Worldwide Pollution Control Association

ESKOM Scrubber Seminar
April 12th – 13th, 2007

Visit our website at www.w pca.info
Overview of Basic Types and Configuration of Wet Scrubber Technologies

Presented by:
Michael A. Walsh, P.E.
Marsulex Environmental Technologies
1. Overview of WFGD Processes
Reagents

• All require use of an alkaline chemical “reagent”

- Limestone
- Lime
- Ammonia
Byproducts

• All convert gaseous SO$_2$ to either liquid or solid waste byproduct
  ➢ Throwaway process
  ➢ Gypsum process
  ➢ Regenerative process
  ➢ Fertilizer product process
2. Comparison of Processes
Limestone Systems

Reactions taking place in absorber & recycle tank:

1. \( \text{SO}_2 + \text{H}_2\text{O} \quad \leftrightarrow \quad \text{H}_2\text{SO}_3 \quad \text{Absorption} 
2. \( \text{CaCO}_3 + \text{H}_2\text{SO}_3 \quad \rightarrow \quad \text{CaSO}_3 + \text{CO}_2 + \text{H}_2\text{O} \quad \text{Neutralization} 
3. \( \text{CaSO}_3 + \frac{1}{2} \text{O}_2 \quad \rightarrow \quad \text{CaSO}_4 \quad \text{Oxidation} 
4. \( \text{CaSO}_3 + \frac{1}{2} \text{H}_2\text{O} \quad \rightarrow \quad \text{CaSO}_3 + \frac{1}{2} \text{H}_2\text{O} \quad \text{Crystallization} 
5. \( \text{CaSO}_4 + 2\text{H}_2\text{O} \quad \rightarrow \quad \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \quad \text{Crystallization} 

Reactions taking place in absorber & recycle tank are very similar to those in the limestone system. The main chemical differences are:

(2) \( \text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 \) Slaking

(3) \( \text{H}_2\text{SO}_3 + \text{Ca(OH)}_2 \rightarrow \text{CaSO}_3 + 2\text{H}_2\text{O} \) Neutralization
Typical Limestone FGD
Ammonia-Based WFGD System
Ammonia WFGD Process

SO₂ + 2NH₃ + H₂O → (NH₄)₂SO₃  (1)

(NH₄)₂SO₃ + 1/2 O₂ → (NH₄)₂SO₄  (2)

• For every pound of SO₂ removed:
  – Need one-half pound Ammonia
  – Produces two pounds of Ammonium Sulfate

• One pound of Ammonia generates four pounds Ammonium Sulfate

4:1 product/feed ratio generates favorable economic leverage
Advantages of Ammonia Systems

1. Reduced Fuel Cost
2. Increased Load Factor
3. Production of high value byproduct
3. Typical FGD Processes
Typical WFGD Processes

1. SO₂ Outlet Emissions
2. pH and Stoichiometry
3. Liquid-to-Gas Ratio
4. SO₂ Inlet Concentration
5. Residence Time
6. Mist Elimination
SO₂ Outlet Emissions

• Allowable SO₂ outlet emissions are based on either maximum outlet level or on overall system SO₂ removal efficiency
• Requirements dictated by environmental regulations
• Depending on requirements, absorbers may be designed to treat all or only a portion of flue gas
pH and Stoichiometry

• Slurry pH is likely the most important control variable for absorber operation

• pH determines amount of reagent used

• pH is related to reagent stoichiometry – the number of mols of reagent added per mol of SO₂ removed.
Liquid-to-Gas Ratio

- L/G is the ratio of recycle slurry (in l/hr) to absorber outlet gas flow (m³/hr, actual)
- The amount of surface system available for reaction with SO₂ is determined by L/G
- L/G ratio can be changed by altering either recycle flow rate or flue gas flow rate
- Liquid flow is typically varied by changing the number of operating recycle pumps
The maximum flue gas velocity sets the absorber vessel diameters and impacts the ability of the mist eliminators to prevent droplet carryover.
At constant operating conditions, increasing the concentration of SO$_2$ (increasing the sulfur content of the fuel) will decrease SO$_2$ removal.

