A Guide to Optimizing Spray Injector Performance

Specification, Design and Fabrication
Spray Injectors: Critical but Often Overlooked Components

At the heart of any spray application is the spray nozzle. Often the smallest component in a spray system, the nozzle is designed to yield very precise performance. Even small deviations in performance can result in serious process quality problems, unscheduled downtime and thousands of dollars of increased operating costs.

Equally important in a spray system is the spray injector (also known as a spray lance or quill) that delivers the liquid and/or gas to the spray nozzle. Spray injectors must also meet exacting standards to ensure optimal performance. Yet spray injectors are often viewed as a means to an end – a simple pipe or fluid delivery device. Important design and manufacturing considerations can be overlooked resulting in performance problems and costly inefficiencies.

Compromised spray performance resulting from injector design can be avoided. To help increase your understanding of those issues, we’ve developed this reference guide to address critical considerations in spray injector specification, design and fabrication. This guide is a compilation of our 70 years of experience in spray technology.

Getting Started: A Custom or Standard Solution?

Relatively simple operations can often use a standard injector. Applications like gas conditioning, chemical injection, secondary fuel injection, emergency quench and lime slurry injection often require a custom solution. Here’s why:

• Spray injectors used in these applications typically require sophisticated designs. Integrating the injector into the available space can be complicated and a standard solution, available in pre-determined designs, may be too simplistic.
• Special materials and coatings are required to withstand high-temperature, erosive and/or corrosive environments.
• Insulated, water- or steam-jacketed injectors often prove to be more effective in high-temperature applications.
• Extreme engineering and safety issues require compliance with ASME® codes such as B31.1, B31.3 and others.
• Retractable and flexible designs are frequently needed to minimize or eliminate process interruption and/or maintenance downtime.

In most applications, standard hydraulic or gas atomizing nozzles are used in conjunction with a custom injector to achieve the desired spray performance.

Designing the Injector Starts with Determining the Desired Spray Nozzle Performance

The first step in injector specification and design is to clearly identify your spray objectives.

Does your application require:

• Gas cleaning treatments in caustic environments?
• Cleaning by leaving specific amounts of two-phase flow downstream?
• Exceptional coverage to ensure optimal chemical reactions?
• Cooling with 100% evaporation?
• Cooling to adiabatic saturation?
• High pressure corrosion inhibitor injection?
• Desuperheating steam to exact temperatures?

Although these are typical spray requirements, there are many others. Start by determining precisely what performance is required, so you can begin the nozzle selection process.

Or, tell us about your operating conditions and spraying objectives. We can guide you through the nozzle selection process.
Nozzle Selection Considerations

There are many factors that will determine which nozzle is suitable for your application. The information that follows addresses many considerations and provides general guidelines. However, you should work closely with us to determine how nozzles will perform in your operating environment.

- Injection rates: Determine the required volumetric or mass flow rates.
- Fluid viscosity, fluid temperature and specific gravity all impact spray performance. See below.

**Spray pattern and angle:** Hydraulic and gas atomizing nozzles are available in many spray patterns ranging from 0° (solid stream) to 180°. Keep in mind:
- Drop size increases as spray angle decreases.
- High pressure process streams force narrower spray angles. Wider spray angles can result from low pressure process streams. Actual spray angles can vary significantly from published data depending on the process stream. Adding another port for an additional nozzle may be an effective way to achieve the needed coverage.

### Summary of Spray Performance Considerations

The chart below summarizes the various factors that affect a spray nozzle’s performance. However, because there are so many different types and sizes of spray nozzles, the effects may vary depending on operating conditions.

<table>
<thead>
<tr>
<th>Nozzle Characteristics</th>
<th>Increase in Operating Pressure</th>
<th>Increase in Specific Gravity</th>
<th>Increase in Viscosity</th>
<th>Increase in Fluid Temperature</th>
<th>Increase in Surface Tension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern Quality</td>
<td>Improves</td>
<td>Negligible</td>
<td>Deteriorates</td>
<td>Improves</td>
<td>Negligible</td>
</tr>
<tr>
<td>Drop Size</td>
<td>Decreases</td>
<td>Negligible</td>
<td>Increases</td>
<td>Decreases</td>
<td>Increases</td>
</tr>
<tr>
<td>Spray Angle</td>
<td>Increases then decreases</td>
<td>Negligible</td>
<td>Decreases</td>
<td>Increases</td>
<td>Decreases</td>
</tr>
<tr>
<td>Capacity</td>
<td>Increases</td>
<td>Decreases</td>
<td>Full/hollow cone – increases, flat – decreases</td>
<td>Depends on fluid sprayed and nozzle used</td>
<td>No effect</td>
</tr>
<tr>
<td>Impact</td>
<td>Increases</td>
<td>Negligible</td>
<td>Decreases</td>
<td>Increases</td>
<td>Negligible</td>
</tr>
<tr>
<td>Velocity</td>
<td>Increases</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Increases</td>
<td>Negligible</td>
</tr>
<tr>
<td>Wear</td>
<td>Increases</td>
<td>Negligible</td>
<td>Decreases</td>
<td>Decreases</td>
<td>No effect</td>
</tr>
</tbody>
</table>
**Additional Nozzle Selection Considerations**

