

REINHOLD ENVIRONMENTAL Ltd.



2010 APC Round Table & Expo Presentation

July 18-20, 2010, in Concord, NC / Hosted by Duke Energy

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BabcockPower



One Source

Many Solutions

One Purpose

Circulating Dry Scrubber Technology

Presentation to:

2010 Air Pollution Control Round Table

20 July 2010

Concord, NC

Terence Ake
Product Manager

Outline

U.S. Emission Regulations

Dry Scrubbers

1. **Circulating Dry Scrubber Features**
 2. **Process Control**
 3. **Construction**
 4. **Experience**
 5. **Performance**
-

Summary

Outline

U.S. Emission Regulations

- **SO₂ CAP and Trade**
- **Clean Air Interstate Rule (CAIR)**
- **06-Jul-10 Transport Rule**

Dry Scrubbers

1. Circulating Dry Scrubber (CDS)
 2. Process Control
 3. Construction
 4. Experience
 5. Performance
-

Summary

U.S. Emission Regulations

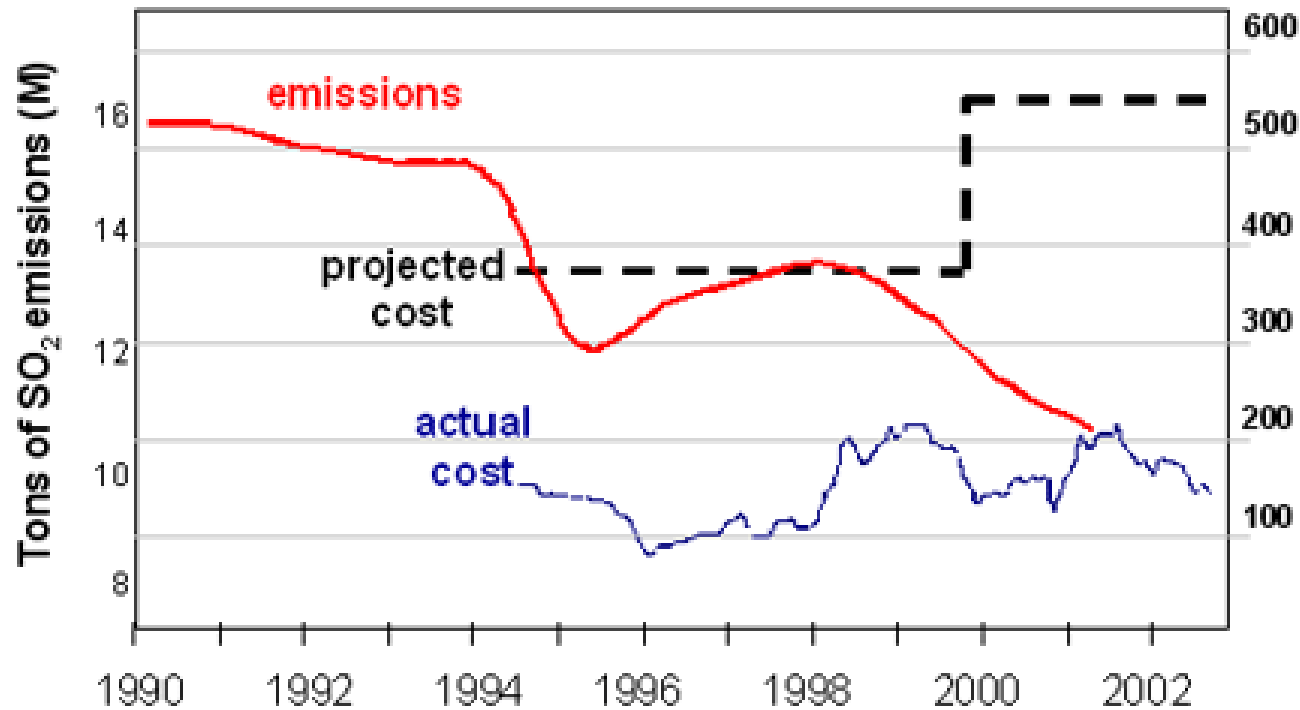
Sulfur Dioxide (SO₂) CAP & TRADE

- Started w/ 1990 Clean Air Act Amendments
 - U.S. Acid Rain Program
- Turned Pollution Reduction into a Marketable Asset
- Elements:
 - A Mandatory Emission Cap
 - Fixed Number of Allowances
 - Banking and Trading
 - Clear Performance Measurements
- Prompted Technological Innovations

<http://www.edf.org/page.cfm?tagID=1085>

U.S. Emission Regulations

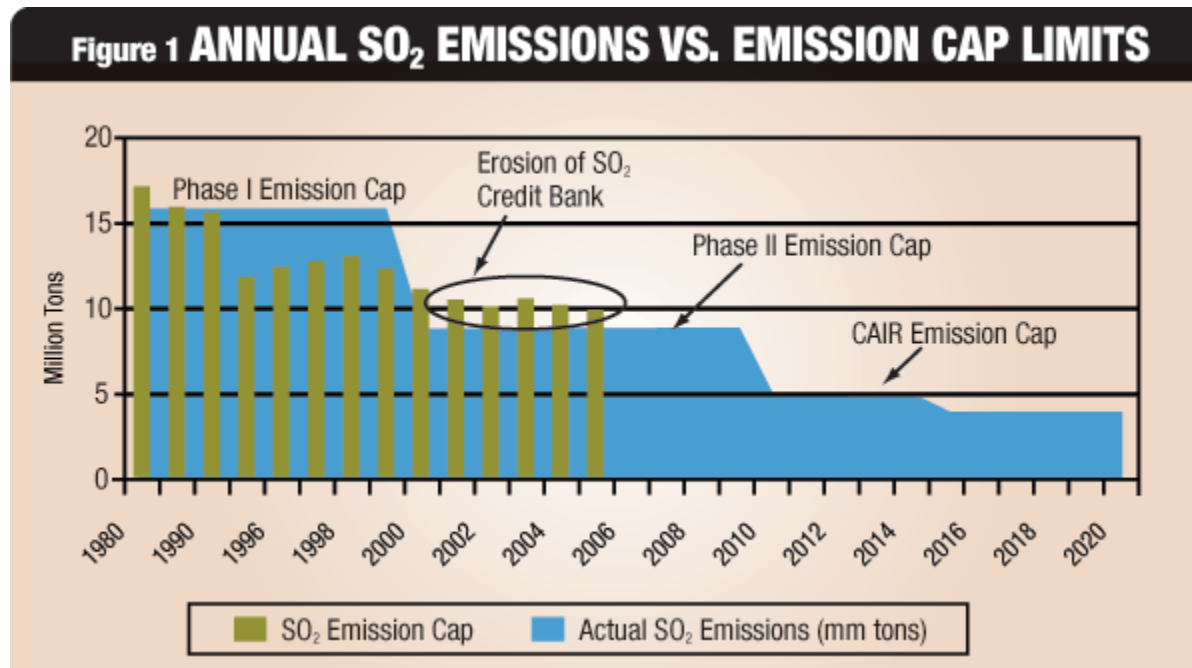
SO₂ CAP & TRADE EXPERIENCE



- In 1990s, the acid rain program achieved 100% compliance for reduced sulfur dioxide emissions

<http://www.edf.org/page.cfm?tagID=1085>

U.S. Emission Regulations



- Phase I units (largest SO₂ emitters) complied first
 - 80% managed fuel sulfur
 - 20% installed FGD retrofits
- In 2000s, credit bank starting to erode with Phase II cap
- Clean Air Interstate Rule (CAIR) was expected to drive FGD retrofits

- Power Engineering
- www.power-eng.com
- November 2007

U.S. Emission Regulations

CLEAN AIR INTERSTATE RULE

- Vacated in July 2008 and sent back to EPA for retooling
 - Court said EPA overstepped authority
- Reinstated in December 2008
 - EPA, Environmental Defense Fund, and several states (led by NC) asked court to reconsider
- In February 2009, Supreme Court invalidated weak Bush Administration EPA Clean Air Mercury rule

U.S. Emission Regulations

CLEAN AIR TRANSPORT RULE

- Published 06-Jul-10
- If fully implemented in 2014, emissions in 31 eastern states and DC will reduce from 2005 levels by:
 - 71% SO₂ (48% from 2009)
 - 52% NO_x (0% from 2009)
- SO₂ reductions required as early as 2012 & Second Phase in 2014
- Sets emissions budgets for each state
- Intrastate pollution allowance trading will be allowed, but interstate trading limited
 - No carry over of existing SO₂ allowances
 - Annual and Seasonal NO_x allowances may be re-distributed to the states under new rule
- EPA Mercury Rule is Pending

Outline

U.S. Emission Regulations

Dry Scrubbers

1. Circulating Dry Scrubber Features
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-

Summary

Dry Scrubbers

TYPES

- ▶ Spray Dryer Absorber (SDA)

- ▶ Circulating Dry Scrubber (CDS)

 - Flash Dryer Absorber (FDA)

 - SDA uses a lime slurry reagent

 - CDS & FDA use dry hydrated lime reagent either delivered or produced on site

Scrubbers

Dry Scrubber Historical Background

First Generation: Spray Dryer Absorber (SDA)

- **Developed as an SO₂ control process**
- **Utilizes a slurry of lime**
- **Atomizing with dual fluid nozzles or rotary atomizer**
- **Became an alternative to wet scrubbers in the 70's and 80's**

Dry Scrubbers

Second Generation: Circulating Dry Scrubber (CDS)

- Developed during late 80's early 90's
- High recycle of solids
- Dry hydrated lime instead of a slurry
- Water sprayed into the system

Principle difference to 1st generation:

Water on solids vs. solids in water

Dry Scrubbers

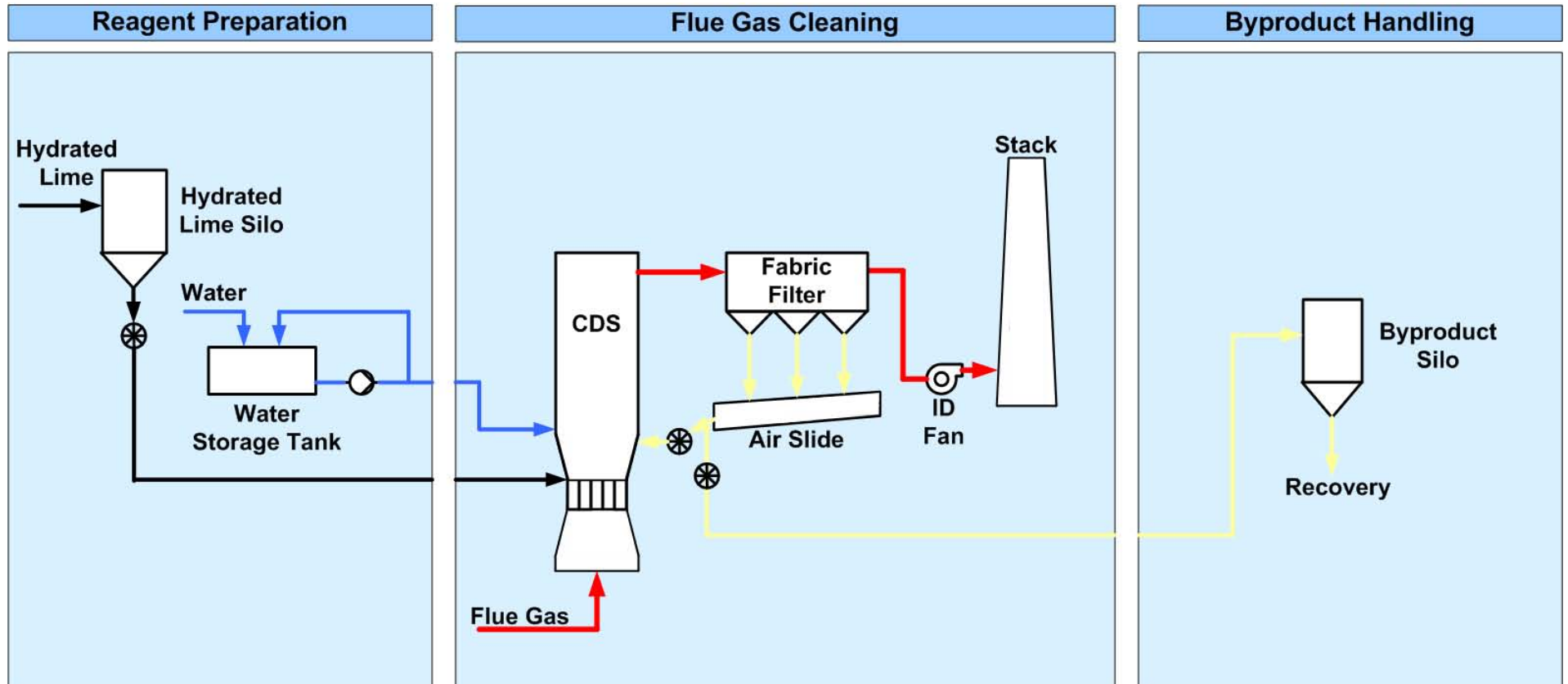
CIRCULATING DRY SCRUBBERS

Applied to:

- Waste Incineration
 - Coal Fired Power Stations from 30 to 300 MW
(Single reactor units)
- CDS removes greater than 95% of the SO_2 , SO_3 , HCl, Particulate, and Hg in flue gas.

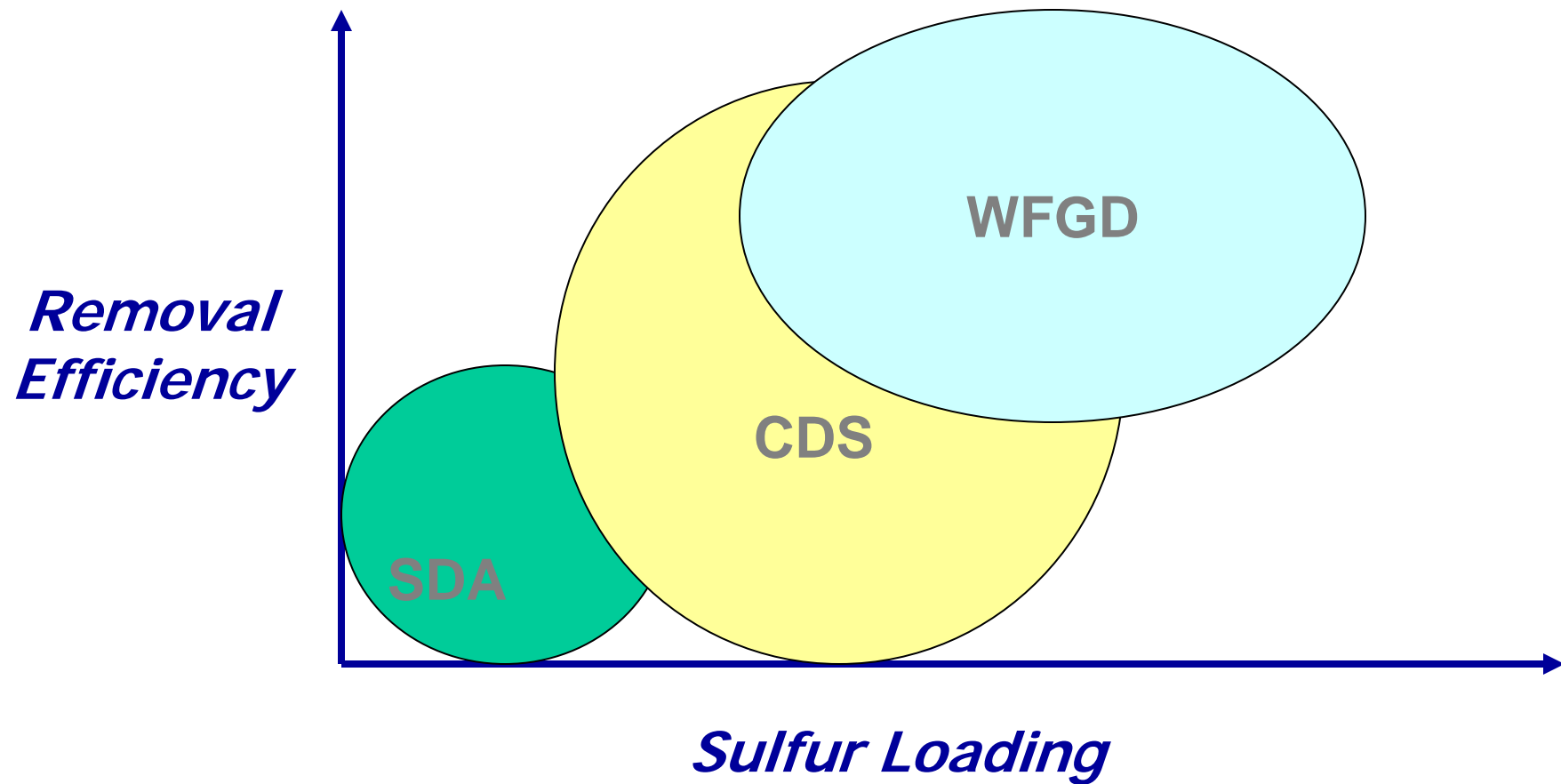
Dry Scrubbers

Circulating Dry Scrubber Process



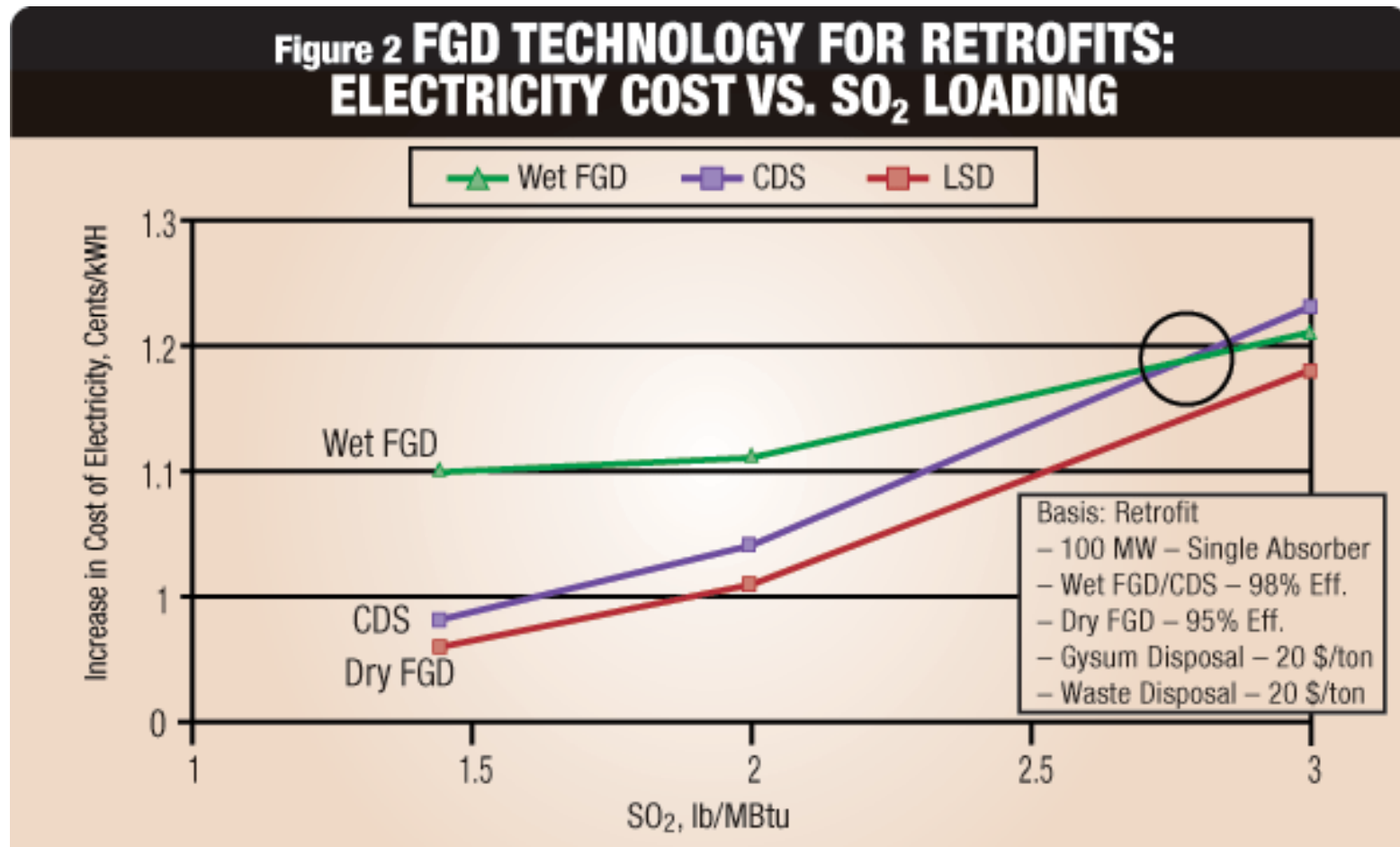
Dry Scrubbers

WET VERSUS DRY



Dry Scrubbers

WET VERSUS DRY (continued)