Increased SO$_2$ concentration causes an increased depletion of liquid phase alkalinity.
Residence Time

- Residence time – the time that slurry spends in the reaction tank before being recycled for further $\text{SO}_2$ absorption
- Residence time allows the liquid to desupersaturate and avoid scaling in lime/limestone systems
- Typically, for limestone systems, a residence time of 3-5 minutes is provided
Mist Elimination

• Important to remove entrained liquid droplets in order to avoid carryover of the liquid into downstream ducts and stack.

• Good performance of mist eliminators depends on:
  – Operation of absorber at flue gas velocities below critical velocity at which re-entrainment of mist occurs
  – Proper washing techniques
Mist Elimination

Outlet Mist Carryover [mg/Nm³] vs. Mist Eliminator Gas Velocity [meters/sec]
Mist Elimination

• Major parameters to be considered for proper mist eliminator washing include:
  – Wash water rate
  – Water quality
  – Timing sequence
  – Washing area coverage
  – Nozzle pressure
  – Nozzle spray angle
Other Areas of Importance

1. Water Balance
2. Forced Oxidation
3. Stack Gas Reheat
4. Primary Dewatering
5. Secondary Dewatering
Water Balance

• Due to water management restraints, utility plant operation will benefit if the WFGD system is designed to:
  – Minimize the consumption of fresh water
  – Maximize the consumption of plant waste water

• WFGD systems consume (lose) water by
  – Evaporation
  – Disposal of Byproduct
Forced Oxidation

• Both gypsum and ammonia processes require that most of the sulfite salt crystals be converted to sulfate salt crystals by means of oxidation.

• This is accomplished by injecting compressed air into the reaction tank.

• The degree of oxidation is based on:
  – Air stoichiometry (rate of oxidation air to SO$_2$ removed)
  – Depth of the air sparger below liquid level
  – pH in the reaction tank
Stack Gas Reheat Systems

- Two approaches are used to address the corrosive nature of wet scrubber carryover, stack gas reheat and stack lining
- Reasons for using reheat
  - Prevention of condensation and subsequent corrosion in downstream equipment such as ducts, dampers, fans and stack
  - Prevention of the formation of a visible plume
  - Enhancement of plume rise and therefore pollutant dispersion
Primary Dewatering

- First stage of dewatering of slurry byproduct
- Limestone systems – increases solids concentration from 15-20% to 40-60% solids by weight
- Ammonia systems – increases suspended solids from 4-6% to 15%
- Hydroclones are typically supplied for modern units rather than thickeners
Primary Dewatering

- **Advantages of Hydroclones**
  - Lower capital costs
  - Better dewatering (higher underflow percent solids)
  - Higher reliability
- **Disadvantages of Hydroclones**
  - The overflow is not as clear as thickener overflow
  - Without the use of an underflow tank, there is no surge capacity between the hydroclone and the secondary dewatering system.
Secondary Dewatering Systems

- Final stage of solids-liquid separation
- Limestone systems – either vacuum filters or centrifuges used
- Ammonia systems:
  - Second set of hydroclones along with a centrifuge for raw product
  - Additional dryer
  - Compactor for granular product
4. Major Components
Absorbers – Traditional Reagents

1. Spray Absorbers – Open Tower
2. Tray Towers
3. Packed Towers
4. Jet Bubbling Reactors
5. Wulff Process
Spray Absorbers

Mist Eliminators

Absorption Sprays

Flue Gas Inlet

Flue Gas Outlet

Mist Eliminator Wash Sprays

Liquid Level

Sparger

Agitator

Recycle Pumps (3 + 1)
Isometric of “Open” Spray Tower
Wall Slip Phenomenon
Tray Towers
Packed Towers

- Gas enters the base of the tower and passes up through the packing countercurrent to the scrubbing liquor which is introduced at the top of the tower.
- The liquid is dispersed by means of inert, stationary or molded packings of various shapes and configurations designed to add surface area and thus promote maximum vapor-liquid contact.
Jet Bubbling Reactor

In one vessel combines concurrent chemical reactions of:
• limestone dissolution
• SO$_2$ absorption
• neutralization
• sulfite oxidation
• gypsum precipitation
• gypsum crystal growth
Jet Bubbling Reactor

Cut-Away of JBR

Gas Sparger Action
Graf / Wulff Fluidized Bed

Reflux Circulating Fluid Bed Technology
1. Marsulex AS System
MET Ammonium Sulfate Process
AS Process Chemistry

