Operational Experience of Commercial, Full Scale Ammonia-Based Wet FGD for Over a Decade

Amy P. Evans
Director of Technology
Marsulex Environmental Technologies Corporation

Claudia Miller
Technical Services Manager
Dakota Gasification Company

Steve Pouliot
Operations Manager
Dakota Gasification Company

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Introduction
A novel and commercially viable process for flue gas desulfurization (FGD), using ammonia as a reagent and producing commercial grade ammonium sulfate (AS) crop fertilizer, was developed by General Electric Environmental Services, Inc. (GEESI) in the early 1990’s and subsequently acquired by Marsulex Environmental Technologies (MET). The first field pilot of this technology was successfully executed at Dakota Gasification Company’s (DGC) Synfuels Plant and led to a subsequent full-scale commercial installation of 350 MWe at that site. The DGC ammonia-based FGD system has been scrubbing flue gas from plant boilers while producing saleable fertilizer under the DakSul 45® label for well over 10 years now. Although this emergent technology was not immediately embraced by electric utilities in favor of conventional-type FGD systems, a second full-scale system (315 MWe) was placed into operation in late 2006 at an oil sand processing facility in Canada and a third system was sold in the People’s Republic of China in 2008. Interest in this FGD approach is increasing today from both abroad (with a fourth system being negotiated for a coal-fired power plant in Eastern Europe) and by increasing inquiries regarding potential U.S. utility coal application. Reasons for the renewed interest in this technology include: the demonstrated commercial, full-scale success of the process; operational reliability and SO₂ scrubbing equal to or greater than conventional wet FGD; offsets to a portion of the yearly operating costs derived by the sale of the AS fertilizer by-product; and the CO₂ friendly nature of the process as, unlike calcium-based wet FGD, no CO₂ is produced in the SO₂ absorption process.

This paper will provide an overview of the technology, data regarding both SO₂ scrubbing performance and fertilizer production at the DGC commercial plant and enhancements made to the DGC plant following original design and comparison of this technology opposite that of conventional FGD systems. This paper will also offer the economic benefits of this novel AS FGD process relative to conventional-type FGD technologies.

System Description
The MET AS scrubbing system uses proven wet flue gas desulfurization (WFGD) equipment with an open spray tower and can achieve the same high reliability/availability
as the more traditional limestone-based WFGD. The produced high-value ammonium sulfate fertilizer by-product is salable and eliminates the potential disposal concerns of gypsum. Additionally, the process greatly minimizes, if not eliminates, wastewater discharge as compared to conventional WFGDs.

The AS WFGD absorber system is similar in many regards to the limestone/gypsum WFGD process, as illustrated in Figure 1. In fact, many components are common between these two processes, including the absorber vessel, recycle pumps, spray nozzles, etc. The ancillary systems which differ are reagent handling and dewatering. Limestone-based WFGD usually requires a fairly complex reagent slurry preparation system, consisting of a limestone storage silo, weigh feeder, wet ball mill with all required accessory equipment, cyclone classifier, ball mill product sump with agitator, ball mill product pumps, limestone slurry tank and limestone slurry feed pumps. In comparison, the simpler AS WFGD ammonia feed system essentially consists of (an) ammonia storage tank(s), ammonia feed pumps and a vaporizer (in the event of anhydrous ammonia supply). The ammonia reagent used for the AS WFGD process can be either anhydrous (<0.1-wt% moisture) or in the aqueous form. The AS WFGD process generally employs centrifuges for dewatering, in lieu of belt or rotary drum filters, based on their ability to produce a low moisture cake and smaller plot area requirement. In some applications, addition of an external crystallization system may be required.

One significant advantage of the AS WFGD is, unlike limestone scrubbing, no or minimal liquid purge is discharged to waste water treatment. The chlorides in the process are controlled by directing a purge stream to the ammonium sulfate product drier, which results in the recovery of more product and serves to strengthen the product.

The economic advantages of the AS WFGD compared to traditional flue gas scrubbing are multiple:

- Higher sulfur fuel may cost less and will benefit the AS production & sales revenue
- Reduces/eliminates solid and liquid waste issues/costs
- No CO₂ greenhouse gas is produced in the AS FGD unlike conventional limestone FGD (where 0.7 ton CO₂ is released per ton SO₂ absorbed.)
Figure 1 – Ammonia and Limestone WFGD Process Comparison
Economics
The favorable economics of the MET AS WFGD technology resides in the ability of the user to fire potentially lower cost, higher sulfur coals or fuels, such as pet coke, while generating a high-value fertilizer product. The economic model of the AS WFGD favors higher sulfur fuels because the sulfur serves as a feedstock in the AS production. The income stream for a specific plant from the sale of AS fertilizer is dependent upon a number of factors. These factors include, but are not limited to, the sulfur in the fuel, unit size, and the cost of ammonia reagent.

