# Increasing capacities by retrofitting mist eliminators

by S.A. Ziebold*


## Synopsis

There is often a need to increase capacity through existing mist eliminator installations without significant tower modifications. Often there is not enough extra space outside existing vessels unless more expensive changes can be justified. Also, plant downtime must be considered. The challenge in retrofitting is to overcome velocity limitations inherent in the design while at the same time extend performance capability. The solution most often is to create new ways to add extra filter area while remaining constrained to the existing space. This strategy, however, can dangerously backfire if basic design principles are not followed. Mist eliminator design is a complex integration of many conflicting performance parameters. Often the objective is to increase scrubbing capacity while maximizing collection efficiency and service life and minimizing operating pressure drop (energy cost), particle regeneration (re-entrainment) and overall maintenance costs.

Results of plant retrofitting using mesh pads, impaction fibre beds and diffusion fibre beds are presented based on actual plant projects. Often the retrofit project can be more effective by increasing the scope and combining other new plant equipment with the upgrade such as new tower components. In some cases, the type of mist eliminators can be upgraded from impaction type (velocity dependent) to Brownian diffusion type (velocity independent) if additional downstream protection or reduced emissions are desirable, especially at turndown rates. Trade-offs between different fibre bed types and styles are discussed as they relate to performance and maintenance.


## Mist collection mechanisms

To better understand the issues for debottlenecking existing mist eliminator installations, a review of mist collection mechanisms will help explain the main classifications of mist eliminators. (see Figure 1).

The inertial impaction mechanism collects a mist particle in a gas stream when it impacts on a fibre. A particle has weight; the bigger the particle, the more it weighs. If the gas velocity is fast enough, weight and inertia of the particle will cause it to impact on a target rather than follow the gas streamline around it. The larger the particle diameter, the more it weighs, and 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 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 its 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 fibre beds utilizing the diffusion collection mechanism are required to eliminate visible opacity.

With the impaction mechanism, efficiency decreases as gas and particle velocity decrease 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

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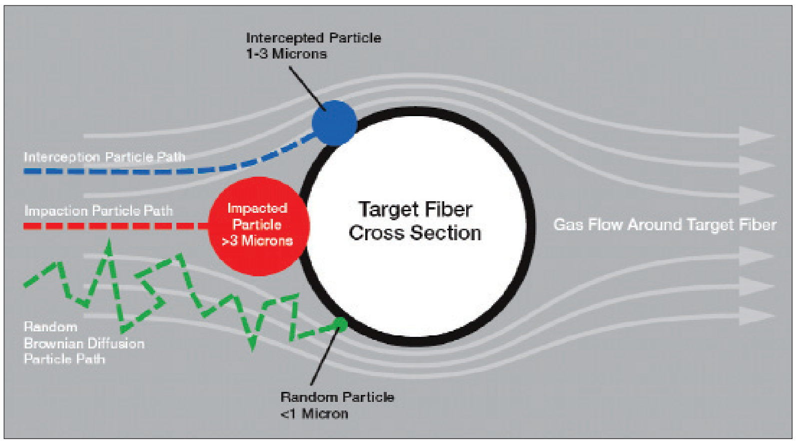



Figure 1—Fibre bed mist collection mechanisms

as the gas velocity decreases. This is because small particles when travelling at a lower velocity will have more residence time in the collecting media, which gives a greater likelihood that a particle will strike a target along its random path through the filter.

### *Mist collection devices*

Mesh pads and impaction fibre 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 fibre beds are considered diffusion devices since for mist capture of smaller submicron particles they utilize the Brownian diffusion mist capture mechanism. Although diffusion fibre bed devices also collect particles by interception and impaction, these devices are primarily selected for high efficiency removal of fine submicron particles by Brownian diffusion.

