# MICROMIST™ VENTURI AND JET VENTURI SCRUBBERS

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# SUMMARY

# ABSTRACT

This paper presents a comprehensive overview of advanced air pollution control technologies for fertilizer production facilities, focusing on the MicroMist™ Venturi (MMV) Scrubber and Jet Venturi Scrubber systems developed by Stamicarbon in collaboration with EnviroCare International. These technologies are engineered to address the stringent regulatory demands for reducing fine particulate and ammonia emissions, with MMV Scrubber optimized for urea granulation and Jet Venturi Scrubber for prilling tower applications. The paper details their operational principles, performance benchmarks—including emission reduction below 10 mg/Nm³ for urea dust and below 5 mg/Nm³ for ammonia—and integration with Wet Electrostatic Precipitators (WESP) to achieve even lower dust levels and 0% opacity. Flexible salt reworking options and downstream crystallization technologies are also discussed, highlighting the potential for producing marketable fertilizer byproducts and supporting sustainable investment strategies. The paper further explores regulatory measurement standards, industry challenges, and the benefits of combining MMV with WESP for comprehensive emission control.

# 1 INTRODUCTION

As global industries face mounting pressure to reduce emissions and align with increasingly stringent environmental regulations, the demand for advanced air pollution control technologies has never been greater. In particular, the control of fine particulate matter and ammonia emissions has become a critical challenge for fertilizer production facilities, where conventional scrubbing systems often fall short, especially as regulatory thresholds drop below 10 mg/Nm³.

To meet these evolving standards, MicroMist™ Venturi (MMV) Scrubber and Jet Venturi Scrubber technologies, developed by Stamicarbon, the nitrogen technology licensor of NEXTCHEM (MAIRE Group), in collaboration with EnviroCare International, have emerged as robust high-efficiency solutions. These systems leverage the principles of venturi scrubbing to effectively capture submicron particulates and ammonia, with MMV Scrubber optimized for urea granulation plants and Jet Venturi Scrubber tailored for prilling towers. Flexible salt reworking options are also offered, allowing for the separation and reuse of ammonium sulfate or nitrate solutions depending on the plant's operational strategy.

MMV Scrubber can reduce urea dust emissions to below 10 mg/Nm³ and ammonia emissions to below 5 mg/Nm³. When paired with a Wet Electrostatic Precipitator (WESP), the system can further lower urea dust levels to below 5 mg/Nm³ and achieve 0% opacity. Jet Venturi Scrubber, when equipped with acidic scrubbing, can deliver dust emissions below 15 mg/Nm³ and ammonia emissions in the range of 20-30 mg/Nm³. These comprehensive solutions not only ensure compliance with EPA Method 5, EPA Method 202, and EPA Method 9 standards, but also address industry-wide challenges in measuring and managing condensable particulate matter.

In addition to regulatory compliance, high-efficiency scrubbers like MMV are increasingly favored by investors and financial institutions. Their ability to meet both current and future emission standards helps secure long-term capital investments and reduce regulatory risk, which is an essential consideration in high-CAPEX projects such as fertilizer plants. MMV and Jet Venturi Scrubber systems can optionally be integrated with downstream crystallization technologies. For example, ammonium sulfate formed during acidic scrubbing of ammonia can be crystallized and separated using industrial crystallizers, producing a marketable fertilizer product. This approach not only minimizes waste and environmental impact but also creates an additional revenue stream.

# 2 MMV TECHNOLOGY

MMV Scrubber, co-developed by Stamicarbon and EnviroCare International, is an advanced wet scrubbing technology designed to meet stringent environmental regulations. The MMV Scrubber is particularly effective in removing submicron particulate matter and ammonia from exhaust gases, making it ideal for applications in urea granulation plants and other industrial processes.

## 2.1 Process overview

The MMV Scrubbing system operates through a multi-stage process integrated within a single vessel to ensure efficient removal of pollutants. The key stages of the MMV scrubbing system are shown in Figure 1.

