

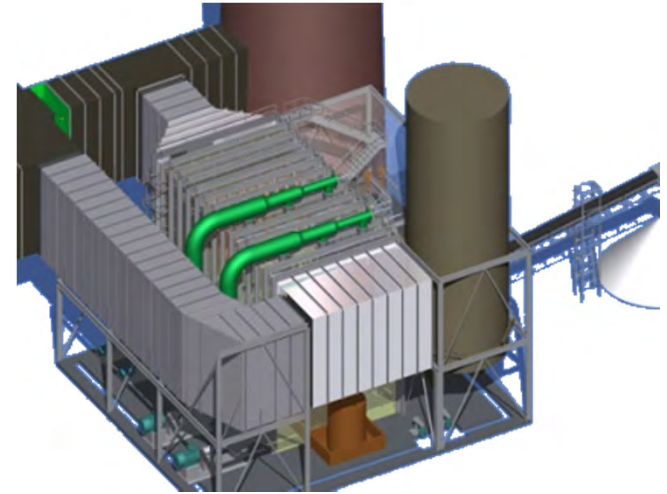
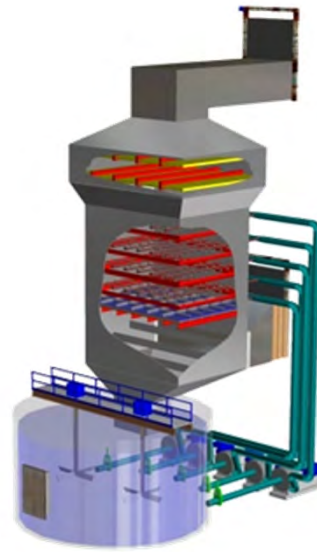
REINHOLD ENVIRONMENTAL Ltd.



**2014 APC Round Table  
& Expo Presentation**

July 14-15, 2014, in Louisville, KY / Hosted by LG&E/KU

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**Wet FGD Operation**  
by  
**Gordon Maller – URS Process Technologies**

*2014 APC Round Table  
Louisville, KY  
July 14, 2014*

# Presentation Organization

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- FGD Safety Considerations
- FGD Operation and Control Concepts
- FGD Performance Variables and the Factors That Control Them
- FGD Process Problems – How to Recognize and Solve

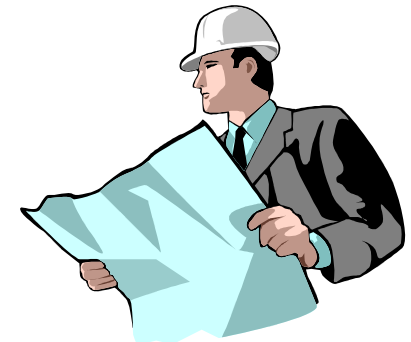
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# FGD Safety Considerations

# General FGD System Safety Considerations

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- Safety practices, procedures and policies should be established to ensure safe, accident-free operation
- Some FGD system operation/maintenance activities require special health/safety considerations
  - Monitoring and sampling
  - Chemical handling
  - General equipment maintenance



# Chemical Hazards

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- Major consideration in operating FGD system is potential exposure to hazardous chemicals
- Major chemical hazards include inhaling gaseous  $\text{SO}_2$  (flue gas) and skin contact with organic acid additives (if used)



# Exposure to Flue Gas

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- Flue gas found in absorber area can have SO<sub>2</sub> levels
  - Caused by duct/damper leakage or result of maintenance
  - SO<sub>2</sub> is a safety and health hazard
- Safety measures include:
  - Monitoring for SO<sub>2</sub>
  - Using a respirator with an SO<sub>2</sub> chemical cartridge



# Noise Hazards

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- Several areas of FGD system present noise hazards:
  - Oxidation air compressors
  - Recirculation pumps
  - Transport blowers
  - Unloading blowers
- During FGD operation, buildings that contain this equipment will require hearing protection
- Hearing protection = ear muffs or plugs



# Dust Hazards

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- Areas where dust hazards can occur are fly ash and scrubber solids handling
- In dusty conditions, personnel should wear:
  - Dust respirator
  - Chemical safety goggles or “spoggles”
  - Glasses instead of contact lenses



# Electrical Hazards

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- During maintenance activities, potential electrical hazards associated with:
  - Pumps
  - Blowers
  - Mixers
  - Tank heaters
- Safety measures include:
  - Following plant procedures for electrical/mechanical equipment to ensure equipment is not energized during maintenance

# Enclosed and Confined Space Entry

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- May be necessary during maintenance on absorbers, tanks, ducts
- Entries must be made with proper preparation/protection
- Important preparations include:
  - Following plant procedures
  - Ventilating the space
  - Testing atmosphere for oxygen deficiency, flammable vapors, hazardous air contaminants
  - Wearing appropriate personal protective equipment
  - Providing trained personnel with emergency rescue equipment

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# FGD Operation and Control Concepts

# FGD System Operating Objectives

- Reduce emissions of SO<sub>2</sub>
- Produce an acceptable byproduct
- Achieve design performance levels
- Achieve high levels for system availability and equipment reliability



# Control Concept For FGD

<b>Control Parameter</b>	<b>Operation Parameter</b>	<b>Comment</b>
pH	Reagent feed rate	<ul style="list-style-type: none"> <li>• Simple control approach</li> <li>• Frequent maintenance of ph sensors required</li> </ul>
Density	Bleed rate of recycle slurry	<ul style="list-style-type: none"> <li>• On/Off control requires flushing of bleed line</li> </ul>
Reaction Tank Level	Make-up water addition rate	<ul style="list-style-type: none"> <li>• Make up includes both reclaim and raw water</li> </ul>
System Water Balance	Mist eliminator wash system dwell time	<ul style="list-style-type: none"> <li>• Raw water quantity varies with load</li> <li>• Minimum wash rate should be maintained</li> </ul>

# Options For Reagent Addition

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## *Feed-Back Control*

- Reagent addition modulated based on recycle slurry pH
- Input signals - slurry pH
- Advantages - simple control
- Disadvantages - does not provide quick response to changing process conditions

# Options For Reagent Addition (cont.)

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## *Feed-Forward Control*

- Reagent addition modulated based on inlet SO<sub>2</sub> loading
- pH feed-back sometimes used to “trim” addition rate
- Input signals:
  - Inlet gas flow
  - Inlet SO<sub>2</sub>
  - Outlet SO<sub>2</sub>
  - Boiler load
  - Reagent slurry flow rate
  - Reagent slurry density
- Advantages - better response to changing process conditions
- Disadvantages - relies on inputs from many instruments

# Options For Reagent Addition (cont.)

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## *Feed-Back Control With Feed-Forward Bias:*

- Reagent addition modulated based on recycle slurry pH
- Flow rate is “trimmed” based on inlet SO<sub>2</sub> or boiler load
- Input signals - slurry pH, inlet gas flow, inlet SO<sub>2</sub>, boiler load
- Advantages:
  - Simple control
  - Provides good response to changing conditions
- Disadvantages
  - Not as simple as straight feed-back control

# Options To Increase SO<sub>2</sub> Removal

<b>Control Strategy</b>	<b>Control Parameter</b>	<b>Advantages</b>	<b>Disadvantages</b>
Increase L/G By Increasing Liquid Recycle Flow Rate	Number of Recycle Pumps In Service	<ul style="list-style-type: none"> <li>• Quick response</li> <li>• Consistent response characteristics</li> <li>• Does not affect process chemistry</li> </ul>	<ul style="list-style-type: none"> <li>• Pump start/stops increase wear on motors and drives</li> <li>• Assumes that there are spare pumps/spray levels</li> </ul>
Increase Recycle Slurry pH	Reagent Feed Rate	<ul style="list-style-type: none"> <li>• Uses existing process control loop</li> <li>• Spare pump(s) not required</li> </ul>	<ul style="list-style-type: none"> <li>• Slow response</li> <li>• Non-linear response characteristics</li> <li>• Limited control range</li> <li>• Can affect process chemistry and cause process problems</li> </ul>

# Options To Increase SO<sub>2</sub> Removal (Continued)

<b>Control Strategy</b>	<b>Control Parameter</b>	<b>Advantages</b>	<b>Disadvantages</b>
Reduce Quantity of Untreated Gas Bypassing FGD	Bypass Damper Position	<ul style="list-style-type: none"> <li>• Quick Response</li> <li>• Consistent Response Characteristics</li> <li>• Does Not Affect Process Chemistry</li> </ul>	<ul style="list-style-type: none"> <li>• Many Systems Designed With No Bypass Capabilities</li> <li>• Can Get Corrosion In Bypass Mixing Zone</li> <li>• Bypass Gas Can Contribute To Leaning Stack</li> </ul>
Adjust Concentration of Performance Enhancing Additive	Additive Feed Rate	<ul style="list-style-type: none"> <li>• Additive Will Extend Performance Range of System</li> <li>• Additive Cost May Be Partially Offset By Lower L/G Requirement</li> </ul>	<ul style="list-style-type: none"> <li>• Slow Response Time</li> <li>• Requires Storage and Delivery System</li> <li>• Increased Operating Costs</li> </ul>

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# FGD Performance Variables and the Factors That Control Them

# Performance Variables That Require Control

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- SO<sub>2</sub> removal efficiency
- Reagent utilization
- Scaling potential



