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Section 1. Experience With Spray Nozzles For FGD Systems

BETE has supplied nozzles for use in open and packed spray towers and jet bubbling reactors since the late 1950s. With the passage of the first Clean Air Act in the United States, it was natural for BETE to use this experience to work with the fledgling FGD industry to provide spray nozzles for use in various applications required for FGD systems.

The original, patented BETE spiral nozzle is known to be the most efficient atomizer of any direct pressure nozzle. In order to take advantage of the design in FGD systems, some modifications were needed. First, BETE extended the range of the spiral nozzle to the very large flow rates needed for FGD systems. To solve the problem of plugging caused by the high solids content in limestone slurries, BETE introduced the XP series of spiral nozzles, a design that has an extra-large free passage.

Due to the combination of erosive and corrosive conditions found in FGD systems, the number of suitable nozzle materials is limited. During the mid-1970s, BETE pioneered the use of Cobalt Alloy 6, a cobalt-base alloy with excellent resistance to abrasion and corrosion. In 1978 BETE established an in-house investment casting foundry in order to gain complete control over the casting of Cobalt Alloy 6, stainless steel, nickel alloy and other alloys.

Because of their unique properties, ceramics were also interesting as nozzle materials. In the late 1960s and early 1970s, BETE worked with Carborundum to develop nozzles made in cast Refrax[®], a nitride bonded silicon carbide material that provides excellent corrosion and abrasion resistance. In 1981 BETE worked with the Norton Company to provide the BETE spiral nozzle in Crystar[®], a reaction bonded silicon carbide (RBSC) material. This material, which is 4-5 times stronger than nitride bonded silicon carbide, allowed the first practical production of the spiral nozzle in a ceramic.

In 1975 BETE introduced the MaxiPass[®], an in-line full cone nozzle with uniform distribution and the largest possible free passage. In subsequent years, BETE developed the design for use with metal alloys, ceramics and polyurethane. This design greatly reduced the plugging of absorber nozzles experienced by the users of full cone nozzles.

From the late 1970s, BETE worked with power plants and FGD system O.E.M.s to troubleshoot existing FGD systems. In the process, BETE developed the BETE Droplet Analyzer, a system that is ideally suited to measure the droplet size distributions of the large nozzles used for FGD slurry service. BETE's work in the field led to the establishment of its state-of-the-art spray laboratory, which has been used by BETE engineers and power plant and FGD system O.E.M. personnel to develop and evaluate spray and nozzle systems.

The mid-1980s brought the passage of the legislation in European countries limiting power plant emissions. In order to serve this new market effectively, BETE established BETE Deutschland GmbH, a daughter company located in Bochum, Germany. Since 1985, BETE has supplied absorber and mist eliminator wash nozzles for over 50 projects in Europe. In 1986 BETE began to manufacture a patented hollow cone, tangential inlet nozzle, now known as the BETE TH series.

In 1988 the investment foundry at BETE became one of the first in the world capable of casting Nickel Alloy C-22, a new chromium nickel-based alloy with greatly improved corrosion resistance.

In 1989 BETE developed the SpiralAir™ nozzle, an extremely efficient two-fluid nozzle with exceptional wear characteristics for use in critical quenching and dry scrubbing applications.

Since 2000, explosive industrial growth plus increasing environmental concerns have driven unprecedented development of the Chinese FGD industry. To facilitate development of this market, BETE engineering has worked directly with numerous Chinese FGD licensee's responsible for specifying and qualifying nozzle designs, thereby ensuring the best product is employed for a given application. The flexibility of this marketplace is evident in the wide range of nozzles used in the new FGD installations, including a strong resurgence in wet scrubbers using the BETE spiral nozzle. In fact, BETE developed a new spiral nozzle specifically to meet present day FGD market needs by combining superior atomization, low operating pressures and high free passage in a modified nozzle envelope to keep the pricing competitive. As a result of these efforts, BETE has supplied over 100 installations worldwide with spray nozzles in the past five years supporting over 50,000 MW of generating capacity.

For over 30 years, BETE has supplied every type of nozzle designed for FGD systems in all available materials. BETE has complete capabilities for engineering, manufacturing and laboratory testing to satisfy the most stringent FGD system nozzle requirements.

MaxiPass is a trademark of BETE Fog Nozzle, Inc.

SpiralAir is a trademark of BETE Fog Nozzle, Inc.

Section 2. Flue Gas Desulphurization

An important element in controlling the cost of operation and maintenance of a wet limestone scrubber is the careful selection of the absorber spray nozzles.

The function of an absorber spray nozzle is to transform bulk limestone slurry into droplets with sufficient surface area to achieve the required SO₂ removal.

2.1 General Considerations

To select the most appropriate nozzle for a particular installation, careful consideration must be given to:

- 2.1.1. Corrosive factors present in the slurry and in the flue gas, particularly the level of chlorides, fluorides and the pH.
- 2.1.2. Factors contributing to erosion, including the percentage of fly ash, the size of the limestone particles and the velocity of the slurry through the nozzle.
- 2.1.3. The efficiency of the nozzle design as measured by the pressure drop across the nozzle required to achieve a given Sauter mean diameter (D₃₂) droplet size.
- 2.1.4. The susceptibility of the nozzle design to plugging, as indicated by the free passage diameter (the diameter of the largest spherical particle that will pass through the nozzle).
- 2.1.5. The ability of the nozzle material to survive physical abuse during installation, operation and maintenance.
- 2.1.6. The nozzle connector design appropriate to the piping system to reduce installation and maintenance costs.

