Spray technology is a powerful tool used to achieve higher levels of overall process performance. Strategic decisions in selecting and employing spray technology can yield dramatic wins. Understanding sprays, drop size, and the strengths and characteristics of nozzle types and correctly positioning them are fundamental to the desired process “response” or result.

The selection of a nozzle is a tactical move that influences the outcome, and is certainly more than just “choosing a spray nozzle.” Misconceptions often limit how well we practice the art and science of engineering. Without state-of-the-art knowledge of fundamentals and “rules-of-thumb,” the technology can be misapplied. The intents of this article are to debunk some misconceptions or overgeneralizations that cause unresolved design conflicts and to provide the fundamentals to enable better spray application.

In many applications in the chemical process industries (CPI), sprays determine performance. By creating a large droplet surface area, sprays are used to generate the high rates of heat and mass transfer that is necessary in spray drying, liquid waste incineration, and spray quenching applications. Understanding the subtleties of drop size — a critical parameter in many spray applications — can result in improved designs. There are many pitfalls to avoid in the robust application of spray technology. The details of nozzle installations can make the difference between a problematic and a trouble-free system.

Bringing together a user’s process understanding and a spray nozzle manufacturer’s applications, knowledge from thousands of designs can yield excellent systems. The user needs basic knowledge of spray characteristics and measures to enable this effective communication. An in-depth understanding of the science and technology improves the user’s interaction with the nozzle manufacturer’s technical support organization.

Spray nozzles are applied in a wide variety of process applications with a wide range of criticality. An example of a critical application is the quenching of hot gases where high performance, high reliability, and robustness are required to handle process upsets. A less demanding usage of nozzles is manual pressure washing of equipment. Single-fluid spray nozzles and two-fluid atomizing nozzles account for the vast majority of nozzle use, therefore these are featured here. Several other types of nozzles, notably rotary disk and ultrasonic, have significant uses but are not discussed here.

Drop size considerations

Misconception. Drop size is the critical nozzle performance criteria for all spray applications. Reality. For many process applications, drop size is one metric of performance, especially where heat and mass transfer are required. Evaporation, combustion and gas scrubbing are examples where a smaller drop size is usually an advantage. Figure 1 shows a plot of specific surface area, which is inversely proportional to drop diameter. Large diameter drops normally have a negative effect on combustion and evaporation applications.

Misconception. The smaller the drop size the better. Reality. In process applications requiring vapor-liquid separation, smaller drops can cause serious problems. Smaller drops can be problematic even in mass-transfer operations, such as a spray tower, because small drops are more easily entrained resulting in back mixing and increased stage...
TABLE 1. APPLICATION GUIDE FOR SPRAY DROP SIZE

<table>
<thead>
<tr>
<th>Example application</th>
<th>Descriptor</th>
<th>Size, $D_{50}$-micron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidification, gas turbine</td>
<td>Aerosol or</td>
<td>5 to 30</td>
</tr>
<tr>
<td>power augmentation</td>
<td>fine mist</td>
<td></td>
</tr>
<tr>
<td>Enhanced heat-and-mass</td>
<td>Fine</td>
<td>50 to 500</td>
</tr>
<tr>
<td>transfer (spray drying)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spray tower</td>
<td>Coarse</td>
<td>500 to 1,000</td>
</tr>
<tr>
<td>Flow distribution, tank cleaning</td>
<td>Very coarse</td>
<td>1,000 to 5,000</td>
</tr>
</tbody>
</table>

TABLE 2. CHARACTERISTICS OF RAIN DROPS

<table>
<thead>
<tr>
<th>Size, micron</th>
<th>Terminal velocity, m/s</th>
<th>Drop volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain drops</td>
<td>2.500</td>
<td>6.5</td>
</tr>
<tr>
<td>Mist</td>
<td>75</td>
<td>0.25</td>
</tr>
<tr>
<td>Cloud</td>
<td>15</td>
<td>0.012</td>
</tr>
</tbody>
</table>

FIGURE 1. The drop size varies linearly with the specific surface area and the number of drops.

Sure forces (drag) can distort the shape of a drop, consider for example a rain drop shape, which is a flattened ellipse unlike the typical artistic depiction of a long drop with a tail. Continuing with the rain drop example, the maximum size a rain drop can grow is about 5 mm because the forces on the drop will result in sufficient distortion to break it up. This shows the complex phenomena in something as common as rain. These same physical processes of drop coalescence and internal circulation are important to many processes.