The linkage between the economics of fertilizer production and the AS WFGD process chemistry is explained below, starting with the following basic reactions which occur in the desulfurization process:

\[
\begin{align*}
SO_2 + 2NH_3 + H_2O & \rightarrow (NH_4)_2SO_3 \\
(NH_4)_2SO_3 + 1/2 O_2 & \rightarrow (NH_4)_2SO_4
\end{align*}
\]

One mass unit of ammonia is consumed for every four mass units of ammonium sulfate \((NH_4)_2SO_4\) fertilizer generated. Market prices for bulk ammonium sulfate and ammonia generally track with each other (Figure 2), with the price of natural gas being one factor common to both. The approximate 4:1 ratio of AS produced per unit of ammonia, applied to the market prices for both commodities, and the amount of sulfur (as SO\(_2\)) absorbed determines the net value of the AS produced over time. Ammonium sulfate has historically maintained a substantial premium over ammonia on a cost per ton basis, as it is a valued fertilizer both for its sulfur and nitrogen content.
Electric Utility Application Scenario

The gross differential between by-product fertilizer value and cost of ammonia reagent can make a compelling economic case for the application of this technology on a large power plant. If one assumes 100 tons AS/year are produced per megawatt of generation, per % sulfur in the fuel, a 600 MW plant at 85% generation would produce 50,000 tons of AS per % fuel sulfur in a year. Given market prices of $450/ton for ammonia and $200/ton for AS, the 4:1 production ratio would relate to a net differential of $87.5/ton of AS produced. Given the production rate of AS per %S, this 600MW plant's differential would be $8.9 million per year at 2% S fuel, and proportional to $17.8 million per year at 4% S fuel, and beyond at higher sulfur levels. This income stream will offset a significant portion of the yearly FGD operating costs.

The viability of application of this technology to any particular plant is very site-specific. Some of the factors include: availability and delivered price of ammonia; infrastructure and ability/willingness to receive, handle and store the ammonia reagent; ability to fire higher sulfur fuels; and the regional marketplace for the AS produced.

A potential roadblock in accepting this technology may be an electric utility’s reluctance to own and operate a fertilizer plant on site. This problem can be addressed by outsourcing to Marsulex, Inc. (MET’s parent) who has the capability and experience to provide, own & operate such a plant under long term contract, which includes AS marketing responsibility.

Capital cost of the AS-FGD approach is typically in the range of 30 to 40% over that of limestone FGD if a fertilizer plant is included. If the fertilizer plant is outsourced on a Build, Own, Operate and Maintain (BOOM) basis as described above, the AS-FGD capital cost can be less than that of conventional limestone, as the reagent system is greatly simplified and the dewatering system is eliminated from the Owner's scope.
Process
The MET AS WFGD process provides equivalent or better SO$_2$ removal efficiency as compared to a conventional limestone/gypsum scrubbing process. The improved SO$_2$ removal efficiency of the AS WFGD over a range of fuel % sulfur content for a constant liquid-to-gas ratio (L/G) is illustrated in Figure 3. The advantage of the ammonia system, due to the water soluble chemistry, improves with increasing sulfur content in the fuel.

![Figure 3 – Impact of Fuel %S on SO$_2$ Removal for Ammonia versus Limestone](image)

Process Description
After particulate removal, hot flue gas flows to the AS WFGD absorber, where it is counter-currently contacted with saturated ammonium sulfate slurry. The ammonium sulfate is formed by reaction of the absorbed SO$_2$, ammonia, oxygen and water. Ammonia (anhydrous, wet-gaseous or aqueous) is introduced into the vessel to maintain the pH of the absorber slurry at the desired value. The flue gas is cooled close to adiabatic saturation temperature and ammonium sulfate is crystallized by the evaporation of water from the slurry. The absorber acts as an evaporator-crystallizer in which the heat of the flue gas is used for the production of ammonium sulfate crystals. The absorber slurry is recirculated from the reaction tank in the bottom of the absorber vessel to individual spray levels by dedicated recycle pumps. SO$_2$ is removed from the flue gas by contact with
absorber slurry recirculated through these spray levels. The cleaned gas passes through a two-stage horizontal mist eliminator for removal of droplets and exits through a stack to atmosphere. By applying MET-patented technology, proprietary design aspects and maintaining proper absorber operation, ammonia slip to the stack can be maintained at less than 10 ppmvw.