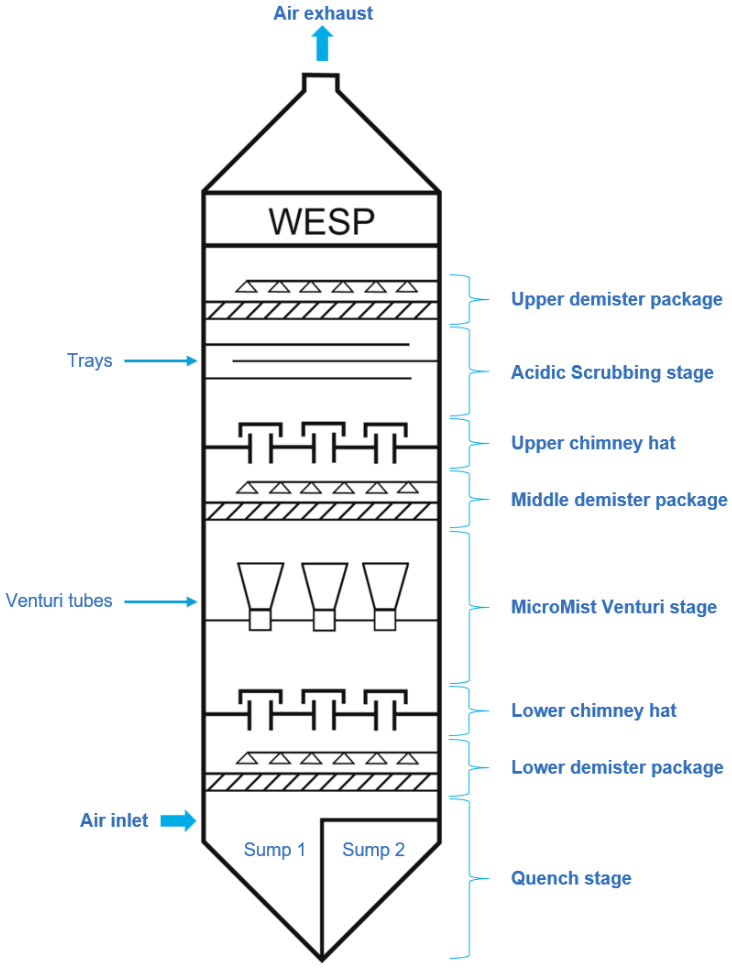


*Figure 1: Optimized MMV configuration with WESP.*

1. **Quench stage**: As an integral part of the MMV Scrubber, the quench stage cools and saturates in humidity the exhaust gases from the plant. Large particulate matter is removed in this stage by spraying recirculated urea solution. The temperature difference between the gas and liquid promotes condensation on dust particles, aiding their removal. Dust-laden air is contacted with a solution containing urea, and the flow and density of the urea solution are monitored and controlled to ensure efficient dust removal.

   The quench stage contains two separate sumps:

   - Sump 1: This sump collects the concentrated urea solution, which is then recirculated back to the quench stage to maintain the scrubbing process.
   - Sump 2: This sump collects the lean urea solution, which is used for various purposes within the scrubber, including initial exhaust air conditioning, duct washing, and recirculation to the venturi tubes.

2. **MMV stage**: The cooled gases then proceed within the MMV Scrubber, where finely sprayed water droplets are introduced. These droplets collide with submicron dust particles and aerosols, effectively capturing them. The venturi effect, generated by high differential velocity between the

gas and liquid phases within the venturi tubes (see Figure 2), significantly enhances the collision and the probability of particle-droplet interactions, thereby improving collection efficiency. Lean urea solution from the sump is used for initial exhaust air conditioning, duct washing, and recirculation within the scrubber.