Size distribution. There are several methods of representing size distributions. Figure 2 shows a spray composed of equal volumes of three diameters of drops, diameter $D$, $\frac{1}{4}D$ and $\frac{1}{8}D$. It requires eight drops of $\frac{1}{8}D$ to equal the volume of one droplet of diameter $D$, and 64 droplets of diameter $\frac{1}{8}D$ to have the same volume. The surface area of each is inversely proportional to the diameter. These relationships are simply the result of the geometry of spherical droplets.

For the collection of drops shown in Figure 2, the number average drop size is slightly over $\frac{1}{8}D$; however, taking the average, according to surface area or mass yields significantly different results. For this example a number-average drop size is 0.2877D, while the surface-area average drop size is 0.3836D, the volume-average drop size is 0.6575D, and the Sauter mean diameter (SMD; surface-to-volume ratio) is 0.5833D, as defined in Equation (5). The choice of the type of average results in a dramatically different numerical value.

In a common spray, the ratio of largest-to-smallest drop diameter is about 30, which results in the ratio of drop volume of 27,000. Because of this, a wide range of drop sizes exist in most sprays, and several measures, also referred to as moments, are used to characterize the spray. Figure 3
shows a spray drop-size distribution, expressed as a cumulative volume distribution as a function of drop diameter. For example, at a diameter of 87 microns, 50% of the cumulative volume of the drops that make up the spray is this size or smaller. Therefore, this size is referred to as the $D_{V50}$ size. Similarly, the small and large portions of the spray can be represented by $D_{V10}$ and $D_{V90}$, respectively. These measures might be important for specific spray uses. If entrainment is an issue, the $D_{V10}$ size is a significant measure, but if complete evaporation is required, then $D_{V90}$ is a good measure to evaluate whether the spray can meet the process requirements.

Another common measure of particle size is the relative span (RS), or relative span factor (RSF), defined below, to express the width of the size distribution normalized by the volume median drop size.

$$RS = RSF = \frac{D_{V90} - D_{V10}}{D_{V50}}$$  \hfill (1)

Besides the volume-median and number-median drop size, several other averages are sometimes used based on other weightings. The number median drop size is given by:

$$D_{10} = \frac{\sum D}{m}$$  \hfill (2)

The area mean drop size is given by:

$$D_{20} = \left[ \frac{\sum D^2}{m} \right]^{1/2}$$  \hfill (3)

The volume mean drop size is given by:

$$D_{30} = \left[ \frac{\sum D^3}{m} \right]^{1/3}$$  \hfill (4)

The Sauter mean drop size is given by:

$$D_{32} = \frac{\sum D^2}{\sum D}$$  \hfill (5)

Of these measures of central tendency ("average size"), the volume median (not volume mean) and Sauter mean are the most commonly used moments. The SMD ($D_{20}$ or Sauter mean) is the most frequently used of the moments described in Equations (2) through (5), however the $D_{V50}$ (defined earlier) is more frequently used. The number mean, $D_{10}$, is the least used because it overemphasizes the small drops.

Other spray characteristics are potentially more important for flow distribution applications, for example uniformity of volume flux (patternation). The spray angle and drop velocity are other critical parameters. In some cleaning operations, the spray impact is a more important measure of nozzle performance and drop size is irrelevant. Larger drop sizes and larger $D_{V10}$ are preferred for some distribution applications to reduce the smaller fraction of the spray entrained with the surrounding gas.

**Misconception.** The Sauter mean diameter, is the best measure of drop size for a spray.

**Reality.** A drop with a diameter of the SMD has the same surface-to-volume ratio as for the spray. This diameter is sometimes used when mass transfer is the desired process result. The moment or characteristic diameter most frequently used today is the $D_{V50}$. Weighing the measure of central tendency on the volume, which is equal to mass, removes the bias that is created with number-based weightings. As shown in Figure 3, the three measures of $D_{V50}$, $D_{V10}$ and $D_{V90}$ provide a consistent set of measures of the whole drop-size distribution. The $D_{V90}$ is frequently used as a measure in applications where the large-diameter fraction limits the performance, for example where all of the drops must completely evaporate. As indicated above, where entrainment is a design factor, the $D_{V10}$ is an important measure of the drop size.