# SO<sub>2</sub> Removal Efficiency

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## *Key Chemical Factors*

- pH or alkalinity
- Excess limestone in recycle slurry (key for forced oxidized process)
- Solution chemistry
- Inlet SO<sub>2</sub> loading (combination of concentration and load)

# SO<sub>2</sub> Removal Efficiency (cont.)

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## *Key Mechanical Factors*

- Liquid-to-gas ratio (L/G)
- Mass transfer characteristics of absorber (e.g., trays, packing)
- Gas / liquid distribution
- Flue gas bypass (where applicable)

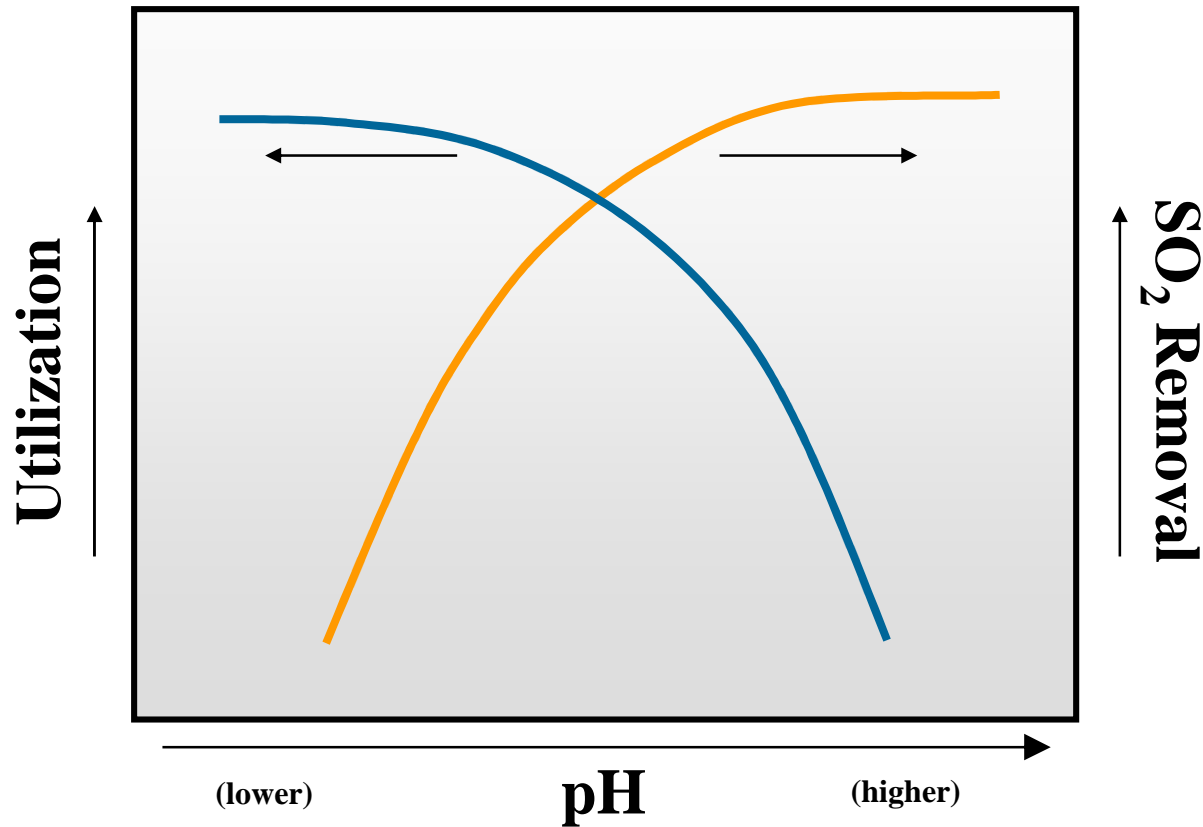
# Reagent Utilization

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## *Key Factors*

- pH
- Solution chemistry
- Solids residence time
- Surface area (grind size)
- Limestone reactivity

# pH / Utilization / SO<sub>2</sub> Removal Relationships



# Causes of Scaling

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## *Key Factors*

- Oxidation (not usually a factor in forced oxidation process)
- Poor limestone utilization
- Slurry density
- Reaction tank volume
- ME wash design or operation
- ME wash water quality

# Factors That Affect FGD Performance and Reliability

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*Operators have direct, limited or no control of key parameters*

- Direct Control
  - pH\*\*
  - Slurry density
  - L/G
- Limited Control
  - Limestone properties
  - Solution chemistry
  - Mechanical factors
  - Water management
- No Control
  - Boiler load cycles
  - Coal S variations
  - Inlet flue gas

# Slurry Density (Slurry Solids Concentration)

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- Minimum slurry density ensures adequate crystal surface area for precipitation. This is important to prevent scaling
- Maintaining a higher slurry density can improve limestone utilization
- Slurry density affects solids residence time which, in turn, affects limestone utilization and scaling potential

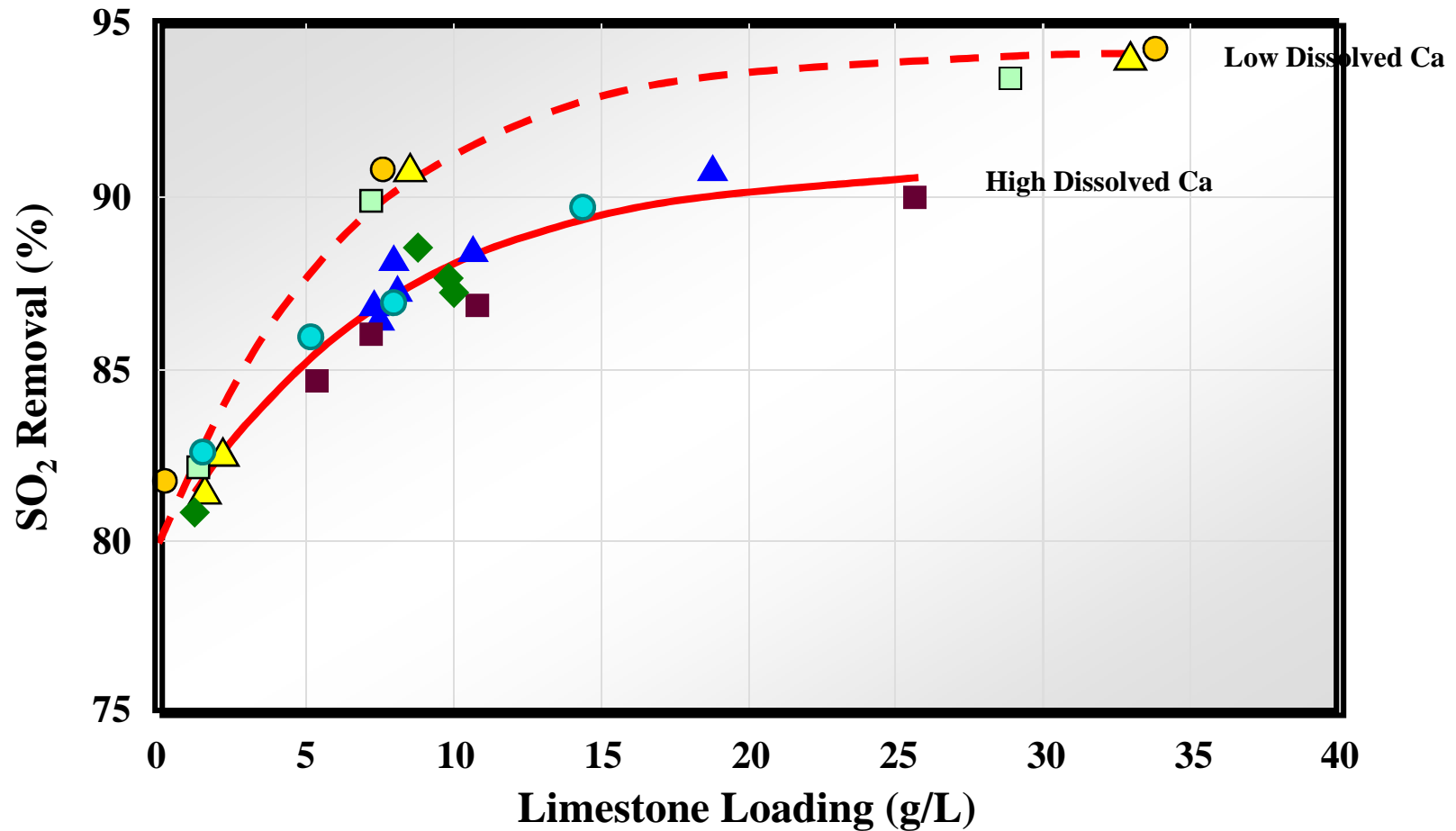
# Solution Chemistry

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- Dissolved  $\text{Cl}^-$  ( $\text{Ca}^{++}$ ) Concentration
  - Inhibits dissolution due to common ion effect
- Forced oxidation vs. natural oxidation
  - Stripping of  $\text{CO}_2$  tends to enhance dissolution
- Aluminum fluoride blinding
- Sulfite blinding
  - Problem during periods of incomplete oxidation
- All can affect the ease with which limestone reagent dissolves and removal performance of scrubber

