WET FGD TYPES
AND FUNDAMENTALS
1. Overview of the WFGD Process

2. Basic Chemistry

3. Typical FGD Processes

4. Dry FGD vs Wet FGD

5. Summary
1. Overview of the WFGD Process
All require use of an alkaline chemical “reagent”

- Limestone
- Lime
- Ammonia
- Sodium
Byproducts

All convert gaseous SO$_2$ to either liquid or solid waste by-product

- Throwaway process
- Gypsum process
- Regenerative process
- Fertilizer product process
2. Basic Chemistry
Reactions taking place in absorber & recycle tank:

1. $\text{SO}_2 + \text{H}_2\text{O} \quad \overset{\text{Absorption}}{\longrightarrow} \quad \text{H}_2\text{SO}_3$
2. $\text{CaCO}_3 + \text{H}_2\text{SO}_3 \quad \overset{\text{Neutralization}}{\longrightarrow} \quad \text{CaSO}_3 + \text{CO}_2 + \text{H}_2\text{O}$
3. $\text{CaSO}_3 + \frac{1}{2} \text{O}_2 \quad \overset{\text{Oxidation}}{\longrightarrow} \quad \text{CaSO}_4$
4. $\text{CaSO}_3 + \frac{1}{2} \text{H}_2\text{O} \quad \overset{\text{Crystallization}}{\longrightarrow} \quad \text{CaSO}_3 + \frac{1}{2} \text{H}_2\text{O}$
5. $\text{CaSO}_4 + 2\text{H}_2\text{O} \quad \overset{\text{Crystallization}}{\longrightarrow} \quad \text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
Reactions taking place in absorber & recycle tank are very similar to those in the limestone system. The main chemical differences are:

(2) \( \text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 \) \hspace{1cm} \text{Slaking}

(3) \( \text{H}_2\text{SO}_3 + \text{Ca(OH)}_2 \rightarrow \text{CaSO}_3 + 2\text{H}_2\text{O} \) \hspace{1cm} \text{Neutralization}
Typical Limestone FGD

Flue Gas Inlet → To Stack

Purge → Oxidation Air

Belt Filter → Limestone Slurry Tank

Gypsum

Limestone Silo

MARSULEX

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
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
SO$_2$ Outlet Emissions

- Allowable SO$_2$ outlet emissions are based on either maximum outlet level or on overall system SO$_2$ removal efficiency
- Requirements dictated by environmental regulations
- Depending on requirements, absorbers may be designed to treat all or only a portion of flue gas
- 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 SO₂ (increasing the sulfur content of the fuel) will decrease SO₂ removal. Increased SO₂ concentration causes an increased depletion of liquid phase alkalinity.
Residence time - the time that slurry spends in the reaction tank before being recycled for further SO₂ 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
4. Major Components
Absorbers - Traditional Reagents

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

Flue Gas Inlet

Mist Eliminators

Absorption Sprays

Mist Eliminator Wash Sprays

Flue Gas Outlet

Liquid Level

Sparger

Agitator

Recycle Pumps (3 + 1)
Isometric of “Open” Spray Tower
Typical Spray Pattern
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
Spray Dryer Absorber

- Rotary atomizer (shown) or dual fluid atomization
- Lime slurry or lime + recycle reagent
- ~95% SO2 efficiency practical limit due to stoichiometry
Reflux Circulating Fluid Bed Technology
4. Dry FGD vs. Wet FGD
## Dry FGD vs Wet FGD

<table>
<thead>
<tr>
<th></th>
<th>WET</th>
<th>DRY</th>
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<tbody>
<tr>
<td><strong>Capital Cost</strong></td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td><strong>Reagent Cost</strong></td>
<td>Lower</td>
<td>Higher</td>
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<tr>
<td><strong>% SO2 Efficiency</strong></td>
<td>High 90's</td>
<td>Mid 90's (Spray Dryer Stoichiometry Limits)</td>
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<tr>
<td></td>
<td></td>
<td>High-90's (CDS)</td>
</tr>
<tr>
<td><strong>Water Usage</strong></td>
<td>Higher</td>
<td>Lower (Approx 40% less)</td>
</tr>
<tr>
<td><strong>Overall Operating $'s</strong></td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td><strong>(Normalized)</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Coal % Sulfur preference</strong></td>
<td>&gt; 2%</td>
<td>&lt;2%</td>
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<tr>
<td><strong>By-Product Usage</strong></td>
<td>Possible</td>
<td>Rare</td>
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<tr>
<td><strong>SO₃ Emissions</strong></td>
<td>Yes</td>
<td>NIL</td>
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Dry FGD vs Wet FGD

Decision

- % Sulfur in coal is the primary driver
- Wet FGD can accommodate lower (than design) sulfur coal
- Dry FGD faces performance limitations with higher (than design) sulfur coal
- Decisions maybe influenced by site-specific:
  - Permit requirements
  - Delivered cost of reagents
  - Disposition of by-product
- SO$_3$ emission requirements may drive economics to dry FGD in some cases
5. Summary
## By-product Values

<table>
<thead>
<tr>
<th>Product</th>
<th>Price Range ($US/ton)</th>
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<tbody>
<tr>
<td>Gypsum</td>
<td>-4 to +4</td>
</tr>
<tr>
<td>Sulfuric Acid (100% basis)*</td>
<td>60 to 88</td>
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<tr>
<td>Elemental Sulfur*</td>
<td>50 to 80</td>
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<tr>
<td>Ammonium Sulfate*</td>
<td>110 to 196</td>
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*Source: Green Markets*
Wet FGD retrofit awarded to MET in 2006

Fayette Power Project, Units 1, 2 and 3 Texas

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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<tr>
<td>Fuel</td>
<td>PRB Coal</td>
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<tr>
<td>% Sulfur</td>
<td>0.8%</td>
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<td>Inlet Gas Volume: (acfm)</td>
<td>2,548,000</td>
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<td>Reagent</td>
<td>Limestone</td>
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<td>Absorber Type:</td>
<td>Spray Tower</td>
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<td>SO₂ Removal Efficiency:</td>
<td>97%</td>
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<td>Startup Date:</td>
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LCRA Fayette Units 1&2

- Wet Limestone FGD for low-sulfur PRB Coal
- “Rules of Thumb” do not always dictate decision
- Site-specifics...
  - Permit % SO₂ efficiency
  - Existing Wet FGD plant on Unit 3
  - By-product disposal issues
  - Reagent costs
- ... can trump the % sulfur in coal in the decision to go Wet

**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”

<table>
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<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>
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