**Misconception.** All drop-size-measurement methods result in the same type and quality of data.

**Reality.** Several methods are in com-
Spray pattern considerations

Misconception. The spray nozzle catalog showing spray coverage has all the information needed to design spray coverage.

Reality. Figure 4 shows two definitions of spray angle, the initial emitting angle of the spray just after emerging from the nozzle, and the effective angle of the spray at a specified distance downstream. This downstream distance varies widely depending on the spray usage, from 10 mm to 10 m. Spray coverage is influenced by the motion of the surrounding gas and gravity. Drop trajectory can be modeled based on drag force equations to provide insight on drop motion, evaporation or mass transfer, and heat transfer. This one-way coupling of momentum transferred to the gas flow often suffices for systems where a high degree of accuracy is not required or where the drop density is low. It neglects the gas phase motion induced by the spray. A common example of the effect of the gas motion induced by sprays occurs in a shower stall where the shower curtain, if not properly attached, will be pulled into the stall by the air circulation induced by the spray from the shower.

Simple models usually assume spherical drops and drag coefficients based on solids. For larger drops there is a significant deformation of the drop resulting in increased drag. The liquid circulation induced in the drop may impact the shear and, therefore, the drag. Computational-fluid-dynamics (CFD) models are often used where the drop density is higher and the momentum transferred to the gas phase is important. An example where more detailed modeling may be needed is a spray tower, where the spray causes a large circulation pattern in the gas and this back mixing influences the tower's performance. Normal spray tower design is based upon a countercurrent flow. The back mixing induced by the spray could mean that a back-mixed Aspen analysis would be more accurate than a countercurrent analysis.

Misconception. A solid cone spray pattern is the most effective in process sprays.

Reality. Selection of the spray-pattern is a critical decision, in part, because this influences the drop size. There are several spray-pattern types available, hollow cone, solid cone, flat fan, tapered fan, and so on. These terms qualitatively describe the spatial distribution of the liquid flux produced by the spray. A quantitative description of the spray pattern is provided by the patterson, which is the spatial distribution of liquid flux in terms of volumetric flow per unit area. An
NOZZLE TYPES AND NOZZLE SELECTION

The types of single-fluid nozzles commonly used are, flat-fan spiral, hollow cone or pressure swirl, solid cone. The hydraulic characteristics of these nozzles can be related by Equation (6), derived from the Bernoulli equation. This equation shows that the flow depends on the pressure drop to a power ranging from 0.40 to 0.50. A nozzle can be viewed as a narrowing of the flow passage where the fluid accelerates. Therefore the pressure drop is primarily due to the inertia effect rather than frictional losses. The type of nozzle influences the exponent, and the size of the nozzle influences k. Nozzles with a core that may induce a swirl, as shown in Figure 6, have a lower value of k, while a nozzle without a core has a value of 0.5. This flow characteristic is described in the equations below where k is for a specific nozzle model. The relationship in this equation can be used to describe tabular flow and pressure drop information often found in a spray nozzle’s technical information. Pressure drop is often the independent variable because it is often determined by the supply system. The dependent parameter is the nozzle size or “k” as shown in the rearranged form in Equation (7).

\[ F = k \frac{\Delta P}{\Delta g} \quad (6) \]

\[ k = F \left( \frac{\Delta g}{\Delta P} \right) \quad (7) \]

A basic consideration for selecting any spray nozzle is the constraint of pressure drop or the requirement of flow. This requirement seems obvious, but the most frequent mistake made is to not fully consider the flow characteristic above of a single nozzle or a group of nozzles. Equation (6) provides a simple means to relate flow and pressure drop when the flow is turbulent, that is, when the Reynolds number at the orifice is above 2,300. This is rarely an issue for fluids with a water-like viscosity.

Two-fluid nozzles, using a gas to atomize the liquid, are often used to achieve certain process requirements. The design requirements depend on the specifics of the materials being atomized and the process itself. Two-fluid nozzles have two independent degrees of freedom: gas mass flowrate and liquid mass flowrate. The gas-to-liquid mass ratio (GLR) typically is in the range of 0.1 to 3.0. The primary means of controlling the drop size for a specific nozzle is the gas-to-liquid ratio.