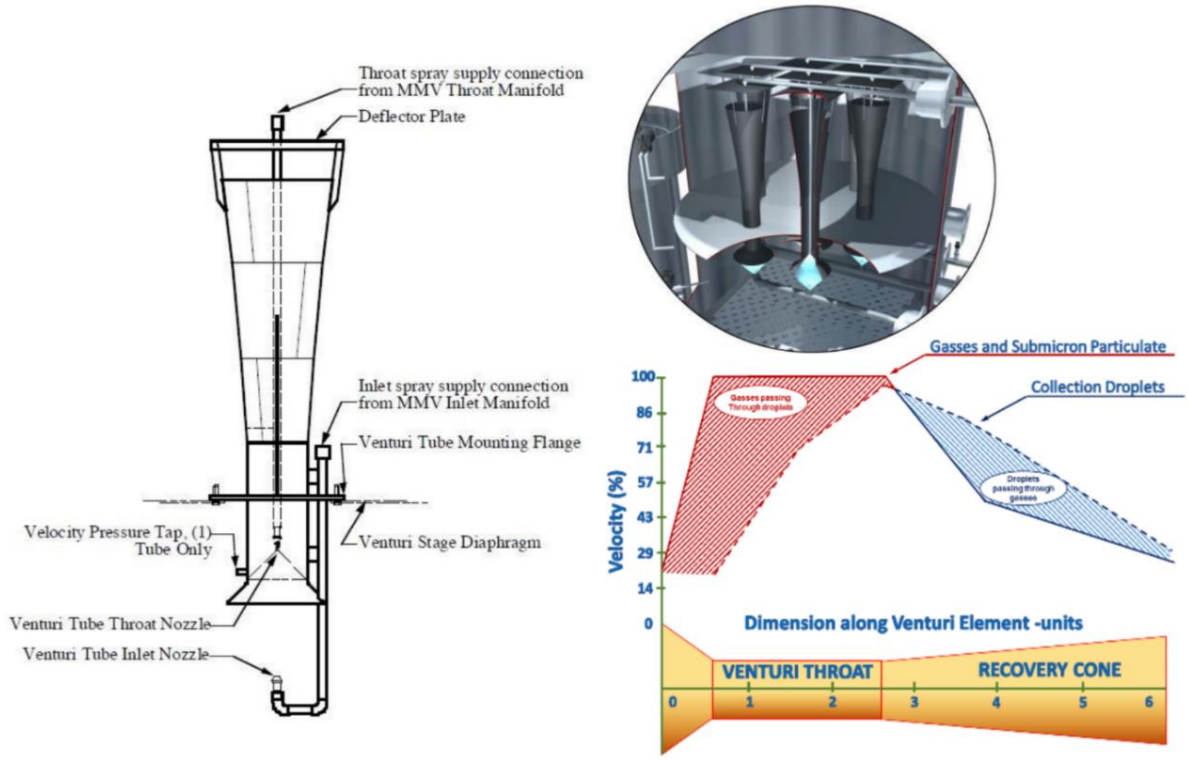


*Figure 2: Venturi tube.*

3. **Acidic scrubbing stage**: The acidic scrubbing stage is designed to remove ammonia from exhaust gases by using sulfuric or nitric acid. This stage consists of several levels of trays, where the scrubbing solution containing sulfuric acid or nitric acid is continuously recirculated. The ammonia in the exhaust gases reacts with acid to form ammonium sulfate or ammonium nitrate, depending on the acid used. These compounds are collected and recycled, ensuring that ammonia emissions are typically reduced to a range between 5 and 25 mg/Nm³. Lower emission levels are technically achievable but come at the cost of increased pressure drop and energy consumption.
4. **Demister packages**: Demister packages are placed after the quench stage, venturi stage, and acidic scrubbing stage. These packages typically use mesh or vane-type elements to remove entrained liquid droplets from the gas stream. Their primary function is to prevent liquid carryover, which protects downstream components and maintains the efficiency of subsequent scrubbing stages. For example, the demister located between the venturi and acidic scrubbing stages plays a critical role in preventing urea solution entrainment into the acid section. By ensuring a clean and dry gas stream, demisters contribute significantly to the overall reliability and performance of the MMV system.
5. **Chimney hats**: Chimney hats are located upstream of both the venturi stage and acidic scrubbing stage. Their primary function is to provide hydraulic separation between scrubbing zones, preventing liquid from upper stages, such as urea solution or acidic solution, from flowing downward into lower sections. This separation is essential for maintaining the chemical and operational integrity of each stage, particularly when different scrubbing solutions are used. By isolating the stages hydraulically, chimney hats help ensure stable and efficient performance of the MMV scrubbing system.