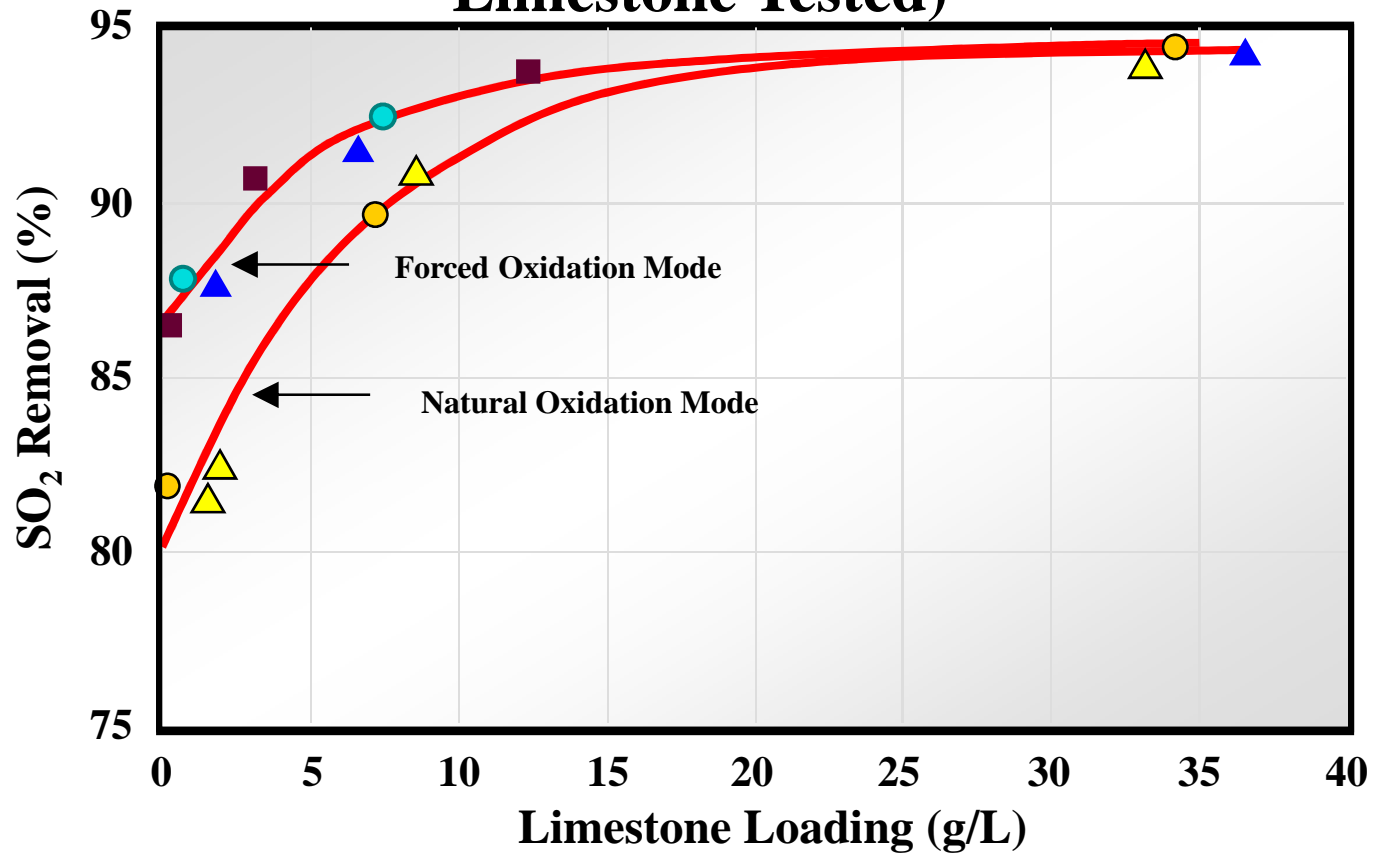
# Effect of Dissolved Calcium Concentration

(Different Shaped Symbols Represent Different Limestone Tested)

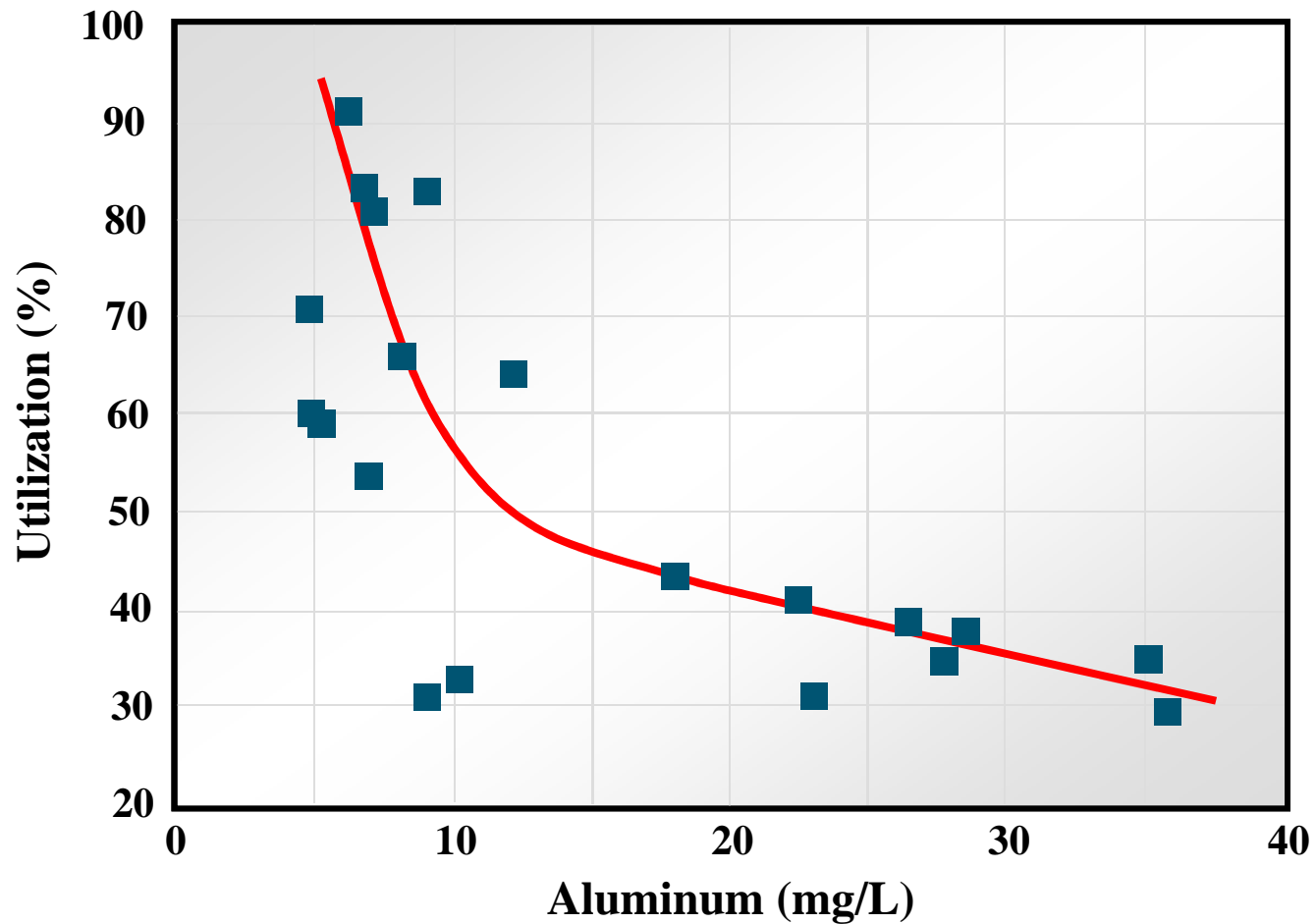


# Effect of Oxidation Mode

(Different Shaped Symbols Represent Different Limestone Tested)