- Power Engineering
- www.power-eng.com
- November 2007

Outline

U.S. Emission Regulations

Dry Scrubbers

1. Circulating Dry Scrubber Features

2. Process Control

3. Construction

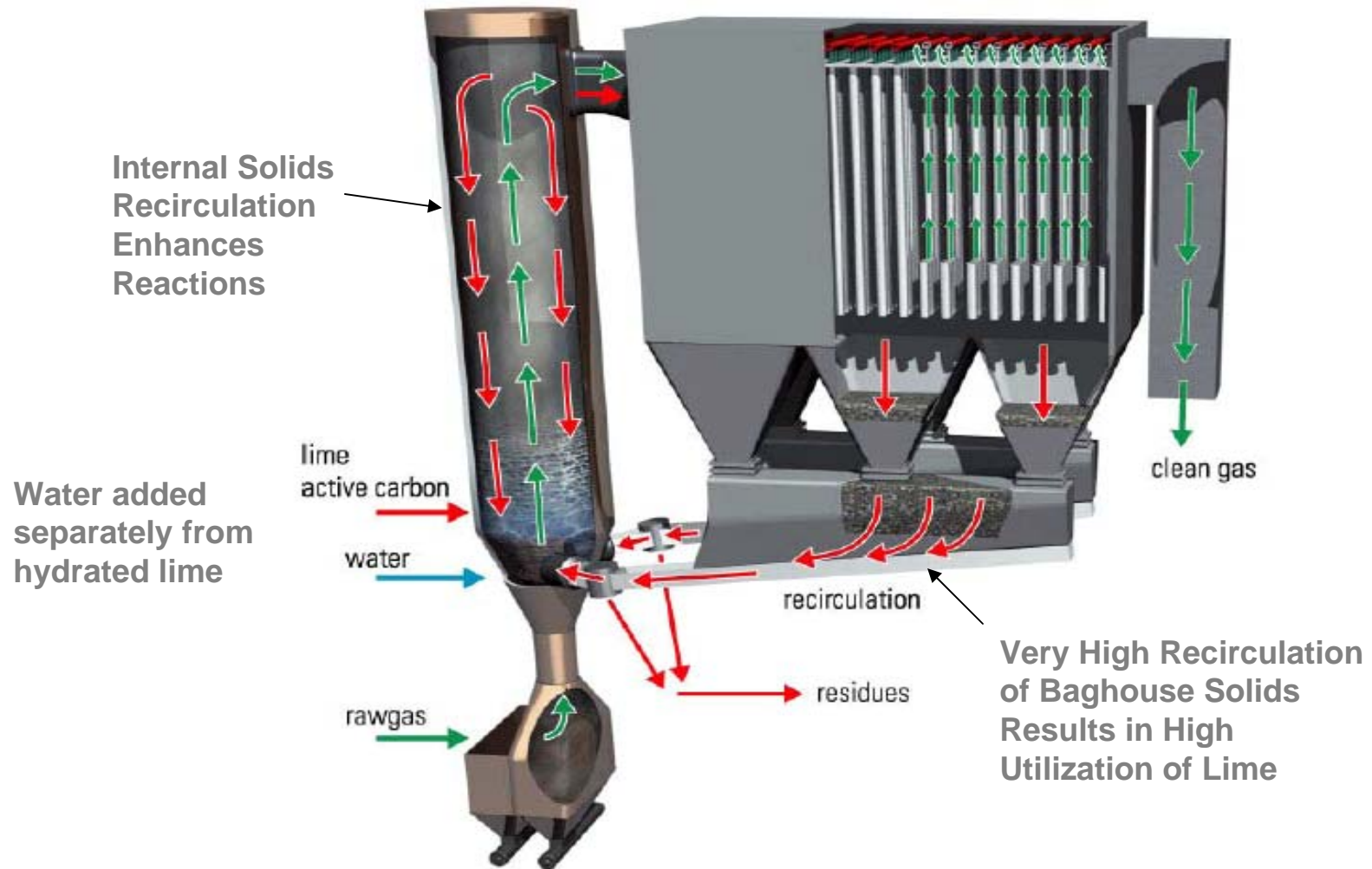
4. Experience

5. Performance

Summary

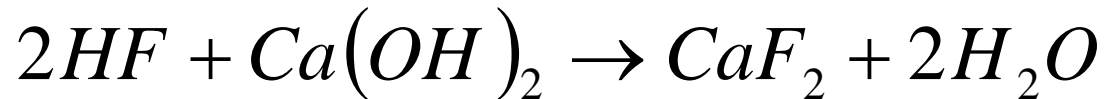
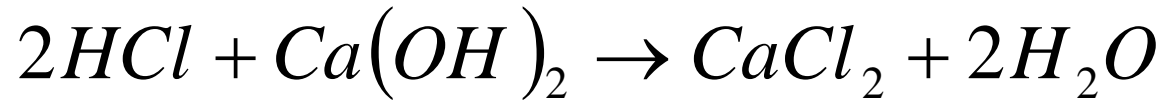
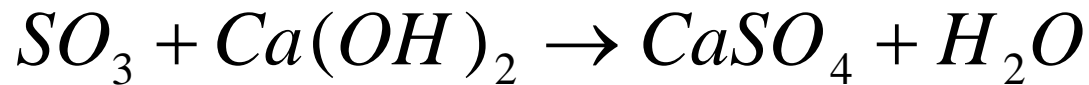
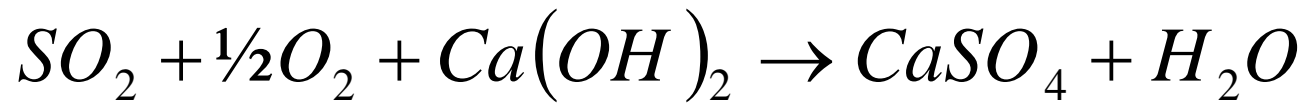
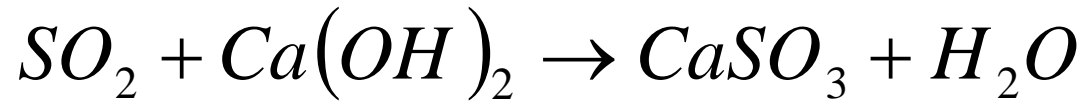
1. Circulating Dry Scrubbers

