Debottlenecking Mist Eliminator Installations in Sulfuric Acid Plants

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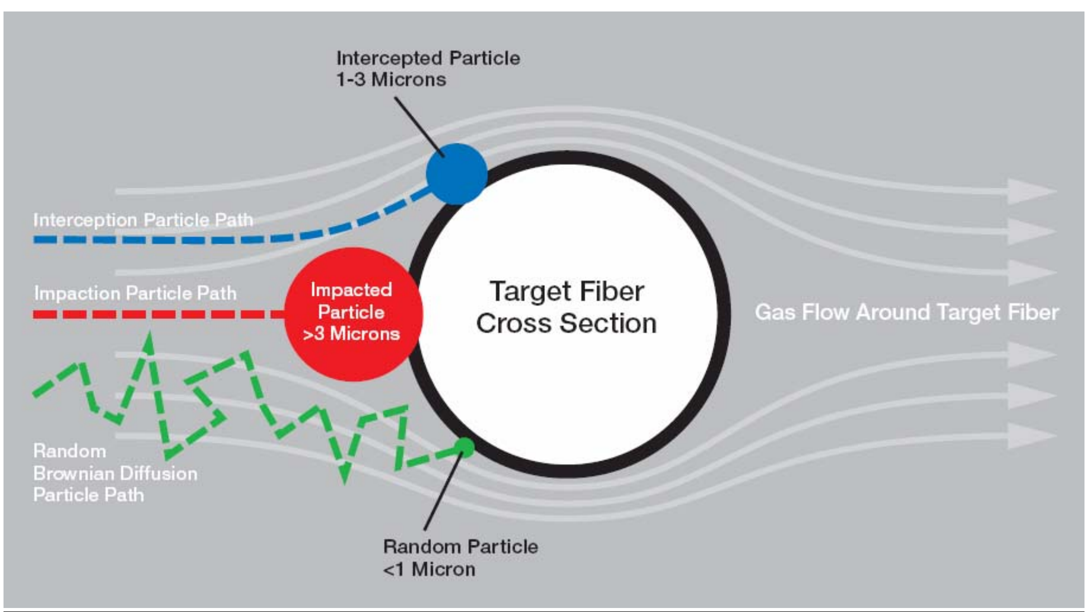
With global upswing in sulfuric demand, there is a growing need to increase capacity of existing mist eliminator installations without significant vessel modifications. Minimizing vessel modifications reduces overall cost.   Also in some cases, local legislation requires re-permitting if mist eliminator housing dimensions change.

De-bottlenecking directly relates to overcoming limiting velocities inherent in mist eliminator design. The solution most often used is to create new ways to add more filtration area in the existing space without sacrificing performance. Mist eliminator performance is multi-faceted, comprised of mist collection, particle regeneration (reentrainment), pressure drop, service life and maintenance (related to plant downtime).

To increase the capacity of existing mist eliminator installations, it is important to understand performance tradeoffs between the different types of common available devices. In sulfuric acid plants these devices are primarily mesh pads, impaction fiber beds and diffusion fiber beds. Performance tradeoffs of these devices are discussed and examples of plant de-bottlenecking are presented. Mist eliminator packing styles for different beds that may have an impact on debottlenecking options are also presented.

To better understand the issues for debottlenecking existing mist eliminator installations, a review of mist collection mechanisms will help to explain the main classifications of mist eliminators.

Mist Collection Mechanisms:



The **inertial impaction** mechanism collects a mist particle in a gas stream when it impacts on a fiber. A particle has weight...the bigger the particle, the more it weighs. If the gas velocity is fast enough, the weight and therefore the inertia of the particle will cause it to impact on a target rather than follow the gas streamline around it. The larger the diameter of a particle, the more it weighs, and the easier it is for it to impact. Once a mist particle touches the surface of the collecting target, it adheres by weak Van Der Waals forces.

The second collection mechanism is **direct interception**. This means the particle is intercepted from the gas stream if it cannot squeeze between two targets (or if it touches a target as it passes by). Consider a particle one micron in diameter that follows a gas streamline passing within a half micron from a target. The particle will touch the target and be collected by interception. This mechanism is somewhat similar to the action of a mesh filter or sieve.

Inertial impaction and interception are the primary collection methods for removing larger mists from a gas stream. However, if fine mist capture is required i.e., remove sub-micron particles out of a gas stream, the mist eliminator must be designed to take advantage of a third mechanism called Brownian movement or **Brownian diffusion**.

All molecules in a gas stream are in constant random motion. The smaller particles pick up random motion by constant collision with surrounding gas molecules. The smaller the particle, the greater it's random motion and the more likely it will contact a target and be captured as the mist particle passes by in the gas stream. Since visible stack emissions are primarily sub-micron in size, high efficient fiber beds utilizing the diffusion collection mechanism are required to eliminate visible opacity.

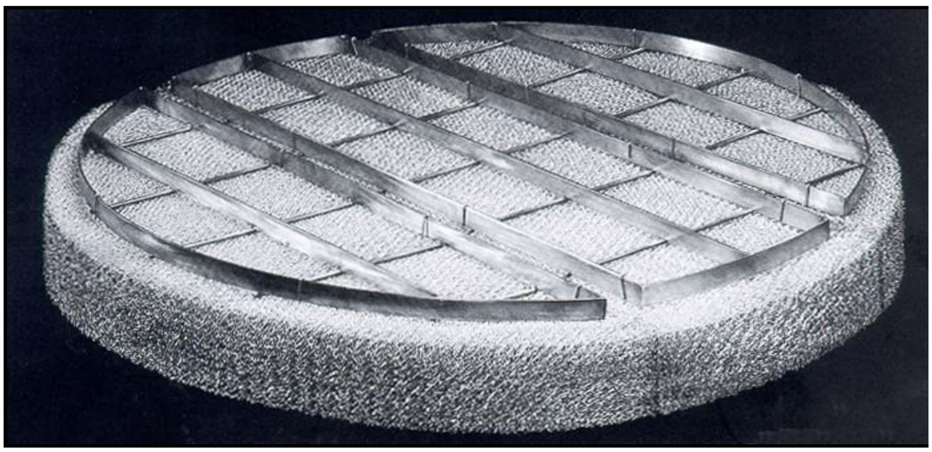
With the impaction mechanism, efficiency decreases as the gas and particle velocity decreases because particles have less momentum and can better move with the gas stream. With the direct interception mechanism, particle collection efficiency is independent of velocity since capture is somewhat similar to sieve collection. With Brownian Diffusion the capture efficiency on small particles increases as the gas velocity decreases. This is because the small particles when traveling at a lower velocity will have more residence time in the fiber media, which gives a greater likelihood that an incident particle will strike a target along its random path through the media.

