DESIGNING TO THE RAZOR'S EDGE

DOUG AZWELL AND EVAN UCHAKER, MECS INC., USA,
DISCUSS THE IMPACTS OF OVERDESIGNING PLANT EMISSIONS ABATEMENT SYSTEMS.

Capital planning requires accuracy. Budgets are tight, schedules are short and expectations are high. With these considerations in mind, designing plant emissions abatement systems is a key pressure facing today's owners and operators. Yet, sometimes the pendulum can swing too far, creating a situation where there is no overdesign, and unforeseen circumstances have detrimental impacts as a result.

Table 1. AN particle size distribution

Particle size (microns)	Mass percentage
≥3	25
1 – 3	25
0.5 – 1	40
0.1 – 0.5	8
<0.1	2

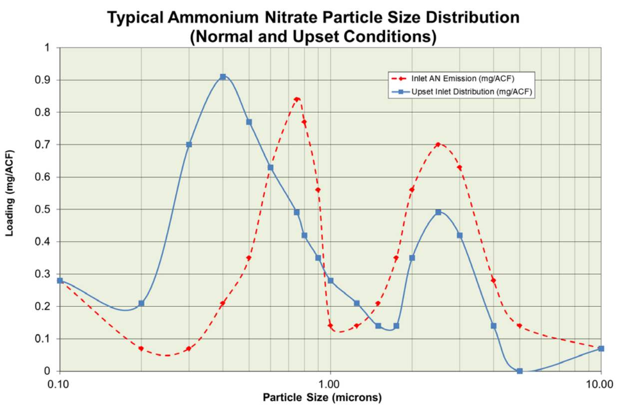

Figure 1. AN prill operation in upset conditions.

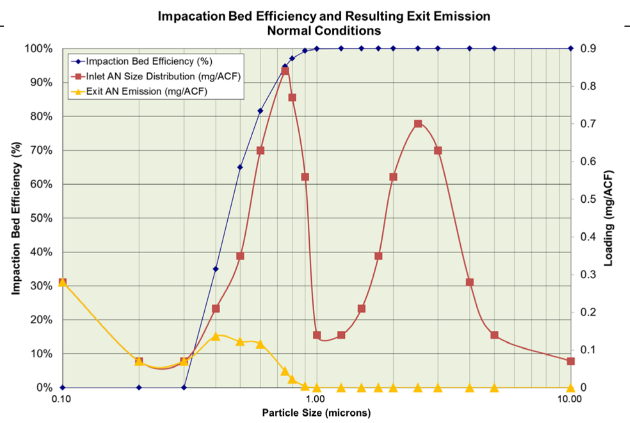

Figure 2. MECS impaction bed efficiency with inlet AN PSD and expected exit AN emissions.

Occasionally, producers get caught in a situation where their emissions control equipment was designed too close to the design criteria. If capacity or emissions from their abatement systems are restricted too much during the design stage (for cost and other reasons), companies risk ending up with a system that cannot cope with upset conditions. This article examines the concept of designing to the razor's edge from the standpoint of ammonium nitrate (AN) prill emissions abatement projects. It will also discuss some of the outfall that can result when designs do not contain sufficient contingency.

With tightening regulations governing particulate emissions at the stack – such as the new US Environmental Protection Agency (EPA) PM2.5 regulations – mist eliminator design is of utmost importance. A proper design must balance emissions, pressure drop, service life and budget. The best place to start is with a firm understanding of mist generation and particle size distribution.

Particle size distribution in AN

The particle size distribution of AN solids presents a challenge. In the 1970s, much work focused on what was needed to meet the newly released EPA emissions regulation for AN point sources. Up until this time, various companies attempted to use impaction devices (such as mesh pads) to meet the existing emissions requirements.

Impaction devices operate in the region of 300 ft/min. velocity or greater, and are good for removing large droplets from process gases. When applied to AN prilling installations, these devices are insufficient.

In 1974, Thomas Metzger, a Monsanto Enviro-Chem Systems employee, gave a presentation at the Ammonium Nitrate Producers Study Group annual meeting concerning AN prill tower emissions. Based on a pilot plant study, Metzger's work proved that 50% of the particulate in the process gas leaving prill tower operations was less than 1 μm in diameter. Table 1 provides details relating to the study. This information explained why impaction devices, such as irrigated mesh pads, were unable to capture the visible particulate or particles in the 0.2 – 0.6 μm size range as they are only efficient on large particulate and droplets.

Not only is overall loading important, but the particle size distribution (PSD) of the inlet mist loading is also a critical factor.