2.2 Designs

There are six commonly used designs for wet scrubber absorber nozzles:

2.2.1. Hollow Cone Tangential: A design in which the slurry is introduced tangentially to a swirl chamber and discharged through an orifice that is at right angles to the inlet. The free passage diameter is equal to 80-100% of the orifice in diameter. There are no internal parts.

The traditional nozzles used in FGD installations have been rather large hollow-cone whirl-tangential nozzles in a cast silicon carbide material (*e.g.*-the BETE TH series). Commonly employed pressures are from 7 – 20 psi (0.5 – 1.5 bar). The whirl tangential design also has much larger free passage diameters than similarly sized traditional full cone whirl nozzles an important feature when spraying recirculated slurries.

2.2.2. Full Cone Tangential: A design similar to the hollow cone tangential that has features in the closed end of the whirl chamber which deflect some of the spray into the center of the pattern, creating a full cone effect. The free passage is equal to 80-100% of the orifice diameter. The BETE TSC series is a tangential full cone design, and is available in SNBSC ceramic for absorber applications.

2.2.3. Double Hollow Cone Tangential: A hollow cone tangential design with

two orifices. In an absorber tower, one orifice sprays down and the other sprays up. The free passage is equal to 80-100% of the orifice diameter. The BETE **DTH** series is a double hollow cone tangential design, and is available in SNBSC ceramic.

2.2.4. Full Cone: A design in which an internal vane imparts a swirl to the slurry that is discharged through an orifice axially in line with the inlet. Depending on the specific design, the free passage diameter varies from 25% to 100% of the orifice diameter. The BETE Maximum Free Passage **MaxiPass (MP)** series was developed to deliver the large free passage diameter characteristics of the whirl-tangential design in a finely atomizing full cone spray configuration.

2.2.5 Spiral: A design in which a laminar jet of slurry is deflected into concentric cones by a continuously decreasing spiral element. There are no internal parts, and the free passage is equal to 30 to 100% of the orifice diameter.

The BETE **ST** spiral design nozzle series have rapidly gained acceptance in FGD installations as their superior spray performance characteristics allow for increased removal rates at significantly lower delivery pressures. Typical operating pressures are from 4 psi to 15 psi (0.3 to 1.0 bar).

2.2.6 Large Free Passage Spiral: A design variation of the spiral, such as the BETE **STXP**, in which the spacing between the spiral turns is increased. The free passage is equal to 100% of the orifice, up to a maximum of 38 mm (1.5"). The **STXP** design has a Sauter mean droplet diameter that is the same as an equivalent **ST** design with the same number of turns.

2.3 Spray Nozzle Performance

The function of a spray nozzle in the absorber of a wet limestone FGD system is to convert bulk slurry into droplets and to bring these droplets into intimate contact with the flue gas in the absorber tower. There are few decisions more critical to the operation of the FGD absorber tower than the selection of the spray nozzles.

The absorption process may be limited by either the speed of the reaction or the surface area of the slurry droplets. It is generally believed that the surface area of the droplets becomes the limited factor for removal rates over 90%, becoming more critical as the removal rate increases to 95% and beyond.

There are a number of factors that influence droplet sized produced by a spray nozzle. The factors of greatest practical interest include the operating pressure of the nozzle, the nozzle's flow capacity (orifice diameter) and the emitting spray angle. The relative effects of these factors on droplet size is summarized in **Figure 1**.

Effect of Influence Factors on Droplet Size

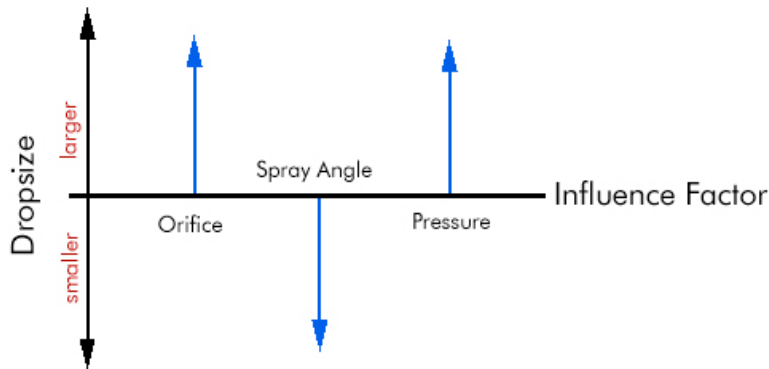


FIGURE 1: RELATIVE EFFECT OF ANGLE, PRESSURE AND ORIFICE DIAMETER ON DROPSIZE

In addition to these factors, the nozzle design itself has an important influence on droplet size. One measure of spray nozzle efficiency is the operating pressure required for a nozzle of a given design and flow rate to produce a specified droplet diameter. Nozzle operating pressure has a direct economic impact on FGD system operating costs: the power required to pump slurry increases in direct proportion to the operating pressure. **Figure 2** illustrates the operating pressure required for constant flow and constant D_{32} (Sauter mean diameter). One of the most common myths about spray nozzles is that they are more or less interchangeable, as long as the flow rate for a given operating pressure is the same. This can be a dangerous assumption, especially when the nozzles have different basic designs.