FEATURES



1. Circulating Dry Scrubbers

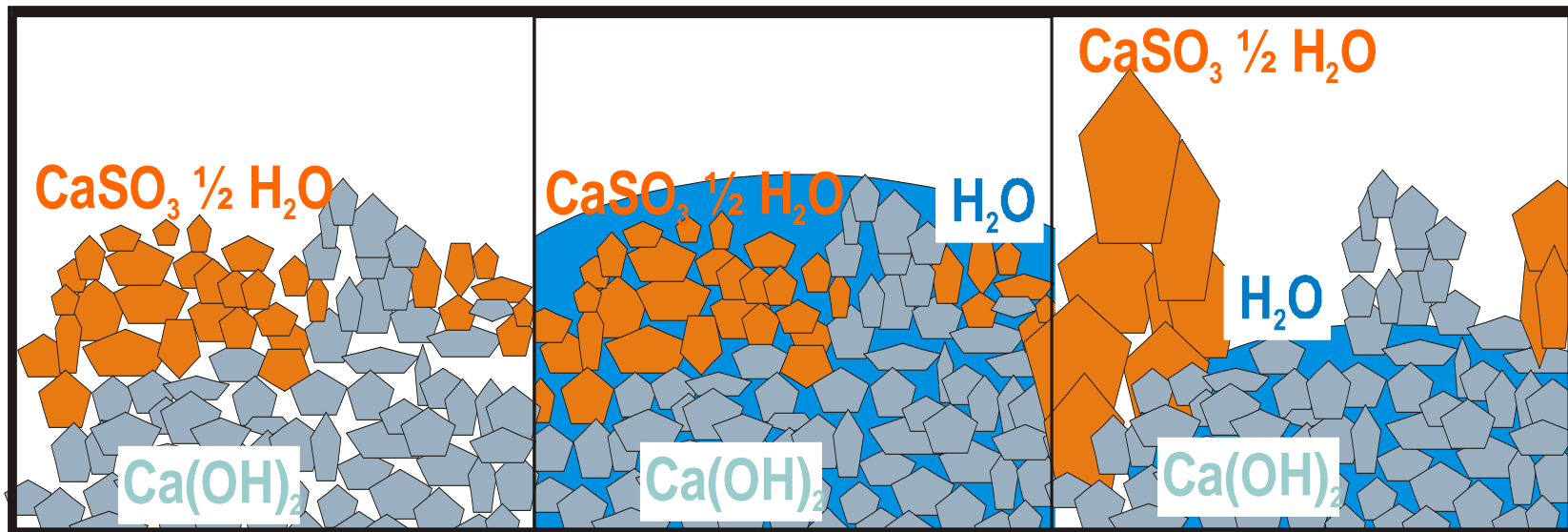
CHEMISTRY



1. Circulating Dry Scrubbers

Reactivation of Reacted Sorbent

Formation of reaction products layer



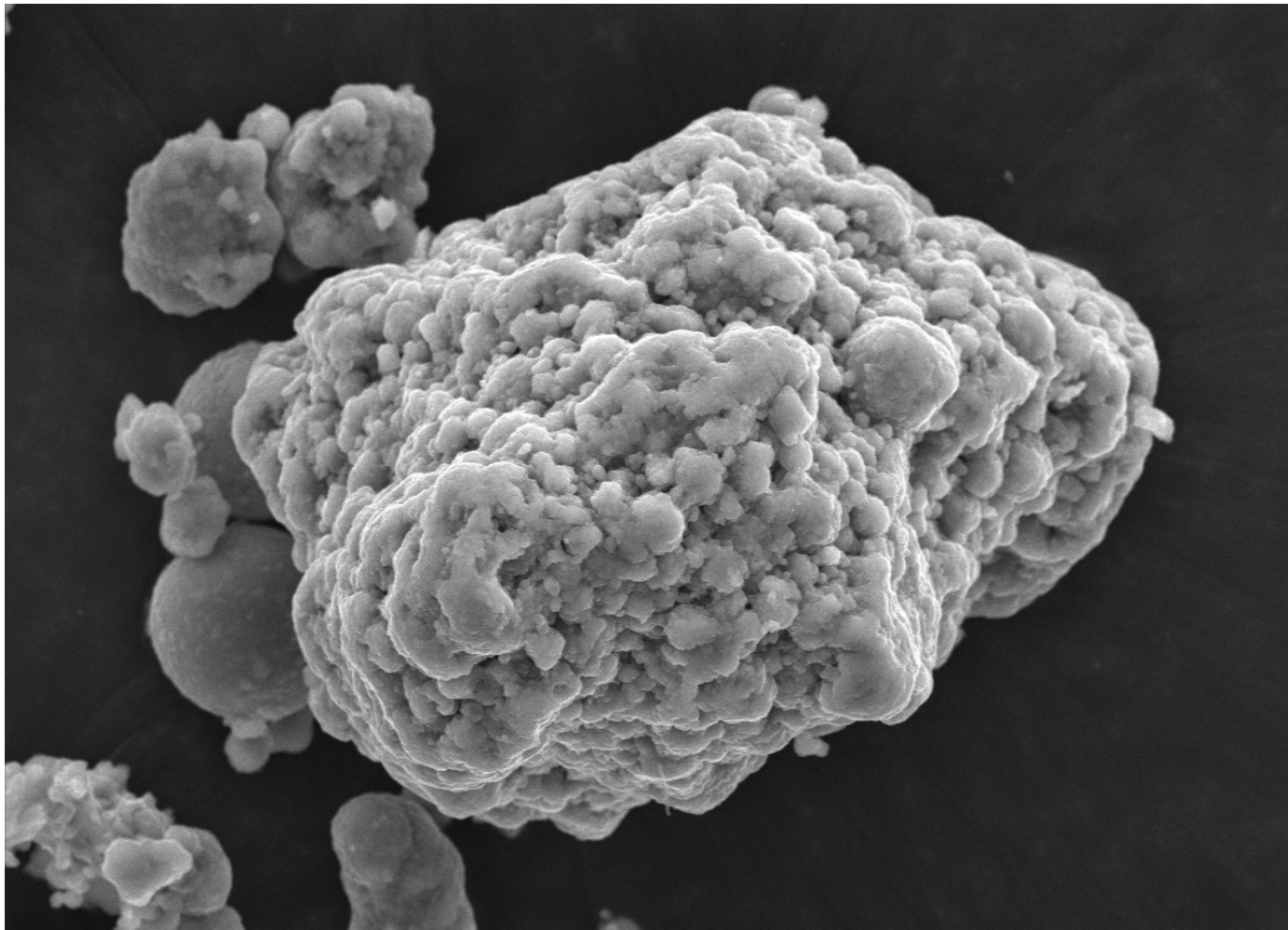
Reaction after first pass

Water added to surface during recirculation

Sulfite crystal forms, exposing fresh surfaces

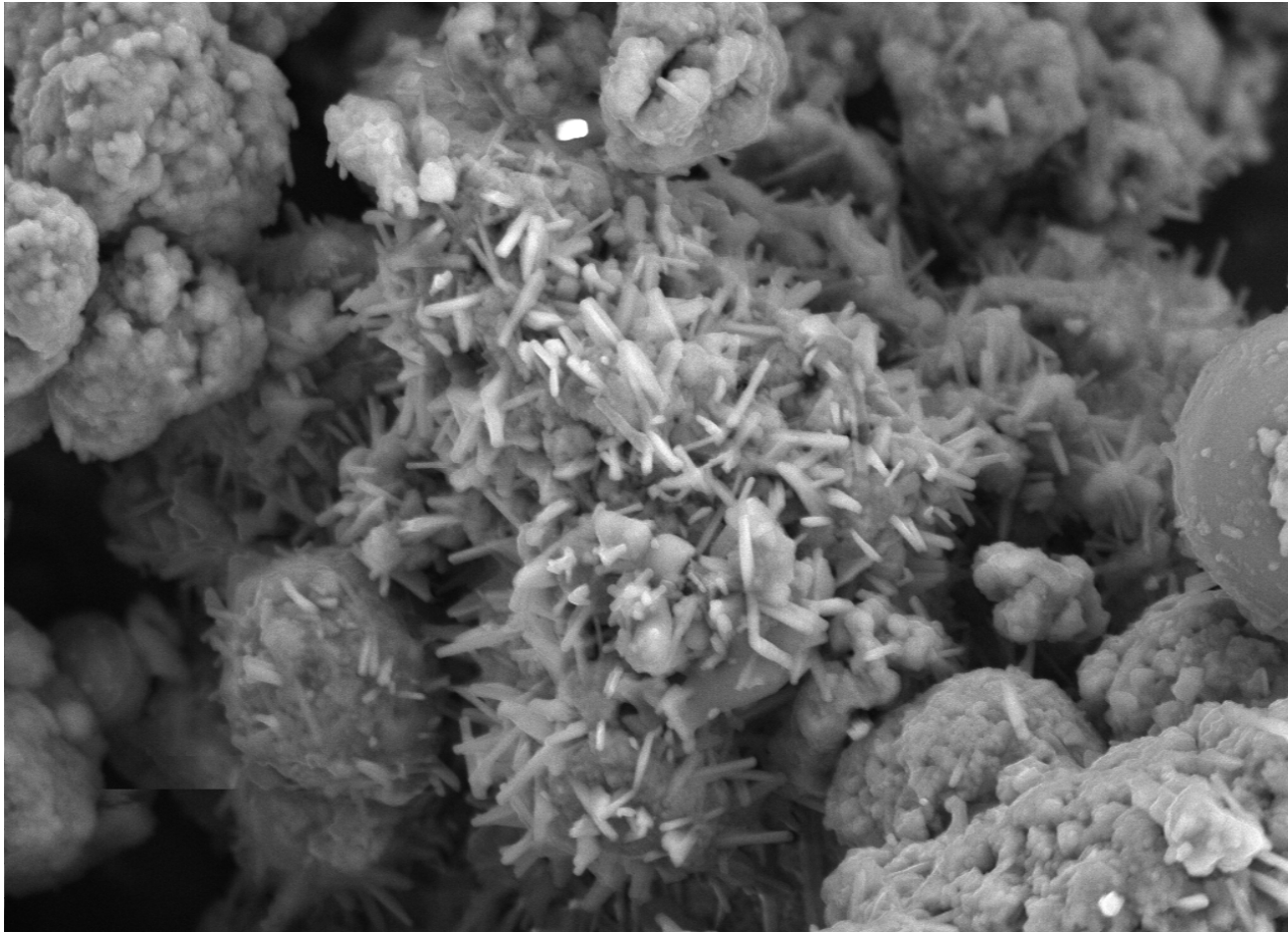
1. Circulating Dry Scrubbers

Electron Microscopy – Product After First Pass



1. Circulating Dry Scrubbers

Electron Microscopy – Re-Crystallization of Product



1. Circulating Dry Scrubbers

- Turbulent Mixing in Reactor
 - Product recycle introduced above venturi
 - High flue gas solid contact
 - Internal reactor solid recirculation
 - Reactor solids rewetting
 - Reverse wall flow reducing sneakage
 - High apparent reactor stoichiometry

1. Circulating Dry Scrubbers

- High solid recirculation from fabric filter
 - Low overall system stoichiometries
 - Multiple exposure and wetting
 - No limit of recirculation due to approach to saturation
 - All dry product handling, no slurries

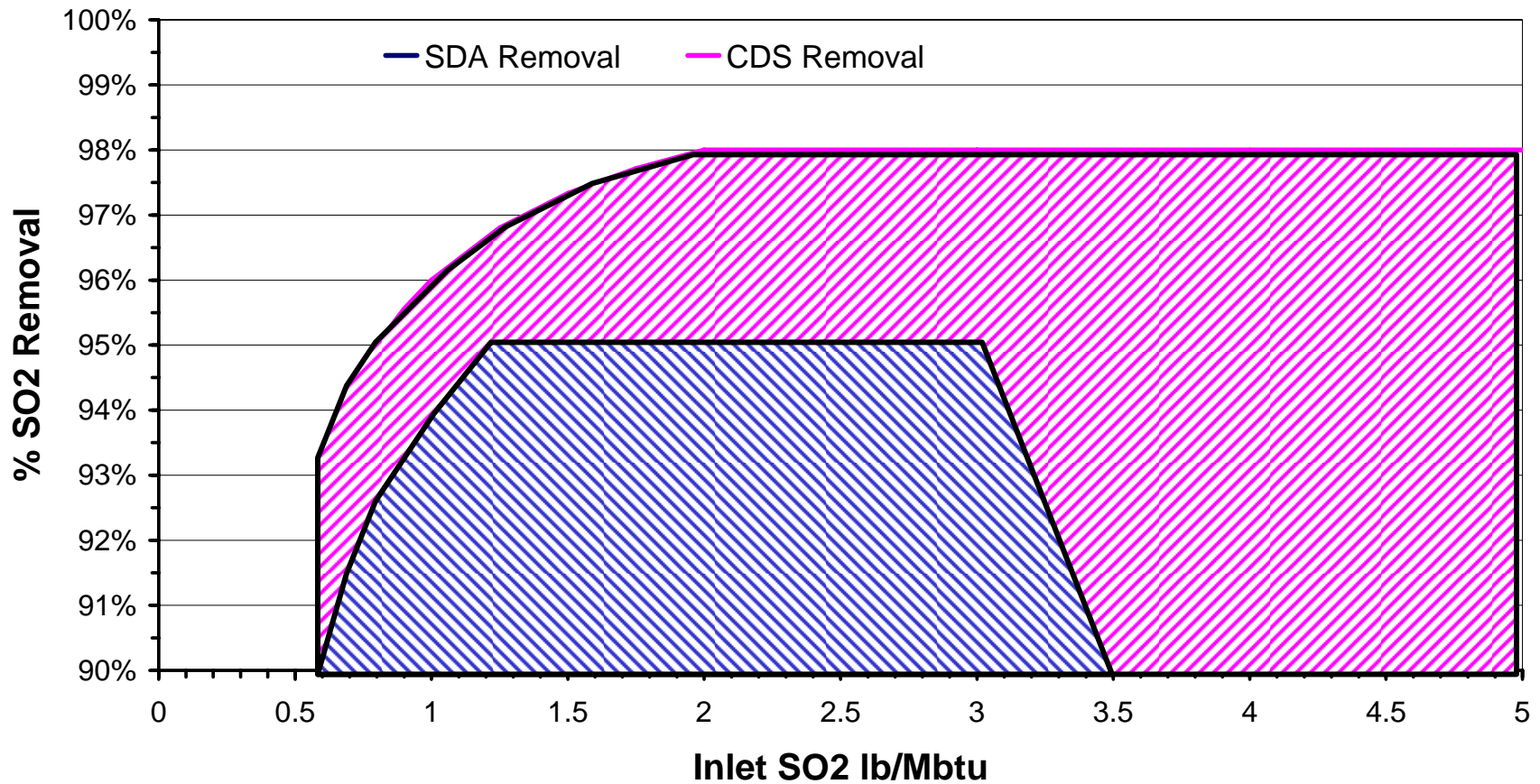
1. Circulating Dry Scrubbers

Process Advantages:

- No slurry handling
- Atomization of water
- Very high solids recycle
 - High solids contact time with gas
 - High sorbent utilization
- Turbulent gas/solids mixing
- Now Applicable to high sulfur fuels
- + 95 % Sulfur Capture
- Lower Power Consumption
- Lower Maintenance Cost

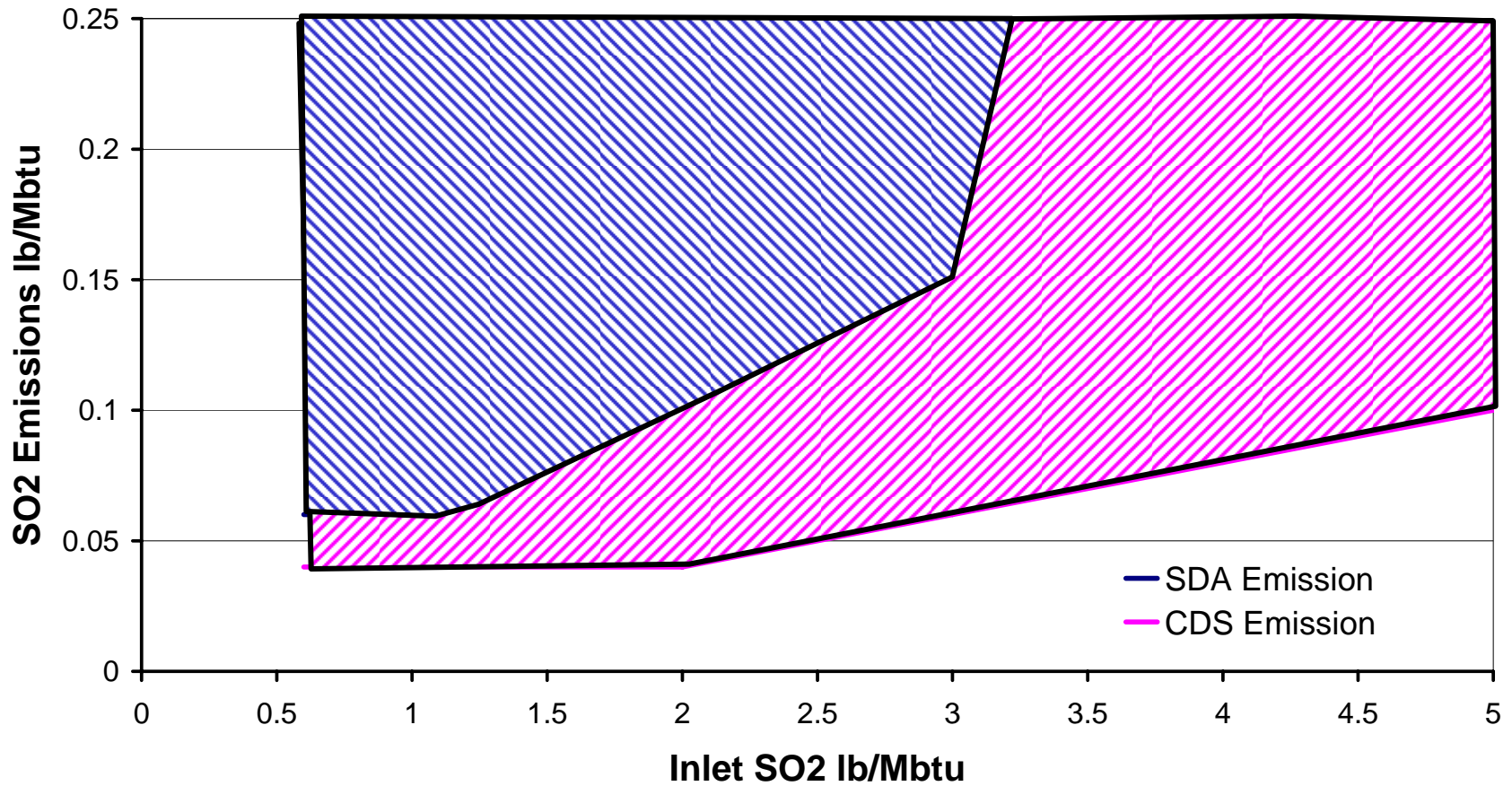
1. Circulating Dry Scrubbers

CDS vs. SDA SO₂ Removal



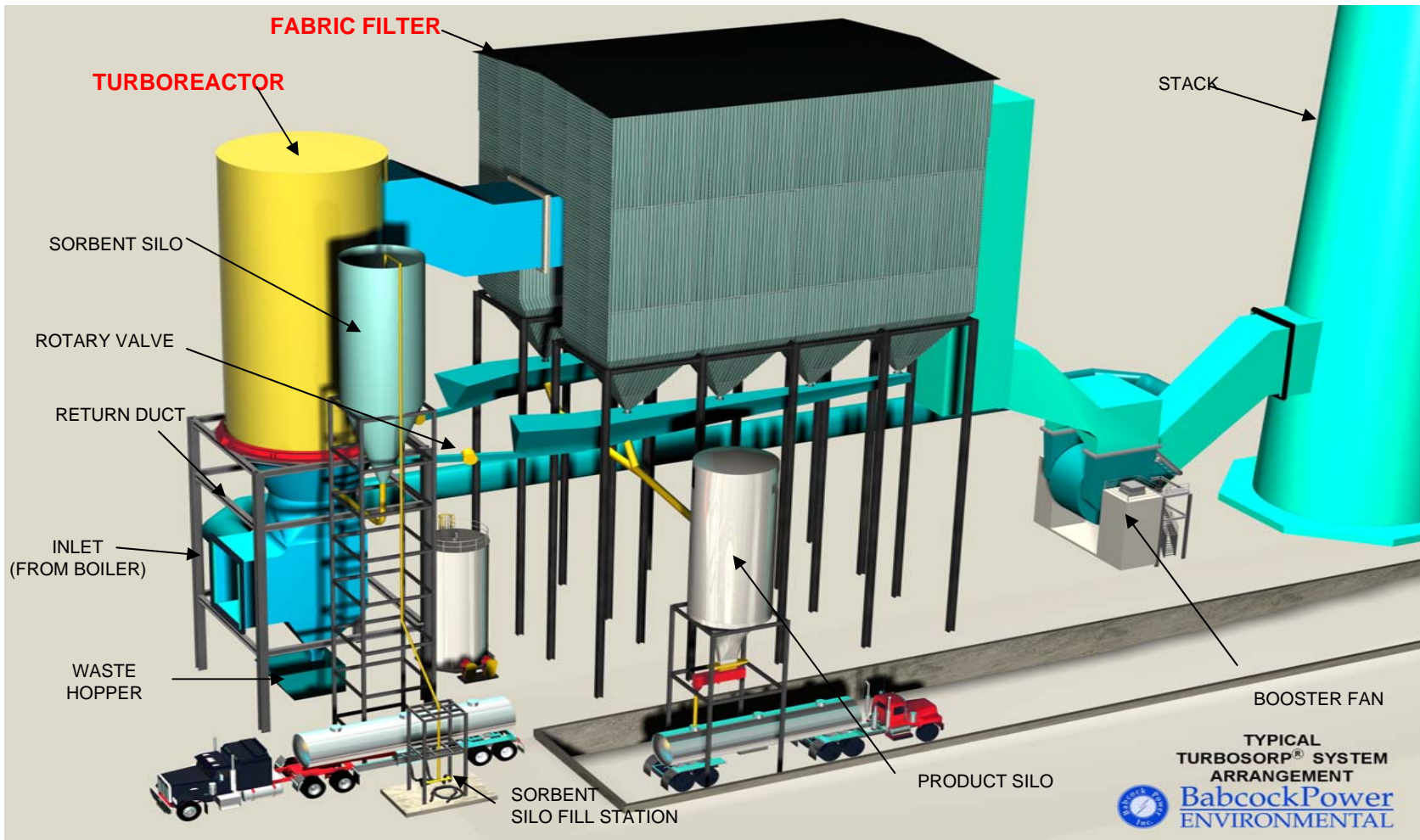
1. Circulating Dry Scrubbers

CDS vs. SDA SO₂ Emissions



1. Circulating Dry Scrubbers

Typical Arrangement



1. Circulating Dry Scrubbers

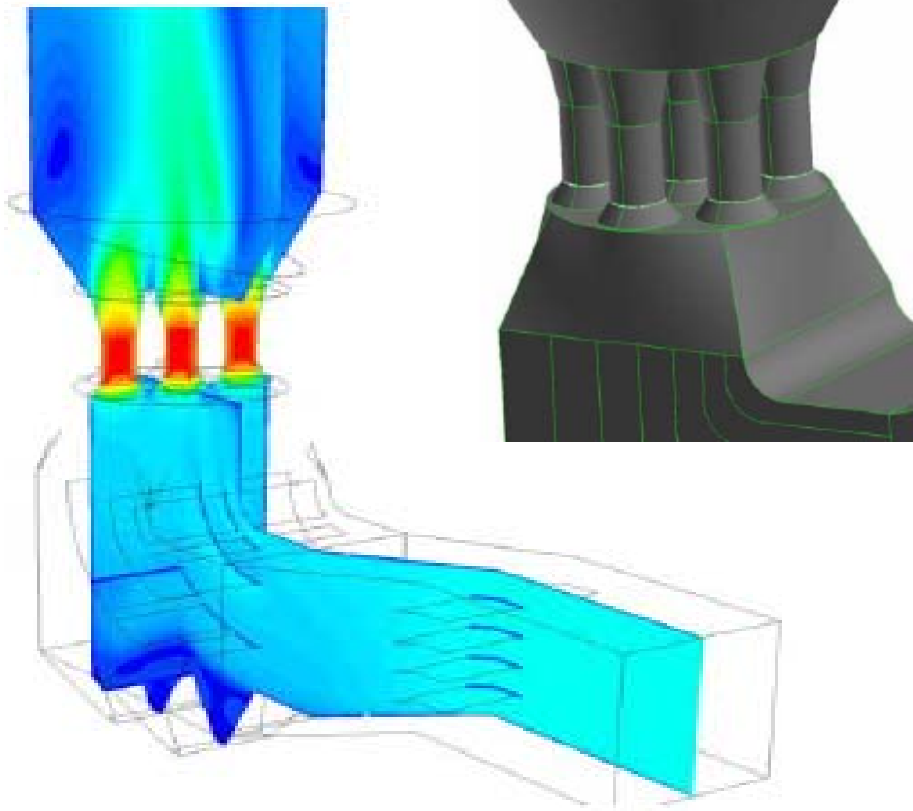
Reactor Design

- Velocity based sizing of main vessel
- CFD modelling; gas, solid and liquid
- Two venturi configurations, 1 and 7
- Turndown based on minimum velocity, recirculation used to control
- Materials, carbon steel