## 2.2 Advantages

The MMV Scrubber offers several key advantages that make it a preferred choice for emission control in various industrial applications:

- **High efficiency**: MMV Scrubber is capable of achieving urea dust emissions below 5 mg/Nm³ with the WESP stage and below 10 mg/Nm³ without the WESP stage. Ammonia emissions can be reduced to below 5 mg/Nm³, while opacity levels can be brought down to 0%.
- **Modular design**: The modular box concept allows for easy installation and adaptation to different process configurations. This design facilitates smooth onsite installation and maintenance.
- **Flexibility**: MMV Scrubber can manage fluctuations in gas volume and be customized by adding or removing venturi tubes. This flexibility ensures that the scrubber can be tailored to meet specific process requirements.
- **Proven performance**: Real-plant experiences with MMV Scrubbers have demonstrated their ability to exceed stringent environmental regulations, ensuring sustainable plant operation.

## 2.3 Salt reworking options

Stamicarbon offers a range of flexible scrubber configurations tailored to client-specific needs, with a strong focus on minimizing waste and enhancing process integration. Depending on selected scrubbing chemistry and plant strategy, the system can be configured to handle and rework salts in several ways:

- **Ammonium sulfate to OSBL**: When sulfuric acid is used for ammonia scrubbing, the resulting ammonium sulfate solution can be directed Outside Battery Limits (OSBL) for further handling or treatment, depending on site-specific requirements.
- **Ammonium sulfate recycled to granulation**: In this configuration, the ammonium sulfate solution generated during scrubbing is recycled back into the granulation process. Although this introduces sulfur into the system, the resulting sulfur content in the final product is very low. As a result, the granules are still marketed as standard urea. This approach supports internal recycling and minimizes waste, while maintaining product consistency.

  *This configuration has been implemented in several latest projects.*
- **Ammonium nitrate to OSBL**: In configurations using nitric acid for scrubbing, the resulting ammonium nitrate solution can also be routed to OSBL for appropriate downstream processing or disposal, depending on the plant's operational strategy.
- **Ammonium nitrate to UAN**: As an alternative, ammonium nitrate can be converted into UAN (Urea Ammonium Nitrate), which is a valuable liquid fertilizer product that can be marketed directly, offering an additional revenue stream.

# 3 EXPERIENCE WITH MMV SCRUBBER

The MMV Scrubber technology has been successfully implemented in several plants around the world. Here are the regions where MMV Scrubbing systems are installed:

- United States: two plants,
- Russia: three plants.

Among these, the Dakota Gasification Company's (DGC) urea granulation plant in Beulah, North Dakota, USA, serves as a prime example of the successful implementation of MMV technology. This was the second operational MMV Scrubber installed.

The MMV Scrubber installed at DGC has demonstrated robust performance under real-world operating conditions. The scrubber was fabricated in eight modular sections for easy transport and on-site assembly.

This modular box concept also allows for future expansion or modification, such as the addition of venturi tubes. During the first year of operation, the DGC team optimized equipment tuning, achieving smooth, upset-free operation. The plant even operated at up to 115% of design capacity for short periods and sustained 105% capacity without compromising emission performance.

A minor issue with ammonium sulfate (AS) carryover into the quench loop was resolved by modifying the lower chimney hat diaphragm during the first scheduled maintenance. This change reduced AS concentration in the quench solution from 0.28% to 0.002%. During inspection, all internal components (including mist eliminators, spray nozzles, and flex hoses) were found to be in good condition, with no signs of wear or misalignment.