### *Mesh pads*

Mesh pads, also called impingement devices have been used in sulphuric acid plants for many years (see Figure 2). 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 size particles, co-knit material is integrated into the pad. Co-knit is comprised of fine fibres woven into the larger matrix of metal mesh filaments. Typically glass or PTFE co-knit fibres are used.

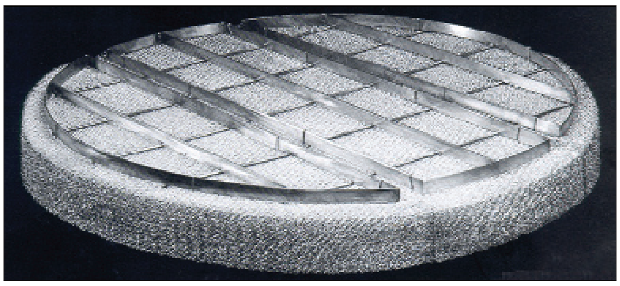
Since mesh pads are relatively low pressure drop devices (25 to 100 mm wc), it is important to ensure proper installation to achieve uniform velocity across the pad surface. Proper design of inlet and outlet duct locations is an often overlooked design principle. Sufficient clearances must be provided 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 rely on proper velocity to optimize performance. Figure 3 illustrates how too low a velocity results in poor efficiency whereas too high a velocity results in re-entrainment. Also for pads with co-knit to boost collection of small particles, pad velocity needs to be lowered to avoid re-entrainment.

### *Plant debottlenecking examples for mesh pad installations*

The installation in Figure 4 shows a 'Z-pad' arrangement used to add more mesh pad surface area to an existing dry tower installation where plant rate was increased significantly. This unit has been in service for several years. The pad is a special metal mesh-glass co-knit composite for 99.9% removal of particles down to 2 microns in size. Design pressure drop was 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