Pressure Requirements by Nozzle Design

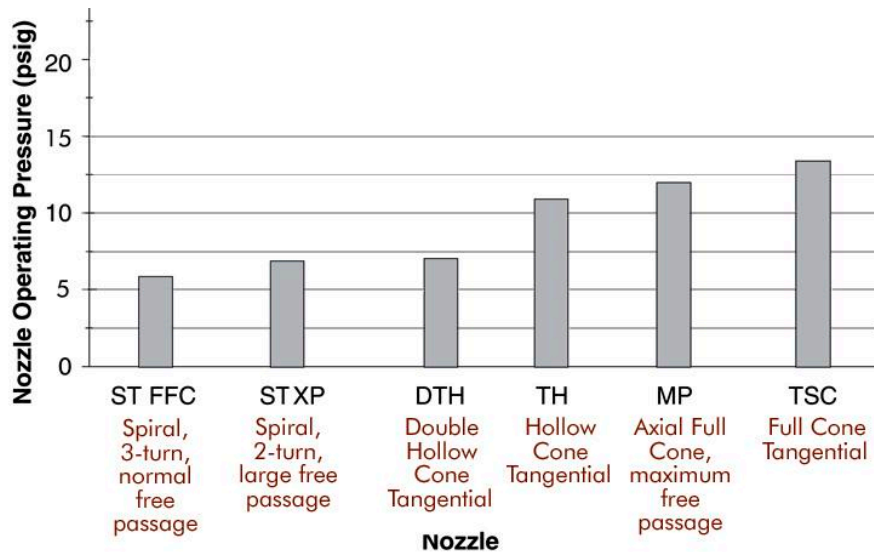


FIGURE 2. REQUIRED PRESSURE FOR CONSTANT FLOW AND CONSTANT D_{32}

2.4 Materials - Absorber Nozzles

Due to the corrosive and erosive conditions present in wet limestone scrubbers, the choice of materials for absorber nozzles is limited:

2.4.1. Silicon Nitride Bonded Silicon Carbide (SNBSC): A ceramic material with excellent resistance to erosion and corrosion. A low modulus of rupture (MOR) and poor resistance to impact limits the material to structurally simple designs with heavy wall sections. SNBSC is typically used for hollow cone, whirl tangential nozzles.

2.4.2. Reaction Bonded Silicon Carbide (RBSC): A ceramic material with excellent resistance to erosion and corrosion. Because the MOR of RBSC is 5-7 times that of SNBSC, it can be used for more complex shapes. RBSC is more costly than SNBSC, and is also susceptible to impact failure. RBSC is typically used for spiral nozzle designs.

Because they are made of brittle ceramic, the life of RBSC spiral nozzles is more difficult to predict. No failures due to wear have ever been observed. When the nozzles fail, they will probably fail due to breakage. This breakage can be caused by faulty installation procedures, pressure spikes (water hammer) during start-up, attempting to clean plugged nozzles or other routine maintenance operations.

2.4.3. Cobalt Alloy 6 (AMS 5387): A cobalt-based super alloy, and one of the only alloy materials capable of withstanding both the erosive and corrosive conditions in wet limestone scrubbers. Cobalt Alloy 6 may be used for spiral and full cone designs.

In other wet limestone scrubbers in the United States, Japan and Europe with similar conditions, spiral nozzles made of Cobalt Alloy 6 have lasted 6 years or longer. The failure mode will most likely be by wear, not breakage.

2.4.4. Polyurethane: A lightweight polymer with good abrasion resistance. Both the MP and TH designs are available in polyurethane. Our experience with nozzles made of polyurethane suggests that effective life for this material is 12 to 24 months in FGD service.

2.5 Nozzle Connections – Absorbers

There are three items to consider in selecting an absorber nozzle connection:

1. **The connection size.**
2. **The connection type.**
3. **The connection material.**

2.5.1. Connection Size

The size of the nozzle connection is determined primarily by the design velocity of the slurry in the piping branch to which the nozzle is attached. The lower velocity limit is dictated by the minimum transport velocity for the slurry and the upper limit is determined by the maximum permitted by the piping system material.

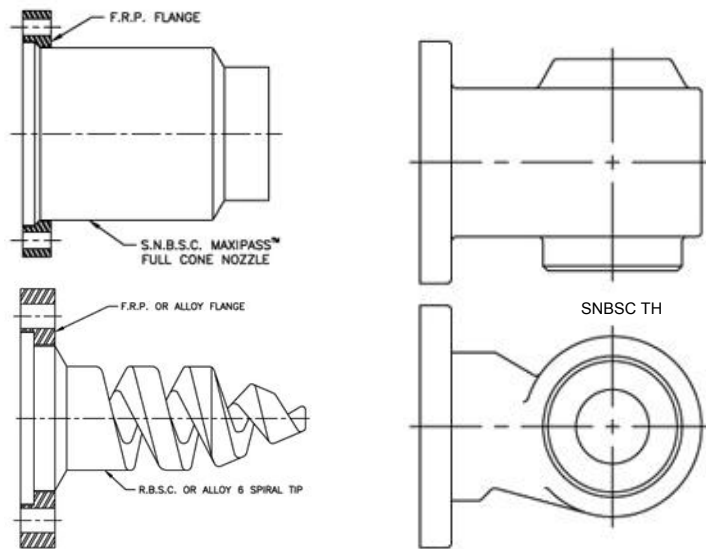
2.5.2. Flange Connections

The flange connection has two disadvantages: the cost of fasteners and the labor required for installation. In spite of those disadvantages, the flange remains the most common connection for FGD absorber nozzles due to constraints imposed by materials used for piping and nozzles.