- **Solids content**: Determine the percentage of solids in the fluid being sprayed. If solids content is high:
  - Consider using Maximum Free Passage (MFP) nozzles to minimize clogging.
  - Consider using nozzles with anti-bearding designs to minimize material build-up on the exit orifices and nozzle tip.
  - Consider using erosion-resistant nozzles made from ceramics or hardened steels.
- **Drop size**: In many processes the goal is 100% evaporation, and this requires precise control of drop size. Critical factors to consider:
  - Drop size refers to the size of the individual drops in the spray pattern. Each spray pattern consists of a range of drop sizes. This range is called drop size distribution.
  - Drop size distribution varies by spray pattern type. The smallest drops are produced by gas atomizing nozzles; the largest are produced by hydraulic full cone nozzles.
- **Smaller capacities produce smaller drops; higher pressures generate smaller drops.**
- **Distance the drops need to travel from the injection point.** Gas temperature, density, viscosity and velocity will impact the spray plume.
- **Drop size terminology can be confusing.** It’s important to understand the measurement values being used and how the data was collected. Our technical handbook, *Spray Technology Reference Guide: Understanding Drop Size*, Bulletin 459B, is widely used as a primer on this subject and available for request/download on www.spray.com.
- **Vapor pressure**: Proper nozzle selection is critical to avoid undesirable phase change. Once spray nozzle selection is complete, the next step is to look at the physical and environmental factors in the area the injector will be installed.

### Actual Drop Sizes

<table>
<thead>
<tr>
<th>Drop Sizes (µm)</th>
<th>500</th>
<th>1,200</th>
<th>5,500</th>
</tr>
</thead>
</table>

Liquid properties, nozzle capacity, spraying pressure and spray angle all affect drop size.

### Drop Size by Spray Pattern Type at Various Pressures and Capacities

<table>
<thead>
<tr>
<th>Spray Pattern Type</th>
<th>10 psi (0.7 bar)</th>
<th>40 psi (2.8 bar)</th>
<th>100 psi (7 bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity</strong></td>
<td><strong>Capacity</strong></td>
<td><strong>VMD</strong></td>
<td><strong>Capacity</strong></td>
</tr>
<tr>
<td><strong>gpm</strong></td>
<td><strong>gpm</strong></td>
<td><strong>microns</strong></td>
<td><strong>gpm</strong></td>
</tr>
<tr>
<td>Gas Atomizing</td>
<td>.005</td>
<td>.08</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>.02</td>
<td>.08</td>
<td>100</td>
</tr>
<tr>
<td>Fine Spray</td>
<td>.22</td>
<td>.83</td>
<td>375</td>
</tr>
<tr>
<td></td>
<td>.43</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Hollow Cone</td>
<td>.05</td>
<td>.19</td>
<td>360</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>45</td>
<td>3400</td>
</tr>
<tr>
<td>Flat Fan</td>
<td>.05</td>
<td>.19</td>
<td>260</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>18.9</td>
<td>4300</td>
</tr>
<tr>
<td>Full Cone</td>
<td>.10</td>
<td>.38</td>
<td>1140</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>45</td>
<td>4300</td>
</tr>
</tbody>
</table>

Based on a sampling of nozzles selected to show the wide range of possible drop sizes available.
Injector Specification and Design Considerations

Consider the following when establishing your requirements:

• What is the size of the duct, vessel or tower? This will influence the number of nozzles and nozzle placement.
• Are there bends in the duct? Elbows can cause secondary flow profiles that negatively impact performance.
• What is the proximity to upstream and downstream equipment? Process problems and/or damage can result if the spray plume is too close to other equipment.
• What are the operating conditions? Gas and liquid properties affect spray plume distance. Temperature and corrosiveness will have an impact on materials of construction.
• What is the composition of the liquid being sprayed? This will affect the materials of construction.
• What is the fluid service category? This may require the injector to meet stringent design requirements for safety.
• Will the spray be co-current or counter-current? Co-current sprays have longer residence times, may produce smaller drops and enable use of a wider spray angle. Counter-current sprays may result in more build-up, vibration, stress on injector pipes, larger drops and wetting.
• What connections are required? Welded, flanged, threaded?
• Can the optimal injector position be determined prior to installation? If not, a flexible design for easy adjustment is an option.
• How often can the injector be serviced? Are there any special considerations? Retractable lances can eliminate or minimize process downtime. Also, if regular maintenance is not feasible, 100% evaporation and purging of air are likely required to reduce the risk of sludge formation.
• What is the desired service life of the injector prior to replacement? This may impact materials of construction and design.
• What is the preventive maintenance (PM) schedule? Injector weight can be reduced and attachments made to accelerate changeout.

There are many other considerations that are specific to the process. Working with us during the design phase will help achieve the best possible performance at the lowest possible cost.

Zoning of injectors is an effective way to ensure optimal performance when process conditions may vary. Injectors can be utilized in certain areas as needed depending on the required residence time, gas flow and temperature.
Common Injector Performance Problems and How to Avoid Them

We’ve worked with dozens of engineering firms and chemical/petrochemical plants on spray injector design. Common problems reported by customers include:

• Wet walls/unevaporated liquid.
• Refractory cracking.
• Failed chemical reactions.
• Additional unanticipated reactions.
• Clogging and build-up.

Poor process performance, unscheduled production downtime, damage to downstream equipment and increased maintenance time/operating costs can result from these problems. Accurately diagnosing the root cause of these problems and identifying the subsequent resolution often require highly specialized tools and resources. However, the best approach is to prevent them from occurring. This can be achieved through careful analysis during the design phase. Here are some of the tools and techniques we use.

Spray Performance Testing Eliminates Guesswork

Many of the problems noted above are caused by premature or incomplete evaporation.

• If drops evaporate too quickly, the desired process reaction may not occur or be compromised and upstream/downstream equipment may be less efficient or damaged.
• If drops don’t evaporate quickly enough, wetting will occur, unplanned steam may result and dust can accumulate in the duct or tower and obstruct gas flow.

The most effective way to determine the required residence time is to conduct spray characterization studies in a fully equipped spray laboratory to simulate operating conditions where the injector will reside. Typically these studies include:

• Testing to determine the optimal drop size and distribution.
• Determination of gas velocity and density and the resulting impact on drop size.
• Evaluating nozzle placement, spray pattern type and angle.
An Alternative to Cold Flow Modeling: The Right Experience and Right Software

In some cases, simulating operating conditions in a laboratory environment and modeling of the data is not feasible. That’s when we call on our engineers that specialize in drop size data. Using Computational Fluid Dynamics (CFD) and proprietary drop distribution functions, they can accurately predict injector performance in industrial processes.

Gas Conditioning Tower
Spray Droplet Concentration at Various Locations in the Tower

Spray Expertise Prevents Many Problems

There’s no substitute for experience and an extensive product line when it comes to avoiding problems. Our process, chemical and mechanical design engineers have decades of experience in spray technology and predict potential problems early in the design process. Here are just a few of the strategies we use to ensure trouble-free performance. You’ll find more specific examples on pages 10 and 11.

- Clogging and build-up: Analysis of liquid properties and use of special anti-bearding nozzle designs.
- Secondary flow distributions: Zone the injectors to keep sprays away from flow-altering devices.
- Corrosion and erosion: Evaluate acid gas saturation point and use special materials of construction and coatings.
- High-temperature: Insulated, water- or steam-jacketed injector designs.
- Fluctuating operating conditions: Flexible injector designs enable easy adjustment of nozzle position.
- Thick or dense solutions: Recirculating designs maintain a consistent temperature and minimize congealing.
How to Select the Right Vendor/Partner

Choosing the right spray injector vendor can be the difference between optimal spray performance and costly process inefficiencies/excessive maintenance downtime. Some companies call on internal design and fabrication resources for spray injectors. Other companies focus on cost and turn to small local fabricators. These providers do not have the required expertise in spray technology or a proven track record in injector design. There is a considerable risk of performance-related problems and spray nozzle integration issues when relying on one of these types of providers.

By choosing a partner with significant experience in spray nozzle and injector design, the likelihood of optimal spray performance increases significantly. And, if a single company supplies the nozzle and the lance, integration issues are eliminated while you enjoy the convenience of working with a single vendor.

Other considerations in the vendor selection process include:

- In-house design and engineering resources.
- ASME® code compliance and manufacturing capacity.
- Spray performance testing.
- Materials testing.
- Comprehensive documentation.
- Efficient project management.