The graph presented in Figure 7 shows a typical relationship between GLR and the drop size. On the right-hand portion of the curve, the drop size is insensitive to changes in GLR, while on the left, modest changes in GLR will have a dramatic impact on the drop size this nozzle produces. The same nozzle can be operated in either mode, depending on the design parameters chosen. Operation with a high GLR tends to result in higher energy consumption due to the larger volume of compressed gas required. Operational constraints and design parameters combine to define the operating range for a specific nozzle. The control system limits on the minimum GLR are often critical to assure a robust design when a minimum drop size is required.

Example of volume flux is a rain rate where 3 in./h is a heavy rain.

Many applications have obvious requirements for a particular spray pattern. For example, a flat-fan spray nozzle is a good choice for applying material on the web of a paper machine or wetting a vertical wall of a vessel. In many process vessels, a solid-cone spray pattern is desirable. Examples include distributing the liquid across a packed bed or a mesh pad for mass transfer or washing. However, the uniformity of the spray may or may not be sufficient for the particular process application.

If uniform coverage is required, the engineering data needed to make a nozzle selection will often be the pattern data described above. At other times, where coverage is not important, but small drop size is critical, a hollow cone may be desirable to achieve a smaller drop size for a given flow and pressure drop. Figure 5 shows common realities of feathered edges, slightly non-symmetrical and non-uniform flux. Pattern measurements are made at a distance that reflects the usage distance.

Misconception. Spray pattern classification is sufficient for selecting nozzles for liquid distribution.

Reality. In many designs, the spray pattern may be one of the important characteristics but certainly not the only one. As discussed previously, terms such as “full cone”, “hollow cone” and “flat spray” provide a qualitative description of the spray. Where the spray pattern is critical to the design, the pattern data for the particular nozzle should be reviewed. Figure 5 is an example of spray pattern data that provides the objective information to compare different potential nozzle choices. Patternation is simply a collection of “rain gauges” often mounted in a linear array across a spray pattern.

Examples where particular types of nozzles are used follows:

- A flat spray is often used for applying materials to a moving web, such as on a paper machine
- A solid-cone spray nozzle is used to distribute a liquid across an area. This may be used to wet a surface, wash a wire-mesh mist eliminator
or distribute liquid across a packing. In applications such as combustion or enhancement of heat or mass transfer, a solid cone nozzle may have no advantage. The selection should be based on the drop size requirements, not on the type of spray nozzle. For flow-distribution applications, it is desirable to have large drops so that a ballistic trajectory is achieved and the smaller drops are readily entrained. This often results in a low design pressure drop typically under 0.5 bar.

Misconception. Spray nozzles make good liquid distributors. Reality. Spray nozzles have been used to distribute liquid across packed beds in distillation towers and tube sheets in heat exchangers. However, when uniform distribution is critical, other options are preferred if they can be practically designed. Even the spray pattern of a full-cone spray nozzle is not uniform with regions of high and low coverage. Overlapping spray patterns also result in areas of high liquid flux. The spray nozzle imparts momentum to the gas, resulting in gas recirculation. This can cause back mixing in the top of a packed tower, increasing the stage height.

If the pressure drop through the heat exchanger is too low, the entrained gas may induce vapor recirculation through the tubes, which can reduce the heat exchanger performance. A third issue is that data on spray nozzle coverage are usually developed in air at ambient conditions. Most plant applications involve gases other than air at pressures other than atmospheric. In these cases, the designer is relying on judgment to adjust the coverage data. Despite these limitations, spray nozzles are used in applications with low coverage rates because other approaches are inadequate at low rates.

Process environment and fluid issues

Misconception. The liquid viscosity is the most important liquid physical property required to specify a nozzle. Reality. This is in part true, and in part false.

Usually, single-fluid nozzles operate in the fully turbulent flow regime where the hydraulic behavior, such as the pressure drop [Equation (6)], is independent of the viscosity. The pressure drop is controlled by the process of accelerating the fluid through the nozzle orifice. Therefore, the fluid density is the most important physical property that influences the nozzle pressure drop, for a given mass flow.