The flange connection may be necessary because of the piping system. For instance, two of the most common piping materials are rubber-lined steel and Fiber Reinforced Plastic (FRP). For both of these systems the flange connection is typically preferred.

The flange connection may also be dictated by the nozzle material. In the case of SNBSC, the flange connection is the most common type, because threads in SNBSC are completely unsatisfactory due to difficulties in manufacture and use.

Although most FGD system designers specify standard ANSI 150# or DIN PN 6 flanges, there are cases when flanges of a non-standard design are more economical. For example, standard ANSI 4", 150# flanges require 8 bolts. Since most FGD slurry nozzles operate at 10-15 psi (0.7 to 1.0 bar), 4" flanges with 4 bolts may be sufficient for the application. Reducing the number of fasteners by 50% will result in significant savings. Before deciding to use a reduced number of fasteners, the designer should carefully evaluate the performance of the joint under the specific design conditions.



F.R.P. FLANGES

AS-CAST BONDED ONE-PIECE
CAST FLANGE

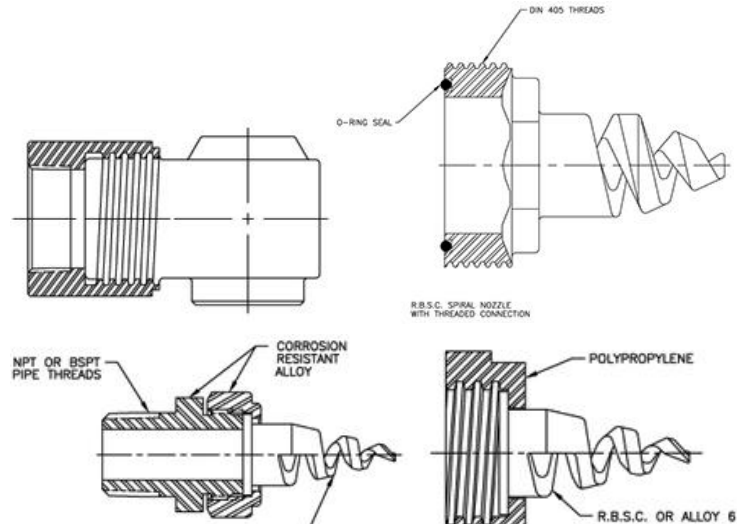
2.5.3 Threaded Connections

Absorber nozzles are infrequently designed with a threaded connection.

RBSC ceramic absorber nozzles may be designed with a thread connection having a rounded thread, such as DIN 405. This design is generally used for

connection to FRP headers, with the seal accomplished with an o-ring.

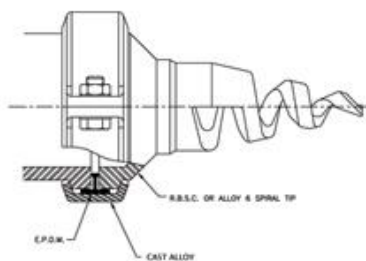
SNBSC ceramic material by itself is not recommended for threaded connections, but threaded FRP bushings can be glued to nozzles made by SNBSC. For the case of tangential nozzles, threads of any type present a special difficulty. Tangential nozzles must be attached to the header with the orifice facing a specific direction. This can create problems when tightening a threaded connection.



2.5.5 Victaulic® Connections

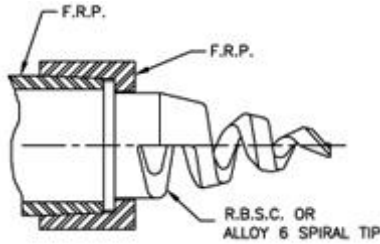
This type of connector is available from pipe connector manufacturers using a two-piece, hinged clamp, secured by a single bolt. The advantage of this design is the reduced labor required to install and to remove the nozzle, however, the disadvantage is higher cost. Materials include alloys and F.R.P.

The grooved piping system of Victaulic® significantly reduces the scrubber cost relative to the flanges and provides the flexibility of a non-permanent nozzle connection that direct-bonded doesn't allow. This saves on the total "as installed" cost relative to flanges by reducing the time needed to install the nozzles, decreasing the quantity of corrosion-resistant fasteners, eliminating the pipe flange and reducing nozzle weight. Victaulic® connections can be specified for all BETE absorber nozzle designs.



2.5.6 Bonded Connections:

Attaching nozzles directly to FRP pipes with adhesives has been used as a way to reduce connection costs by eliminating fasteners. Once attached, the nozzles are removed either by chiseling them from the pipe or sawing the inlet stub. Either way, it is nearly impossible to remove a ceramic nozzle without breaking it. The FRP stub must then be re-surfaced in order to attach a new nozzle. This connection technique should not be used without a careful analysis of both first.



2.5.7 Materials Considerations

Where the choice of material for a connection is not completely determined by the piping system and nozzle design, two other factors will influence the selection: cost and environmental considerations. In the case of a flange connection, for example, alloys are more expensive than FRP, but if the connection is likely to be exposed to high temperatures, alloys may be the only choice. Where corrosive attack is more significant than temperature limitations, plastics or FRP may be the preferred materials.