Mist Collection Devices:

Mesh pads and impaction fiber beds are primarily impaction devices. For mist particle capture, these devices rely on momentum (mass and velocity) of larger mist particles to collect by the impaction mechanism. High efficient fiberbeds are considered diffusion devices since for mist capture of smaller submicron particles they utilize the Brownian diffusion mist capture mechanism. Although diffusion fiberbed devices also collect particles by interception and impaction, these devices are selected for their high efficiency removal of fine submicron particles by Brownian diffusion.

Mesh Pads:

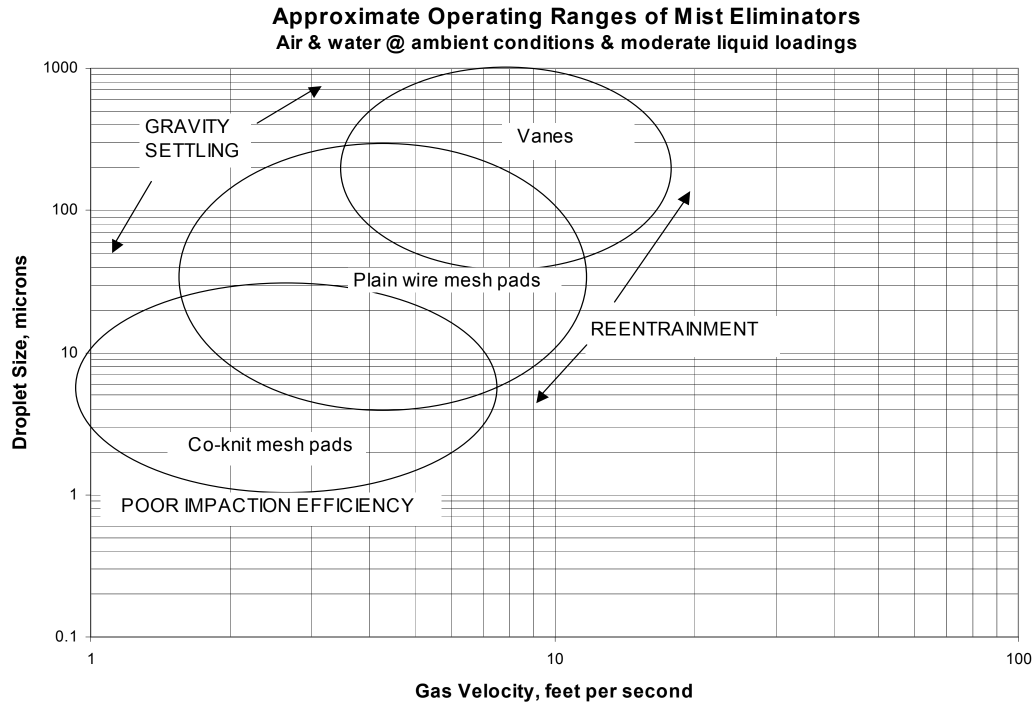
Mesh pads, also called impingement devices, have been in sulfuric acid plants for several decades. These devices have high efficiency on mist particles 5 microns and greater. Pad filament diameter, thickness and density can be varied to optimize performance. More recently, to boost collection efficiency down to 2-micron sized particles, coknit material is often integrated into the pad. Coknit is comprised of fine fibers woven into the larger matrix of metal mesh filaments. Typically glass or PTFE coknit fibers are used in sulfuric service.



TowerGARD™ Mesh Pad Comprised of Three Segments

Since mesh pads are relatively low pressure drop devices (25 to 100 mm wc), it is important to ensure proper installation to achieve uniform velocity across the pad surface. Proper design of inlet and outlet duct locations are an often overlooked design principle. Sufficient clearances must be provided for introducing and removing gas from the pad otherwise poor flow distribution through the pad can lead to poor pad performance.

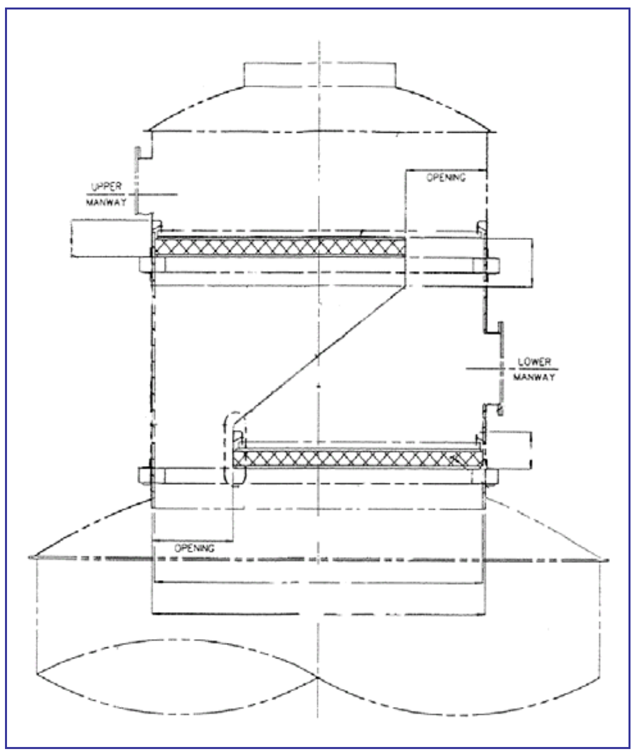
Since mesh pads are impaction devices, they also rely on proper velocity to optimize performance. The figure below illustrates that too low a velocity results in poor efficiency whereas too high a velocity results in reentrainment. Also for mesh pads that utilize coknit material to boost collection of smaller particles, the pad velocity needs to be lowered to avoid reentrainment.



Plant Debottlenecking Examples for Mesh Pad Installations:

Z-Pad Arrangement:

The installation on the right shows a "Z-pad" arrangement used to add more mesh pad surface area to an existing dry tower installation where plant rate was significantly. increased. This unit has been in service for several years. The pad is a special metal mesh-glass coknit composite for 99.9% removal of particles down to 2 microns in size. Design pressure drop is about 60 mm wc.



The Z-pad design avoids the cumbersome "apex" angled style pads that are sometimes used to add extra pad surface area. The horizontal Z-pads are matched and easier to install compared to the "apex" design.

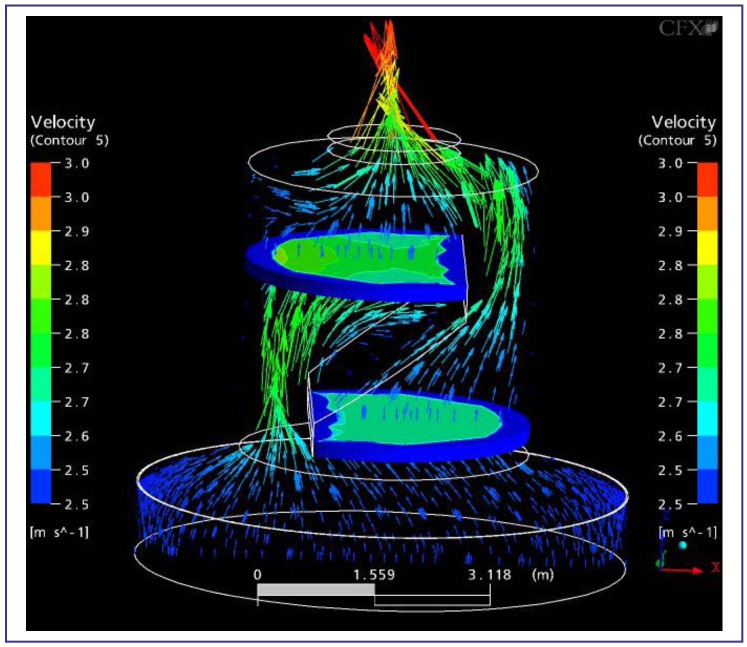
To assure proper operation, the openings around the Z-pad sections are designed to balance the gas flow through the two Z-pad sections.