Figute 2—TowerGARD™ mesh plad comprising of three segments

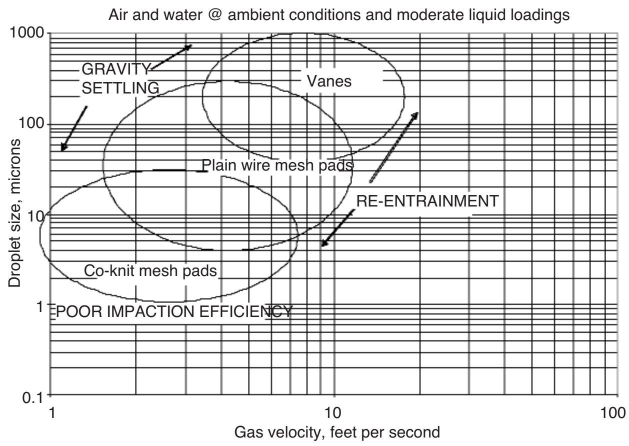



Figure 3—Approximate operating ranges of mist eliminators

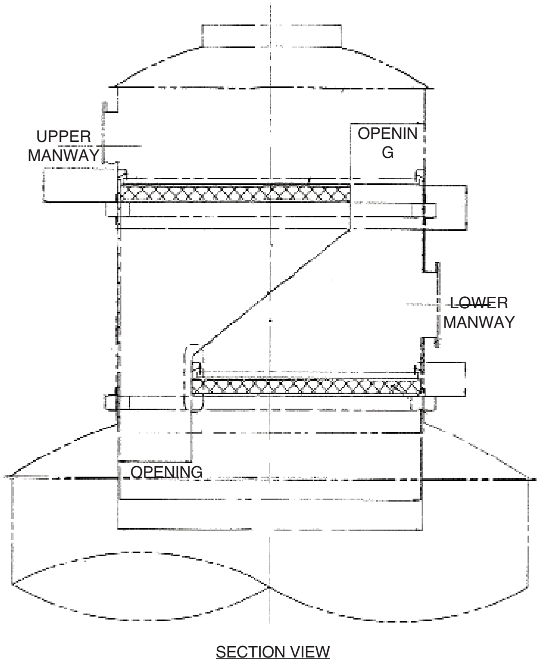



Figure 4—Compact Z-pad retrofit installation example

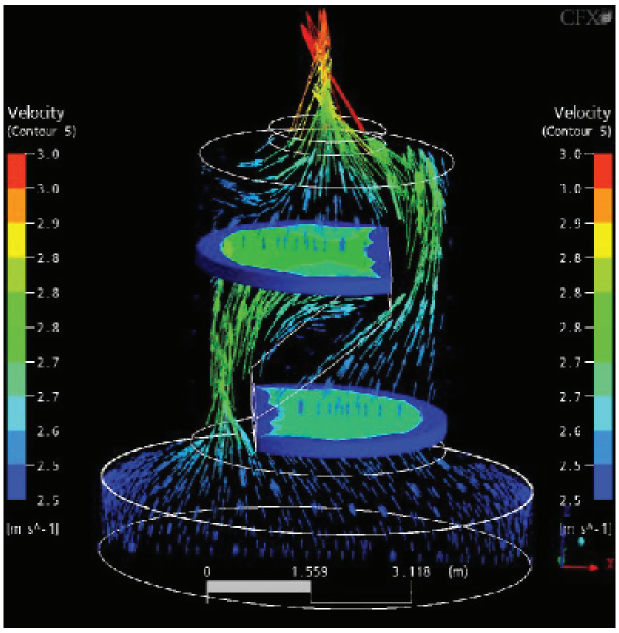



Figure 5—CFD velocity profile analysis

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.

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 pads and to check pad velocity profiles. The CFD velocity profile analysis is shown in Figure 5.

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 of top and bottom pads were within 2 per cent at design rate. Peak velocities were within a few per cent of average velocities and within acceptable levels.

### *Double Z-pad*

Another recent extended area mesh pad design was installed in an existing US sulphuric acid plant dry tower. The style is called the 'double-Z pad' shown in Figure 6. This double-Z pad design provides even more flow area compared to the Z-pad arrangement. The centre section is dropped to provide a more balanced flow arrangement. This pad construction was a multi-mesh Zecor™ alloy /PTFE co-knit composite with a design collection efficiency of 99.9% on 2 micron particles and 50 mm wc maximum pressure drop.

## Impaction fibre beds

In the 1960s, panel style impaction fibre beds were developed to provide enhanced performance compared to mesh pads. Impaction fibre beds contain more fine collecting fibres than co-knit mesh pads and are used when some submicron small particle mist capture is desirable. These fine fibres 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. The only drawback was that installation cost was high with panel housing construction and there were many attachment points to maintain.

In the '80s an improved cylindrical impaction style fibre bed was developed. Typical impaction fibre bed and tower installation are shown in Figures 7 and 8. The CS-IP impaction fibre bed was designed for improved dry tower performance in sulphuric acid plants. The element is a cylindrical bi-component fibre bed design using a fibreglass mat for collecting small particles plus an alloy mesh re-