• For every pound of SO$_2$ removed:
  – Need one-half pound Ammonia
  – Produces two pounds of Ammonium Sulfate

• One pound of Ammonia generates four pounds Ammonium Sulfate
Advantages of the Marsulex Ammonium Sulfate Process

**MACT Environmental Compliance:**
- Meets and exceeds strictest environmental regulations
- >98% SO₂ removal efficiency burning highest available sulfur content fuels
- Gaseous emissions are converted into environmentally desirable high value byproduct which eliminates waste product disposal requirements
- Compliance with strictest opacity regulation requirements
- Reduction in CO₂ emissions
- Achieves > 99% system availability / reliability

**Lowest Cost Scrubbing Process:**
- Flexibility to use higher sulfur content fuels
- Lower overall operating costs through elimination of waste product disposal & high value byproduct production
- High SO₂ removal efficiency without costly additives which minimizes costs and the need to purchase SO₂ credits

**Additional Benefits of the Technology:**
- Patented, proprietary technology
- Eliminates potential costs and liability from waste product disposal
Process Comparison

Ammonium Sulfate Process

- Gas Handling & Sulfur Dioxide Absorption
- Reagent Preparation
- Ammonium Sulfate Dewatering / Compaction
- Gas Handling & Sulfur Dioxide Absorption
- Gypsum Dewatering
- Reagent Tank
- Filter Press
- Centrifuge
- Hydroclone
- Ammonia Storage Tank
- Optional Reheat
- Stack
- Boiler
- Dust Collector
- ID Fan
- Bleed Water
- Absorber
- Water
- Air
- Ash Removal
- Feed Tank
- Filter Press
- Feed Tank

Limestone/Gypsum Process

- Gas Handling & Sulfur Dioxide Absorption
- Reagent Preparation
- Limestone
- Ball Mill Grinding System
- Slurry Storage Tank
- Gypsum
- Conveyor
- Centrifuge
- Reclaim Water Tank
- Waste Water
- Water
- Air
- Ash Removal
- ID Fan
- Boiler
- Dust Collector
- Absorber
- Stack
- Bleed Water
- Absorber
- Water
- Air

Same Proven Equipment - Different Reagent
Ammonium Sulfate Process Chemistry

\[ \text{SO}_2 + 2\text{NH}_3 + \text{H}_2\text{O} \rightarrow (\text{NH}_4)_2\text{SO}_3 \]  
(1)

\[ (\text{NH}_4)_2\text{SO}_3 + \frac{1}{2} \text{O}_2 \rightarrow (\text{NH}_4)_2\text{SO}_4 \]  
(2)

• For every pound of SO\textsubscript{2} removed:
  – Need one-half pound Ammonia
  – Produces two pounds of Ammonium Sulfate

• One pound of Ammonia generates four pounds Ammonium Sulfate ($175 - $200 / ton)

Ammonium Sulfate Production
100 tpy per % Sulfur per MW
Ammonium Sulfate Development History:
- 1985-87 Developed bench-scale ammonia scrubbing (AS) technology
- 1987 GEESI awarded first AS patent
- 1992-93 10 MW pilot demonstrated for two modes of operation
- 1994 Awarded commercial contract with DGC
- 1994 Second AS patent awarded
- 1996-97 Startup and successful demonstration of 350 MW eq. AS with production of granular ammonium sulfate
- 1997 Marsulex purchased substantially all the assets of GEESI
- 1998 Applied for three (3) additional patents
- 4/2001: Syncrude contracted with MET under long-term agreements for AS Technology Services
- 1Q2006: Commercial operation of Syncrude AS operations

Commercial NH₃ System Performance at DGC:

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Guarantee</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂ Removal Efficiency</td>
<td>93%</td>
<td>95-98+%</td>
</tr>
<tr>
<td>Ammonia Slip, ppm</td>
<td>&lt; 10</td>
<td>3 - 7</td>
</tr>
<tr>
<td>Opacity</td>
<td>&lt;4% from NH₃</td>
<td>0% from NH₃</td>
</tr>
<tr>
<td>Pressure Drop, “WC”</td>
<td>&lt; 11</td>
<td>7 - 8</td>
</tr>
<tr>
<td>Purity, %</td>
<td>99</td>
<td>99.5</td>
</tr>
<tr>
<td>Moisture, wt%</td>
<td>&lt; 1.0</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Hardness, %</td>
<td>&lt; 5</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Size Guide Number</td>
<td>240 - 290</td>
<td>240 - 260</td>
</tr>
</tbody>
</table>
Proven Technology