CFD Flow Modeling Example of Z Pad:

Since the Z pad style creates a complex gas velocity distribution, a computational fluid dynamics evaluation was made. This was to assure balanced flow between top and bottom Z pads and to check pad velocity profiles. The CFD color velocity profile analysis is shown below:

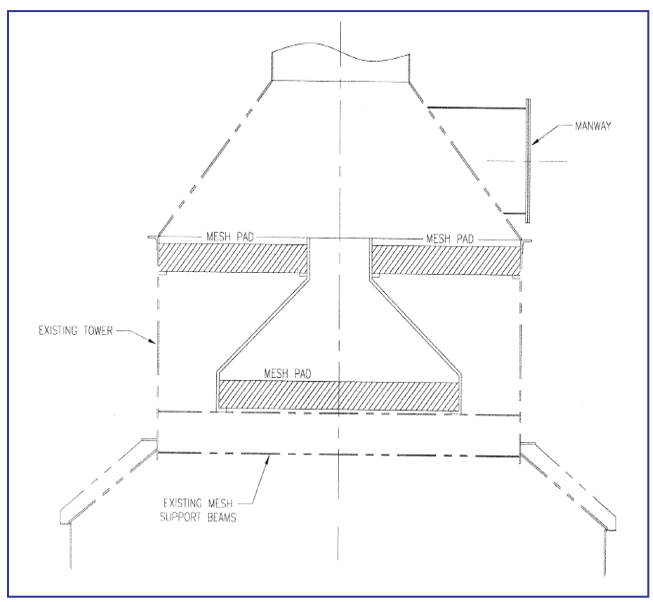
Results of the evaluation found a slight velocity variance in the top pad but not enough to cause problems. For future designs, baffling could be added to help smooth out the top pad velocity profile if higher throughput is desired.

Average velocities (flows) of top and bottom pads were within 2 percent at design rate. Peak velocities were within a few percent of average pad velocities and within acceptable levels.



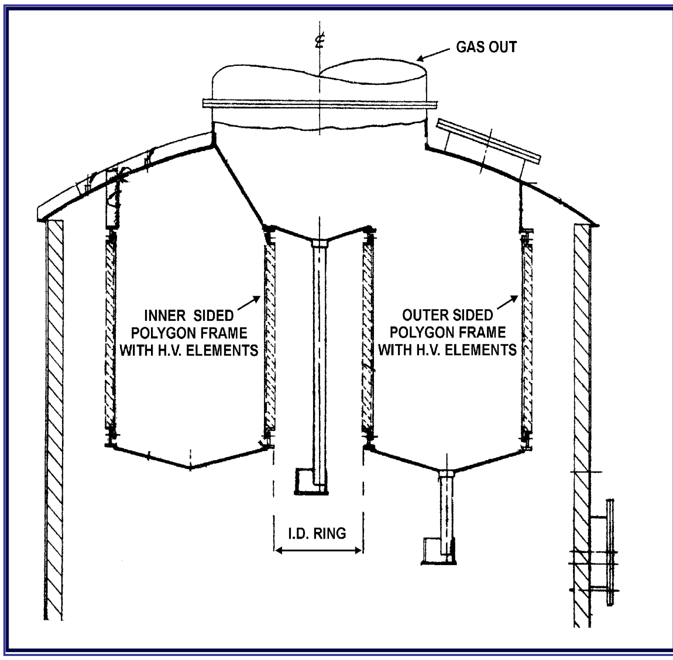
Double Z-Pad Arrangement:

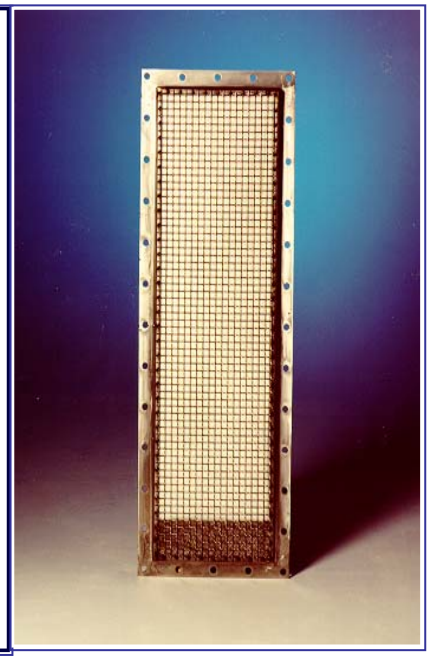
Another recent extended area mesh pad design was installed in an existing US sulfuric acid plant dry tower. The style is called the "Double-Z Pad" shown on the right. This Double-Z pad design provides even more flow area compared to the Z-Pad arrangement. The center section is dropped to provide a more balanced flow arrangement. This pad construction was a multi-mesh Zecor™ /PTFE coknit composite with a design collection efficiency of 99.9% on 2 micron particles and 50 mm wc pressure drop.



Impaction Fiber Beds:

In the 1960's, panel style impaction fiber beds were developed to provide enhanced performance compared to mesh pads. Impaction fiber beds contain more fine collecting fibers than coknit mesh pads and are used when some submicron small particle mist capture is desirable. These fine fibers collect a portion of the submicron mist particles by the interception collection mechanism. Design pressure drop was 250 mm wc and collection efficiency was increased down to one micron size particles and smaller. These devices were installed in many dry and interpass and final absorbing towers around the world. A typical panel is shown below along with a concentric polygon arrangement that maximized filter area in the installation. The only drawback was installation cost was high with panel housing construction and there were many attachment points to maintain.