# Effect of Soluble Aluminum on Limestone Utilization



# Limestone Properties Affecting Scrubber Performance

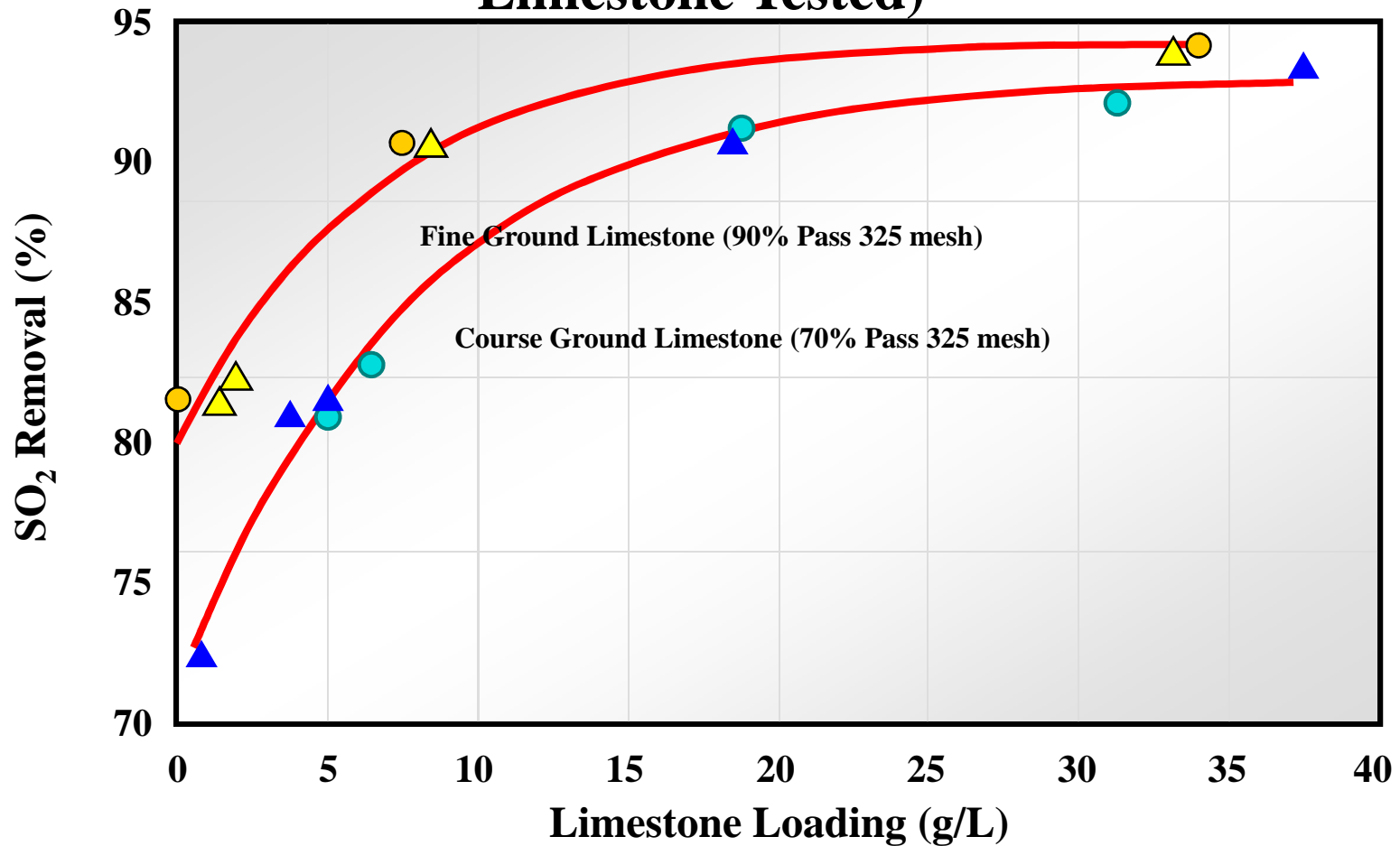
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*Limestone properties will affect pH-Utilization-removal relationship*

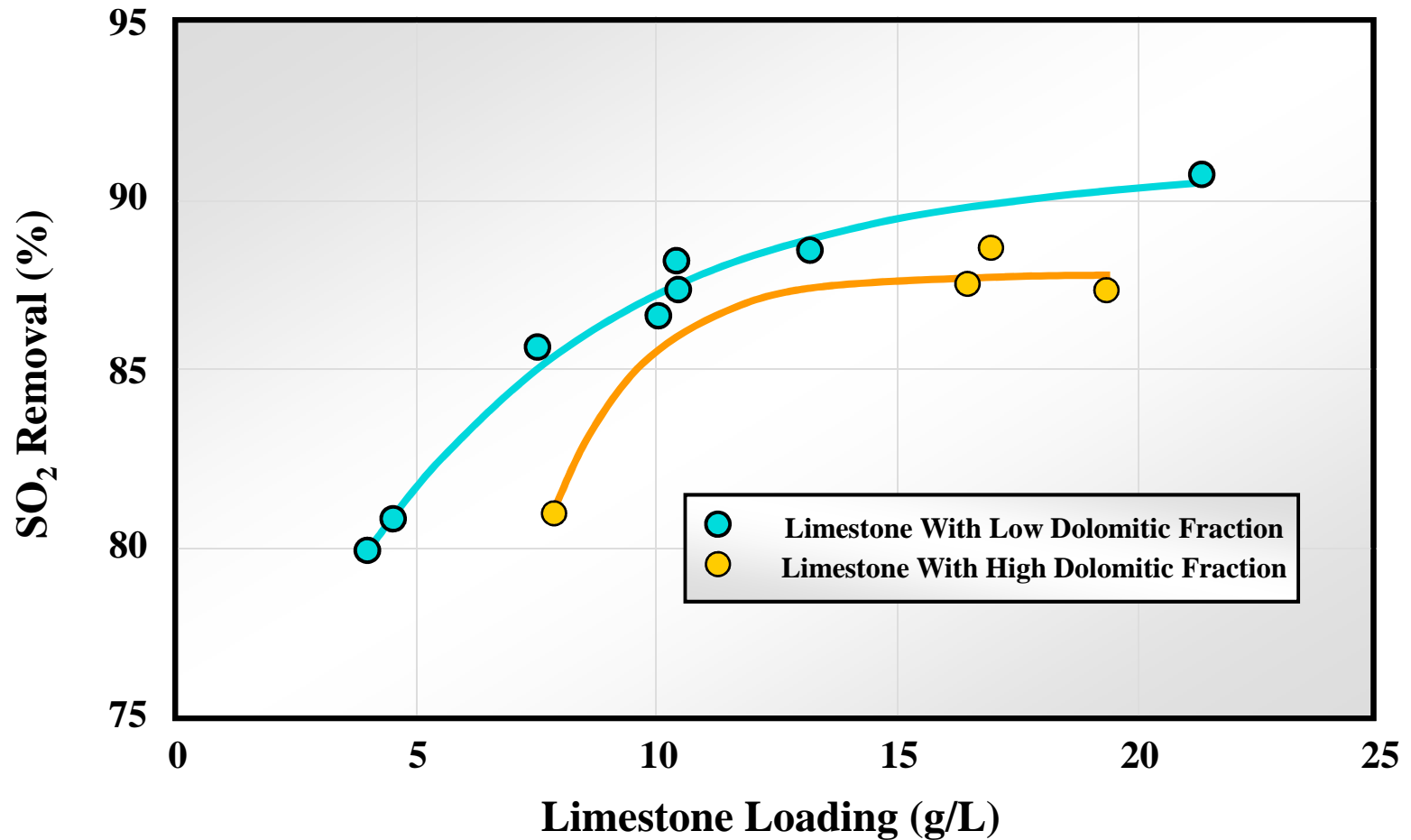
- Grind
- Composition
- Reactivity (dolomitic fraction)

# Effect of Limestone Grind

(Different Shaped Symbols Represent Different Limestone Tested)



# Effect of Limestone Dolomitic Fraction



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# FGD Process Problems – How to Recognize and Solve

# Problem Areas To Be Discussed

- Scaling and solids buildup
- Mist eliminator pluggage
- Limestone blinding
- Poor SO<sub>2</sub> removal
- Poor reagent utilization
- Poor gypsum byproduct quality



# Scaling and Solids Buildup

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*Common areas for scaling:*

- Scrubber inlet
- Absorber internal walls and support structure
- Absorber spray headers
- Inside spray piping
- Trays
- Reaction tank walls



# Causes of Scaling and Solids Buildup

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- Chemical (high gypsum relative saturation)
  - Oxidation
  - Insufficient seed solids
  - Solid residence time that is too short
  - Poor wash water quality
- Wet-dry interface and recirculation of slurry
- Poor reagent utilization

# Causes of Scaling in FGD Systems – High Gypsum Relative Saturation

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- Relative saturation is a measurement of tendency for solid to precipitate or dissolve
- High relative saturation can be result of insufficient seed material or driving forces for precipitation that are (e.g., short residence time)
- In a natural oxidation process, scaling can occur in oxidation range of ~15% to ~35%
- Scaling in ME may result from poor quality wash water (water saturated or nearly saturated with gypsum)

# Causes of Scaling in FGD Systems – Wet/Dry Interface

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- Occurs in area of absorber where hot flue gas is quenched
- Scaling results from fluctuations in gas flow and distribution. Causes areas along duct walls or inlet ducts to vary from wet to dry
- If slurry is carried back into this area, it may dry and accumulate as a hard scale composed of calcium sulfate, and/or fly ash
- Scaling is eliminated by:
  - Modifying the physical design of the absorber inlet to eliminate the flow disturbance
  - Controlling the location of the wet/dry interface by modifying the way flue gas is quenched

# Mist Eliminator Pluggage

- Chemical causes
  - Poor reagent utilization
  - Poor quality wash water
- Mechanical causes
  - Poor design of wash system
  - Broken or plugged wash system
  - High gas velocity
  - Non-uniform gas flow and liquid loading distribution



# Mist Eliminator Pluggage (continued)

- Indication
  - Increase in pressure drop
  - Visual observation during inspection
- ME pluggage can:
  - Result in increased gas velocity through ME and liquid carryover into outlet duct and stack
  - Cause stack rainout and particulate emissions
  - Damage ME due to weight of solids



# Inhibited Dissolution of Limestone

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- Limestone must dissolve in scrubber to provide alkalinity
- Certain dissolved chemical species can significantly slow or stop the dissolution of limestone
- Inhibition - Slowing of dissolution
- Blinding - Significant slowing or stopping of dissolution
- High concentrations of dissolved chloride and magnesium will inhibit dissolution
- The mechanism for this inhibition is called “common-ion” effect

# Limestone Blinding

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- In forced oxidation process, limestone blinding can result from high concentrations of dissolved sulfite or aluminum-fluoride complex
- Either sulfite or aluminum-fluoride complex will react on surface of limestone particle to block dissolving site
- Aluminum-fluoride blinding often initiated by high concentration of inlet fly ash
- Sulfite blinding initiated by incomplete oxidation