Ammonium Sulfate Basis of Design

First Generation Ammonia Systems

- As a Result, Early Generation Ammonia Scrubbers Resulted Very High Ammonia Slip and High Opacity Issues
- Higher pH’s and Incomplete Oxidation Produce Free Ammonia in the Gas Phase

MET Ammonium Sulfate Process

- MET Demonstrated and Patented Optimum Operating Range to Minimize Ammonia Slip And Opacity
- Free Ammonia in the Gas Phase Determines Opacity Levels and is a function of Three Process Parameters; pH, Degree of Oxidation and Ammonia Injection Methods
- MET Demonstrated Minimal Gas Phase Ammonia and Zero Impact on Opacity From Ammonia and Ammonium Salts

Essence of MET Patents Ensures Operation In Optimum pH Range, Complete Oxidation and Optimum Ammonia Injection Methods
Ammonium Sulfate

Product Quality Characteristics

**Purity - 99+%**
- Nitrogen - 21.0 - 21.1%
- Sulfur - 24.0 - 24.2%
- Water Insoluble Matter - < 0.1%
- Color - White to Beige
- Heavy Metals - < 10 ppm

*Exceeds Fertilizer Standard*

**Particle Size**
- 1.0 mm - 3.5 mm
- 240 - 275 SGN
- Uniformity Index - 45 - 50

*Ideal for Bulk Blending & Direct Application*

**Residual Moisture**
- Multiple Drying Steps
- Less Than 1.0 wt% Moisture
- Coated with Anti-caking Agent

*Excellent Storage & Handling*

**Hardness**
- Demonstrated Compaction Technology
- Expertise in Product Hardening Technology
- 1 - 3% Attrition in Industry Test

*Can be Handled and Transported Without Generating Dust*
World Nitrogen Fertilizer Market

Ammonium Sulfate & Total Nitrogen ("N") Basis

Conclusions:
- Each 500 MW ammonium sulfate plant (3% S) represents approximately 3% N. American capacity and 0.6% of world capacity.
- Ammonium sulfate will compete with urea, ammonium nitrate and other nitrogen based fertilizers at its "floor" value ("N" content value only).
- Once competing at "N" value, each 500 MW plant represents only 0.2% of N. American capacity and 0.04% of world capacity.
Ammonium Sulfate Technology

Opportunity Profile

The best opportunities to apply MET’s AS technology will be found at power plants that match the following profile:

- High fuel cost
- Proximity of navigable water, or good rail access for PetCoke, Ammonia and ammonium sulfate transportation
- Preferably in a location with high ammonium sulfate prices
2. Powerspan ECO System
Powerspan ECO Process

ECO® Process Flow

(graphic courtesy Powerspan Corp.)
3. Benetech Clean & Green System
Clean & Green

(graphic courtesy Benetech, Inc.)
4. Lentjes-Lurgi Ammonia Water System
Mechanical Equipment

1. Mist Eliminators
2. Spray Nozzles
3. Agitators
4. Slurry Pumps
5. Fans
6. Dampers
7. Instrumentation
Mist Eliminators

- Corrosion protection for downstream equipment
- Impingement-type most common in use today
  - Simplest method of mist elimination
  - Low pressure drop
  - High collection efficiency
  - Less likely to plug
- Two basic types – horizontal and vertical
Spray Nozzles

Hollow Cone Spray Nozzle
(courtesy Spraying Systems Co.)
Agitators

Recycle Tank Side-Mounted Agitator
Pumps - Slurry
Fans

Typical Centrifugal Booster Fan
(courtesy Howden Power)

Typical Axial Booster Fan
Dampers

- Used for flow control and / or isolation of equipment for maintenance
Instrumentation

- pH Measurement
- Density Measurement
- $\text{SO}_2$ Measurement
- Liquid Level Liquid Flow
5. Factors Affecting Performance
Process Related Factors

• Low $\text{SO}_2$ Removal Efficiency
• Mist Eliminator Pluggage and Solids Carryover
• Poor Water Balance / Excessive Fresh Water Consumption
Equipment Related Problems