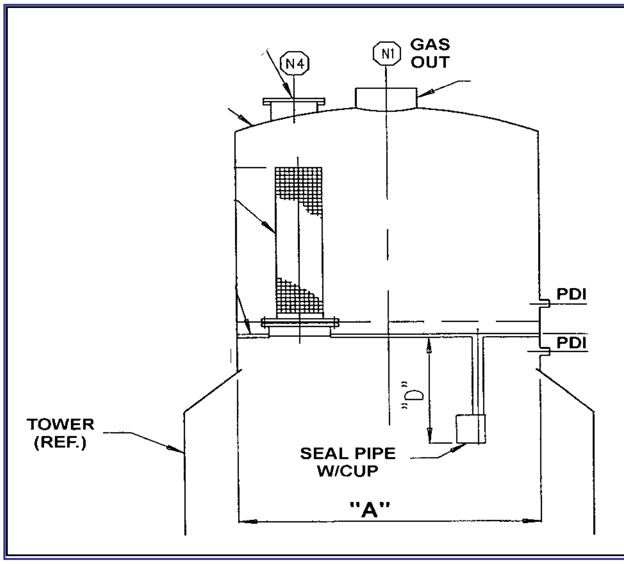




Cylindrical Style Impaction Fiberbeds:

In the 80's an improved cylindrical impaction style fiberbed was developed. The CS-IP impaction fiber bed (shown below) was designed for improved dry tower performance in sulfuric acid plants. The element is a cylindrical bi-component fiberbed design using a fiberglass mat for collecting small particles plus an alloy mesh re-entrainment control or "drainage" layer. The standard size is 30 inches diameter and 65 inches tall. Smaller sizes are available. In drying tower service, metal mesh is usually Alloy 20 and the cage is 316 SS. An optional Alloy 20 cage provides increased service life.

The CS-IIP is designed for final absorbing tower service. Standard CS-IIP size is 26 inches in diameter and 40 inches tall. In final absorbing tower installations, metal mesh is usually 310 SS and the cage is 316 SS. A typical cylindrical impaction candle tower installation is shown below.



In sulfur burning drying tower service, conventional CS-IP elements are washed on a regular basis depending on tower design and plugging agents. Service life increases when alloy tower construction and efficient upstream air filter are used. Note in absorbing towers, CS-IP element service life is significantly longer compared to dry tower service since dirt levels are less at these locations in the process. Dirt and dust particles penetrating the upstream air filter can penetrate dry tower packing and collect in the mist eliminators. This particulate combines with sulfates carried by acid spray off tower components (see below) to form a paste in the mist eliminator fiber packing affecting element service life.

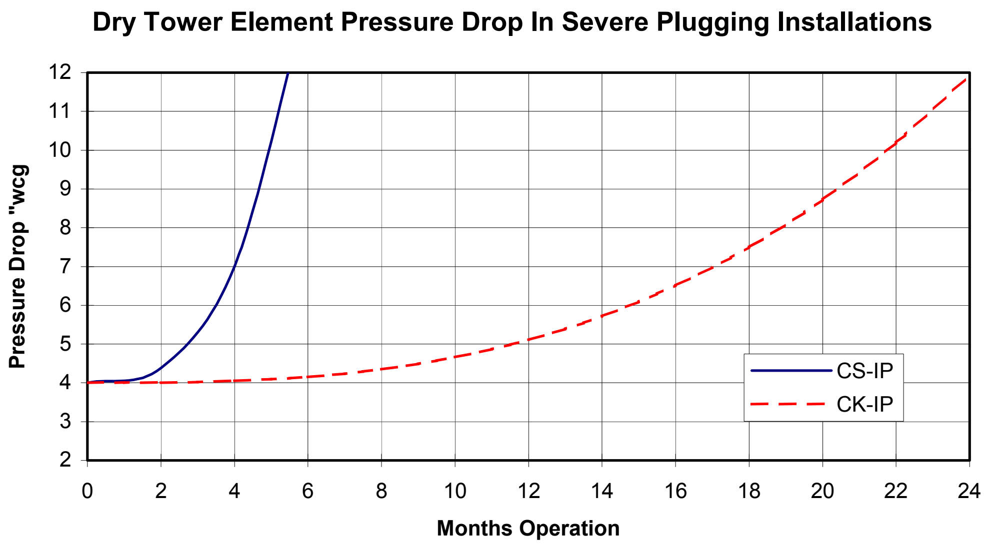
The CK impaction fiberbed was developed in the 1990's to provide longer operation between service cycles. For sulfur burning plants, dry tower service life is typically two years or longer. Although CK elements look the same as CS elements from the outside, the internal co-knit collection layer is significantly different than standard CS collecting glass media (see co-knit photo). CK beds are identical in size and capacity to standard CS beds operating at the same gas volume and clean pressure drop. Like the CS design, CK elements include an alloy metal mesh re-entrainment control layer.

Dirt & Sulfates Affect Element Service Life

CK elements use a metal mesh structure with small diameter acid resistant glass fibers knitted together with the metal wires to increase the collection targets and thus small particle collection efficiency. The co-knit metal mesh collecting layer is considerably thicker and has a higher void fraction than the glass collecting layer used in standard CS elements. In severe plugging situations, CK elements operate much longer between cleanings than regular CS elements.

CK Co-Knit Collecting Layer

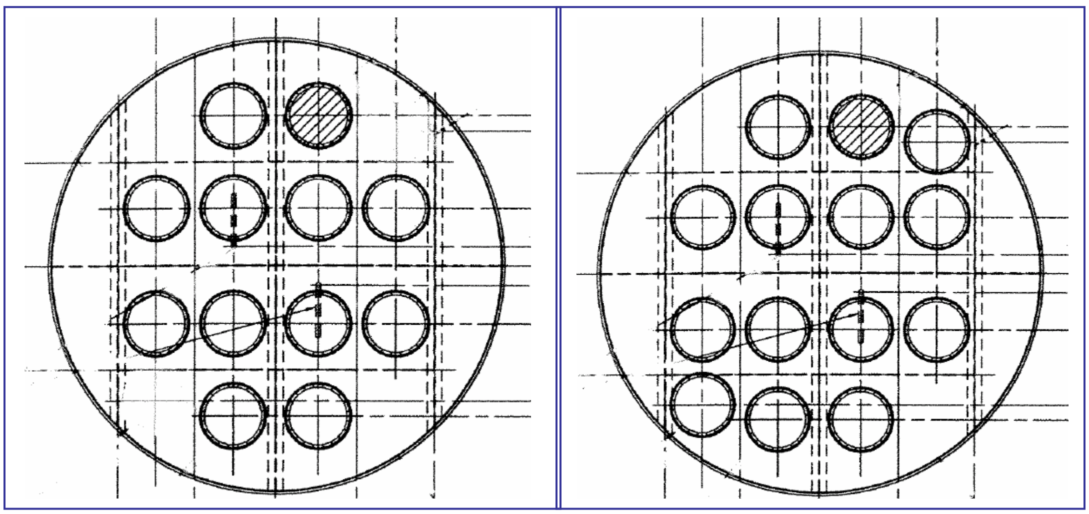
The chart below shows actual dry tower field pressure drop measurements of standard CS-IP elements compared to new CK-IP elements in severe plugging installations. Installations had no upstream air filters and tower components were highly sulfated. As shown, the new CK elements operated significantly longer in dry tower service before needing to be washed or repacked.