	Flange	Victualic	Direct-bonded
Nozzle weight	High	Low	Low
Hardware costs	Moderate-high	Moderate	Low
Installation time	Moderate	Low	Low
Maintenance difficulty	Moderate	Low	High

2.6 Summary

There is no single nozzle material and design that is ideal for the complete range of operating conditions possible in wet limestone scrubbing. Each installation must be carefully examined in order to select the nozzle with the combination of attributes that will result in the lowest operating and maintenance costs. Each nozzle design being considered must be evaluated for free passage and the efficiency with which it atomizes. Each material must be evaluated not only for cost and service life, but also in terms of its use in the working environment in an FGD scrubber. It is important to consider the realities of operating and maintenance as well as laboratory performance characteristics. Applications Engineers at BETE Fog Nozzle, Inc. are your resource for assistance in making critical FGD absorber spray nozzle decisions.

Section 3 Quality Assurance of Nozzles for FGD

BETE has worked for over 35 years to refine our processes to deliver high quality nozzles that meet the stringent requirements of FGD customers. Every step of the process from design, prototype test, manufacture, spray test and final inspection maintains the nozzle quality in accordance with our ISO 9001:2000 quality system.

3.1 Design

The BETE design team has developed the technical understanding of FGD nozzles and demonstrated it through years of experience satisfying FGD customer specifications. We use our Computer Aided Design system to develop detailed nozzle designs. Highly skilled toolmakers use CNC equipment to produce prototypes to verify performance of the nozzle during development. Each design must pass a final detailed review and approval process to assure customer requirements are met before release into manufacture.

3.2 Manufacturing

The manufacturing process uses the highest quality raw materials, precision equipment, in-process inspections and trained personnel to assure high quality standards are met.

3.3 Nozzle Performance Testing

The BETE spray laboratory uses the combined resources of state-of-the-art technology and a team of knowledgeable and experienced staff to characterize nozzle performance.

The BETE spray laboratory capability includes:

- Flow rates (water) to 2000 gpm (7500 L/min)
- Flow rates (air) to 3000 scfm (5000 Nm³/h)
- Pressure measurements to 10000 psig
- Droplet size distribution analysis
- Liquid distribution analysis
- Spray impact tests
- Customized test equipment and fixtures as required

Utilizing the latest in digital imaging, analysis and data processing, our unique ***Droplet Analyzer*** is designed for fast, accurate dynamic droplet size analysis. This remarkably versatile system is capable of in-the-spray measurement of droplets at high velocities. For each test thousands of droplets are imaged and analyzed at locations throughout the spray. Since the early 1980s, members of BETE's technical staff have been active members of ASTM committee E29.04 on Liquid Particle Size Measurement. All data gathering and reporting formats used by the BETE Video Imaging Particle Analyzer system conforms to those established by ASTM Standards E 799-87.

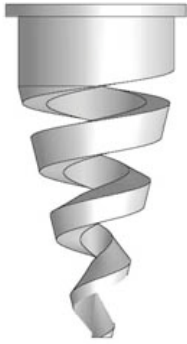
Distribution of liquid discharge from spray nozzles is critical for gas/liquid contact and precise measurement of the distribution is necessary to determine the proper sampling

areas for droplet size measurement. Our high speed *Patternator* for liquid distribution measurement is completely integrated with the Droplet Analyzer system, enabling precise measurement of spray coverage, uniformity and density.

3.4 Final inspection

Each order receives a final inspection to assure compliance to BETE standards and customer specifications. The BETE Quality Department compiles and reviews all required tests and inspection reports. Quality documentation reports are provided to customers as required.

Section 4: BETE FGD Nozzles



4.1 ST & STXP Series Absorber Spray Nozzles

Type of component: BETE ST Series Absorber Spray Nozzles

Nozzle Type: Spiral impingement

Spray Pattern: Full cone

Specific Function in FGD System:

Deliver atomized slurry into absorber tower section

Materials of Construction: Cobalt Alloy 6 (AMS 5378)
Reaction Bonded Silicon Carbide (RBSC)
Other materials available on request

Maintenance Requirements: No routine maintenance other than inspection

Expected Service Life Under Design Range of Conditions:

Cobalt Alloy 6: 40,000+ hours

RBSC: 80,000+ hours

Environmental Limitations:

Free Passage: 1-1.5" (28-38mm) 30%-100% of orifice diameter)

Temperature: 1900°F (1038°C) (Cobalt Alloy 6)
2500°F (1370°C) (RBSC)

Features:

The BETE spiral design nozzle series have rapidly gained acceptance in FGD installations as their superior spray performance characteristics allow for increased removal rates at significantly lower delivery pressures. The savings in pumping costs alone will often recoup the initial nozzle investment within months. Typical operating pressures range from 4 psi to 15 psi (0.3 to 1.0 bar).

The BETE ST series spiral nozzle line produces sprays composed of droplets significantly smaller than conventional designs at equivalent pressures. This finely atomized spray presents an extraordinarily large amount of droplet surface area over which mass transfer can occur. The nozzles are a compact, rugged, one-piece design having no internal plates or disks. The absence of internals makes the ST series a low-maintenance unit remarkably resistant to clogging. The expanded spiral nozzles, the BETE STXP series, achieves a free-passage diameter 2-3 times larger than the ST series, making it the spiral design of choice when nozzle plugging is a major consideration.