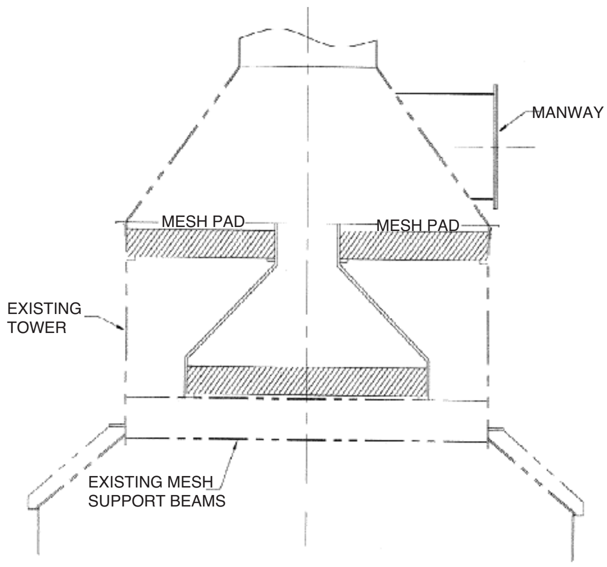



Figure 6—Compact double Z-pad retrofit installation example

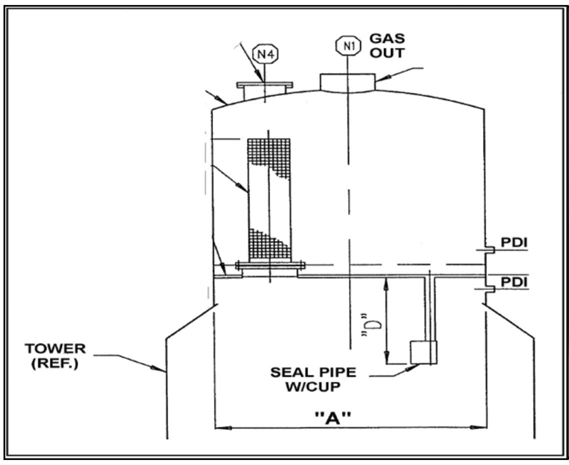



Figure 7—Example cylindrical impaction candle tower installation

Figure 8—CS-IP impaction fibre bed

entrainment control or 'drainage' layer. The standard CS-IP size is 760 mm outer diameter by 1650 mm 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 660 mm outer diameter by 1020 mm tall. In final absorbing tower installations, metal mesh is usually 310 SS and the cage is 316 SS.

Figure 9—Dirt and sulphates affect mist eliminator service life

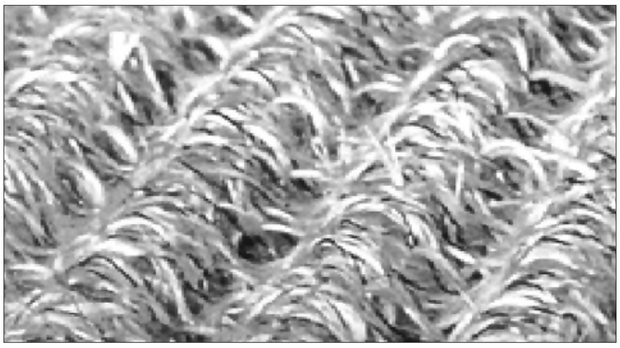


Figure 10—CK co-knit collecting layer

In sulphur 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 an 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 sulphates carried by acid spray off tower components (see Figure 9) to form a paste in the mist eliminator fibre packing, affecting element service life.

The CK impaction fibre bed was developed in the 1990s to provide longer operation between service cycles. For sulphur 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 from standard CS collecting glass media (see Figure 10). 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.

CK elements use a metal mesh structure with small diameter acid resistant glass fibres knitted together with the metal wires to increase collection targets and thus small particle collection efficiency.

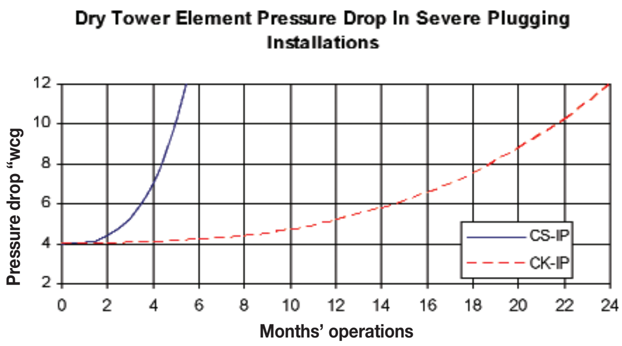



Figure 11—Dry tower element pressure drop in severe plugging installations

The co-knit metal mesh collecting layer is much 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 CS elements. Figure 11 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 sulphated. 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 fibre 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 sulphate 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 plugging 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 conventional cast iron components due to reduction in sulphate build-up in the process. For metallurgical plants, CK elements can provide easier maintenance as an alternative to co-knit mesh pads.