Some plants have adopted novel methods for washing CS or CK beds such as slow dunking of the elements in a specially designed tank or process sump outside the tower to flush solids out of the fiber or using low pressure water flushing. Washing this way normally restores beds to their original pressure drop. Time between washings varies widely depending on the amount of insoluble particulate in the inlet gas and the amount of sulfate carried forward by acid spray from the distributor and packing. Some clients have quick washing routines to minimize plant downtime. In many cases, the experience has been that plants prefer to collect the fouling agents in the mist eliminators to prevent downstream equipment and catalyst fouling. Plants that operate with alloy distributor components also have typical longer mist eliminator service life than plants operated with standard stainless components due to reduction in sulfates buildup in the process.

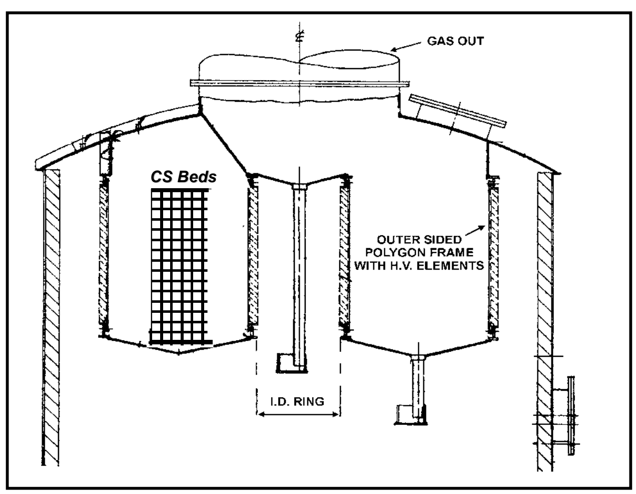
Plant Debottlenecking Examples for Impaction Fiberbeds:

As mentioned earlier, it is important to operate impaction devices at the proper velocity. A client was increasing plant rate ~15 percent. They had CS elements in both their dry and final towers. An evaluation was carried out and it was found that additional CS elements could be installed on their existing tubesheets. The resultant before and after tubesheet layouts for the dry tower looked as follows ("before" is on left and "after" is on the right side):



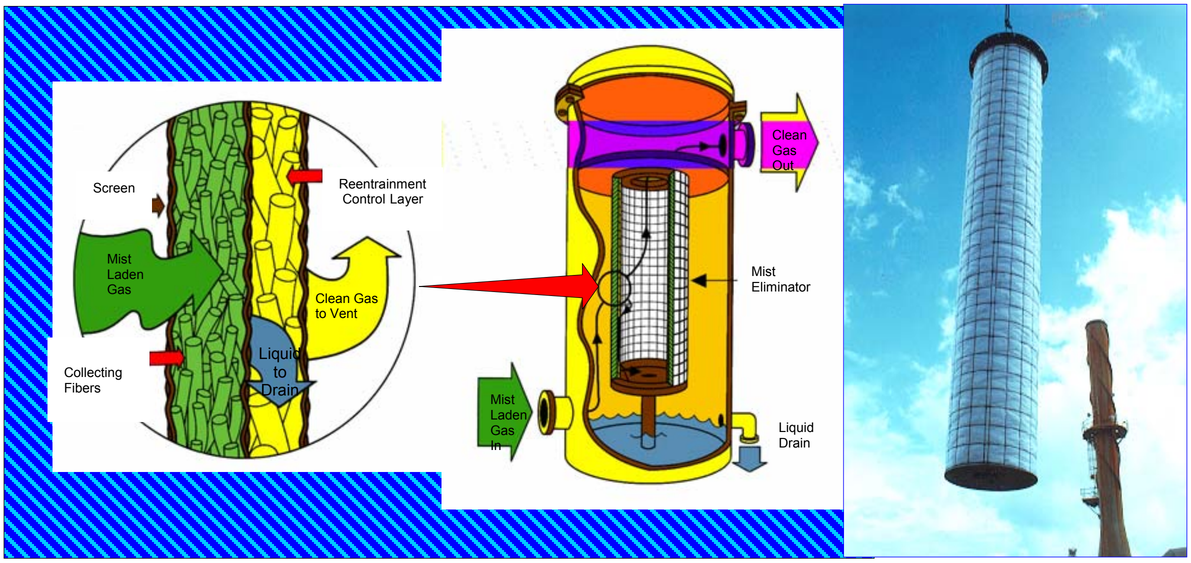
Two extra elements were installed on the existing tubesheet resulting in an 18 percent increase in overall bed area. The original blank (shown cross lined) was not used in case further capacity was needed. In the final tower, additional small diameter CS elements were installed to provide the proper design velocity to accommodate the plant rate increase.

For existing installations with panel impaction fiberbeds one way to increase the flow capacity has been to install small diameter cylindrical CS impaction fiberbed candles as shown between the double polygon HV panel arrangement. This has been implemented in plants in the US. With this type of retrofit, care must be taken to assure proper flange attachments to provide proper gas sealing.



Diffusion Fiber Beds

For high efficiency removal of submicron particles, Brownian diffusion fiberbed mist eliminators are used. Dr. Joe Brink invented the first High Efficiency (HE) Brownian diffusion fiber bed mist eliminator in the 1950's. Brownian fiber bed mist eliminators use a bed of packed fibers to collect liquid particles. The original HE was a hand packed bed using chemical resistant fiberglass. Later generations include ES (Energy Saver) bi-component diffusion fiberbeds made with glass roving. More recently, FP field packable diffusion fiberbeds were developed using engineered bi-component fiberglass sleeves. All three diffusion fiberbed types have been used in sulfuric acid plant service. High efficiency diffusion fiberbed mist eliminators are "more forgiving" with less maintenance in severe corrosive mist service compared to impaction style elements. They also maintain high collection efficiency on submicron mist particles at low turndown rates.