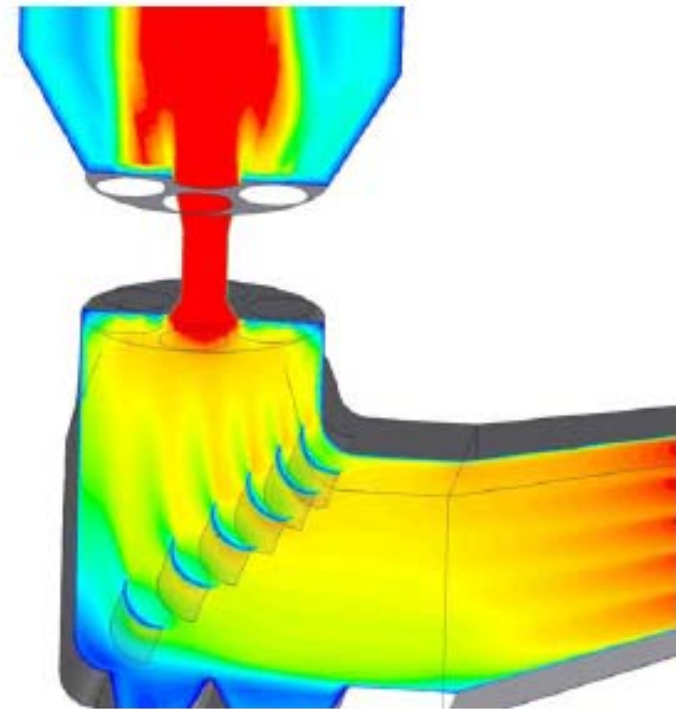
1. Circulating Dry Scrubbers

Computational Fluiddynamic Modeling

Initial



Final



1. Circulating Dry Scrubbers

Physical Flow Modeling



1. Circulating Dry Scrubbers

Fabric Filter Types



High Pressure Low
Volume Pulse Jet

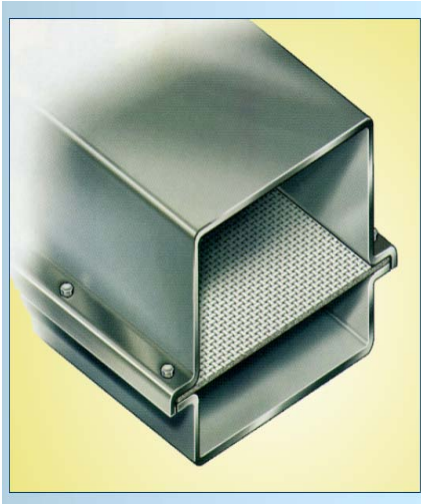


Low Pressure High
Volume Pulse Jet

3:1 Air to Cloth Ratio

1. Circulating Dry Scrubbers

Air Slide & Dosage Roller



- 7° slope



Solids fluidized with 5 psig blowers

Air Cloth
Polyester Fabric w/ 1/16" wire mesh overlay

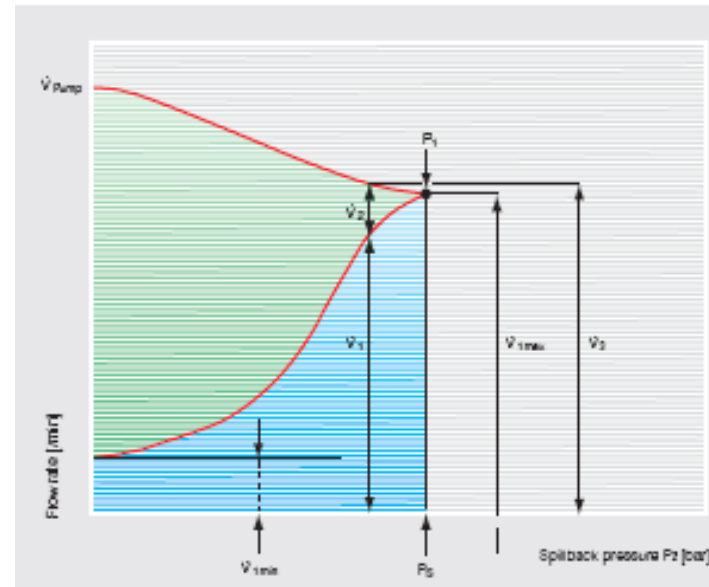
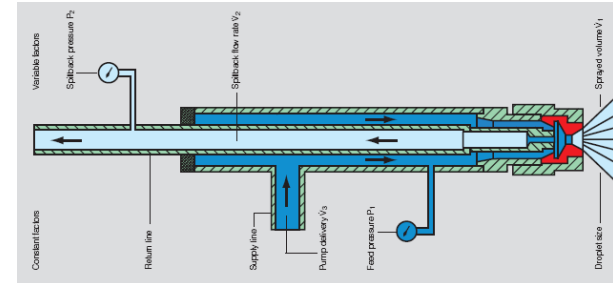
1. Circulating Dry Scrubbers

Water Injection System

Spill-back nozzle

550 psig

250 micron droplets

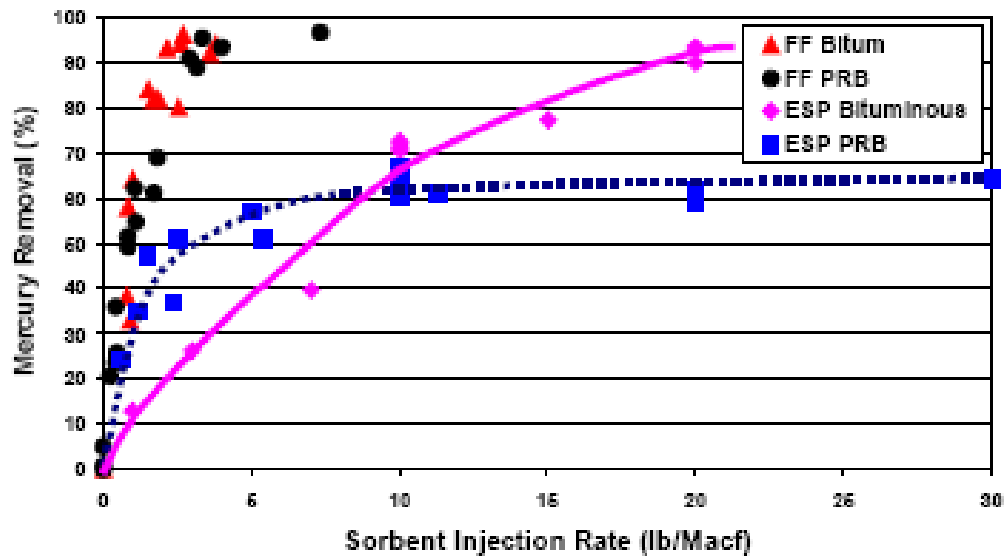


- \dot{V}_1 = Sprayed volume
 - \dot{V}_{1max} = Max. sprayed volume (return line closed)
 - \dot{V}_{1min} = Min. sprayed volume (return line completely open)
 - \dot{V}_2 = Spillback flow rate
 - \dot{V}_3 = Pump delivery
 - \dot{V}_{pump} = Pump delivery per nozzle
 - P_1 = Constant feed pressure
 - P_2 = Spillback pressure
 - P_3 = Spillback pressure at \dot{V}_{1max} (P_{max} for control valve)
- Turn down ratio = $\dot{V}_{1max} / \dot{V}_{1min}$

1. Circulating Dry Scrubbers

Powdered Activated Carbon System for Enhanced Mercury Removal

Figure 2. Mercury Removal with Activated Carbon Injected Upstream of a Fabric Filter



Results Of Activated Carbon Injection For Mercury Control
Upstream Of A COHPAC Fabric
C. Bustard, 2003



Outline

U. S. Emission Regulations

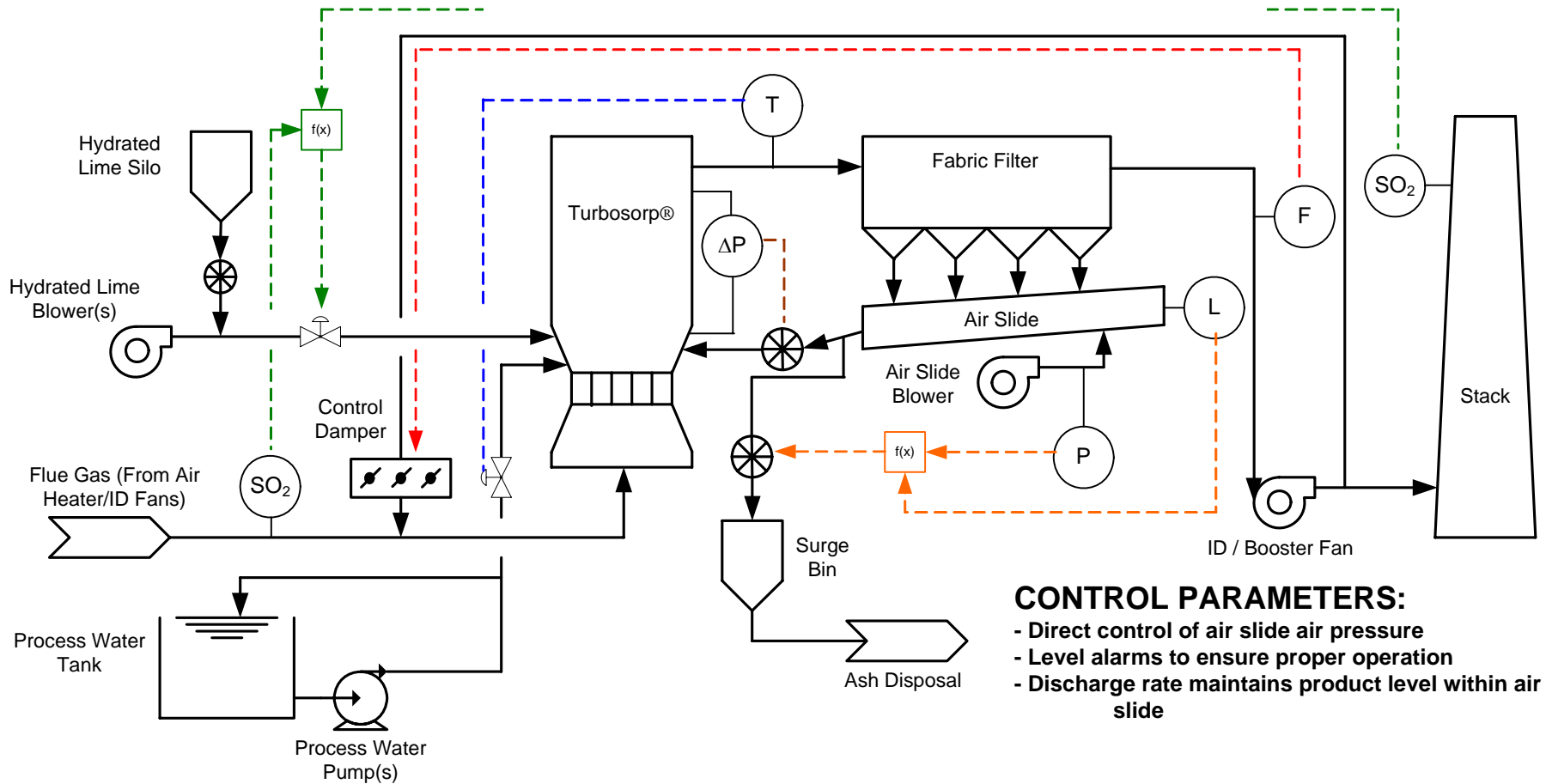
Dry Scrubbers

1. Circulating Dry Scrubber Features
 - 2. Process Control**
 - **Five Control Loops**
 - **Startup, Operation, Shutdown**
 3. Construction
 4. Experience
 5. Performance
-