### *Plant debottlenecking examples for impaction fibre beds*

As mentioned earlier, it is important to operate impaction devices at the proper velocity. A client was increasing plant rate ~15 per cent. It had CS elements in both its dry and final towers. An evaluation was carried out and it was found that additional CS elements could be installed on existing tubesheets. The resultant before and after tubesheet layouts for the dry tower looked as shown in Figure 12 (‘before’ is on the left and ‘after’ is on right):

Two extra elements were installed on the existing tubesheet, resulting in an 18 per cent 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.

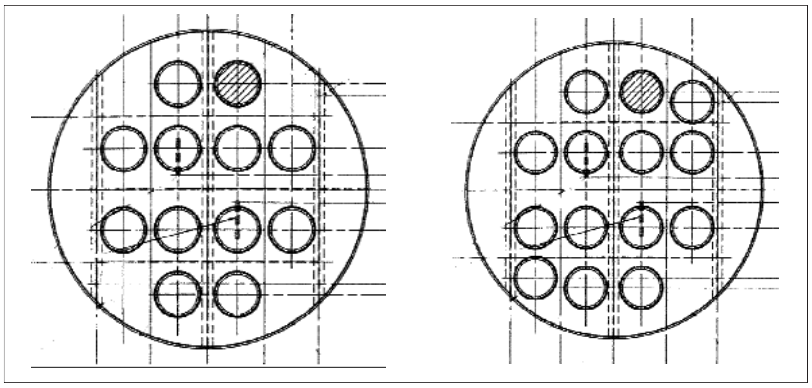


**Figure 12—Plant debottlenecking example for impaction fibre beds**

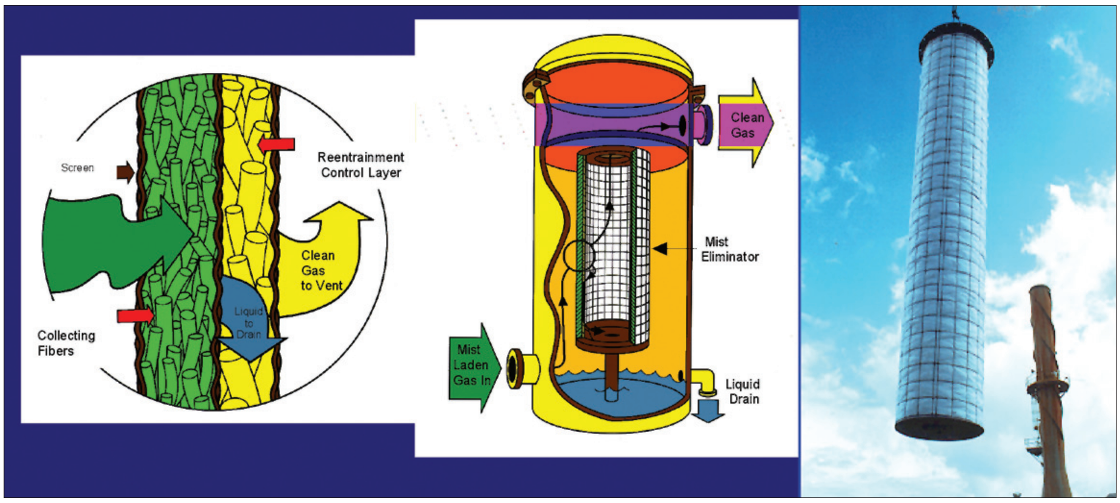



**Figure 13—Bi-component diffusion fibre bed**

### *Diffusion fibre beds*

For high efficiency removal of submicron particles, Brownian diffusion fibre bed mist eliminators are used. Dr. Joe Brink invented the first high efficiency (HE) Brownian diffusion fibre bed mist eliminator in the 1950s. Brownian fibre bed mist eliminators use a bed of packed fibres to collect liquid particles. The original HE was a hand packed bed using chemical resistant fibreglass. Later generations include ES (Energy Saver) bi-component diffusion fibre beds made with glass roving.

