements in the nozzle selection process. This section gives some insight into the issues related to choosing the proper spray nozzle for your application.

TYPES OF SPRAY NOZZLES

Spray nozzles fall into three basic categories:

- Hydraulic
- Air-assisted (pneumatic, two-phase, or twin-fluid)
- Ultrasonic (electrically driven)

Hydraulic nozzles operate on the principle of driving a liquid under pressure through an orifice considerably smaller than the diameter of the feed line. The change from large to small diameter results in a large increase in the liquid's velocity, which in turn causes the stream of liquid exiting the nozzle to become unstable and to break up into small drops. Nozzles operating on this principle are the most commonly used type because of their inherent simplicity.

Air-assisted nozzles utilize high-speed air (or any other gas, including steam) to produce atomization. The liquid, which can be under pressure or drawn into the nozzle by siphoning, is introduced into an air or gas stream and sheared into drops by the energy contained within the gas stream.

This type of atomization produces drops that are finer than can be achieved with hydraulic nozzles. In addition, the range of flow rates over which fine drops can be generated is not dependent on liquid pressure, as is the case with hydraulic nozzles.

A subgroup of air-assisted nozzles utilize ultrasonic energy, in the form of a high pressure chamber that resonates at ultrasonic frequencies, to further reduce the size of the drops introduced into it.

Ultrasonic nozzles that are electrically driven operate on an entirely different principle. A titanium nozzle body vibrates at ultrasonic frequencies, ranging from 25 to 120 kHz, driven by an electronic power generator. Drop size is dependent on the operating frequency. Higher frequencies produce smaller drops. The median diameter of drops at 120 kHz is approximately 17 microns. The atomization process is virtually unpressurized. The liquid is delivered through the nozzle to an atomizing surface where the device's ultrasonic vibrational energy is concentrated. The liquid film created on this surface is ejected as small drops.

The principal features of this technique are finer drops than can be produced by pressure atomization methods, very low drop velocity (about 1/100th the velocity of the spray from hydraulic or air-assisted nozzles), very low flow rate capabilities (as low as a few microliters per minute), narrow spray patterns (as small as 0.070 inches wide), and freedom from clogging.

IMPORTANT NOTES:

- **Our products are continuously evaluated and modified in order to maintain the highest levels of quality and functionality.**
- **The data and product specifications presented in this catalog should be understood only as illustrative of the products we offer. PNR America reserves the right to make changes in the designs or specifications of its products contained herein at any time without notice or obligation.**
- **In the event your application should require absolute adherence to one or more characteristics contained in the specifications, we ask that you obtain written confirmation from PNR America for such requirements before placing an order.**
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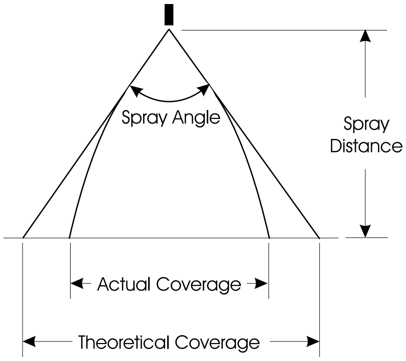
SPRAY COVERAGE

The table demonstrates how the theoretical coverage from a spray nozzle of a specific included angle varies as a function of distance from the nozzle. In practice, the value of coverage deviates from the actual value, particularly at large distances, as shown on the accompanying diagram.

The table illustrates the values obtained using water. More viscous liquids generally produce narrower spray angles than water under the same operating conditions. Surface tension also plays a role in pattern width. Liquids with surface tensions less than water will produce a wider spray than will water.



Calculated Coverage (in inches) for Various Spray Angles as a Function of Distance from a Nozzle's Orifice