A portion of the absorber slurry containing ammonium sulfate crystals is automatically withdrawn for dewatering and separation of the AS product. This slurry bleed is first dewatered in a hydroclone and then in a centrifuge to produce ammonium sulfate cake with low moisture. All liquor recovered from the dewatering process is returned to the absorber. The centrifuge cake is dried and cooled to produce a sugar-like crystal ammonium sulfate product that can be applied directly as a fertilizer. Alternately, depending on the regional or national fertilizer market, the centrifuge cake can be processed in a drying and compaction system that generates a hard granular AS product. The crystal and granular products generated from the AS WFGD process are shown in Figure 4. Granular AS can be blended with other fertilizers to achieve a custom-designed mixture which is optimal for the crops to be grown. In either case, the dried AS product is easily handled, transported and stored in weather-protected storage facilities.

![Figure 4 – Examples of Granular (Left) and Standard Crystal Ammonium Sulfate Product](image-url)
Chemistry

Similar to the chemistry using a limestone reagent, the major steps of the AS WFGD chemistry are absorption and oxidation. As previously described, the overall reactions which occur in the MET AS absorber are as follows:

\[
SO_2 + 2NH_3 + H_2O \leftrightarrow (NH_4)_2SO_3 \quad (1)
\]
\[
(NH_4)_2SO_3 + \frac{1}{2}O_2 \leftrightarrow (NH_4)_2SO_4 \quad (2)
\]

The actual chemical mechanism is more complex and involves sulfite-bisulfite and sulfate-bisulfate reactions:

\[
SO_2 + H_2O \leftrightarrow H_2SO_3 \quad (3)
\]
\[
H_2SO_3 + (NH_4)_2SO_4 \leftrightarrow NH_4HSO_4 + NH_4HSO_3 \quad (4)
\]
\[
H_2SO_3 + (NH_4)_2SO_3 \leftrightarrow 2NH_4HSO_3 \quad (5)
\]

SO₂ in the flue gas first comes into contact with spray droplets of aqueous slurry. In reaction (3), SO₂ from the flue gas dissolves in the water to form sulfurous acid. In reactions (4) and (5), the sulfurous acid reacts further with dissolved ammonium sulfate and sulfite salts in the solution to form intermediate acidic species. The formation of the sulfurous acid, including the acidic species, lowers the pH of the slurry.

\[
H_2SO_3 + NH_3 \leftrightarrow NH_4HSO_3 \quad (6)
\]
\[
NH_4HSO_3 + NH_3 \leftrightarrow (NH_4)_2SO_3 \quad (7)
\]
\[
NH_4HSO_4 + NH_3 \rightarrow (NH_4)_2SO_4 \quad (8)
\]

The ammonia added to the process in reactions (6) to (8) neutralizes the acidic species to ammonium sulfite and ammonium sulfate. This neutralization serves to restore the pH to its desired value.

\[
(NH_4)_2SO_3 + \frac{1}{2}O_2 \rightarrow (NH_4)_2SO_4 \quad (9)
\]
Oxidation air injected into the absorber tank in reaction (9) oxidizes the remaining ammonium sulfite to ammonium sulfate.

\[
(NH_4)_2SO_4 \text{ (aqueous) + heat of evaporation} \rightarrow (NH_4)_2SO_4 \text{ (solid)}
\] (10)

The resulting ammonium sulfate solution is saturated and ammonium sulfate crystals, in reaction (10), precipitate from the solution due to chemical reaction and water evaporation into the flue gas. The heat of evaporation is supplied by the residual heat in the flue gas.

**Dakota Gasification Company (DGC)**

The Great Plains Synfuels Plant is the only commercial-scale coal gasification plant in the United States that manufactures natural gas for sale. The Synfuels Plant is owned and operated by Dakota Gasification Company (DGC), a wholly owned subsidiary of Basin Electric Power Cooperative (BEPC), based in Bismarck, North Dakota.