More recently, FP field packable diffusion fibre beds were developed using engineered bi-component fibreglass sleeves. All three diffusion fibre bed types have been used in sulphuric acid plant service. High efficiency diffusion fibre bed 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.

Figure 13 shows a typical forward flow hanging style bi-component diffusion fibre bed. Other fibre bed arrangements used in sulphuric acid plants are described in the next section. The bi-component fibre bed includes a special drainage layer to control re-entrainment. Forward flow is the most common style in sulphuric acid plants since maintenance is on the clean side. Mist laden gas flows from the outside through the fibre media to the inside. As the gas flows through the fibre bed, mist particles are collected when they contact fibres and are collected as a result of impaction, interception, or Brownian motion. The collected mist accumulates on the fibres and coalesces into larger droplets and films. Because of gas drag forces, the collected liquid is moved to the downstream side of the fibre bed. The collected mist then drains to the bottom of the element and discharges to the bottom sump through a seal leg (in sulphuric 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.

Fibre bed mist eliminators come in various shapes. Conventional high efficiency Brownian diffusion devices are usually cylindrical, 610 mm in diameter, and 1.8 to 7.3 meters tall.

### Limiting design velocities for mist eliminator installations

There are three principle mist-eliminator installation configurations (or styles) used for cylindrical diffusion and impaction fibre beds: forward-flow flanged, reverse-flow flanged and reverse-flow flangeless (no flanges protruding past the outer diameter of the mist collector). (see Figure 14) 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 re-entrainment and maximum service life.

When choosing an installation style for a particular application, there are mechanical and maintenance trade-offs. For example, because of higher gas throughput, cylindrical impaction fibre 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 and maintenance issues, especially with corrosive processes.

### *Large installations*

Forward flow style has some disadvantages with large multiple-element installations. 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 2 to 3 meters (which often makes a full body flange impractical or very expensive), the required vessel height

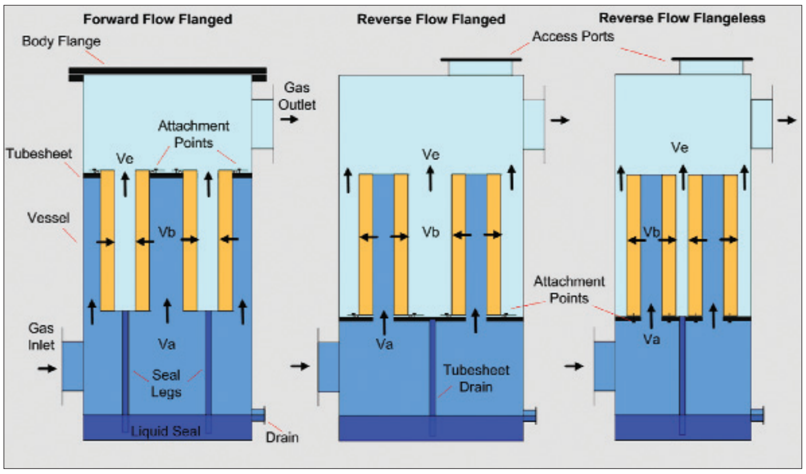



**Figure 14—Design velocities for conventional mist eliminator installations**

then must increase to accommodate element removal. Alternately, some plants elect to cut the vessel shell when access to elements is required for maintenance. One advantage of the forward-flow style is 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 are removed by first detaching from the topside of the tubesheet and then moved sideways 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 24 inch (610 mm) diameter elements, spacing must be provided so workers can reach all attachment points on the tubesheet, which increases vessel diameter and cost. Alternately, smaller diameter elements (described later) can be used allowing closer element spacing since attachment points are easier to access, resulting in a smaller vessel diameter. 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 elements.