Summary

2. Process Control

PRODUCT DISCHARGE / AIR SLIDE LEVEL CONTROL LOOP



CONTROL PARAMETERS:

- Direct control of air slide air pressure
- Level alarms to ensure proper operation
- Discharge rate maintains product level within air slide

2. Process Control

Five Process Control Loops

- Outlet temperature (approach) - water
- SO₂ removal or outlet emission - lime
- Reactor bed density – product recycle
- Air slide product level – product rejection
- Minimum velocity (turndown) – flue gas

2. Process Control

Startup Preconditions

- Preheat Fabric Filter and Air Slide Hoppers
- Fill Process Water Tank
- Fill Hydrated Lime Silo
- Start Booster Fan(s)
- Start Fabric Filter Cleaning
- First Start or New Bags:
 Inject Lime to Precoat Bags

2. Process Control

Startup

Cold Start ← Air Slides Empty

Warm Start ← Air Slides Full

- 1) Start Injecting Hydrated Lime at 100% to Fill Air Slides (Cold Start Only)
- 2) Start Boiler
- 3) Start Turbosorp to Remove SO₂ and Acid Gases
 - o Start Recirculating Product in Auto
 - o Start Injecting Water in Auto
 - o (Start) Hydrated Lime in Auto
 - o Product Removal in Auto

2. Process Control

Shutdown

- 1) Stop Injecting Hydrated Lime
- 2) Stop Injecting Water
- 3) Stop Product Recirculation
- 4) If shutting down < 10 days:
 - o Stop Removing Product (Leave Air Slides Full)If shutting down > 10 days:
 - o Continue Removing Product Until Air Slides Empty
- 5) Stop Fabric Filter Cleaning
- 6) Stop Booster Fan (At Low Boiler Load)

Outline

U.S. Emission Regulations

Dry Scrubbers

1. Circulating Dry Scrubbers Features

2. Process Control

3. Construction

4. Experience

5. Performance

Summary

3. Construction

Construction Optimizing

- Semi-modular baghouse design
- Ductwork large C or box sections
- Semi-modular air slides
- Skid mounted mechanical equipment
 - Water injection
 - Air compressors
 - Transport blowers
- PAC system complete modularized

3. Construction

Construction Optimizing (continued)

- Constructability, planning and review
- Shop fabricated tanks
 - Hydrated lime day bins
 - Ash surge bins
 - Process water tanks
- Semi-modular lime hydrator
- Barge ship ductwork, reactor, etc.

3. Construction

Semi-Modular Baghouse Design



3. Construction

Semi-Modular Baghouse Design (continued)



3. Construction

Process Water - Injection Skid



3. Construction

Semi-Modular Lime Hydrator



3. Construction

Semi-Modular Air Slide



Outline

U.S. Emission Regulations

Dry Scrubbers

1. Circulating Dry Scrubber Features
 2. Process Control
 3. Construction
 - 4. Experience**
 - **European**
 - **Chinese**
 - **US**
 5. Performance
-

Summary

4. Experience

Circulating Dry Scrubbers Suppliers:

- Graf-Wulff
- Allied Environmental
- Babcock Power Environmental
 - Turbosorp© Circulating Dry Scrubber
 - Licensee to Austrian Energy & Environment For North American Coal-Fired Applications

4. Experience

Worldwide Circulating Dry Scrubber Experience

- Systems have been in operation since 1994
- 60 CDS systems in Europe
 - 34 units on coal
- 14 CDS projects in China
- Five Turbosorp© CDS Coal-fired Systems Operating in the U.S.

4. Experience

Turbosorp© CDS Coal-Fired Application Example European Experience Zeltweg Power Station Austria

Design Data

Boiler	130 MW
Fuel	Bituminous Coal
S-Content in Coal	1.3 %
By-Product	Stabilized Product
Volume Flow	333,000 SCFM wet
SO₂ Inlet	785 ppmv
SO₂ Removal	> 90 %
Startup	1994
	(Shutdown since 2001)



4. Experience

Turbosorp© CDS Coal-Fired Application
Example Chinese Experience
Linyi Power Plant, (Shandong, PRC)

Design Data

Boiler	135MW
Flue gas capacity:	400,000 SCFM wet
SO₂ concentration:	1,000 ppmv
SO₂ Removal:	> 90%
Product:	for landfill
Start-up:	2007



4. Experience

Turbosorp© CDS Coal-Fired Application U.S. Experience AES Greenidge Unit # 5

Design Data

Boiler	115 MW
Fuel	Bituminous Coal
S-Content in Coal	2.9%
By-Product	Stabilized Product
Volume Flow	277,800 SCFM wet
SO₂ Inlet	2,100 ppmv
SO₂ Removal	> 95 %
Startup	2006



4. Experience

Turbosorp© CDS Coal-Fired Application U.S. Experience (continued) Roquette Keokuk, Iowa

Design Data

Boiler:	80 MW CFB boiler
Fuel:	Coal+ pet coke
Flue gas capacity:	210,000 SCFM wet
SO₂ concentration:	400 ppmv
SO₂ separation:	> 90%
Sorbent:	Fly ash from CFB boiler
Start-up:	2007



4. Experience

Turbosorp© CDS Coal-Fired Application
U.S. Experience (continued)
AES Westover SCR/CDS System

Design Data

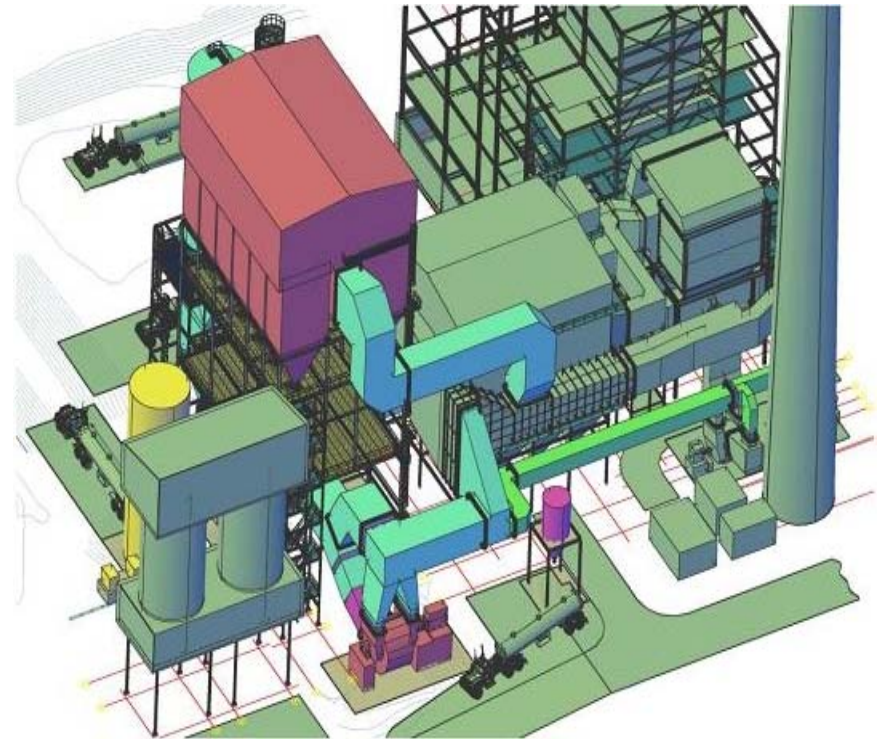
Boiler	87 MW
Fuel	Bituminous Coal
S-Content in Coal	2.2 %
By-Product	Stabilized Product
Volume Flow	240,000 SCFM wet
SO₂ Inlet	1,700 ppmv
SO₂ Removal	> 95 %
Startup	2008

4. Experience

Turbosorp© CDS Coal-Fired Application U.S. Experience (continued) First Light Power Resources – Mount Tom

Design Data

Boiler	155 MW
Fuel	Bituminous Coal
S-Content in Coal	1.5 %
By-Product	Stabilized Product
Volume Flow	452,950 SCFM wet
SO₂ Inlet	1,300 ppmv
SO₂ Removal	> 95 %
Startup	2009

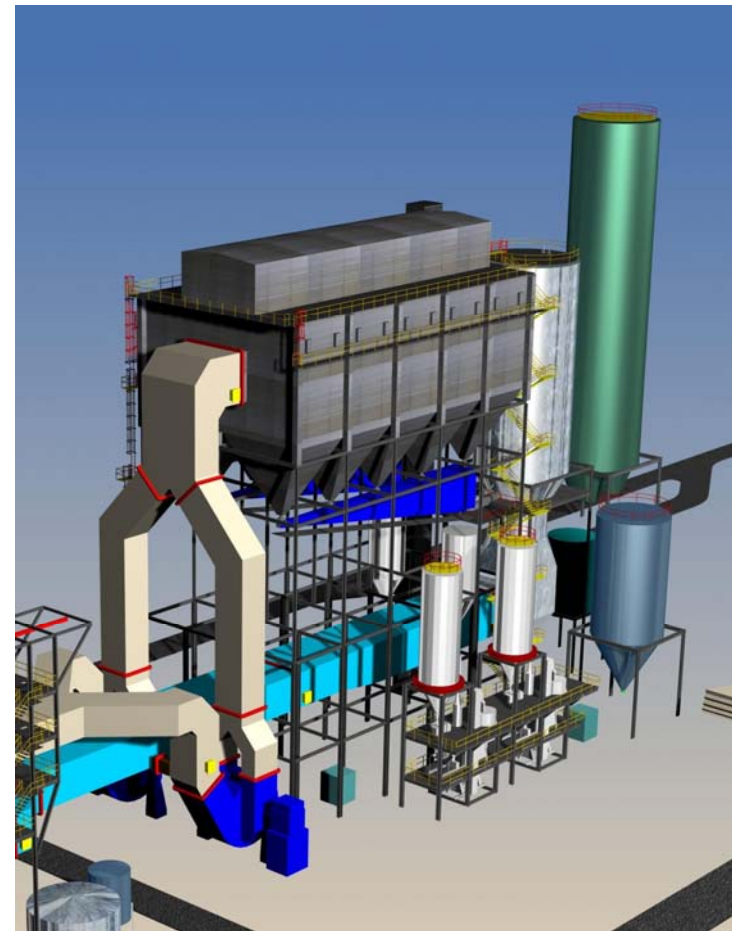


4. Experience

Turbosorp® CDS Coal-Fired Application U.S. Experience (continued) Deerhaven SCR/CDS System