Process upset consideration

In some cases, process upsets can mean a high amount of sub-micron sized mist production. If companies use impaction devices, these elements cannot remove this newly-generated mist.

In the examples outlined in this article, a simple upset scenario, as demonstrated by Figure 1, will be considered. If an AN prilling operation is run beyond its original design limits, if cooling is inadequate during the hot summer temperatures, if the unit is operated in extreme cold temperature conditions, which provides sufficient 'shock cooling' to produce higher quantities of small AN solids, or if other conditions are out of specification, then the resulting PSD can be altered. In Figure 1, this results in substantially higher quantities of sub-micron AN particulate emissions from the prill tower. These smaller solids are more difficult to capture.

The total exit particulate loading from a high density AN prill tower operation is often approximately 7 mg/Aft^3 (247.2 mg/Am^3). A significant portion of the particulate given off by this process is larger than 1 μm, but the system designer has to be aware of the mist fraction that is in the optically active range. This is smaller than approximately 0.6 μm.

In the examples considered in this article, an AN prilling operation is faced with meeting a limit of 0.0708 mg/Aft^3 (2.5 mg/Am^3) in order to comply with a regional PM2.5 requirement from the EPA. The AN prill tower emission was measured in a point source study of the facility and found that its average inlet mist loading is 7 mg/Aft^3 (247.2 mg/Am^3) with a typical PSD.

Impaction mist eliminators as an equipment choice

There are a few ways in which designers have tried to save capital expenditure for potential clients in AN prilling operations. The simplest means is to use impaction devices, which maintain bed velocities of greater than 350 ft/min., typically with only 4 – 8 in. WC (1 – 2 kPa) pressure drop. While this seems like a pertinent strategy, the examples below will demonstrate the critical flaws in this design philosophy.

Using the MECS impaction bed model, it is possible to predict the effectiveness of these types of devices at various particles sizes. Efficiency of an impaction style mist eliminator falls off for particles of less than 1 µm. While the overall efficiency of the impaction device seems high, it is ultimately dictated by the particle size on the efficiency curve. When considering the inlet PSD with the efficiency of the device, the problems that may arise become apparent.

In Figure 2, the red line represents the inlet PSD, and the orange line represents the outlet PSD as calculated using the efficiency of the impaction type device shown by the blue line. If impaction only equipment is used in an AN emission abatement installation with the inlet PSD shown, the efficiency of the elements would be nearly 88% overall, whereas 98% tends to be expected for a world-class facility. The lesson is that acceptable outlet emissions cannot be met with impaction type devices due to the relatively high proportion of sub-micron mist.

Table 2 demonstrates the effect of using impaction devices for an AN prill tower abatement system. If the AN production process is operated under upset conditions, such as being pushed beyond its originally-designed output, then the resulting PSD is downshifted and can have disastrous effects on the exit emissions. As shown in Figure 3, when combined with the efficiency of the capture device, the resulting PSD leads to an exit mist loading that has a larger amount of sub-micron AN loading. This then leads to an increase in opacity for the exit gas.

In this scenario, overall collection efficiency drops below 70% and opacity is approximately doubled compared to the original base case. A summary of the emission implications is shown in Table 3.

Upon examination of Figure 2 and Table 2, it is apparent that the efficiency of an impaction bed is inadequate for the capture of particulate that is smaller than 0.8 – 1 µm during normal operation, and the installation would have a resulting opacity of nearly 25%. When considering upset conditions as shown in Figure 3 and Table 3, it is obvious that impaction devices cannot provide protection during upset conditions and the resulting opacity would be approximately 50%.

Using Brownian diffusion mist eliminators in AN

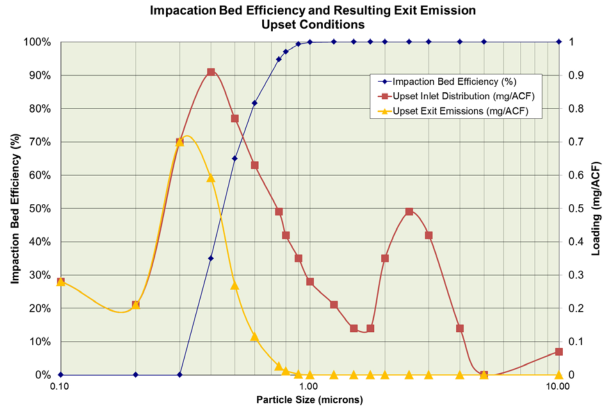

Figure 3. MECS impaction bed efficiency with upset inlet AN PSD and resulting exit AN emissions.