# Poor SO<sub>2</sub> Removal as Result of Chemical Problem

<b>Cause</b>	<b>Analytical Indication</b>	<b>Corrective Action</b>
Insufficient Limestone In Scrubber	Low carbonate measured in scrubber solids	Increase pH set-point
Malfunctioning pH Monitor	Poor agreement during pH calibration check	Make repairs to pH monitor system
Sulfite Blinding	Poor reagent utilization along with elevated levels of soluble sulfite	Verify operation of oxidation air system. Correct as required
Aluminum Fluoride Blinding	Poor reagent utilization along with elevated levels of aluminum and fluoride	Improve particulate removal upstream of scrubber
Poor Limestone Quality or Off-Spec Grind Size	Sieve analysis, composition analysis	Modify grind circuit and/or obtain better limestone

# Poor SO<sub>2</sub> Removal as Result of Mechanical Problem

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<b>Cause</b>	<b>Indication</b>	<b>Corrective Action</b>
Plugged Spray Header(s) or Spray Nozzle(s)	Low recycle flow As indicated by flow meter or motor amps	Clean during outage
Broken Spray Header	Indication from flow meter or motor amps. Observed during inspection	Repair during outage
Loss of Recycle Pump Capacity	Low recycle flow as indicated by flow meter or motor amps	Repair during outage

# Poor Reagent Utilization

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<b><i>Cause</i></b>	<b><i>Analytical Indication</i></b>	<b><i>Corrective Action</i></b>
Malfunctioning pH Monitor	Poor agreement during pH calibration check	Make repairs to pH monitor system
Sulfite Blinding	Poor reagent utilization along with elevated levels of soluble sulfite	Verify operation of oxidation air system. Correct as required
Aluminum Fluoride Blinding	Poor reagent utilization along with elevated levels of aluminum and fluoride	Improve particulate removal upstream of scrubber
Poor Limestone Quality or Off-Spec Grind Size	Sieve analysis, composition analysis	Modify grind circuit and/or obtain better limestone

# Poor Gypsum Byproduct Quality

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- High acid insoluble (inerts) fraction
  - Verify operation of particulate control device upstream of scrubber
  - Optimize operation of process hydroclones to maximize concentration of inerts in overflow
  - Increase liquid purge rate
- Poor reagent utilization
- Low sulfite oxidation
  - Verify operation of oxidation air system



# Poor Gypsum Byproduct Quality (cont.)

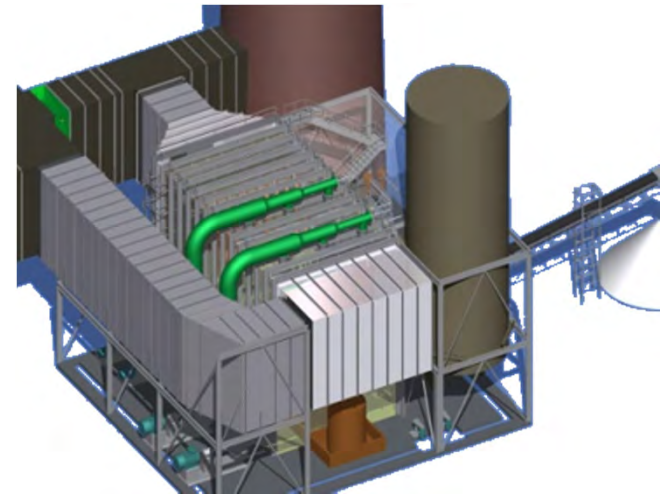
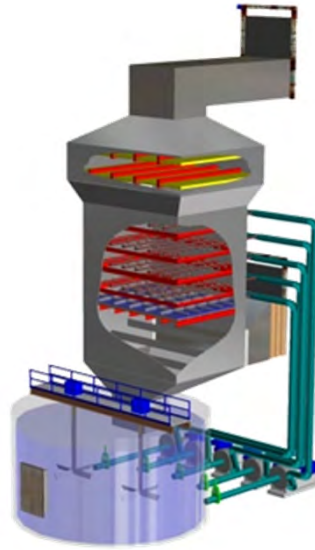
- High Moisture Level
  - Verify operation of primary and secondary dewatering system
  - Purge fines from process
  - Check filter cloth for blinding. Clean or replace as required
  - Increase temperature of filter cake wash water
  - Verify system chemistry
    - High level of limestone
    - High level of acid insolubles (inerts)
    - Presence of crystal modifier





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**URS**



**FGD WWT and ZLD Operation and Performance**  
by  
**Gordon Maller – URS Process Technologies**

*2014 APC Round Table  
Louisville, KY  
July 14, 2014*

# Presentation Organization

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- What is FGD wastewater?
- Design considerations for WWT processes
- Discussion of WWT technology and Operation
  - Physical-chemical treatment
  - Biological treatment
  - Constructed wet lands
- Discussion of ZLD technology
- Conclusions and parting thoughts

# What is FGD Wastewater?

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- Wastewater a result of need to purge chlorides from scrubber
  - Corrosion of alloy materials
  - Ability of scrubber to obtain acceptable limestone utilization
- Ways that Chlorides are purged from scrubber
  - Free moisture in FGD byproducts
  - Low solids purge stream
- Characteristics of wastewater:
  - Suspended solids
  - Major species: Ca, Mg, Na, SO<sub>3</sub>, SO<sub>4</sub> and Cl
  - Trace species: As, B, Br, F, I, Hg, Se, Mn
  - Heavy metals
  - Nitrogen (nitrates and nitrites)

# What is FGD Wastewater? (continued)

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- ORP: Can affect oxidation state of Se and Hg
- Wastewater from FGD can be saturated with gypsum. Can lead to scaling in WWT filtration and evaporation equipment

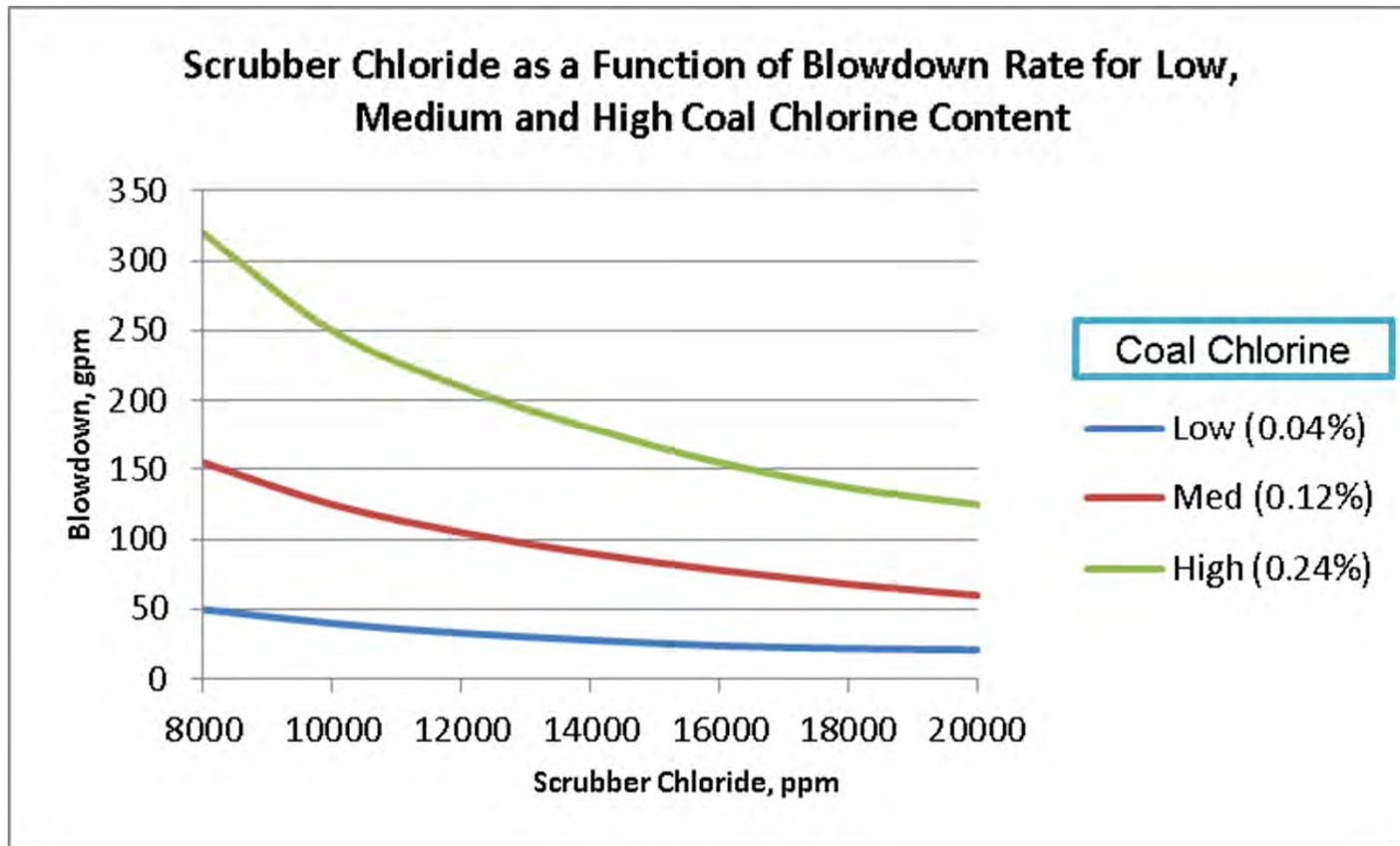


# FGD Design and Operation Can Affect Wastewater Properties

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- Forced oxidation versus natural or inhibited oxidation
  - ORP
  - Amount of free moisture in byproducts
- High versus low chloride – Can affect sulfate levels and degree of gypsum supersaturation
- Operation
  - Filtercake wash?
  - Filtercake free moisture