Included Spray Angle (degrees)	Distance from Nozzle Orifice (inches)										
	2	**4**	**6**	**8**	**10**	**12**	**15**	**18**	**24**	**30**	**36**
15	0.5	1.1	1.6	2.1	2.6	3.2	3.9	4.7	6.3	7.9	9.5
20	0.7	1.4	2.1	2.8	3.5	4.2	5.3	6.3	8.5	10.6	12.7
25	0.9	1.8	2.7	3.5	4.4	5.3	6.7	8.0	10.6	13.3	16.0
30	1.1	2.1	3.2	4.3	5.4	6.4	8.0	9.6	12.9	16.1	19.3
35	1.3	2.5	3.8	5.0	6.3	7.6	9.5	11.4	15.1	18.9	22.7
40	1.5	2.9	4.4	5.8	7.3	8.7	10.9	13.1	17.5	21.8	26.2
45	1.7	3.3	5.0	6.6	8.3	9.9	12.4	14.9	19.9	24.9	29.8
50	1.9	3.7	5.6	7.5	9.3	11.2	14.0	16.8	22.4	28.0	33.6
55	2.1	4.2	6.2	8.3	10.4	12.5	15.6	18.7	25.0	31.2	37.5
60	2.3	4.6	6.9	9.2	11.5	13.9	17.3	20.8	27.7	34.6	41.6
65	2.5	5.1	7.6	10.2	12.7	15.3	19.1	22.9	30.6	38.2	45.9
70	2.8	5.6	8.4	11.2	14.0	16.8	21.0	25.2	33.6	42.0	50.4
75	3.1	6.1	9.2	12.3	15.3	18.4	23.0	27.6	36.8	46.0	55.2
80	3.4	6.7	10.1	13.4	16.8	20.1	25.2	30.2	40.3	50.3	60.4
85	3.7	7.3	11.0	14.7	18.3	22.0	27.5	33.0	44.0	55.0	66.0
80	3.4	6.7	10.1	13.4	16.8	20.1	25.2	30.2	40.3	50.3	60.4
95	4.4	8.7	13.1	17.5	21.8	26.2	32.7	39.3	52.4	65.5	78.6
100	4.8	9.5	14.3	19.1	23.8	28.6	35.8	42.9	57.2	71.5	85.8
110	5.7	11.4	17.1	22.9	28.6	34.3	42.8	51.4	68.6	85.7	102.8
120	6.9	13.9	20.8	27.7	34.6	41.6	52.0	62.4	83.1	103.9	124.7
130	8.6	17.2	25.7	34.3	42.9	51.5	64.3	77.2	102.9	128.7	154.4

IMPACT

Impact is a measure of the force at which a spray impinges on a surface. One way to express impact quantitatively is in pounds of force per square inch. Its value depends on the nozzle style, the spray angle, the spray pattern distribution and the distance from the nozzle at which impact occurs.

To perform the calculation, we first express the theoretical total impact F (in pounds of force) by the equation:

$$F = 0.0526 \times [\text{flow rate (in gpm) at the operating pressure}] \times \sqrt{\text{operating pressure (psi)}}$$

Then referring to the chart at the right, multiply the total impact, F obtained above times the factor labelled "Percent Impact per sq. in." for a given spray pattern to obtain the actual impact per square inch.

As can be seen from the chart, smaller spray angles result in greater impact. Flat-jet nozzles, which concentrate the spray over a narrow width, produce greater impact than either full-cone or hollow-cone nozzles. Maximum impact is obtained from solid steam nozzles. In that case, the impact is calculated by multiplying the operating pressure (in psi) by 1.9.

Spray Pattern	Spray Angle (degrees)	Impact per sq. in. Factor
Flat Jet	15	0.300
	25	0.180
	35	0.130
	40	0.120
	50	0.100
	65	0.070
	80	0.050
Full Cone	15	0.110
	30	0.025
	50	0.010
	65	0.004
	80	0.002
	100	0.001
Hollow Cone	60	0.020
	80	0.010

FACTORS AFFECTING SPRAY

All the data relating to nozzles contained in this catalog are based on spraying water at standard temperatures.. When spraying liquids other than water, performance is likely to be different. The following presentation describes how various liquid properties and operating conditions affect performance.

CAPACITY

A nozzle's flow rate capacity is primarily dependent of the operating pressure. For hydraulic nozzles, this relationship is straightforward. Capacity **C** increases in direct proportionality to the square root of the operating pressure **P**; that is $\mathbf{C} \sim \mathbf{P}^{1/2}$. For air-assisted nozzles, in which both air pressure and liquid pressure play a role, this simple relationship does not generally hold although the trend of increasing capacity with pressure does.