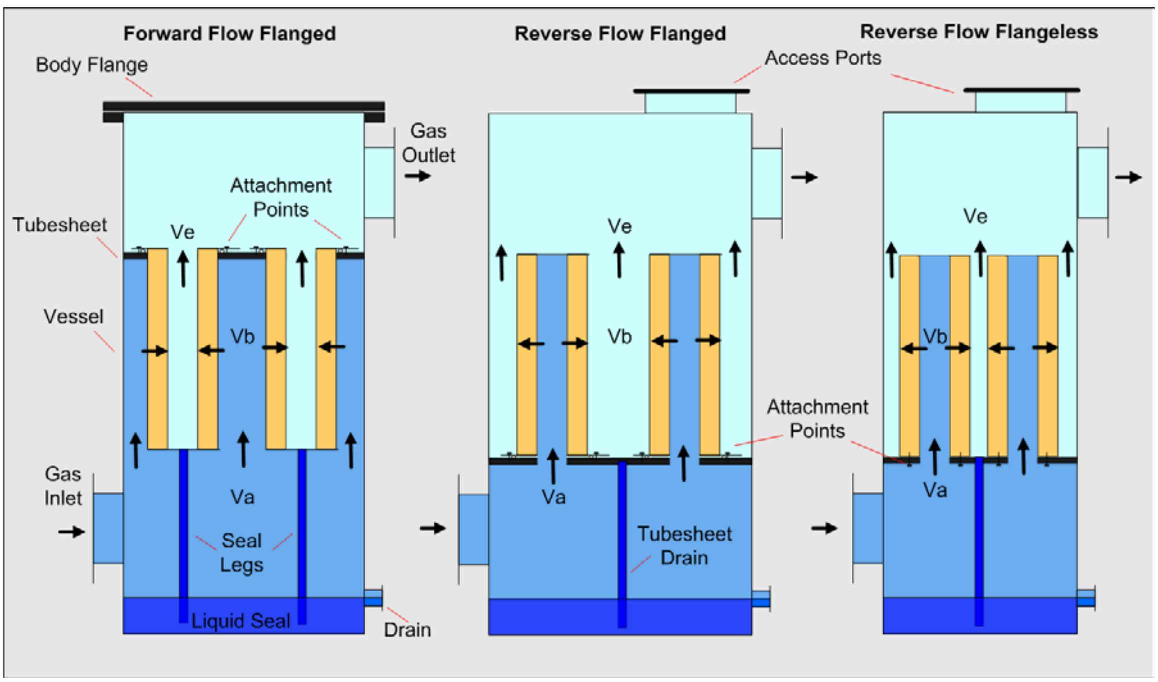
The figure above right shows a typical forward flow hanging style bi-component diffusion fiberbed. The bi-component fiberbed includes a special drainage layer to control reentrainment. A typical installation is shown on the left. Forward flow is the most common style in sulfuric acid plants since maintenance is on the clean side. Mist laden gas flows from the outside through the fiber media to the inside. As the gas flows through the fiberbed, mist particles are collected when they contact fibers and are collected as a result of impaction, interception, or Brownian motion. The collected mist accumulates on the fibers and coalesces into larger droplets and films. Because of gas drag forces, the collected liquid is moved to the downstream side of the fiber bed. The collected mist then drains to the bottom of the element and discharges to the bottom sump through a seal leg (in sulfuric acid towers, seal legs are often routed to trough style distributors). The clean gas then discharges upwards through the end of the element and out the top of the vessel.

Fiber bed mist eliminators come in various shapes. Conventional high efficiency Brownian devices are usually cylindrical, 2 feet in diameter, and 6 to 24 feet tall. Another fiberbed arrangement used in sulfuric acid plants is the reverse flow standing style where mist-laden gas flows from the inside through the fiber media to the outside.

Limiting Design Velocities for Mist Eliminator Installations

There are three principle mist-eliminator installation configurations (or styles) used for cylindrical diffusion and impaction fiber beds: forward-flow flanged, reverse-flow flanged and reverse-flow flangeless (no flanges protruding past the outer diameter of the mist collector). Forward-flow is also referred to as hanging style since the mist collector "hangs" from the tubesheet by the element flange. Reverse flow is also referred to as standing style since the mist collector "stands" on the tubesheet.

The proper installation of the unit in each case depends upon three key design velocities: the entrance or approach velocity (Va), the bed velocity (Vb), and the exit velocity (Ve). Va is normally kept under 15 m/s to minimize entrance losses, and to help prevent erosion in corrosive environments. Values for the bed velocity (Vb) and exit velocity (Ve) are experiential and application specific for optimizing performance i.e., maximum collection efficiency, minimum pressure drop, minimum reentrainment and maximum service life.



When choosing an installation style for a particular application, there are mechanical and maintenance tradeoffs. For example, because of higher gas throughput, cylindrical impaction fiber beds almost always use reverse-flow flanged style since this results in an optimum balance of gas velocities. Factors that influence installation style include large installations, corrosive processes and maintenance issues.

Large installations: With large, multiple-element installations, the forward-flow style has some disadvantages. In order for each element to be completely removed from the vessel, it must be lifted straight up through the tubesheet hole. This means that either the entire top of the vessel must be removed, or the vessel must be designed such that the distance between the tubesheet and the vessel ceiling equals the filter bed's height above the tubesheet. As a general rule, once a vessel's diameter exceeds roughly seven to ten feet (which often makes a full body flange impractical or very expensive), the required vessel height then must increase to accommodate element removal. Alternately, some plants elect to cut the vessel shell when access to elements is required for maintenance.

With reverse-flow flanged style, elements are removed by first detaching from the topside of the tubesheet and then moved side-ways to beneath an access port, and extracted one at a time through the opening. This style allows for a shorter vessel height with fewer manways which reduces vessel cost. However, with conventional 24 inch (610 mm) diameter elements, elements need to be spaced apart so that workers can reach all of the attachment points on the tubesheet which increases vessel diameter and cost. Alternately, smaller diameter elements can be used which allows closer element spacing since attachment points are easier to access resulting in a smaller vessel diameter.

With reverse-flow flangeless style, elements are detached from underneath the tubesheet. Conventional 24-inch (610 mm) diameter elements can then be located closer together resulting in a smaller vessel diameter which reduces cost.

Corrosive processes: One advantage of the forward-flow style is that mist collectors can be inspected and removed from the clean gas side, by working from the top side of the tubesheet. Workers are protected from the "dirty-gas" side.

With reverse-flow flanged style, elements can also be removed from the clean gas side on top of the tubesheet however element attachment points are more difficult to inspect and workers are in closer contact with the elements.

Reverse-flow flangeless style configuration poses safety problems in severe environments because elements are attached underneath the tubesheet on the “dirty side” of the process. In this case, special plant maintenance services are often contracted to safely remove and install these type of mist collectors.

Maintenance issues: With the forward flow style, it is easier to access the points at which elements are bolted to the tubesheet. For example, if PTFE impregnated fiberglass type gaskets are used, these need to be re-tightened a second time several hours after the first tightening to assure a gas tight seal since PTFE cold flows. To minimize the cold flow problem, full face Gortex Gylon #3545 gaskets have been used.

The forward-flow style makes trouble-shooting easier, as in the case of gasket or tubesheet leaks. If process conditions allow, observation ports can often be installed on manways in the top of the vessel, allowing the tubesheet to be viewed during operation.

In some cases where continuous irrigation or flushing sprays are required to dissolve soluble salts (e.g., mist eliminators after tailgas ammonia scrubbers) or wash away plugging agents without shutting down the process and entering the vessel, the reverse flow standing style is preferred.