These operational insights confirm the MMV Scrubber's ability to meet stringent environmental regulations while offering long-term reliability and adaptability for high-capacity fertilizer production.

# 4 FROM MMV TO JET VENTURI SCRUBBERS

Building on the success of the MMV Scrubber technology, Stamicarbon and EnviroCare have developed Jet Venturi Scrubbers to address the specific challenges of prilling towers. This section highlights the transition from MMV to Jet Venturi Scrubbers and their unique features.

## 4.1 Proven venturi design

The Jet Venturi Scrubber technology leverages the proven venturi design used in granulation plants and adapts it for prilling plants. This adaptation ensures high efficiency in capturing submicron dust particles, making it suitable for the unique conditions of prilling towers.

## 4.2 Design development

Jet Venturi Scrubbers have been developed with different designs to accommodate various prilling tower configurations, ensuring effective emission control in both new and existing installations. The design includes the following (see Figure 3):

- **Quench and primary Jet Venturi dust scrubbing**: In the first stage, hot exhaust gases from the prilling tower are quenched to near saturation using atomizing nozzles. This rapid cooling reduces gas temperature and humidity, promoting condensation on coarse dust particles. The quench also initiates agglomeration of fine particulates, making them easier to capture. The primary Jet Venturi tubes then accelerate the gas stream through narrow throats, creating high relative velocity between gas and scrubbing droplets. This intense turbulence ensures efficient collision and capture of larger particles and aerosols. The scrubbing liquid in this stage typically contains concentrated urea solution (30-40 wt%), which helps minimize water consumption and maintain process compatibility.
- **Secondary Jet Venturi dust scrubbing**: After the primary stage, the gas enters a second set of Jet Venturi tubes designed for fine particulate removal. Here, the focus is on submicron particles that escaped the first stage. The secondary venturi operates with dilute urea solution (5-10 wt%) and optimized nozzle positioning to generate finer droplets, increasing the probability of particle-droplet collisions. This stage also contributes to partial ammonia removal and ensures that overall dust emissions meet stringent limits.
- **Acidic scrubbing for ammonia capture**: The final stage targets ammonia emissions using an acidic scrubbing system. Sulfuric or nitric acid is introduced to react with ammonia, forming ammonium sulfate or ammonium nitrate solutions. These byproducts can be segregated and recycled back into the plant or processed externally, depending on site strategy. This stage is critical for achieving ammonia levels below regulatory thresholds.

- **Mist eliminators**: Chevron-type demisters are installed after each venturi stage and the ammonia scrubbing stage to remove entrained droplets and prevent liquid carryover. This configuration ensures stable operation and protects downstream equipment.