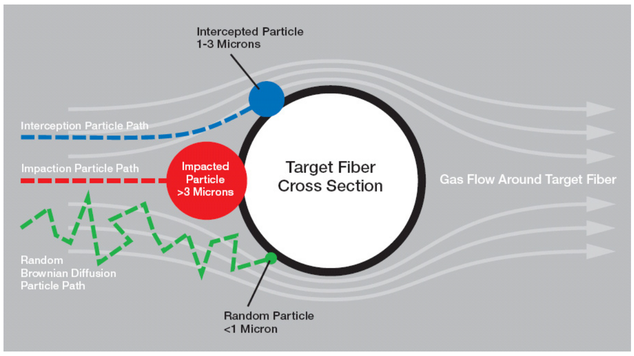

Figure 4. Fibrebed capture mechanisms.

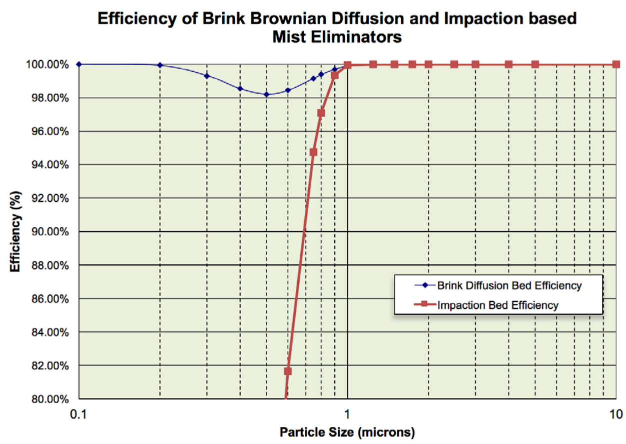

Figure 5. Brink diffusion mist eliminator efficiency in AN applications.

In order to meet both large and small mist and particulate removal requirements, the more appropriate choice of capture device is Brownian diffusion mist eliminators. Not only are these devices exceedingly efficient on large particles, but they have unparalleled efficiency on particles in the less than 1 µm range. These devices are, therefore, able to assist in meeting both mass emission and visual opacity requirements simultaneously. MECS developed Brownian diffusion fibrebed mist eliminator technology in the 1950s and began to use the device in various industrial applications quickly thereafter. In the early 1970s, MECS began using

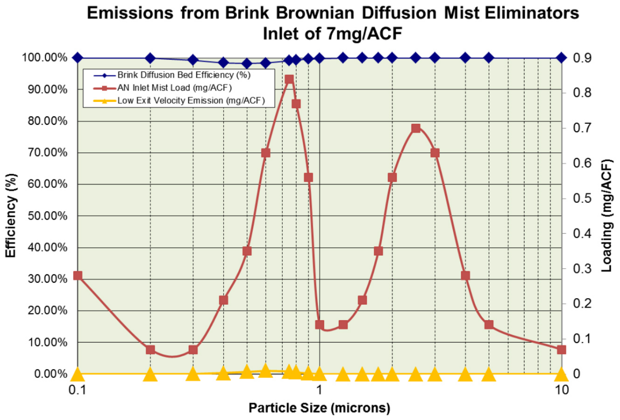

Figure 6. Emissions from Brownian diffusion beds in normal AN conditions.

Table 2. Emissions implication of impaction fibrebeds in normal operation

Mist particulate size range	Efficiency	Resulting opacity* (%)
Overall	87.6	-
≤1 µm	77.9	-
≤0.6 µm	50.6	23

*For the opacity example, a stack diameter of 72 in. (1.83 m) is assumed.

Table 3. Emissions implication of impaction fibrebeds during upset conditions

Mist particulate size range	Efficiency	Resulting opacity* (%)
Overall	68.5	-
≤1 µm	56.2	-
≤0.6 µm	38.1	48

*For the opacity example, a stack diameter of 72 in. (1.83 m) is assumed.

Table 4. Emissions from Brink diffusion mist eliminators

	Mist particulate size range	Efficiency	Resulting opacity* (%)
Emissions from Brink diffusion mist eliminators	Overall	99.51	-
	≤1 µm	99.13	-
	≤0.6 µm	98.76	<5 – 0
Emissions from Brink diffusion mist eliminators operated in upset conditions	Overall	99.27	-
	≤1 µm	98.99	-
	≤0.6 µm	98.78	<5 – 0

*For the opacity example, a stack diameter of 72 in. (1.83 m) is assumed.

Brownian fibrebeds in AN applications in North America after the successful pilot plant trial.