# Theoretical Scrubber Cl<sup>-</sup> Blowdown Rate



Assumptions: 600 MW; Fuel HHV – 12,000 Btu / lb; Heat Rate – 10,500

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# Discussion of WWT Technology and Operation

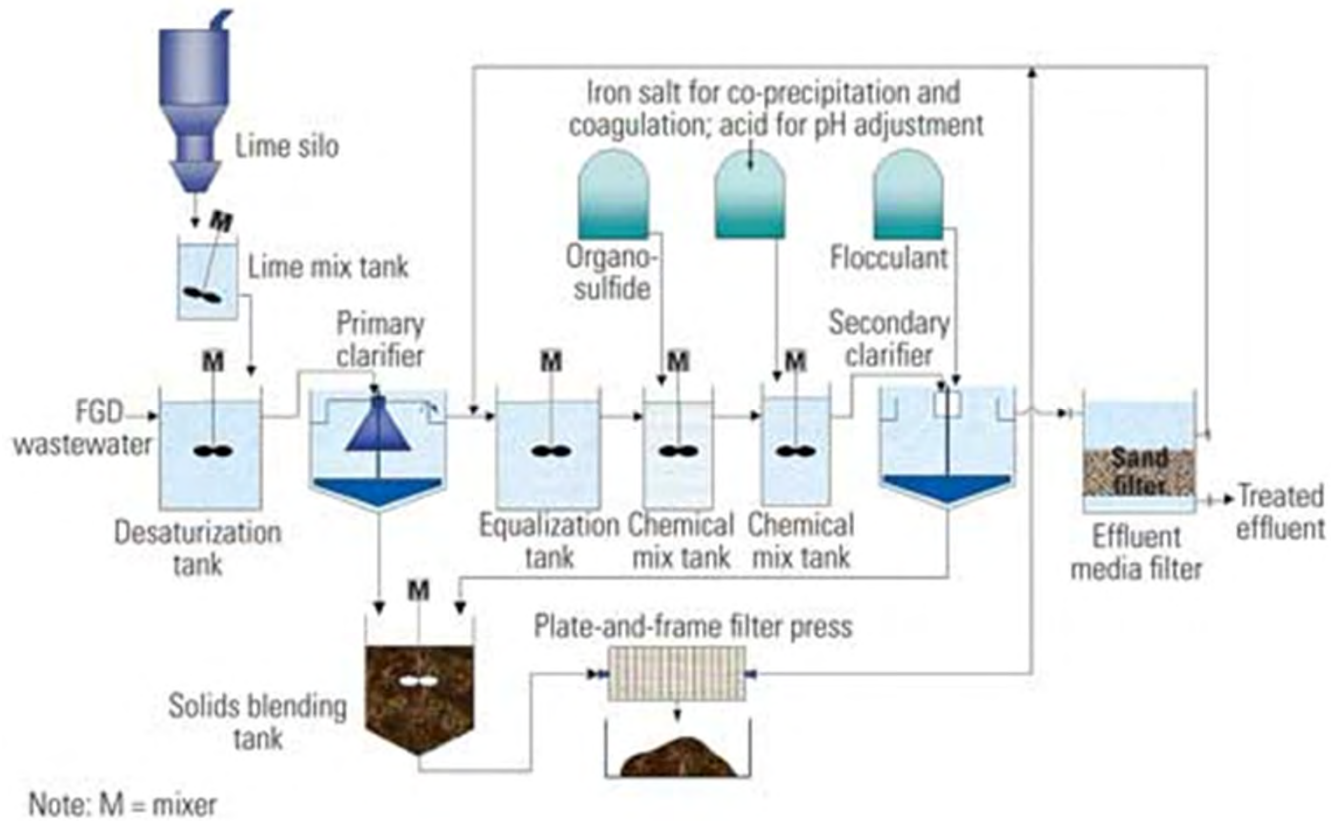
# WWT Treatment Options

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- Physical-chemical treatment
- Biological treatment
- Constructed wet lands



# Overview of Physical-Chemical Treatment



Source of flow diagram –

# Discussion of Treatment Steps

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## 1. Desaturation

- a. Raise pH to about 8.5 – 9.0 with lime to precipitate metal hydroxides and gypsum
- b. Do not want to allow pH get too high and precipitate all of the Ca and Mg
- c. Retention time – about 30 minutes
- d. Sludge from first clarifier recycled to provide seed solids (nucleation sites)

## 2. 1<sup>st</sup> Clarifier

- a. Remove fine gypsum and other suspended solids
- b. Design similar to FGD sludge thickener
- c. Common to add flocculent to improve settling of solids
- d. Targeting 10 to 20 wt.% in underflow
- e. Typical overflow rate – 0.5 gpm/sft

# Discussion of Treatment Steps (continued)

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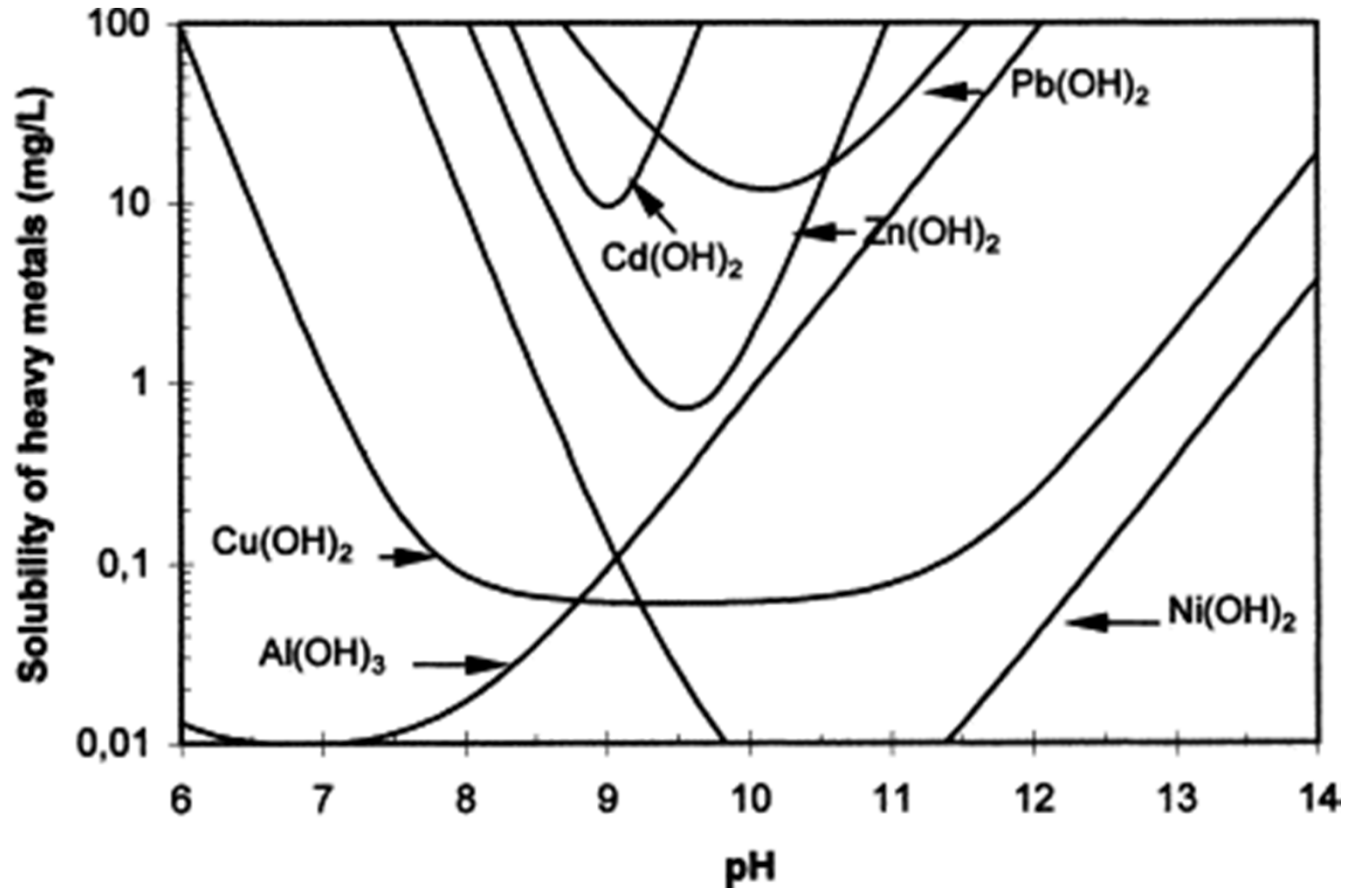
## 3. Equalization Tank

- a. Used to provide consistent flow and composition for chemical treatment
- b. May be located upstream of desaturation tank or close to scrubber depending on number and location of influent streams

## 4. Chemical Treatment Tanks

- a. Metals removed by precipitation as metal-hydroxide or metal-sulfide (example: mercury-sulfide [cinnabar])
- b. Metal-sulfides precipitate rapidly and are very fine and difficult to settle. To overcome this, sulfide is bonded with large organic molecule, organo-sulfide. This increase size of precipitate and makes it easier to settle
- c. Ferric chloride is dosed at high concentration and precipitates
- d. Metals co-precipitate with the iron and are removed (example – selenite)
- e. Retention times in chemical treatment tanks typically 10 – 15 minutes