Process fluids can range in viscosity from 0.1 centipoise (cP) to well over 1,000 cP. In this range the spray created is greatly affected by the change in fluid viscosity. Generally, high-viscosity fluids produce larger drop sizes and a larger relative span than fluids with water-like viscosity. Although a power law has been used to describe the effect of viscosity on drop size, this is not suitable for the wide range of fluid properties encountered in process applications. Many of the literature correlations were developed for transportation fuels where the viscosity varies only by an order of magnitude.

Surface tension has a significant impact on the mean drop size. Larger drop sizes are produced with higher surface-tension liquids. In addition, where the process involves a gas other than ambient air, a higher gas density will have a smaller mean drop size.

Misconception. All non-Newtonian fluids are difficult to atomize

Reality. High viscosity Newtonian liquids are more difficult to atomize than water-like liquids. Atomizing nozzles, both single-fluid and two-fluid nozzles expose the liquid to high shear rates, 1,000 to 100,000 s⁻¹. Shear-thinning fluids atomize more easily than Newtonian fluids with a similar low-shear viscosity, because at the high shear rates in the spray nozzle the effective viscosity is lower. The rheology of the fluid is critical to predict nozzle performance. Often, testing is required to evaluate the performance for complex fluids, slurries and liquids that exhibit non-Newtonian characteristics. At high concentrations of solid particles, the atomization process is inhibited by the solid particles, while at low concentrations slurry slurry and in other cases as the base fluid itself because a dilute slurry has little interaction between particles. Characterization of the fluid rheology is required for many highly formulated fluids where non-Newtonian characteristics are expected.

Misconception. An air-water test indicates the performance of a nozzle operating in a vacuum or high-pressure gas environment.

Reality. The environment surrounding a spray nozzle impacts performance because aerodynamic breakup is affected by the gas density. The regimes are often characterized by the dimensionless Weber number based on gas density, Equation (8). The Weber number is the ratio of aerodynamic drag force to surface tension force. A high drop velocity in a dense gas causes additional breakup of the largest drops in a spray as compared to the same velocity in an ambient pressure gas. Conversely, in vacuum systems aerodynamic breakup will not be as significant in reducing drop size. For low viscosity water-like liquids, an aerodynamic Weber number above 12 results in a drop breaking-up into smaller drops. Drop deformation changes the drag coefficient at a Weber number.
greater than 2. The breakup process in Figure 8 proceeds left to right, from a distorted drop to smaller drops, on the microsecond timescale.

$$W_e = \frac{\rho \cdot D_f^2}{\sigma}$$

(8)

The maximum initial drop velocity can be calculated using Equation (9), based on the Bernoulli equation.

$$V_{max} = \sqrt{\frac{2aP}{\rho_L}}$$

(9)

The maximum drop sizes shown in Figure 9 are based on the properties of water droplets in air at ambient pressures. This figure shows the relative velocity between the droplets and the surrounding gas that causes breakup. Very small droplets require an extraordinarily high velocity to cause further breakup due to aerodynamic forces, while larger droplets require significantly lower relative velocity to induce breakup into smaller drops. The aerodynamic drag on drops from nozzles quickly reduces the relative velocity, thus the break-up potential.

**Nozzle design choices**

*Misconception.* A single spray nozzle is better than multiple nozzles.

*Reality.* A single spray nozzle is often used, but there are some significant limitations in many process applications. Multiple spray nozzles mounted on a single head, a compound nozzle, or mounted on a header are required in many cases. If the area to be covered is too large, a single nozzle may not provide the uniform coverage or spray penetration required. For the same total flow rate and pressure drop, multiple nozzles will provide a smaller drop size than one large nozzle.

Multiple nozzle design is an effective strategy to consider for scaling between the experimental and plant scale. The technical challenge of using multiple spray nozzles is to assure the appropriate amount of overlap between spray plumes. With too much overlap, very dense regions of spray will be present as well as regions of potentially inadequate drop density.

Figure 10 illustrates this issue with nozzle scale up for a family of three single-fluid nozzles. Although the shapes of the curves are similar, larger nozzles, with a larger orifice size, have a larger drop size at a given pressure. A very small nozzle can easily achieve a 500-µ drop size, while a larger nozzle requires significantly greater operating pressure to achieve the same result. A larger nozzle will always produce a larger drop size for a given pressure drop. A common scaleup mistake is to use the same pressure drop, but the larger diameter nozzle results in a larger particle-size distribution. Large-scale systems often use a number of nozzles operating at somewhat higher pressure after giving considerable consideration to the influence of drop size and velocity on process performance.