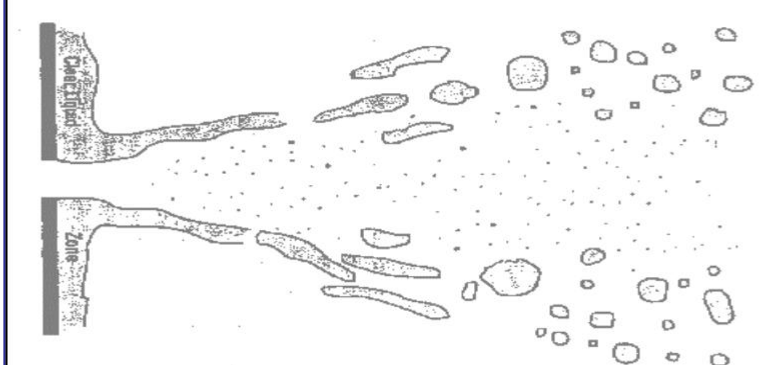
For both flanged element styles, nozzles with mating flanges can be raised up from the tubesheet to provide more reliable and easier to maintain attachment points for mist collectors since raised flanges can be made thicker and flatter than the tubesheet surface.

Also nuts and bolts are used to make the attachment. Thus, if the bolt or nut is stripped during installation or removal, these can be easily replaced. This arrangement also minimizes the generation of spray (reentrainment) caused with even slight gas leaks, since gaskets are not submerged in liquid that normally pools on the tubesheet.

<u>Mist Eliminator Entrainment Control:</u>

One constraint with all mist eliminator operation is the potential to regenerate particles or form “reentrainment” as shown below. On a “macro” scale, entrainment is generated at high gas velocity and mist loading conditions. On a “micro” scale, entrainment can also be formed when localized flooding of the fiber bed occurs e.g., heavy acid spray in one tower location due to deteriorated distributor or a leak in an acid feed header.

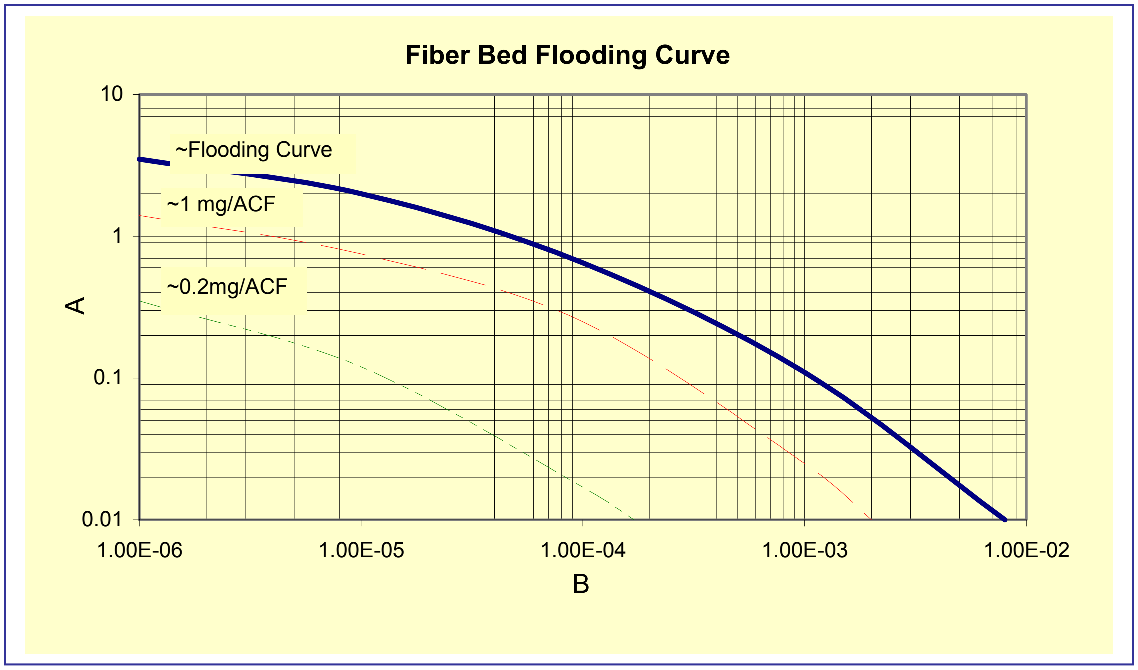
Entrainment is also called reentrainment since this refers to mist that has been previously captured, coalesced and then “reentrained” into the process gas. As gas velocity or liquid loading increase, portions of the bed where gas discharges can become flooded as shown below. This causes reentrainment typically in the form of large particles called “carry-over”. This is undesirable in corrosive applications where downstream equipment protection is critical such as for heat exchangers after interpass absorbing towers and also in applications where there is a “tight” guarantee on mass emissions. In this case reentrainment can significantly increase measured exit mass loading.



Reentrainment Example

The figure below is the fiber bed flooding curve for bulk packed diffusion style mist eliminators. Parameters “A” and “B” are similar to the classical parameters used to calculate flooding in packed columns. The iso-reentrainment curves were derived from sulfuric acid plant data taken over two decades. Basically for a given mist eliminator installation, the A parameter increases as the square of element velocity and the B parameter increasing linearly with mist loading. Note as the operation of the mist eliminator approaches the flooding curve, reentrainment increases exponentially.

As a result of entrainment, an improved bi-component fiber bed was developed. The bi-component fiber bed design helps prevent the formation of reentrainment. For this reason, bi-component diffusion fiber bed mist eliminators can operate at higher velocities compared to the bulk packed diffusion fiber beds developed in the late 50’s. An effective drainage layer is important especially in compact installations where intra-bed and exit velocities are high. Note if the process has a wide spectrum of mist particles, in some cases it is beneficial to also use an impaction device ahead of a diffusion device. This is because diffusion devices work better when operated in a more dry condition.

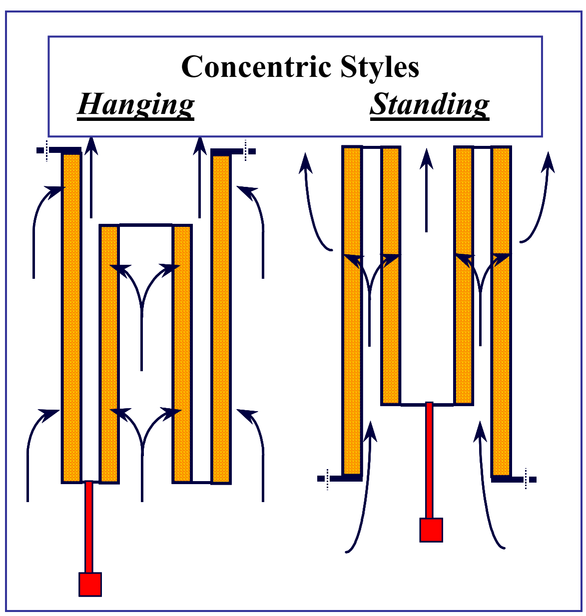


<u>Plant Debottlenecking Examples for Diffusion Fiberbeds:</u>

One strategy used in many installations is to add extra mounting locations on the tubesheet or install taller elements if there is sufficient room in the vessel. Sometimes on standing element installations, shorter beds can be located near the gas exit while the taller beds are placed farther away to prevent gas mal-distribution.