# Solubility of Metal Hydroxides



# Discussion of Treatment Steps (continued)

---

## 5. 2<sup>nd</sup> Clarifier

- a. Used to settle precipitated metals to a solids concentration of 10 to 20 wt.%
- b. Typical overflow rate – 0.33 gpm/sft
- c. Lamella clarifiers are an option if space is limited
- d. Polymers (coagulant and flocculent) often added to facilitate settling

## 6. Effluent media filtration

- a. Used to remove un-settled suspended solids and metal precipitates
- b. Filters will need to be back-flushed
- c. Control of gypsum RS is important because filters are prone to scaling

## 7. Ion-exchange technology

- a. Sometimes used for challenging treatment applications (example – B removal)
- b. Very prone to scaling. Should not be regenerated with H<sub>2</sub>SO<sub>4</sub>

# Discussion of Treatment Steps (continued)

8. Sludge dewatering
  - a. Filter presses most common
  - b. Work best at feed solids concentration of 10 to 20 wt.%
  - c. Typical dewatered solids concentration 60 to 70 wt.%
  - d. Sludge transported and disposed of in dry landfill



# Overview of Biological Treatment

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- Biological treatment (SBR) are located downstream of phys-chem treatment
- Needed to remove BOD/COD, NO<sub>3</sub>, NO<sub>2</sub>, ionic Hg
- Activated sludge process – need to maintain population of anaerobic bacteria to treat waste water
- Anaerobic bacteria reduce ionic Hg to elemental form which is no longer soluble
- Process typically more challenging for O&M
  - Problems with high or low temperature
  - Problems with high salinity
  - Works best with consistent influent flow and influent properties, does not work well as a batch operation

# Constructed Wetlands

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- Wastewater flows through microbial and bacteria rich material such as compost
- Requires a large area for treatment
- Novel vertical flow design is being evaluated as means to reduce size
- At some point the bacteria rich material needs to be removed and disposed



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# Discussion of ZLD Technology

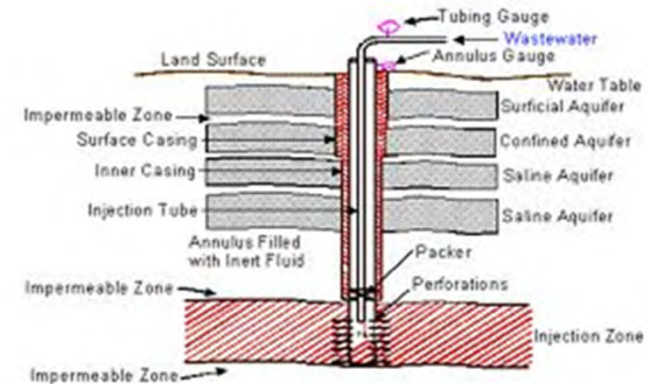
# ZLD Treatment Options

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- Deep well injection
- Evaporative thermal process
- In duct evaporative process
- Wastewater spray dryer
- Non-thermal process

# Deep Well Injection

- Deep well injection:
  - Waste must be treated before injection
  - Lower capital and O&M costs
  - Higher environmental risk
  - Not an option in some regions

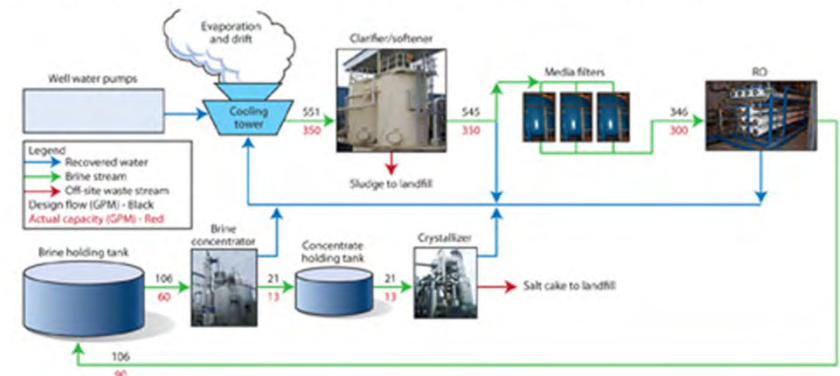


# Evaporative Thermal ZLD

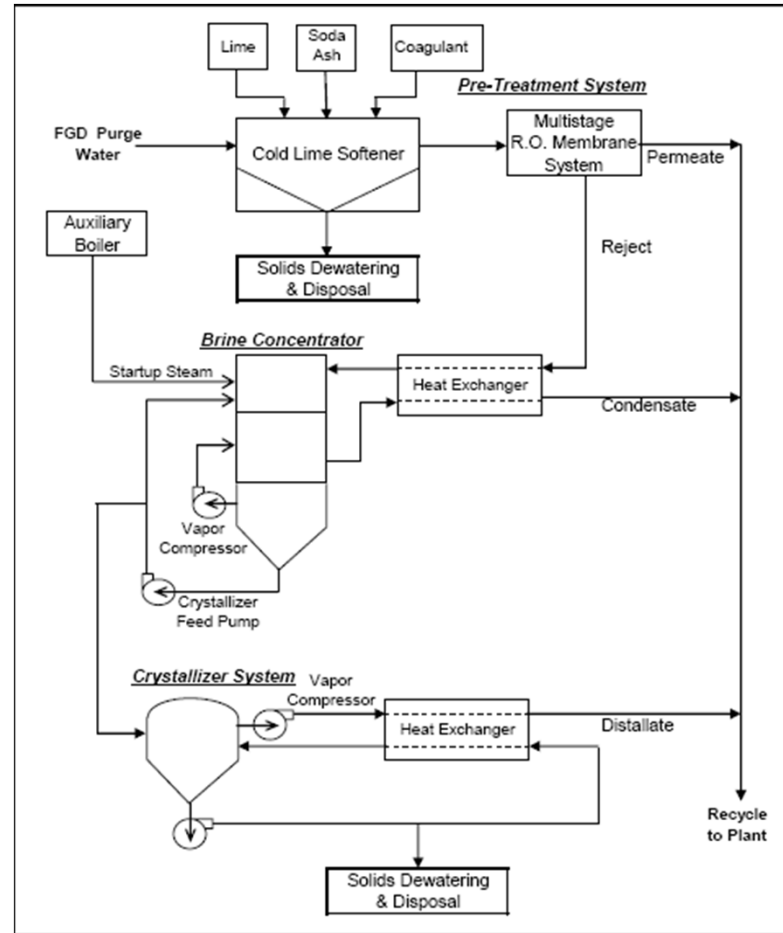
- Evaporative thermal process:
  - Brine concentrator for initial concentration of wastewater
    - Reverse osmosis treatment
    - Thermal evaporative (e.g., Vertical tube falling film)
  - Crystallizer
  - Removal of suspended solids and  $\text{Ca}^{++}$  required prior to treatment
  - High capital and energy requirements
  - Dissolved salts present in FGD wastewater, like  $\text{CaCl}_2$ , hydrolyze at high temperature and become acidic and corrosive
  - Fairly complex operating and maintenance requirements



Figure 1. Flow Diagram of a 720-MW Power Generation Facility Showing Bottlenecks in the Zero Liquid Discharge System