*Misconception.* A single-fluid nozzle is always the best choice of nozzle type.

*Reality.* A single-fluid or hydraulic nozzle is by far the most common nozzle used, accounting for approximately 90% of the applications. Many times, a hydraulic nozzle provides the simplest and most reliable option. However, there are exceptions, such as the following:

- Operation with very low liquid flows, less than 0.5 L/min, where the nozzle orifice size is quite small and plugging can be an issue in process service.
- Operation with a fluid containing some particulate that limits internal free-passage dimensions resulting in plugging.
- Applications where the total liquid flow is limited, small drop sizes are required and momentum is required to carry the spray.
- Requirements for drop sizes smaller than achievable with a single-fluid nozzle.
- Limited pressure drop for the liquid phase that results in too large of a drop size or insufficient flow.
- Operation with a wide range of liquid flows that causes poor performance at either the high or low flow limit.
- Fluids with high viscosity (not water-like).

Single-fluid nozzles have a limited throughput, so at a low flowrate the drop size increases significantly. Figure 11 shows a single-fluid nozzle operating over a range of flow rates around the design point of one. Pressure drop, drop size and surface area of the spray are dramatically impacted with a 50% increase or decrease in flow.

Process constraints such as no atomizing gas being allowed in the process or as no atomizing gas being available may rule out two-fluid nozzles.

**Operations and maintenance**

*Misconception.* Equal flow from each spray nozzle on a distribution header is guaranteed.

*Reality.* The flow distribution depends on the pressure drop in the header, momentum recovery in the header and pressure drop across the spray nozzles. Generally, if the pipe size is selected so the pressure drop through the spray nozzle is at least ten times the velocity head within the pipe, the maldistribution will be in the order of 5%. The velocity head of the flow within the header is defined by:

$$VH = \frac{\rho V^2}{2}$$

(10)

Long manifolds with a large number of spray nozzles require a more detailed header design. Maldistribution is rarely an issue in headers installed within vessels, where the design rule above is followed. Problems are typically those where the pressure drop is limited, such as in cooling towers, which use very large numbers of spray nozzles.

*Misconception.* Drilling out plugged nozzles fully restores performance.

*Reality.* Solids deposits inside a spray nozzle often adhere to the exterior surfaces and to the outlet orifice like they have been glued in place. Metal drill bits distort the shape, surface condition and size. Drilling may also damage or remove nozzle internals that induce swirl in the flow. Nozzle manufacturers recommend only soft materials be used for cleaning nozzles. For metal nozzles, the material used to clean the nozzle should be no harder than wood. The spray pattern can be distorted even though the hydraulic characteristics (flow at a specified pressure drop) have been restored.

*Misconception.* My process liquid is clean — nozzles will never plug.

*Reality.* When solids are present, erosion and plugging may occur. Most streams contain some solids — perhaps debris from piping assembly. It
is critical that the minimum free passage, which is often provided in the nozzle catalog or product bulletin, be evaluated in design. The most common complaint is of a plugged nozzle in a "clean" process stream. Because a few particles can plug a nozzle, manufacturers' have developed integral strainers to solve the design conflict of a small outlet orifice to produce a small drop and a large opening to avoid plugging. The alternate approach is to install strainers or filters that are accessible for servicing. You should determine the necessities of design based on your knowledge of the stream. Nozzles with small internal passages, under 5-mm dia., deserve deliberate consideration of the plugging potential.

Misconception. Spray nozzles will last the lifetime of equipment.

Reality. Some nozzles have the same performance over a span of 20 years of operation; however, many require periodic replacement. The service life of a nozzle depends on many factors, including the pressure drop, material being sprayed, material of construction, corrosion, plugging, and performance expectations, see Ref. [2].

Erosion of the nozzle orifice is a common cause of degradation of nozzle performance. The process fluids sprayed vary from the cleanest of liquids to highly concentrated slurries. When solids are present, erosion and plugging may occur. As a first approximation, the rate of erosion is proportion to the velocity cubed ($v^3$). Nozzle wear that is imperceptible to the eye can cause degradation in the spray pattern and an increase in the drop size. One sign of wear is an increase in flow at a constant operating pressure drop. Ceramics and other wear-resistant materials are sometimes more cost effective when compared to routine replacement.