The design of the nozzle develops concentric rings of spray. The outer-ring contains heavier flow and large droplets, with the inter-ring volumes filled with the more finely atomized liquid. This configuration aids in minimizing the entrainment of the smaller droplets into the gas stream, resulting in a significant increase of available transfer surface. The spray is essentially a hybrid full cone pattern composed of two or three separate concentric hollow cones.

4.2 MP Series MaxiPass Absorber Spray Nozzles



Type of component:	BETE MaxiPass Series Absorber Spray Nozzles
Nozzle Type:	In-line whirl maximum free passage
Spray Pattern:	Full cone
Specific Function in FGD System:	Deliver atomized slurry into the absorber tower section

Materials of Construction:	Silicon Nitride Bonded Silicon Carbide (SNBSC) Cobalt Alloy 6 (AMS 5378) Polyurethane Other materials available on request
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Maintenance Requirements:	No routine maintenance other than inspection
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Expected Service Life Under Design Range of Conditions:	Cobalt Alloy 6: 40,000+ hours SNBSC: 80,000+ hours Polyurethane: 8,000-18,000+ hours
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Environmental Limitations:	Free Passage: 1.5”– 2.5”+ (36-64mm) (Free Passage Orifice diameter) Temperature: 1900°F (1037°C) (Cobalt Alloy 6 & SNBSC) 155°F (68°C) (Polyurethane) 3000°F (1650°C) (SNBSC)
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Features:
The BETE **MaxiPass (MP)** Maximum Free Passage series was developed to deliver the large Free Passage Diameter in-line whirl design with a finely atomizing full cone spray. At equivalent flow rates and pressures, the BETE **MaxiPass** series produces sprays with droplet diameters finer than the tangential inlet whirl design.

The BETE **MaxiPass** series provides uniform spray distribution combined with the large free passage diameters necessary for maximum clog resistance when spraying re-circulated slurries. Two unique S-shaped internal vanes allow the **MaxiPass** series to pass large particles, easily handling dirty, lumpy, and stringy recycle. Its highly energy efficient design can mean significant reductions in pumping pressure and operating costs.

4.3 TH Series Absorber Spray Nozzles



Type of component: BETE TH Series Absorber Spray Nozzles

Nozzle Type: Tangential whirl



Spray Pattern: Hollow cone

Specific Function in FGD System:

Deliver atomized slurry into scrubber tower section



Materials of Construction: Silicon Nitride Bonded Silicon Carbide (SNBSC)
Other materials available on request

Maintenance Requirements: No routine maintenance other than inspection

Expected Service Life Under Design Range of Conditions:
SNBSC: 80,000+ hours

Environmental Limitations:
Free Passage: 1.5"– 2.5"+ (36-64mm+) (typical)
Temperature: 3000°F (1650°C)

Features:

The BETE TH series has a patented geometry that has been designed to give the most uniform possible liquid distribution around the periphery of the spray.

The compact size and efficiency of the design allow higher flow rates for a given connection size than competing designs.

4.4 DTH Series Absorber Spray Nozzles



Type of component: BETE DTH Series Absorber Spray Nozzles

Nozzle Type: Double hollow cone tangential

Spray Pattern: Two hollow cone spray patterns, one spraying down; one spraying up



Specific Function in FGD System:
Deliver atomized slurry into tower section

Materials of Construction: Silicon Nitride Bonded Silicon Carbide (SNBSC)
Other materials available on request

Expected Service Life Under Design Range of Conditions:
SNBSC: 80,000+ hours

Environmental Limitations:
Free Passage: 1.5"-2.5"+ (36-64mm+)
Temperature: 3000°F (1650°C)

Features:
The BETE **DTH** series features two orifices, each of which forms a hollow cone pattern, with one spraying downward and the other spraying upward. The geometry of the design has been developed to produce the most uniform possible spray distribution in each cone.

The upward spraying cone accomplishes two objectives: 1.) reduces the pressure drop across the absorber and 2.) increases the average droplet residence time. The **DTH** is also available with unequal flows in the cones such as 70% upward spraying and 30% downward spraying.

4.5 TSC Absorber Spray Nozzles



Type of component: BETE TSC Series Absorber Spray Nozzles

Nozzle Type: Full cone tangential



Spray Pattern: Full cone

Specific Function in FGD System:
Deliver atomized slurry into tower section

Materials of Construction: Silicon Nitride Bonded Silicon Carbide (SNBSC)
Other materials available on request

Expected Service Life Under Design Range of Conditions:
SNBSC: 80,000+ hours

Environmental Limitations:
Free Passage: 1.5"-2.5"+ (36-64mm+)
Temperature: 3000°F (1650°C)

Features:
The BETE TSC series is a tangential-inlet design with specific features in the closed end of the whirl chamber that deflects some of the spray into the center of the pattern, creating a full cone effect.