Capacity is affected by other factors, including the specific gravity and viscosity of the liquid. In general the capacity is related to specific gravity by the equation:

$$\text{Capacity of Liquid} = \text{Capacity of water x} \sqrt{\text{Specific gravity}}$$

Viscosity also plays a role in capacity. Increasing viscosity reduces the turbulence of the rotational flow inside full-cone and hollow-cone nozzles at a given pressure since the internal flow velocity decreases. The net effect is an increase in capacity, although usually, at the expense spray pattern integrity. Other types of nozzles, such as flat-jet nozzles, which do not rely on rotational flow, generally show a decrease in capacity with increasing viscosity, simply because of a lower exit velocity.

VISCOSITY

The effects of viscosity on capacity were discussed in the previous paragraph. Viscosity is a property of liquids that measures the intermolecular attraction between its molecules. The greater this attraction (higher viscosity), the greater will be the resistance for the molecules to move over one another, which is what occurs during liquid flow. High viscosity liquids have a profound effect on the spray pattern. In general the pattern deteriorates and the spray angle narrows considerably compared to the equivalent value for water.

Viscosity is highly temperature dependent. Small increases in a liquid's temperature can dramatically reduce its viscosity.

TEMPERATURE

The liquid temperature is an important factor in nozzle performance since it has a direct bearing on the other elements that affect performance; namely specific gravity, viscosity, and surface tension. The chart below summarizes these effects.

SURFACE TENSION

This property of liquids refers to the behavior of those molecules that lie at or near its surface and are in contact with a different medium (either a solid surface or air.) The surface tension is essentially a force at this interface that minimizes the potential energy of all the molecules involved. Water has a very high surface tension (~73 dynes/cm at 70 °F). Most all other liquids exhibit lower values. The "beading up" of water on a glass surface is indicative of a high surface tension. Adding soap or some other surfactant to water dramatically lowers the surface tension as evidenced by the water now "spreading out" over the glass surface.

Surface tension affects spray angle, drop size, and the operating pressure required. See the chart at the right.

	Increase in Specific Gravity	**Increase in Viscosity**	**Increase in Liquid Temperature**	**Increase in Surface Tension**	**Increase in Operating Pressure**
Pattern Quality	Negligible	Deteriorates	Improves	Negligible	Improves
Capacity	Decreases	(1)	(2)	No Effect	Increases
Spray Angle	Negligible	Decreases	Increases	Decreases	Increases then Decreases
Drop Size	Negligible	Increases	Decreases	Increases	Decreases
Velocity	Decreases	Decreases	Increases	Negligible	Increases
Impact	Negligible	Decreases	Increases	Negligible	Increases
Wear	Negligible	Decreases	(2)	No Effect	Increases

(1) Full-cone and hollow-cone nozzles **Increase**; flat-jet nozzles **Decrease**

(2) Depends on the nature of the liquid and the type of nozzle used

DROP SIZES AND DISTRIBUTIONS

The size of drops in a spray is often a key element in choosing a nozzle for a specific application. For example, many applications require very fine drops, such as humidification or some types of spray coating. Other application require relatively coarse sprays. The study and measurement of drop sizes has become quite important for many industrial applications.

A spray is characterized by what is called a drop size distribution. Simply put, the drop size distribution counts how many drops are there of each drop size produced. Typically, a spray contains a broad range of drop sizes. For example, a nozzle may produce drops ranging in diameter from 200 to 5000 microns. In order to quantify the overall distribution of drops in a spray, it is convenient to define certain parameters referred to as *mean* and *median* diameters.

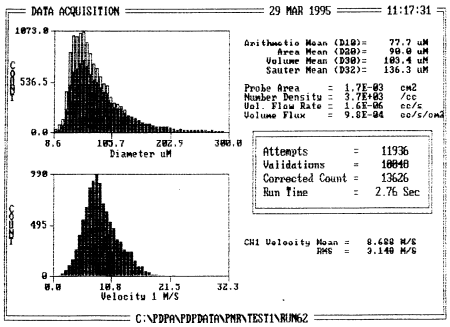
A *mean* drop size is essentially the average size of the drops in a sample. The *median* drop size is the size of that drop for which one-half of the drops in the sample are smaller than that value and the other half are larger. For each of these two definitions, we can attach additional meaning by specifying whether we are talking about drop volume, surface area, or diameter. The upshot of this classification is a series of mean and median diameters defined as follows:

Number Mean Diameter, D_{10}:	The arithmetic mean value of the total number of drops in the sample.	Number Median Diameter, $D_{N0.5}$:	That diameter for which half of the drops in the sample are smaller in diameter than and the other half larger than $D_{N0.5}$.
Surface Mean Diameter, D_{20}:	The diameter of that drop whose surface area is the arithmetic mean of the surface areas for all drops in the sample.	Surface Median Diameter, $D_{S0.5}$:	That diameter for which half of the drops in the sample are smaller in surface area than and the other half larger than $D_{S0.5}$.
Volume Mean Diameter, D_{30}:	The diameter of that drop whose volume is the arithmetic mean of the volume for all drops in the sample.	Volume Median Diameter, $D_{V0.5}$:	That diameter for whichhalf of the drops in the sample are smaller in volume than and the other half larger than $D_{V0.5}$.

In addition to these definitions, there is one other that has particular importance in liquid spray combustion called the Sauter Mean Diameter, D_{32}. The combustion of fuel occurs only at the interface between a drop's surface and the surrounding oxygen. As a consequence, fuel burns best when the drop surface area is maximized and the internal drop volume is minimized. The Sauter mean diameter is defined as:

> The diameter of that drop whose volume to surface area ratio is equal to the arithmetic mean of the volume to surface area ratio calculated for all drops in the sample.

A small Sauter mean drop size infers better combustion efficiency since the surface area is large in relation to the volume or amount of fuel being burned.



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DATA ACQUISITION                29 MAR 1995        11:17:31

Arithmetic Mean (D10)=    77.7 uM
      Area Mean (D20)=    90.0 uM
    Volume Mean (D30)=   103.4 uM
    Sauter Mean (D32)=   136.3 uM

Probe Area     =  1.7E-03   cm2
Number Density =  3.7E+03   /cc
Vol. Flow Rate =  1.6E-06   cc/s
Volume Flux    =  9.8E-04   cc/s/cm2

Attempts        =    11936
Validations     =    10040
Corrected Count =    13626
Run Time        =  2.76 Sec

CH1 Velocity Mean =   8.688 M/S
             RMS  =   3.140 M/S

              C:\PDPA\PDPDATA\PNR\TEST1\RUN62
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PNR America can supply, upon request, test reports pertaining to the performance parameters discussed above, and additional information for all PNR nozzles.

A typical report is shown to the left. It contains the distribution curves for drop diameters and velocities of the nozzle under test, as well as various mean diameters.

The photograph to the right shows one of our test facilities in which drop size distributions and other spray characteristics are being recorded by a laser interferometer. Control parameters, such as flow rates and pressures, are monitored using high quality instrumentation.

INTRODUCTION

Nozzles produce a range of drop sizes as discussed on the previous page. Several factors determine a nozzle's drop size distribution. We have already discussed the effects of material properties on drop size on page 4. In addition, the following factors pay a significant role:

- spray pressure
- nozzle type and design
- flow rate capacity
- spray pattern

Some general comments can be made regarding a nozzle's performance with respect to drop size as follows:

- Drop size is pressure dependent. Lower operating pressures yield larger drops while higher pressures produce smaller drops.
- Air-atomizing nozzles produce the finest drops. In general, full-cone hydraulic nozzles produce the largest drops.
- Within a given series of the same style nozzle, those with the lowest capacities produce the smallest drops.
- Within the family of hydraulic spray nozzles, the finest drops are produced by hollow-cone nozzles.

The table below presents data representative of what can be expected from various types of pressure nozzles operating at selected pressures. The volume median drop diameter, $D_{V0.5}$ is used as the measure of drop size in the table since it is one of the more common parameters cited in the literature.

Nozzle Type	10 psi		40 psi		100 psi	
	Capacity gpm	$D_{v0.5}$ microns	Capacity gpm	$D_{v0.5}$ microns	Capacity gpm	$D_{v0.5}$ microns
Air Atomizing	0.005 0.02	20 100	0.008 8	15 200	12	400
Multiple Orifice Fine Spray	0.22	375	0.03 0.43	110 330	0.05 0.69	110 290
Hollow Cone	0.05 12	360 3400	0.10 24	300 1900	0.16 38	200 1260
Flat Jet	0.05 5	260 4300	0.10 10	220 2500	0.16 16	190 1400
Full Cone	0.10 12	1140 4300	0.19 23	850 2800	0.30 35	500 1720

Actual Drop Sizes