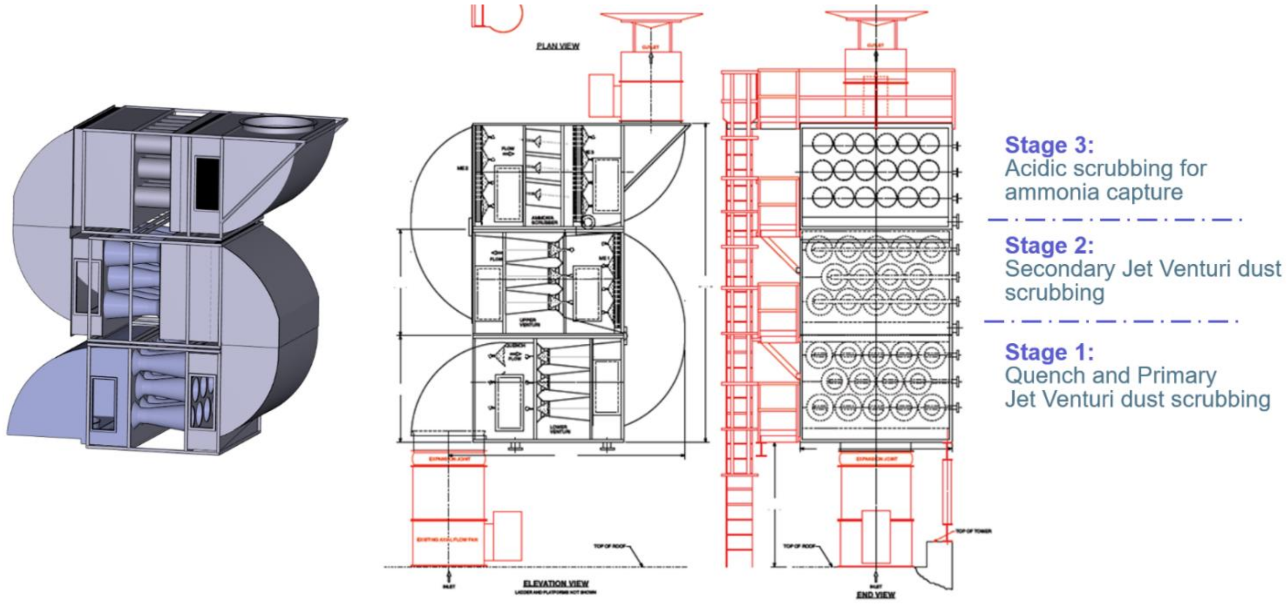


*Figure 3: Jet Venturi Scrubber design.*

## 4.3 In-field pilot testing

A two-stage Jet Venturi Scrubber pilot was installed on a urea prilling tower of the client and tested under real plant conditions with a third-party company taking measurements (see Figures 4 and 5). Sampling was performed isokinetically on inner and outer stacks to capture worst-case emissions. The pilot used two venturi elements of different sizes, adjustable atomizer/nozzle configurations, and chevron-type mist eliminators. No acidic scrubbing stage was included in the pilot.


*Figure 4: A two-stage Jet Venturi Scrubber pilot unit.*


*Figure 5: In-field pilot testing.*

**Key results:**

- Two venturi stages in series achieved dust emissions consistently below 15 mg/Nm³, meeting EU requirements. One stage alone was insufficient for compliance.
- Significant ammonia reduction was observed even without acidic scrubbing: adding acid is expected to achieve 20-30 mg/Nm³ ammonia emissions.
- Mesh demisters tested initially caused excessive pressure drop and were removed. Chevron demisters provided the best balance between droplet removal and energy efficiency.
- PSD analysis during tests showed ~20 wt% <1 µm, but design must accommodate up to 70 wt% fines in worst-case scenarios.

### 4.4 Key features

- **High dust capture capability**: Venturi design is optimized for submicron particles and high dust loads typical of prilling towers.
- **Ammonia abatement**: Acidic scrubbing stage can be added for stringent ammonia emission limits in full-scale installations.
- **Adaptable design**: The design is suitable for both natural and forced draft prilling towers, with installation options at the top of the prilling tower or at grade level.
- **Energy efficiency**: The pressure drop is low compared to conventional scrubbers, reducing operating costs.

## 5 EMISSION MEASUREMENT STANDARDS AND INDUSTRY CHALLENGES

As emission regulations become more stringent, not only the performance of scrubbing technologies but also the methods used to measure emissions have become critical. Regulatory compliance is increasingly tied to standardized testing protocols that assess both visible and non-visible emissions.

## 5.1 Regulatory methods

The EPA[1] has established a series of standardized methods to evaluate different types of emissions:

- Method 5: Measures filterable particulate matter (PM) – particles that can be collected on a filter at stack conditions.
- Method 202: Measures condensable particulate matter – particles that form after the gas stream cools and condenses. These are often underestimated or overlooked by conventional systems such as SICK-based optical measurement systems.
- Method 9: A visual method for determining the opacity of emissions. It is widely used for regulatory compliance and is especially relevant for visible plume control.