The $2.1 billion plant began operating in 1984. Using the Lurgi gasification process, the Synfuels Plant gasifies lignite (a low-rank form of coal) to produce valuable gases and liquids. The gas path portion of the plant is configured in two 50% trains, with a maximum total capacity of 170 million standard cubic feet per day (MMSCFD) of Synthetic Natural Gas (SNG). Including planned and unplanned outages and rate reductions, the average annual plant loading factor is typically about 90 to 92%. The product SNG is piped into the Northern Border pipeline, which runs to Ventura, Iowa, for distribution in the Midwestern and Eastern United States.

The Synfuels Plant also produces up to 1150 tons per day of anhydrous ammonia, approximately 150 MMSCFD of CO\(_2\), and a variety of other byproducts. The ammonia is primarily sold into the regional agricultural market. The CO\(_2\) is compressed and delivered through a 205-mile pipeline to EnCana Oil & Gas Partnership and Apache Canada Ltd. oilfields near Weyburn, Saskatchewan, Canada, for use in enhanced oil recovery. As an added environmental benefit, virtually all of the injected CO\(_2\) is expected to remain sequestered in the depleted oil fields long after they have been abandoned.
The Synfuels Plant consumes about 18,500 tons of lignite daily. The coal is supplied by the nearby Freedom Mine. The mine is owned and operated by the Coteau Properties Company, a subsidiary of the North American Coal Corporation.

![Figure 5 – DGC AS- WFGD Site](image)

The first commercial AS WFGD located at DGC is shown in Figure 5. In the foreground is the storage dome which protects the marketed DakSul 45° ammonium sulfate product from the elements. The tan-colored building to the left of the storage dome is the dewatering building. The tan-colored building to the left of this and in front of the gray concrete stack is the WFGD building. Surrounding the AS-FGD is the DGC gasification complex.
The Flue Gas Desulfurization unit (FGD) at the Great Plains Synfuels plant removes 93% of the Sulfur Dioxide from the flue gas leaving the plant’s three Riley boilers, producing a marketable Ammonium Sulfate fertilizer. The FGD unit consists of a prescrubber and absorber where the Sulfur Dioxide (SO$_2$) is recovered through Absorption, Neutralization, Oxidation, and Crystallization processes. After the FGD, a Dewatering and Compaction unit further refines the ammonium sulfate crystals to the saleable product.

The prescrubber humidifies and cools the incoming flue gas while crystallizing the ammonium sulfate. For later installations, the design was simplified by eliminating the prescrubber such that the absorber combines both crystallization and absorption functions. The SO$_2$ in the humidified flue gas is absorbed in the absorber forming bisulfite anions (HSO$_3^-$) in solution. The SO$_2$ free flue gas passes through an electrostatic precipitator (not shown in Figure 6) to remove particulates before being routed to the atmosphere through a
400 foot tall chimney. The SO₂ now in solution is recovered as ammonium sulfate ((NH₄)₂SO₄). 

Oxidation air is blown into the solution to oxidize the bisulfite anions to bisulfate anions (HSO₄⁻). The dissociation of the bisulfite and bisulfate anions acidifies the absorber solution leaving sulfite (SO₃⁻) and sulfate (SO₄²⁻) anions. Vaporized ammonia is mixed with the oxidation air to neutralize the absorber solution forming ammonium cations (NH₄⁺). Part of the absorber solution is pumped back to the prescrubber, where the incoming flue gas evaporates some of the water causing the ammonium and sulfate ions to precipitate out as ammonium sulfate crystals.

The prescrubber solution containing the ammonium sulfate crystals is pumped to the Dewatering and Compaction unit. The slurry is dewatered by hydroclones, centrifuges, and dried in the raw product dryer. A small amount of water (< 0.5%) is added to the dewatered crystals in a pugmill mixer just before compacting. The crystals are compacted together in cigar shaped sticks. The amount of water added controls the hardness of the stick. The compacted product is granulated by primary and secondary crushing machines.

After secondary crushing, the fines are screened off. The remaining product is processed by three finishing steps: wetting, drying, and cooling. Water is blended with the oversize and on-size product to round off the granules and polish the surface. Then the ammonium sulfate is dried in the final product dryer with a co-current flow of air. After drying, the product is cooled in the cooler with a countercurrent flow of air. Air is drawn through the raw product dryer, final product dryer and cooler by a baghouse. The baghouse filters out any dust from the air. The captured dust is blended with the raw product and reprocessed by the compaction unit.