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. However, this style 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 attachment points where elements are bolted to the tubesheet. This style also makes troubleshooting easier, as in the case of gasket or tubesheet leaks. Observation ports can often be installed on manways in the top of the vessel, allowing the tubesheet to be viewed during operation.

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 (re-entrainment) caused with even slight gas leaks, since gaskets are not submerged in liquid that normally pools on the tubesheet.

## Mist eliminator entrainment control

One constraint with all mist eliminator operation is the potential to regenerate particles or form 're-entrainment'. 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 fibre 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 re-entrainment since this refers to mist that is previously captured, coalesced and then 're-entrained' into the process. As gas velocity or mist loading increase, portions of the bed where gas discharges can become flooded. This causes re-entrainment in the form of large particles called 'carry-over'. This is undesirable in corrosive applications where downstream equipment protection is critical such as heat exchangers after interpass absorbing towers and applications where there is a 'tight' guarantee on emissions. In this case re-entrainment can significantly increase exit mass loading.

Figure 15 shows how the bi-component fibre bed design helps prevent entrainment. The photo on the left is the element before being injected with a surfactant. Notice two areas where drainage layers have been removed. After injecting surfactant into the bed on the upstream side and operating at design gas flow (inside out gas flow), the photo on right shows how foam was formed in the two areas where drainage layers were removed. The drainage layer suppresses entrainment generation since it is made of fibres and packing density resulting in fewer capillary forces. Consequently with the drainage layer, there is no significant bubble or film formation of the collected liquid as it drains vertically by gravity in the mist eliminator near the surface where gas discharges.

Figure 16 is the fibre bed flooding curve for bulk packed diffusion style mist eliminators. Parameters 'A' and 'B' are similar to the classical parameters used to calculate flooding.