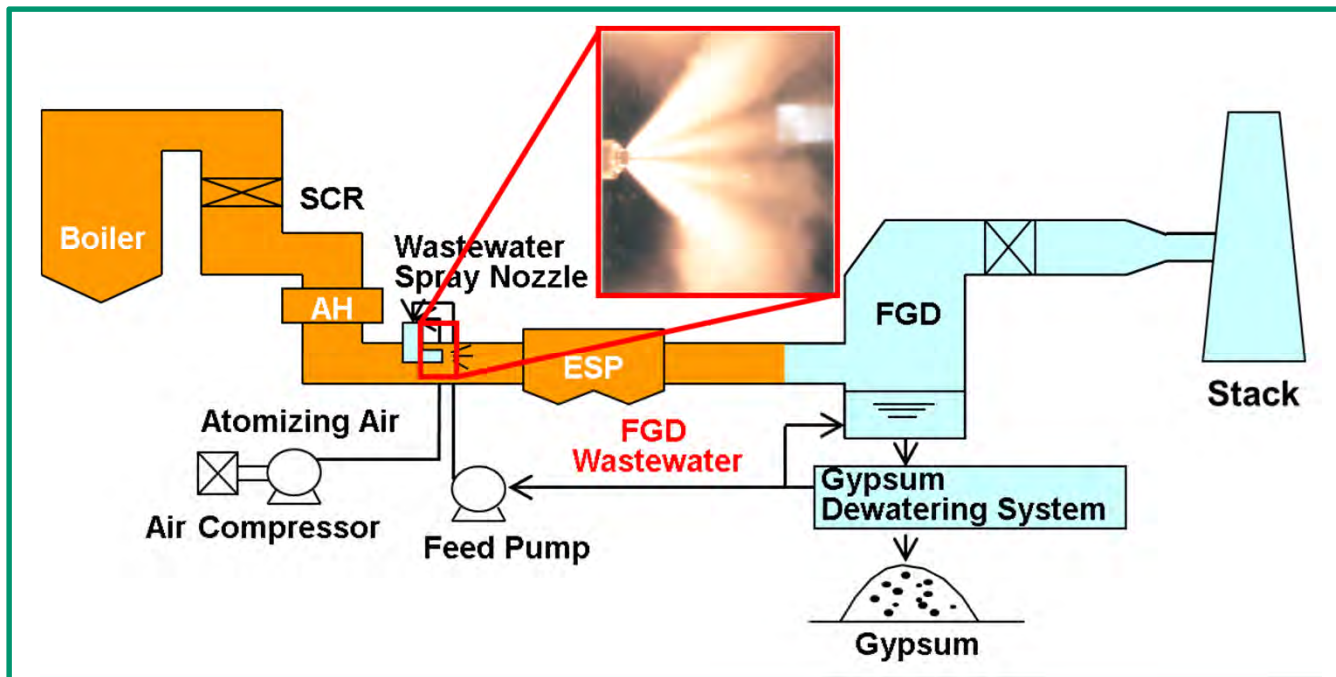


# Block Diagram for Evaporative Thermal ZLD



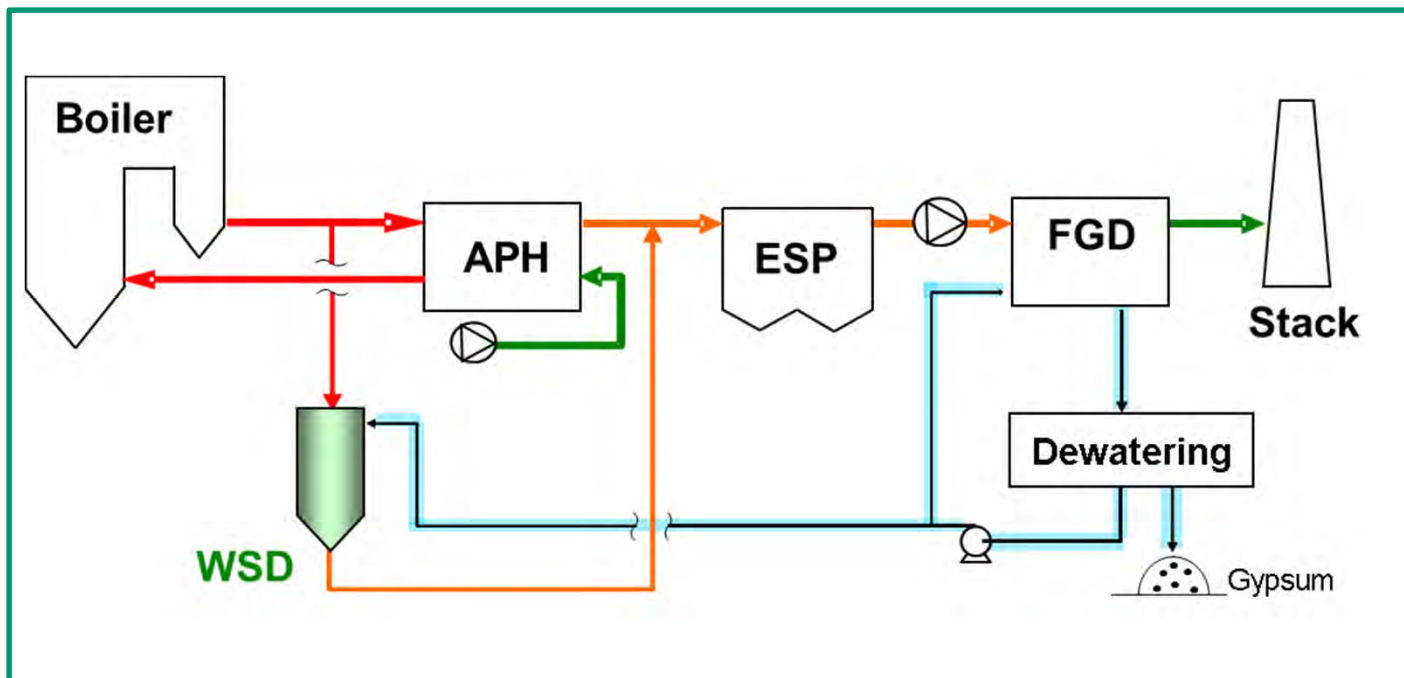
# Wastewater Evaporation System

- Direct injection of wastewater into ductwork
- Salts collected with fly ash in particulate control device



# Wastewater Spray Dryer

- Addition of wastewater to small spray dryer installed in flue gas slipstream bypassing air heater
- Salts collected with fly ash in particulate control device

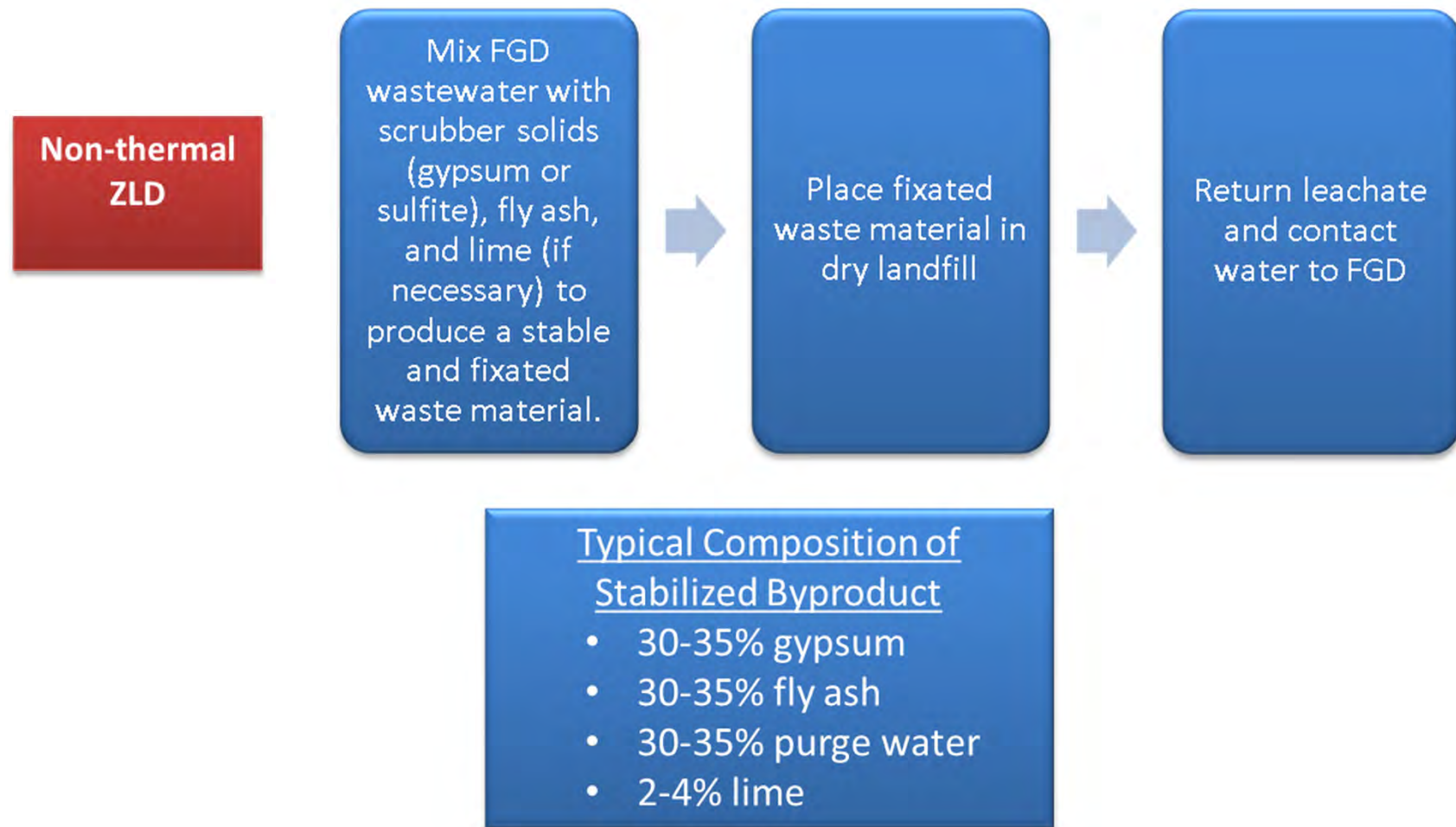


# Overview of Non-Thermal ZLD Process

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- Fixation and Blending for Disposal in Landfill:
  - Mixture of scrubber solids (e.g., gypsum), fly ash, lime (if required) and waste water to produce a cement-like product suitable for disposal in landfill
  - Non-thermal technology
  - No pretreatment of wastewater
  - Has potential to eliminate all discharges from plant (operate as ZLD plant)
  - Low capital and operating costs
  - Reduce quantity of ash available for resale
  - May be preferred option due to low cost and simple O&M

# Application of Non-Thermal ZLD Process



# Conclusions and Parting Thoughts

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1. Have good understanding of FGD process chemistry to improve ability to predict properties of purge water and capability of FGD system to process miscellaneous plant wastewater
2. Have a reasonable and accurate design basis for fuel, inlet flue gas properties, reagent and water
3. Operate and optimize FGD system to reduce and minimize quantity of wastewater and to produce a consistent purge stream in terms of volume and properties
4. Optimize plant water management to reduce volume of process streams
5. Consider full range of load conditions and fuel properties in design
6. Operate landfill to minimize volume of leachate and contact water



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