After cooling, the product passes through a double-deck screen to screen off the oversize and fines. The double-deck screen controls the ammonium sulfate product’s size guide number and uniformity index. The oversize product is recycled back through secondary crushing. The fines are recycled back to the compactors. The on-size product is coated to minimize the dusting of any remaining fines and minimize the likelihood of the product
clumping together (caking) in storage. The ammonium sulfate is coated a second time prior to shipping for anti-dusting and anti-caking. A 50,000-ton dome stores the fertilizer on-site until it is shipped by rail or truck.

The original design parameters for DGC are provided in Table 1 below.

**Table 1– AS WFGD Design Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>DGC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate Equivalent Boiler Power Rating</td>
<td>MW</td>
<td>350</td>
</tr>
<tr>
<td>Fuel Type</td>
<td>-</td>
<td>Heavy resid / Gaseous Fuel</td>
</tr>
<tr>
<td>Approximate Sulfur in Fuel</td>
<td>wt %</td>
<td>5</td>
</tr>
<tr>
<td>Gas Flow to WFGD</td>
<td>Nm³/h</td>
<td>1,107,933</td>
</tr>
<tr>
<td>SO₂ Concentration to WFGD</td>
<td>mg/Nm³</td>
<td>10,567</td>
</tr>
<tr>
<td>SO₂ Removal Efficiency</td>
<td>%</td>
<td>&gt;93</td>
</tr>
<tr>
<td>Number of Spray Levels</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Design AS Production</td>
<td>te/y</td>
<td>145,000</td>
</tr>
<tr>
<td>Type of Ammonia Used</td>
<td>-</td>
<td>Anhydrous &amp; aqueous</td>
</tr>
</tbody>
</table>

**DGC Absorption Plant Process Improvements**

Since this was the first commercial installation, upgrades have been made to improve quality, efficiency and reliability. An opacity meter was installed on the inlet to the FGD to provide indication when carbon was contaminating the slurry to improve product quality. Additional Absorber Liquid Redistribution Devices (ALRD - a MET patented technology) were added in the spray section of the absorber and the speed of the prescrubber and absorber recycle spray pumps were increased. The ALRDs improve open spray tower performance by improving liquid to gas contact. These changes increased SO₂ removal.
DGC Compaction Plant Process Improvements

As is the case for first of a kind installation, modifications were made to improve plant reliability and the quality of the ammonium sulfate fertilizer product. The primary parameters associated with the compaction system included water addition, fines recycle, dryer temperature and cooler temperature.

A dehumidifier was added upstream of the cooler to condition the air before it enters the cooler. High humidity and temperatures in the summer months cause the product to cake very easily. The dehumidified air reduces the product caking, making the product quality more consistent in the summer months.

A paddle mixer was installed upstream of the final product dryer to uniformly wet the product. The attenuation water was originally applied from a spray header inside the final product dryer. Any overspray caused product to build up on the dryer flights. The product would dry out and then harden, requiring a shutdown to clean the flights. The spray header did an inadequate job of wetting the product and often broke inside the dryer. The improved blending from the paddle mixer resulted in better rounding, polishing, and hardening of the fertilizer particles.

The sizing mills were labor intensive due to blinding in the internal screens. A single deck screen was installed to separate the fines and on-size product from the oversize product before the sizing mills. However, while this reduced the amount of fines sent to the sizing mills, there were still issues with blinding. Subsequently, the sizing mills were removed. This left only the chain mill for secondary crushing. It was not adequately sized to handle all the feed. Therefore, oversized material cycled up within the process. A hammer mill was later installed to address the oversized material. The net result of these changes was an overall increase in the compaction throughput.

A variable frequency drive was added to the second compactor. The variable speed allows the compactor to be adjusted for varying feed rates, producing a consistent compacted product.
Dampers installed in the duct work out of the two dryers and cooler tightened the airflow control through each rotary drum. Adjusting the airflows through the final product dryer and cooler heavily influence the product caking.

A wax coating system was installed in the storage dome to eliminate the dust when transporting and loading/unloading the fertilizer. The wax coating is biodegradable and acceptable for use in the agricultural industry.

**System Performance**

Although system improvements were made subsequent to the initial start-up of the system, performance testing of the original design demonstrated that guarantees for SO$_2$ removal, ammonia slip and AS characteristics as listed in Table 2 were achieved.