4.6 MP Series MaxiPass Packing Spray Nozzles



Type of component: BETE MaxiPass Series Packing Spray Nozzles

Nozzle Type: In-line whirl with maximum free passage

Spray Pattern: Full cone

Specific Function in FGD System:
Distribute slurry onto packing

Materials of Construction: Silicon Nitride Bonded Silicon Carbide (SNBSC)
Cobalt Alloy 6 (AMS 5387)
Polyurethane
Other materials available on request

Maintenance Requirements: No routine maintenance other than inspection

Expected Service Life Under Design Range of Conditions:

Cobalt Alloy 6: 40,000+ hours
SNBSC: 80,000+ hours
Polyurethane: 8,000-18,000+ hours

Environmental Limitations:

Free Passage: 1.5"-2.5"+ (38-64mm+)
Temperature: 1900°F (1037°C) (Cobalt Alloy 6 & SNBSC)
155°F (68°C) (polyurethane)
3000°F (1650°C) (SNBSC)

Features:

The BETE **MaxiPass (MP)** series provides a uniform spray distribution combined with the large free passage diameters necessary for maximum clog resistance when spraying re-circulated slurries. Two unique S-shaped internal vanes allow the **MaxiPass** series to freely pass large particles, easily handling dirty, lumpy and stringy recycle. Its high energy-efficient design can mean significant reductions in pump sizing and operating costs.

The BETE **MaxiPass** series was developed to deliver the large free passage diameter characteristics of the whirl-tangential design in a finely atomizing full cone spray configuration.

The BETE **MaxiPass** series provides uniform spray distribution combined with the large free passage diameters necessary for maximum clog resistance when spraying re-circulated slurries. Two unique S-shaped internal vanes allow the **MaxiPass** series to pass large particles, easily handling dirty, lumpy, and stringy recycle. Its highly energy efficient design can mean significant reductions in pumping pressure and operating costs.

4.7 SA Series SpiralAir Quench Nozzles



Type of component:	BETE SpiralAir Quench Nozzles
Nozzle Type:	High-flow air atomizer
Spray Pattern:	Full cone
Specific Function in FGD System:	Inject highly atomized liquid in each quench section

Materials of Construction:	Cobalt Alloy 6/SS316L Nickel Alloy C22 Cobalt Alloy 6 Other materials available on request
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Maintenance Requirements:	No routine maintenance other than inspection
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Expected Service Life Under Design Range of Conditions:	Cobalt Alloy 6: 15,000+ hours (water) 5,000+ hours (slurry) Nickel Alloy C22: 12,000+ hours (water) 4,000+ hours (slurry)
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Environmental Limitations:	Free Passage: 0.106”-0.365” (2.7-9.3mm) Temperature: 2200°F (1093°C) (Nickel Alloy) 1900°F (1037°C) (Cobalt Alloy 6) 800°F (427°C) (316L)
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Features:

The **SpiralAir (SA)** is a two-fluid nozzle utilizing either steam or air as the second fluid.

Although the **SpiralAir** was developed for lime slurry spray drying in FGD installations, it has demonstrated equally impressive performance enhancement in gas quenching applications. It has operated very successfully under the harsh conditions generally associated with the FGD process. Tests run on a **SpiralAir** removed after 2000 hours of operation in a FGD installation using a 10% lime slurry showed a maximum droplet degradation of 4%.

The **SpiralAir** features:

- droplets of small diameter and a low relative span value
- non-clogging operating characteristics
- low air volume rates
- capability to dynamically balance air flow rates to tightly metered liquid flow

Demanding maximum droptime limitations of the typical gas conditioning section require the efficient and reliable production of fine sprays with a narrow relative span of drop diameters. The BETE **SpiralAir (SA)** series combines low air-consumption and extremely fine atomization into a rugged uncomplicated design.

Various compact single- and multi-nozzle lance assemblies are available to deliver the spray where it is needed, minimizing the number of expensive access ports.

4.8 ST Series Quench Nozzles



Type of component:	BETE ST Series Quench Nozzles
Nozzle Type:	Spiral impingement
Spray Pattern:	Full cone
Specific Function in FGD System:	Inject highly atomized liquid in quench section
Materials of Construction:	Nickel Alloy C22 Cobalt Alloy 6 (AMS 5387) 316L Other materials available on request
Maintenance Requirements:	No routine maintenance other than inspection
Expected Service Life Under Design Range of Conditions:	25,000+ hours (water)
Environmental Limitations:	Free Passage: 0.93”-0.75” (19-24mm) (typical) Temperature: 2200°F (1093°C) (Nickel Alloy C22) 1900°F (1037°C) (Cobalt Alloy 6) 800°F (427°C) (316L)

Features:

The BETE high-efficiency spiral **ST** nozzle design brings significant improvements to quenching applications over the performance possible with traditional whirl nozzles. The finely atomized spray of the spiral **ST** nozzle presents an extraordinarily large amount of droplet surface area over which evaporation can occur.

These nozzles are a compact, rugged, one-piece design having no internal plates or disks. The absence of internals makes the BETE **ST** a low-maintenance unit remarkably resistant to clogging. The expanded spiral nozzles, the BETE **STXP** series, achieve a free-passage diameter equal to the orifices diameter. For quench applications, the **ST 6**, **ST 8** and **ST 10 FC** or **W** are often chosen. Where available residence times are short, the **L** series hollow-cone spirals provide the finest atomized fog.