## 5.2 Industry challenges

In practice, not all emission control systems are equally equipped to meet the full scope of regulatory requirements. Some technologies perform adequately under Method 5 but struggle with condensables measured under Method 202. Additionally, certain facilities rely on SICK-based optical measurement systems for continuous dust monitoring. These systems operate at stack temperatures, where condensable particulate matter remains in vapor form and is therefore not detected. Unlike regulatory methods such as Method 202, which involve cooling the gas stream to allow vapors to condensate into measurable particles, optical systems lack this capability. This leads to underreporting of total particulate emissions and creates a potential compliance gap, especially as regulators place greater emphasis on total PM and condensable fractions.

## 5.3 MMV + WESP: A comprehensive solution

The combination of MMV and WESP technologies offers a robust and proven approach to meeting these challenges:

- **MMV** is the core of our emission control solution which effectively removes submicron particulate matter and ammonia.
- **WESP** can be added downstream to further reduce fine and condensable particulates, ensuring compliance with both Method 5 and 202.
- **Opacity control**: The combined system can reduce visible emissions to 0% opacity, ensuring full compliance with Method 9.

*Figure 6: Zero opacity observed at the stack outlet (photograph taken at one of the reference plants).*

[1] *While the methods listed are based on the US EPA standards, comparable European standards (e.g., EN 13284-1 for dust) exist. Stamicarbon's experience to date has been based on EPA methods, but the MMV and WESP systems are technically capable of meeting equivalent European requirements.*

This integrated approach not only ensures regulatory compliance but also provides confidence in emission reporting and long-term operational reliability. This combination of MMV and WESP has been implemented in one of the running large-scale urea reference plants (see Figure 6).

# 6 CONCLUSION

The MMV Scrubber and Jet Venturi Scrubber are the core technologies for controlling emissions in industrial processes. Where the most stringent standards apply, WESP can be integrated as add-on to further enhance fine particulate removal. Together, these technologies achieve high efficiency in capturing fine particulates and ammonia in the fertilizer industry.

**Key takeaways:**

- **High efficiency & regulatory compliance**: MMV Scrubber, either standalone or in combination with WESP, delivers robust reductions in urea dust and ammonia emissions. Specifically, MMV Scrubber achieves urea dust emissions below 10 mg/Nm$^3$ and ammonia emissions below 5 mg/Nm$^3$, while the addition of WESP further lowers urea dust to below 5 mg/Nm$^3$ and ensures 0% opacity. Jet Venturi Scrubber can achieve dust emissions below 15 mg/Nm$^3$ and ammonia emissions in range between 20 and 30 mg/Nm$^3$ when acidic scrubbing is included. All measurements are conducted in accordance with recognized regulatory standards, ensuring reliable and verifiable performance.
- **Modular design and flexibility**: The MMV Scrubber features a modular construction that enables efficient transportation, straightforward on-site assembly, and seamless adaptation to various process configurations. This design not only simplifies installation and future upgrades but also enhances operational flexibility. The system can easily accommodate fluctuations in air flow while consistently meeting emission targets. Additionally, venturi tubes can be added or removed with minimal effort to adjust performance as needed, all while requiring virtually no routine maintenance.
- **Proven performance**: Real-plant experiences, such as DGC's urea granulation plant, demonstrate the robustness and reliability of MMV Scrubber technology. The system has operated smoothly with continuous improvements and optimizations.
- **Versatility**: MMV technology is not only suitable for new installations but also highly adaptable for revamping or retrofitting existing scrubbers to achieve high-efficiency performance. This makes it a cost-effective solution for upgrading older systems to meet modern emission standards. Jet Venturi Scrubbers offer versatile installation options for prilling towers, including both natural and forced draft configurations, with minimal pressure drop.
- **Future potential**: Ongoing research and development efforts aim to further enhance the performance and adaptability of MMV, Jet Venturi, and WESP technologies, ensuring they remain at the forefront of emission control technologies.

In summary, MMV and Jet Venturi Scrubber technologies provide advanced solutions for controlling emissions in industrial processes. Where required, WESP can be integrated to further enhance fine particulate removal. Their high efficiency, modular design, and flexibility make them preferred choices for emission control, contributing to environmental sustainability and compliance with stringent regulations.

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