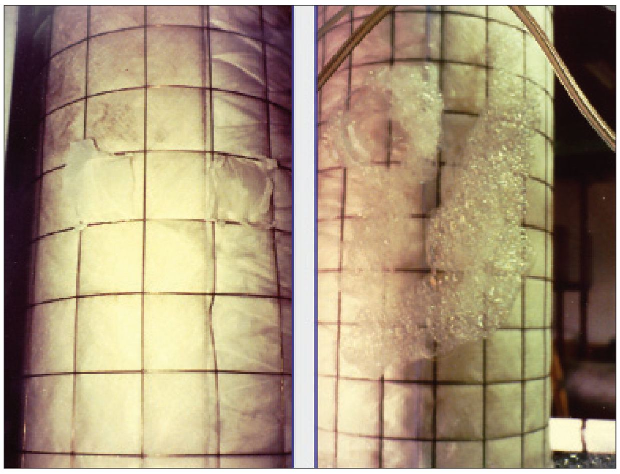


**Figure 15—Entrainment demonstration**

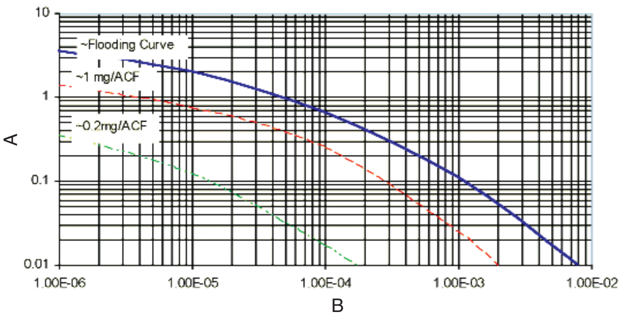



**Figure 16—Fibre bed flooding curve**

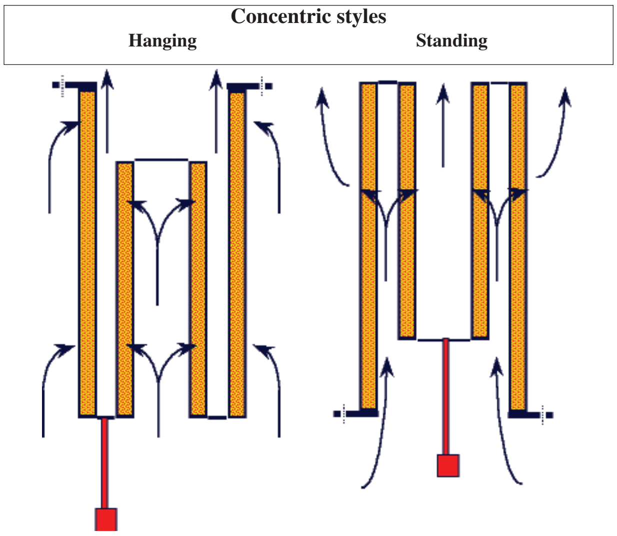



Figure 17—Concentric fibre beds

Figure 18—Hanging style concentric element installation

The iso-re-entrainment curves were derived from sulphuric 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 increases linearly with mist loading. Note as the operation of the mist eliminator approaches the flooding curve, re-entrainment increases exponentially.

As a result of entrainment, an improved bi-component fibre bed was developed. The bi-component fibre bed design helps prevent the formation of re-entrainment. For this reason, bi-component diffusion fibre bed mist eliminators can operate at higher velocities compared to the bulk packed diffusion fibre beds developed in the late 50s. An effective drainage layer is important, especially in compact installations where intra-bed and exit velocities are high.

## Plant debottlenecking examples for diffusion fibre beds

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 fibre beds*

Another way to retrofit more bed area into the existing installation is to use a concentric element design. (see Figure 17) The concentric design is an 'element inside an element' design originally used by Monsanto in the 1960s. A concentric element has an element in the normally void volume in the centre 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 per cent, depending upon element style and application. Increasing fibre bed 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 (Figure 18) compared to non-concentric beds and drain legs need to be rerouted around exiting equipment or tower internals below the tubesheet.

### *Small diameter diffusion fibre beds*

Another way to achieve higher capacity or lower pressure drop in existing installations is to use small diameter fibre beds. Small diameter fibre beds are available in ES or FP style. The installation shown in Figure 19 has been in service for several years.

These beds have smaller inner and outer diameters compared to conventional size fibre bed elements, providing upwards of 50 per cent increase in filtration area. This advantage is due to the dramatic increase in fibre area that is achieved by having a larger number of individual fibre beds in a specific volume. The small diameter fibre beds 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 per cent 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.

## Conclusions

There are many available options to help increase capacity in existing sulphuric acid plants. Several advancements in

Figure 19—Example of small diameter high efficiency diffusion fibre bed retrofit replacing impaction candles

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 has 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 (re-entrainment).

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 optimum performance with least risk and greatest profit. ◆

# South African coal student of the year*

Metallurgy student, Jacqueline Monama recently achieved the South African Coal Student of the Year award at this year's South African Coal Process Society dinner dance at the Sandton Convention Centre.

Jacqueline is studying at the University of Johannesburg (previously Wits Technikon) where she is doing process economics, project management, mineralogy, and non-ferrous metallurgy; she also has to complete a project on her own by year end.

She says that she chose metallurgy after completing a BSc in Chemistry and was unemployed for a year. Over the past year she has been sponsored by Anglo Platinum where she will work for a year after qualifying at the end of 2007.

Each year the South African Coal Process Society awards a student of the year and looks at results from all universities. Jacqueline is from Lebowakgono on the outskirts of Polokwane.

The Coal Man of the Year award was presented to Pat Fogarty. Pat is the managing director of specialist coal laboratory, Witlab (Pty) Limited, who assess coal from all over the world. ◆

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