• Absorber Impact
  – Materials of Construction
  – Pluggage and Scaling
  – Mechanical failures of internal components
Materials of Construction

Absorber Reaction Tank
- Carbon steel with flakeglass linings
- Carbon steel with rubber lining
- Stainless steels
- High Nickel alloys
- Carbon steel with C-276 alloy cladding
- Carbon steel with C-276 alloy wallpapering
- Concrete with Stebbins acid brick tile lining
- Fiberglass reinforced plastic

Inlet Nozzle
- Carbon steel with PennGuard block linings
- Stainless steels
- Carbon steel with C-276 alloy wallpaper
- C-276 / C22 alloy steels

Spray Piping
- Carbon steel with rubber lining
- Fiberglass reinforced plastic
- Stainless steel
- High Nickel alloys

Spray Zones
- Carbon steel with abrasion resistant flakeglass lining
- Carbon steel with rubber lining
- Stainless steels
- High Nickel alloys
- Carbon steel with C-276 alloy wallpaper
- Concrete with Stebbins acid brick tile lining
- Fiberglass reinforced plastic

Outlet Duct
- Carbon steel with flakeglass lining
- Carbon steel with PennGuard block
- Carbon steel with C-276 alloy wallpaper
- Fiberglass reinforced plastic
- Solid Alloy
Mechanical Failures

- Heat excursions
- Defects in material
- Excessive plugging
- Abuse by maintenance personnel during cleanup and inspections
- Erosion from slurry sprays
6. Summary
Soil Sulfur Deficiency

Removing $\text{SO}_2$ from industrial and utility stack gases has caused a depletion of sulfur in the soil.

Environmental controls also have detrimental effects on agriculture production.
## Byproduct Values

<table>
<thead>
<tr>
<th>Product</th>
<th>($US/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum</td>
<td>-4 to +4</td>
</tr>
<tr>
<td>Sulfuric Acid (100% basis)*</td>
<td>60 to 88</td>
</tr>
<tr>
<td>Elemental Sulfur*</td>
<td>50 to 80</td>
</tr>
<tr>
<td>Ammonium Sulfate*</td>
<td>110 to 196</td>
</tr>
</tbody>
</table>

*Source: Green Markets

**Ammonium Sulfate is the Highest Value Byproduct**

<table>
<thead>
<tr>
<th>Year</th>
<th>Carbon Dioxide (CO₂)</th>
<th>Sulfur Dioxide (SO₂)</th>
<th>Nitrogen Oxides (NOₓ)</th>
<th>FGD Installations</th>
<th>Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>2,513,609</td>
<td>10,340</td>
<td>3,961</td>
<td>248</td>
<td>101,648</td>
</tr>
<tr>
<td>2004</td>
<td>2,456,934</td>
<td>10,309</td>
<td>4,143</td>
<td>248</td>
<td>101,492</td>
</tr>
<tr>
<td>2003</td>
<td>2,415,680</td>
<td>10,646</td>
<td>4,532</td>
<td>246</td>
<td>99,567</td>
</tr>
<tr>
<td>2002</td>
<td>2,395,048</td>
<td>10,881</td>
<td>5,194</td>
<td>243</td>
<td>98,673</td>
</tr>
<tr>
<td>2001</td>
<td>2,389,745</td>
<td>11,174</td>
<td>5,290</td>
<td>236</td>
<td>97,988</td>
</tr>
<tr>
<td>2000</td>
<td>2,429,394</td>
<td>11,297</td>
<td>5,380</td>
<td>192</td>
<td>89,675</td>
</tr>
<tr>
<td>1999</td>
<td>2,326,559</td>
<td>12,444</td>
<td>5,732</td>
<td>192</td>
<td>89,666</td>
</tr>
<tr>
<td>1998</td>
<td>2,313,008</td>
<td>12,509</td>
<td>6,237</td>
<td>186</td>
<td>87,783</td>
</tr>
<tr>
<td>1997</td>
<td>2,223,348</td>
<td>13,520</td>
<td>6,324</td>
<td>183</td>
<td>86,605</td>
</tr>
<tr>
<td>1996</td>
<td>2,155,452</td>
<td>12,906</td>
<td>6,282</td>
<td>182</td>
<td>85,842</td>
</tr>
<tr>
<td>1995</td>
<td>2,079,761</td>
<td>11,896</td>
<td>7,885</td>
<td>178</td>
<td>84,677</td>
</tr>
<tr>
<td>1994</td>
<td>2,063,788</td>
<td>14,472</td>
<td>7,801</td>
<td>168</td>
<td>80,617</td>
</tr>
</tbody>
</table>