Figure 4 illustrates the three major capture mechanisms involved in the operation of fibrebed mist eliminators: impaction, interception and Brownian diffusion. This image illustrates particles of various sizes suspended in the gas stream. The particles flow from the dirty side on the left to the clean side on the right.

The green particle represents the Brownian diffusion mechanism. Thermally-induced molecular motion of the gas imparts random motion to particles smaller than approximately 0.6 µm as they move within the gas stream.

The combination of all three capture mechanisms provides overall high efficiency. MECS tailors the efficiency of its fibrebeds to meet the client's requirements for mitigation of stack plumes, maintaining product purity, protecting downstream equipment and capturing product in a myriad of industrial applications.

The effectiveness of any of these mechanisms depends on a number of factors, including fibre diameter, fibre surface properties, fibre bulk density, fibrebed packing density, fibrebed uniformity, gas velocity during operation, liquid properties, gas molecular weight, and process temperature. Additionally, the overall performance of the installation is dependent upon mist eliminator packing uniformity, installation and process conditions.

The drawback of the Brownian diffusion mechanism is that if removal of less than 1 µm particles is required, the bed velocity must be substantially less than 100 ft/min., making installations of such devices larger than installations that use impaction devices.

In order to meet the ever-tightening EPA AN emission requirements, more and more companies will need to depend on the capabilities of Brownian diffusion mist eliminators. Figure 5 demonstrates the efficiency that Brownian diffusion beds offer. Notice that the scale to the left of the curve is from 95 – 100% efficiency. These mist eliminators provide high efficiency over the broad spectrum of particle sizes.

Figure 6 shows the resulting emission curve on the basis of the normal operation inlet AN PSD as shown earlier in the impaction operation example. In the case of the impaction fibrebeds, the overall collection efficiency was only 88% while the Brownian fibrebed achieves a collection efficiency of over 99.5%, representing a 25-fold reduction in outlet emission levels.

Table 4 shows a breakdown of the emissions that are realised from a Brownian diffusion emission control approach. When looking at a case in which the upset conditions are encountered, diffusion beds continue to offer promising results since they provide effective protection under these conditions.

Figure 7 illustrates the exit emissions (orange line) when adopting the diffusion efficiency curve and the upset condition inlet PSD (red line). The diffusion beds offer continued protection for the plant with minimal disruptions to the exit emissions. In fact, the overall collection efficiency is changed by less than 0.5% and opacity is unaffected.

Table 4 also shows the emissions and an estimation of the resulting opacity for diffusion beds operated in an AN facility with upset conditions. Not only do the Brownian diffusion beds meet the emission requirements

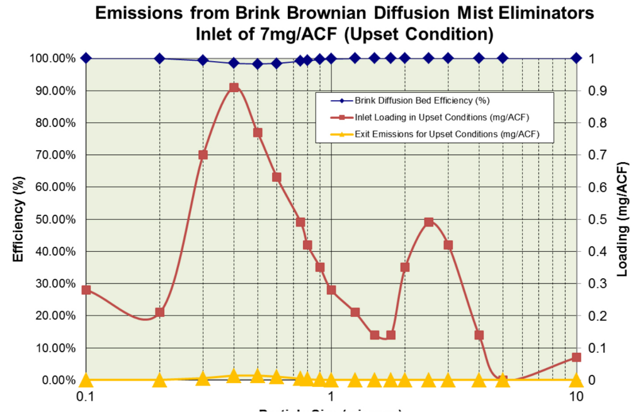

Figure 7. Upset condition emissions for Brownian diffusion beds.

during normal operation, but they are also sufficiently robust to handle reasonably foreseeable process upsets. Brownian diffusion mist eliminators are an effective choice in the removal of the emissions from the AN installation's stack gas in AN prill tower particulate emission abatement control systems.

Conclusion

With so many different technologies available for emissions reduction projects, how are owners and operators to make a choice? The answer is to consider solutions where the technology provider has a deep understanding of the process in order to ensure that enough pragmatic overdesign is utilised and that the installation is sufficiently robust to ensure that the project will meet its objectives during normal operation as well as reasonable upset cases.

The continual reigning in of industrial emissions, especially to meet EPA PM2.5 emissions requirements, will require the industry to consider the best available control technology option as a sustainable solution to its emissions regulation requirements. When it comes to AN emissions abatement and Brownian diffusion devices, MECS offers a field demonstrated, client accepted and industry respected long-term solution for safe, reliable and environmentally responsible AN prill tower operation. As regulations continue to tighten, owners and operators will be forced to challenge their own conventions and past experiences as the world evolves from a 'compliance under steady state' mindset, to a broader view of the leadership role that they can play in defining environmental excellence. WF