A single source solution for nozzles and custom injectors:

1. Nozzle selection
2. Injector specification and design
Why Spraying Systems Co. is Uniquely Qualified to Design and Fabricate Custom Spray Injectors

When it comes to injector design, you won’t find another company with comparable credentials. We have a unique combination of capabilities.

Experience and expertise:
- Decades of experience with a sole focus on spray technology.
- Dozens of engineering specialists.
- Staff qualified to ASME® Section IX and American Welding Society (AWS) standards.
- Active participation in ILASS-Americas, the Institute for Liquid Atomization and Spray Systems.
- Professional Engineers (PE) on staff.

Certifications and quality programs:
- ASME qualified welding procedures.
- On-site quality records and worker qualifications.
- ASME B&PV Code Section VIII.

Code compliance – manufacturing:
- ASME Boiler and Pressure Vessel Code.
- Welding to ASME B&PV Code Section IX.

ANSI®, ASTM®, testing and more:
- Ultrasonic.
- Radiographic.
- Liquid penetrant.
- Hardness.
- Hydrostatic.
- Spray and flow testing in the world’s largest spray laboratories.
- Magnetic particle examination.
- Positive Material Identification.

Project management and documentation:
- Development of project plans as required with time-tables for design, production, testing and delivery.
- Data Books as needed for your records that include drawings, material traceability documents, material test reports, weld procedures, welder certifications/test reports, weld maps, weld logs, coupons and certificates.
- Interaction with all appropriate departments – process, mechanical, piping, welding and maintenance – to facilitate project success.
Here’s How We’ve Helped Others and How We Can Do the Same for You

Application: NOx Control Using Aqueous Ammonia Injection
Challenge: Uninterrupted Process Operation
Solution: Two Retractable Injectors
We designed and manufactured two identical, retractable injectors for permanent placement in the process stream. Only one injector is in use at a time. When the operational injector requires service, the other injector is used and the process is unaffected.

Application: Chemical Injection in Pressurized Steam Vessel
Challenge: Meet Stringent Design Challenges and Aggressive Production Schedule
Solution: Highly Engineered Injector Fabricated from Specialty Alloys
Injector was manufactured to ASME® B31.3 code and rigorous non-destructive examination (NDE). Project completion time was short but required bi-weekly updates, hold points, witness points, third-party inspection and a comprehensive turnover package.

Application: Evaporative Cooling in Unevenly Distributed Gas Stream
Challenge: Resolve Wall Wetting Problem in Cooling Tower Without Replacing Existing Inlet Geometry
Solution: Zoned Lance Operation
A combination of CFD and experience with zoned cooling led to zoning the injectors. The injectors in the area opposite the inlet are only used in the event emergency quench is required.
Application: Desuperheating Steam to Reduce Pressure and Temperature for Downstream Equipment

Challenge: One Port Limitation and A Single Standard Nozzle Couldn’t Meet Performance Requirements

Solution: Custom Attemperator Injector Design with Four Standard Hydraulic Nozzles

High-end construction, NDE and use of multiple hydraulic nozzles provided the necessary high flow rates and precise drop size to desuperheat steam.

Application: Emission Control

Challenge: Incomplete Chemical Reactions

Solution: Multi-Nozzle Injector Design to Provide Uniform Coverage

The injector, constructed of high nickel alloys, includes four standard gas atomizing nozzles. The use of standard nozzles allows easy changeout so larger capacity nozzles are used in the summer to keep pace with increased demand and an increase in ambient temperatures. In the winter, smaller capacity nozzles are used to conserve energy.
Additional Resources

We hope the information provided in this guide was helpful. If you are interested in learning more about spray nozzles and spray injectors, the following publications are available.

36-page guide delves into drop size measurement, instrumentation and data analysis/interpretation.

Optimizing Your Spray System, Technical Manual 410
52-page handbook explains how to evaluate your spray system, uncover and solve costly problems, improve quality, reduce maintenance time and more.

Gas Cooling and Conditioning Guide, Bulletin 540
12-page bulletin describes how to optimize efficiency and performance in gas cooling and conditioning applications.

FloMax® Air Atomizing Nozzles, Bulletin 487C
8-page bulletin explains how these high-efficiency nozzles work to provide precise spray performance through tight control of drop size.

Improving Process and Product Quality in Chemical Production through Spray Technology, Bulletin 568
12-page bulletin provides an overview of how spray technology is used in a wide range of applications.

Industrial Spray Products, Catalog 70
400-page catalog provides detailed information on our full line of spray products and accessories.

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