Note: These data are for plants with a fossil-fueled steam-electric capacity of 100MW or more. Beginning in 2001, data for plants with combustible renewable steam-electric capacity of 10 MW or more were also included. Data for Independent Power Producers and Combined Heat and Power Plants are included beginning with 2001 data. Totals may not equal sum of components because of independent rounding.

Source: Energy Information Administration, Form EIA-767, "Steam-Electric Plant Operation and Design Report"
### Average US FGD Costs 1994 through 2005

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Overhead &amp; Maintenance Costs (mills per kilowatt hour)</th>
<th>Average Installed Capital Costs (US dollars per kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>1.14</td>
<td>127</td>
</tr>
<tr>
<td>1995</td>
<td>1.16</td>
<td>126</td>
</tr>
<tr>
<td>1996</td>
<td>1.07</td>
<td>128</td>
</tr>
<tr>
<td>1997</td>
<td>1.09</td>
<td>129</td>
</tr>
<tr>
<td>1998</td>
<td>1.12</td>
<td>126</td>
</tr>
<tr>
<td>1999</td>
<td>1.13</td>
<td>125</td>
</tr>
<tr>
<td>2000</td>
<td>0.96</td>
<td>124</td>
</tr>
<tr>
<td>2001</td>
<td>1.27</td>
<td>130.8</td>
</tr>
<tr>
<td>2002</td>
<td>1.11</td>
<td>124.18</td>
</tr>
<tr>
<td>2003</td>
<td>1.23</td>
<td>123.75</td>
</tr>
<tr>
<td>2004</td>
<td>1.38</td>
<td>133.64</td>
</tr>
<tr>
<td>2005</td>
<td>1.23</td>
<td>141.34</td>
</tr>
</tbody>
</table>

Note: These data are for plants with a fossil-fueled steam-electric capacity of 100MW or more. Beginning in 2001, data for plants with combustible renewable steam-electric capacity of 10 MW or more were also included. Data for Independent Power Producers and Combined Heat and Power Plants are included beginning with 2001 data. Totals may not equal sum of components because of independent rounding.

Source: Energy Information Administration, Form EIA-767, "Steam-Electric Plant Operation and Design Report"
## Summary of FGD Cost Information

<table>
<thead>
<tr>
<th>Scrubber Type</th>
<th>Unit Size (MW)</th>
<th>Capital Cost (US $/kW)</th>
<th>O&amp;M Cost&lt;sup&gt;b&lt;/sup&gt; (US$/kW)</th>
<th>Annual Cost (US$/kW)</th>
<th>Cost per Ton of Pollutant Removed (US$/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>400</td>
<td>100 – 250</td>
<td>2 – 8</td>
<td>20 – 50</td>
<td>200 – 500</td>
</tr>
<tr>
<td>Wet</td>
<td>&lt; 400</td>
<td>250 – 1,500</td>
<td>8 – 20</td>
<td>50 – 200</td>
<td>500 – 5,000</td>
</tr>
<tr>
<td>Spray Dry</td>
<td>200</td>
<td>40 – 150</td>
<td>4 – 10</td>
<td>20 – 50</td>
<td>150 – 300</td>
</tr>
<tr>
<td>Spray Dry</td>
<td>&lt; 200</td>
<td>150 – 1,500</td>
<td>10 – 300</td>
<td>50 – 500</td>
<td>500 – 4,000</td>
</tr>
</tbody>
</table>

---

<sup>a</sup> (EIA, 2002; EPA, 2000; Srivastava, 2001)

<sup>b</sup> Assumes capacity factor >80%
### Comparison Wet vs Dry FGD

<table>
<thead>
<tr>
<th></th>
<th>Wet FGD</th>
<th>Dry FGD</th>
</tr>
</thead>
<tbody>
<tr>
<td>% removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% sulfur in coal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO3 removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfill costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water requirements</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>