*Table 2– DGC AS WFGD Tested Performance vs. Guarantee Level*

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Units</th>
<th>Guarantee</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO$_2$ Removal Efficiency</td>
<td>%</td>
<td>93</td>
<td>95-98+</td>
</tr>
<tr>
<td>Ammonia Slip</td>
<td>ppmv, wet</td>
<td>&lt;10</td>
<td>3-10</td>
</tr>
<tr>
<td>Particulate</td>
<td>lb/hr</td>
<td>&lt; 86</td>
<td>&gt;100*</td>
</tr>
<tr>
<td>AS Product Purity</td>
<td>wt %</td>
<td>≥99.0</td>
<td>99.5</td>
</tr>
<tr>
<td>AS Product Moisture Content</td>
<td>wt %</td>
<td>&lt;1.0</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>AS Product Hardness</td>
<td>%</td>
<td>&lt;5</td>
<td>1-2</td>
</tr>
<tr>
<td>Size Guide Number</td>
<td>-</td>
<td>240-290</td>
<td>250-280</td>
</tr>
</tbody>
</table>

*Subsequent to the start-up of the FGD system, it was determined that the addition of a wet electrostatic precipitator (WESP) as a final gas clean-up device was needed in order to
control particulate emissions and opacity to regulated levels. WESP technology had been installed and evaluated in the early pilot work at site. The WESP system was installed and placed into service in 2002 and subsequently performed as required.

**Fertilizer Product**
The MET AS WFGD can be designed to meet the requirements outlined in Table 3. There are several influences on the quality of the AS fertilizer product as it relates to the characteristics in Table 3. For appearance, the color of the crystal is naturally white, but can be influenced by impurities such as flyash and unburned carbon particles that enter the AS WFGD system in the flue gas. The more efficient the particulate control device upstream of the AS WFGD, the fewer such impurities enter the AS WFGD and discolor the product. Other sources of impurities can be in the makeup water to the system and from corrosion products within the system. A quality source of clean makeup water should be used for the WFGD system. Corrosion products can be mitigated by using the proper corrosion-resistant materials of construction.

**Table 3 – Ammonium Sulfate Product Characteristics**

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purity</td>
<td>%</td>
<td>99+</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>wt.%</td>
<td>21.0 - 21.1</td>
</tr>
<tr>
<td>Sulfur</td>
<td>wt.%</td>
<td>24.0 - 24.2</td>
</tr>
<tr>
<td>Water Insoluble Material</td>
<td>wt.%</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Moisture</td>
<td>wt.%</td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>Color</td>
<td></td>
<td>White to beige</td>
</tr>
<tr>
<td>Heavy Metals</td>
<td>ppm</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

The nitrogen assay reflects on the purity of the AS product. The lower the quantity of impurities that enter the system via the makeup water and flue gas, the higher the N
assay. If needed, a filter/purge stream can be designed into the system to remove impurities and improve the AS product purity. The desired moisture content of the AS product can be achieved by a properly designed drying and cooling system and by protecting the AS product from the weather.

The AS fertilizer product is ready for direct application to crop land. It may be used as is, or blended with other fertilizers. In contrast to some other nitrogen-based fertilizers, ammonium sulfate has less loss due to volatilization and leaching in the soil. Sulfur from ammonium sulfate occurs in the soil as the sulfate anion, which remains in the soil solution, so it is readily available for crop uptake. The sulfur works in synergy with nitrogen to produce protein and chlorophyll. Studies show increased crop yields ranging from 10 to more than 60 percent when maintaining a proper nitrogen-to-sulfur ratio in the soil and applying ammonium sulfate fertilizer.

**Conclusion**

The AS WFGD technology can be an economically attractive alternative to conventional limestone-based wet scrubbing at selected plant sites. Economical benefits include the sale of AS as a byproduct to offset operating cost, potentially lower fuel costs, lower capital cost (assuming outsourced fertilizer production, and the reduced cost/liability of handling and disposing solid and liquid wastes that are present with the traditional limestone process. In addition to economic benefits, the process is environmentally friendly because no additional CO2 is produced in the process and the product fertilizer keeps crops growing to consume the CO2 greenhouse gas. This process has been commercially-proven in full-scale for over a decade at Dakota Gasification, at a Canadian site for over 3 years, and will be first installed outside of North America with the installation in China currently in construction.
References