Concentric Fiberbeds:

Another way to retrofit more bed area into the existing installation is to use a concentric element design. The concentric design is an "element inside an element" design originally used by Monsanto in the 1960's. A concentric element has an element in the normally void volume in the center of a conventional size mist eliminator. The internal element is in opposite orientation as the main mist eliminator. Thus the gas splits between inner and outer elements as it is filtered. A proper design must account for the effects of higher inlet (approach) and exit velocities.



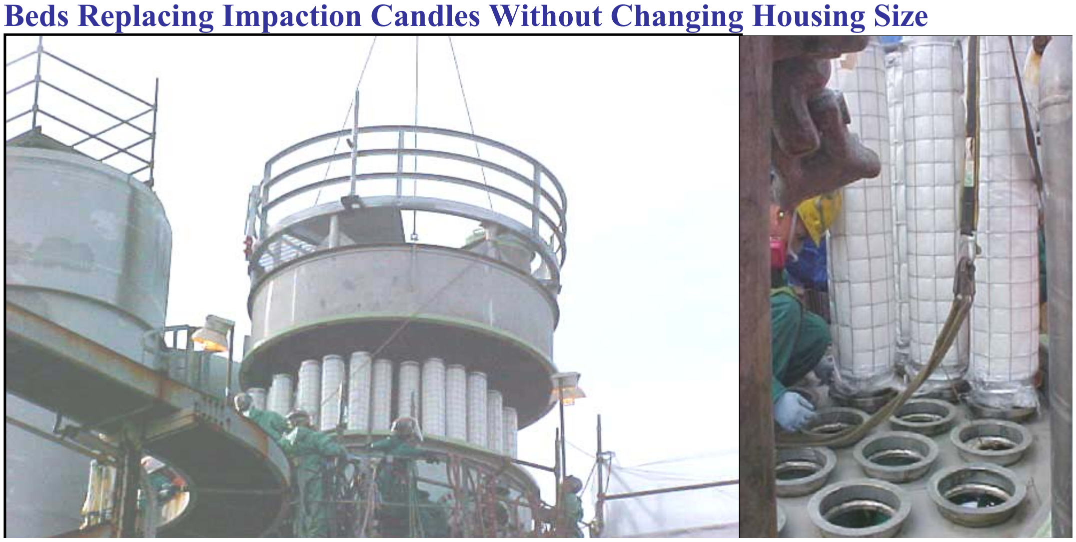
There are distinct advantages to this approach because use of concentric beds increases filtration area while using the same conventional bolting making retrofitting possible. The use of concentric elements can lead to lower pressure drop by as much as 30 to 50 percent depending upon element style and application. Increasing fiberbed area obtained when installing concentric beds often allows for increased gas flow and/or plant capacity at the same pressure drop across those elements.

One trade-off with concentric elements is they are heavier, so the extra weight may require additional tubesheet reinforcement. In the case of standing style, an extra drain leg is required for the internal forward flow element. With hanging style concentric elements, the drain legs are off-set (shown on right) compared to non-concentric beds and drain legs need to be re-routed around exiting equipment or tower internals below the tubesheet.

Small Diameter Diffusion Fiberbeds:

Another way to achieve higher capacity or lower pressure drop in existing installations is to use small diameter fiberbeds. Small diameter fiber beds are available in ES or FP style. The installation shown below has been in service for several years.

Example of Absorbing Tower Installation with Small Diameter Diffusion Beds Replacing Impaction Candles Without Changing Housing Size



These beds have smaller inner and outer diameters compared to conventional size fiberbed elements providing upwards of 50 percent increase in filtration area. This advantage is due to the dramatic increase in fiber area that is achieved by having a larger number of individual fiberbeds in a specific volume. The small diameter fiberbeds are much lighter and easier to handle than conventional or concentric beds. For standing style, attachment points used in the installation are reduced by ~75 percent due to a unique clamp arrangement for attaching elements above the tubesheet. In order to reap the benefits of this technology however a new tubesheet is likely required.

Mist Eliminator Conversions:

Dr. Joe Brink's experience and legacy continues through MECS Process and R&D groups. The requirements and operating parameters of all types and designs of sulfuric acid plants are known by MECS and that knowledge is transferred to our designs for replacement fiberbeds or enhancements through design of new Brink elements or re-manufacturing and conversion of others' filters to achieve higher performance. MECS shop stocks 30 different fiber types and configurations for building new or repacking any type of fiber bed mist eliminator. Our inventory complement includes varieties of fine fiberglass packing for diffusion applications and coarse fiberglass and wire mesh, including Alloy 20 and Zecor corrosion resistant metals for impaction fiberbed types.

Delivery is important. Fast repair and repack turnaround can be achieved because screens, repair parts, gaskets, flanges and fasteners of all MOC varieties are also stocked. Computerized winding and pressure drop testing, strict material control and fabrication standards assure consistent repacking quality. The final mark of Brink quality is embodied in the people and their skills in building and repacking fiber beds. Certified welders, fully trained packers and experienced shop technicians, typically with 15+ years tenure, provide Brink customers with service levels to meet the planned and unplanned demands of sulfuric acid plant clients.

If you have Brink elements, repack them using Brink technology, materials and people to maintain your high performance; if you use brand X and need higher collection efficiency, better service life, or optimized pressure drop for higher throughput - consider Brink re-engineered repacks and debottlenecking modifications for your plant. The example below illustrates potential pressure drop reduction by converting other's parallel wrapped roving elements to ES style angle wrapped roving beds based on recent field measurements.

Wet Operating Pressure Drop Comparisons for Glass Roving Beds			
	Parallel Wrapped Roving Element	**Angle Wrapped Roving Element**	**Angle Roving Concentric Element**
~Operating Pressure Drop Reduction(%)	**------**	**25**	**48**

Conclusions

There are many available options to help increase capacity in existing sulfuric acid plants. Several advancements in debottlenecking mist eliminator installations have been made over the years and many times these translate into increased plant production. Strategies including installing more or longer elements on the existing tubesheet if room is available have worked well for many clients. Alternately, using extended area concentric beds or a number of small diameter elements have also worked for others.

Performance is more than just collection efficiency and pressure drop. Often alternative compact mist eliminator designs may work initially but down the road maintenance problems appear. For this reason, performance considerations after the retrofit must also include factors such as; element service life, maintenance time affecting plant downtime and the amount of regenerated mist (reentrainment).

As with any instance of applying technology to industrial applications, project complexity and cost are the most significant factors in determining the option that offers the best return with minimal investment of time and capital along with minimal impact on process. What may be a solution for one location may not be applicable for another due to many factors. This is why it is essential to solicit input on how to proceed in a debottlenecking operation from experienced reputable engineering source such as MECS, Inc. to determine what option is best for the installation. Adherence to basic engineering principles as well as drawing from plant experience are important in considering how best to direct the project that offers the least risk and greatest profit for clients.