4.9 MP Series MaxiPass Mist Eliminator Wash Spray Nozzles



Type of component: **BETE MaxiPass Series Mist Eliminator Wash Spray Nozzles**

Nozzle Type: In-line whirl with maximum free passage

Spray Pattern: Full cone

Specific Function in FGD System:
Periodic wash down of mist eliminator pads/vanes

Materials of Construction: Polypropylene
PVDF
316L
Other materials available on request

Maintenance Requirements: No routine maintenance other than inspection

Expected Service Life Under Design Range of Conditions:
40,000+ hours (water)

Environmental Limitations:
Free Passage: 0.152”-0.5”+ (4-13mm) (typical)
Temperature: 155°F (68°C) (Polypropylene)
800°F (427°C) (316(L))
245°F (118°C) PVDF

Features:

The BETE **MaxiPass (MP)** series provides a uniform spray distribution combined with the large free passage diameters necessary for maximum clog resistance when spraying re-circulated slurries. Two unique S-shaped internal vanes allow the **MaxiPass** series to freely pass large particles, easily handling dirty, lumpy and stringy recycle. Its high energy-efficient design can mean significant reductions in pump sizing and operating costs.

The BETE **MaxiPass** series was developed to deliver the large free passage diameter characteristics of the whirl-tangential design in a finely atomizing full cone spray configuration.

The BETE **MaxiPass** series provides uniform spray distribution combined with the large free passage diameters necessary for maximum clog resistance when spraying re-circulated slurries. Two unique S-shaped internal vanes allow the **MaxiPass** series to pass large particles, easily handling dirty, lumpy, and stringy recycle. Its highly energy efficient design can mean significant reductions in pumping pressure and operating costs.

4.10 NC Series Mist Eliminator Wash Spray Nozzles



Type of component: **BETE NC Series Mist Eliminator Wash Spray Nozzles**

Nozzle Type: In-line whirl

Spray Pattern: Full cone

Specific Function in FGD System:

Periodic wash down of mist eliminator pads/vanes

Materials of Construction:

Polypropylene
PVC
PTFE
Other materials available on request

Maintenance Requirements:

No routine maintenance other than inspection

Expected Service Life Under Design Range of Conditions:

40,000+ hours (water)

Environmental Limitations:

Free Passage: 0.141”-0.281”+ (3.6-7.1mm) (typical)
Temperature: 155°F (68°C) (Polypropylene)
135°F (57°C) (PVC)
300°F (150°C) (PTFE)

Features:

The BETE NC series are conventionally designed full cone nozzles, primarily made in polymers or plastics, employing a flat whirl plate upstream of the orifice. This series produces a substantially uniform spray coverage and medium to coarse atomization. Due to the presence of the whirl plate, Free Passage Diameters are limited to approximately 50% of the orifice diameter.

4.11 WL & SC Series Mist Eliminator Wash Spray Nozzles



Type of component: BETE WL and SC Series Mist Eliminator Wash Spray Nozzles

Nozzle Type: In-line whirl



Spray Pattern: Full cone

Specific Function in FGD System:
Periodic wash down of mist eliminator pads/vanes

Materials of Construction:
SC – 316L
WL – Polypropylene, 303L, 316L
Other materials available on request

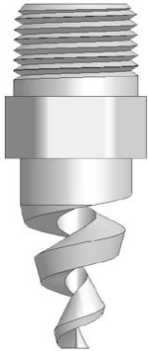
Maintenance Requirements: No routine maintenance other than inspection

Expected Service Life Under Design Range of Conditions:
40,000+ hours (water)

Environmental Limitations:
Free Passage: 0.141”-0.281”+ (3.6-7.1mm) (typical)
Temperature: 155°F (68°C) (Polypropylene)
800°F (427°C) (303(L)), (316(L))

Features:
The BETE WL and SC series are conventionally designed full cone nozzles, primarily made in alloys, employing a flat whirl plate upstream of the orifice. These series produce a substantially uniform spray coverage and medium to coarse atomization. Due to the presence of the whirl plate, Free Passage Diameters are limited to approximately 50% of the orifice diameter.

4.12 TF-XP(N) Series Cooling Pond Spray Nozzles



Type of component: **BETE TF-XP(N) Series Cooling Pond Spray Nozzles**

Nozzle Type: Spiral impingement

Spray Pattern: Full cone

Specific Function in FGD System:
Spray cooling pond water for direct-contact cooling

Materials of Construction: 316L
Other materials available on request

Maintenance Requirements: No routine maintenance other than inspection

Expected Service Life Under Design Range of Conditions:
80,000+ hours

Environmental Limitations:

Free Passage: 13-38mm (0.5"-1.5"+) (typical)
Temperature: 427°C (800°F) (316L)

Features:

Although the cooling of sprayed water is produced by losing heat to the surrounding environment through conduction, radiation, and evaporation, evaporation provides the majority of the cooling. All three of these heat loss processes are surface-area dependent. Thus, the finer the spray, the larger the droplet surface area produced and the higher the cooling efficiency.

The BETE **TFXP(N)** series produces sprays composed of droplets smaller than conventional designs at equivalent pressures. This finely atomized spray presents an extraordinarily large amount of droplet surface area over which all three cooling processes can occur. The nozzles are a compact, rugged, one-piece design having no internal plates or disks.

The expanded spiral nozzles, the BETE **TFXP(N)** series, achieves a free-passage diameter equal to the surface orifice diameter. In many spray pond applications the liquid being sprayed contains large solid particles that may plug the nozzle. The BETE **TFXP(N)** series provides the large free passage required for low-maintenance operation with no degradation in performance.

The actual cooling range achievable depends on site-specific conditions such as Wet Bulb Temperature. Further cooling can be achieved by adding a second cooling pond using the cooled water from the first pond as the water supply. An evaporation loss of 1% to 2% of the volume spray should be expected.