Corrosive environments can quickly degrade many metal nozzles with low cost metallurgy. Plastic nozzles serve as a potential low-cost alternative to high-cost metal alloys; however, the maximum allowable pressure drop is lower, especially at elevated temperatures.

Deposits on the exterior can obstruct a spray, degrading the performance. This scaling or buildup has process-specific root causes. This failure mode can be either very rapid or very slow.

For many process applications the system of spray nozzles should have a defined replacement schedule, often after five years, to maintain process performance. The frequency depends on the specific process; corrosive or erosive services may require a more frequent change. The replacement should be scheduled in the preventive maintenance plan in conjunction with other planned work. Change out is often preferred to simple visual inspection because wear of internal passages may not be obvious without removal of the nozzle. Viewing a spray nozzle as an expendable component is critical to assure high reliability of spray systems and the enhanced transport these systems deliver.

Upset conditions should be considered, a momentary loss of quench flow has melted a metal spray nozzle in a high temperature quench. The thermal radiation load on the protruding nozzle was obviously too high.

Misconception. Spray nozzles don’t require any instrumentation or control system.

Reality. A single-fluid nozzle has the minimal control system because this nozzle has only one degree of freedom in the operation, pressure or flowrate. Measuring both flow and pressure drop is useful to detect changes in the hydraulic characteristic of the nozzle caused by erosion or plugging. In contrast, a two-fluid nozzle has two degrees of freedom, the gas mass flowrate and the liquid flowrate. The gas-to-liquid mass flow ratio is useful as a comparative parameter. It may also be used as a control parameter in critical systems. Specifying a throughput of liquid, and then the gas liquid ratio provides a robust means of control.

The performance of a specific nozzle must be evaluated to determine the appropriate control settings to assure effective control over the normal operating range.

Misconception. Two-fluid nozzles are easy to control.

Reality. Two-fluid spray nozzles inherently require two flow-metering functions. External mix nozzles are the easiest to control because there is little interaction between the gas and liquid. A change in atomizing gas flow results in little change in the back pressure on the liquid system. Control of a critical spray application requires the gas-to-liquid mass ratio to be controlled at least indirectly. Ideally, for critical applications the gas-to-liquid mass ratio would be directly controlled.

Internal mix atomizers have more complex control issues because of the interaction between the gas and liquid hydraulics. As one flow changes, the back pressure created in the nozzle...
impacts the other flow. Applying simple controls to the flow of each stream without proper tuning of these controls can result in dramatic swings in flows and therefore the drop size. The control challenge is to adjust quickly to changes, and yet avoid oscillatory behavior. One common solution is to utilize relatively long time constants on the gas-to-liquid flow control to dampen the system.

Another issue is managing startup and shutdown sequences. Ideally the gas flow is introduced at some minimum level before the liquid on startup, and this sequence is reversed on shutdown. Sometimes process constraints may limit these options. Careful consideration is required to manage these operations, as some process systems require deliberate clearing of the process liquid on shutdown to avoid major issues on startup. These are very process-specific issues.

Misconception. Mechanical damage of spray nozzles affecting process performance is rare.

Reality. Although most spray nozzles are robust, damage can occur during installation. Nozzles with a protruding component, sometimes called a pintle, that are mounted on a header or dip pipe inserted into a vessel, are easily damaged. Inspection of nozzles after installation is highly recommended especially for critical systems. The old saying, “you get what you inspect not what you expect” is useful in this case. Consider choosing a nozzle type without a pintle, as this minimizes the installation issue in many processes if the nozzle chosen can achieve the desired performance.

Conclusion

Misconceptions and myths should be put aside to allow effective design using sprays. The starting point for good design is to clearly express the desired process objective. With this objective in mind, nozzle type choices and parameters and constraints can be brought together. Many spray nozzles achieve the desired results in less demanding applications. However, some process applications require considerably more finesse in the design to optimize performance and minimize the negative consequences. Like chess pieces, nozzles types with different characteristics may be placed in the same space to achieve different results. Single-fluid nozzles are like the pawn — frequently used but with limited characteristics. Two-fluid nozzles are more powerful like the queen, capable of exerting greater influence by virtue of her inherent power as a more complex piece.

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