Design Data

Boiler	238 MW
Fuel	Bituminous Coal
S-Content in Coal	1.5 %
By-Product	Stabilized Product
Volume Flow	584,600 SCFM
SO₂ Inlet	1,450 ppmv
SO₂ Removal	> 95 %
Startup	2009



Outline

U.S. Emission Regulations

Dry Scrubbers

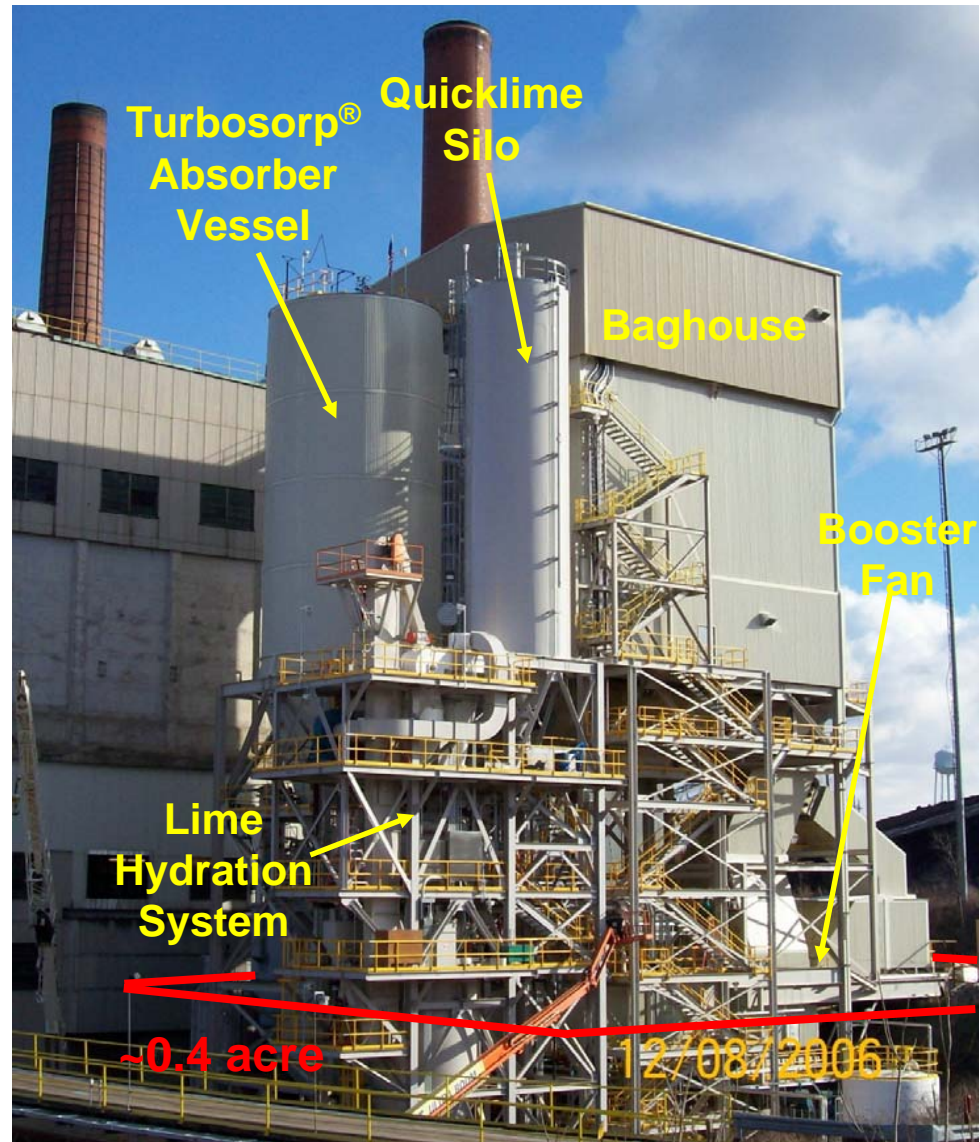
1. Circulating Dry Scrubber Features
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-

Summary

5. Performance

AES Greenidge Performance Data

- Acceptance test:
March 28 – 30, 2007
- Independent third party
testing – Consol
- All Turbosorp® CDS
guarantees met



5. Performance

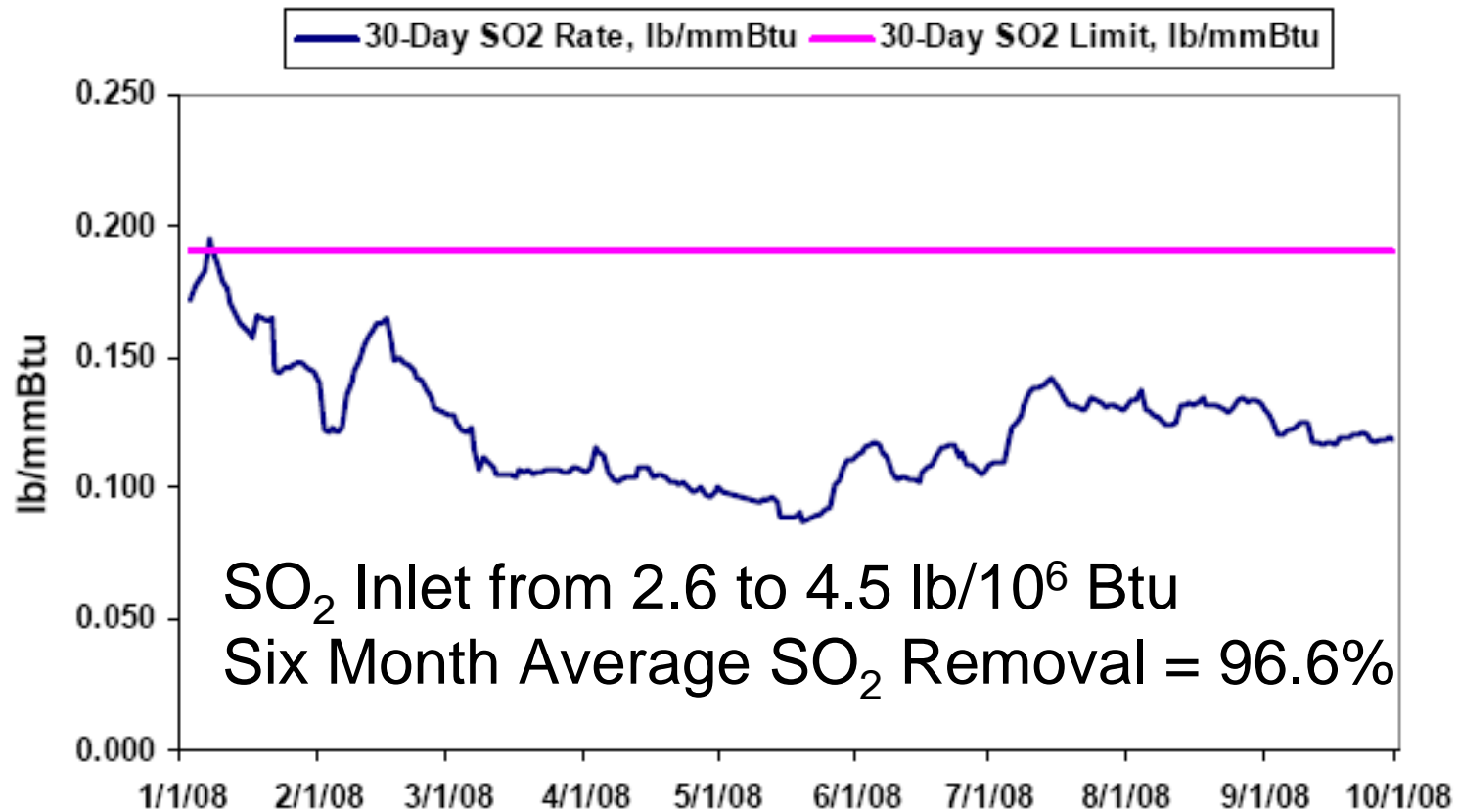
AES Greenidge SO₂ Removal

- Three test runs
- Inlet SO₂, 3.61 lb/MBtu
- Outlet SO₂, 0.146 CEMS lb/MBtu
- Removal 96%
- Guarantee 95% with 4.04 lb/MBtu

**Greenidge Multi-Pollutant Control Project Final Report
DOE DE-FC26-06NT41426 April 2009**

5. Performance

AES Greendige SO₂ Removal (cont'd)



Greenidge Multi-Pollutant Control Project Final Report
DOE DE-FC26-06NT41426 April 2009

5. Performance

AES Greenidge SO₃ Removal

- Inlet SO₃, 14 ppm average
 - Stack SO₃, 0.7 ppm average
- } 95% Removal
- Removal 95% to 98%
for inlet SO₃ > 10 ppm
 - Guarantee 95% with
4.04 lb SO₂/10⁶Btu coal

**Greenidge Multi-Pollutant Control Project Final Report
DOE DE-FC26-06NT41426 April 2009**

5. Performance

AES Greenidge HCl Removal

- Inlet HCl, 38.4 ppm average
 - Stack HCl, 1.3 ppm average
- } 96.6%
Removal
- 96% Average Removal
 - Guarantee 95%

Greenidge Multi-Pollutant Control Project Final Report
DOE DE-FC26-06NT41426 April 2009

5. Performance

AES Greenidge Performance Data

- HF Removal
 - Inlet below detection limit
 - Stack below detection limit
- Particulate Emission
 - Average test emission 0.0017 lb/10⁶Btu
 - Guarantee: 0.015 lb/10⁶Btu

**Greenidge Multi-Pollutant Control Project Final Report
DOE DE-FC26-06NT41426 April 2009**

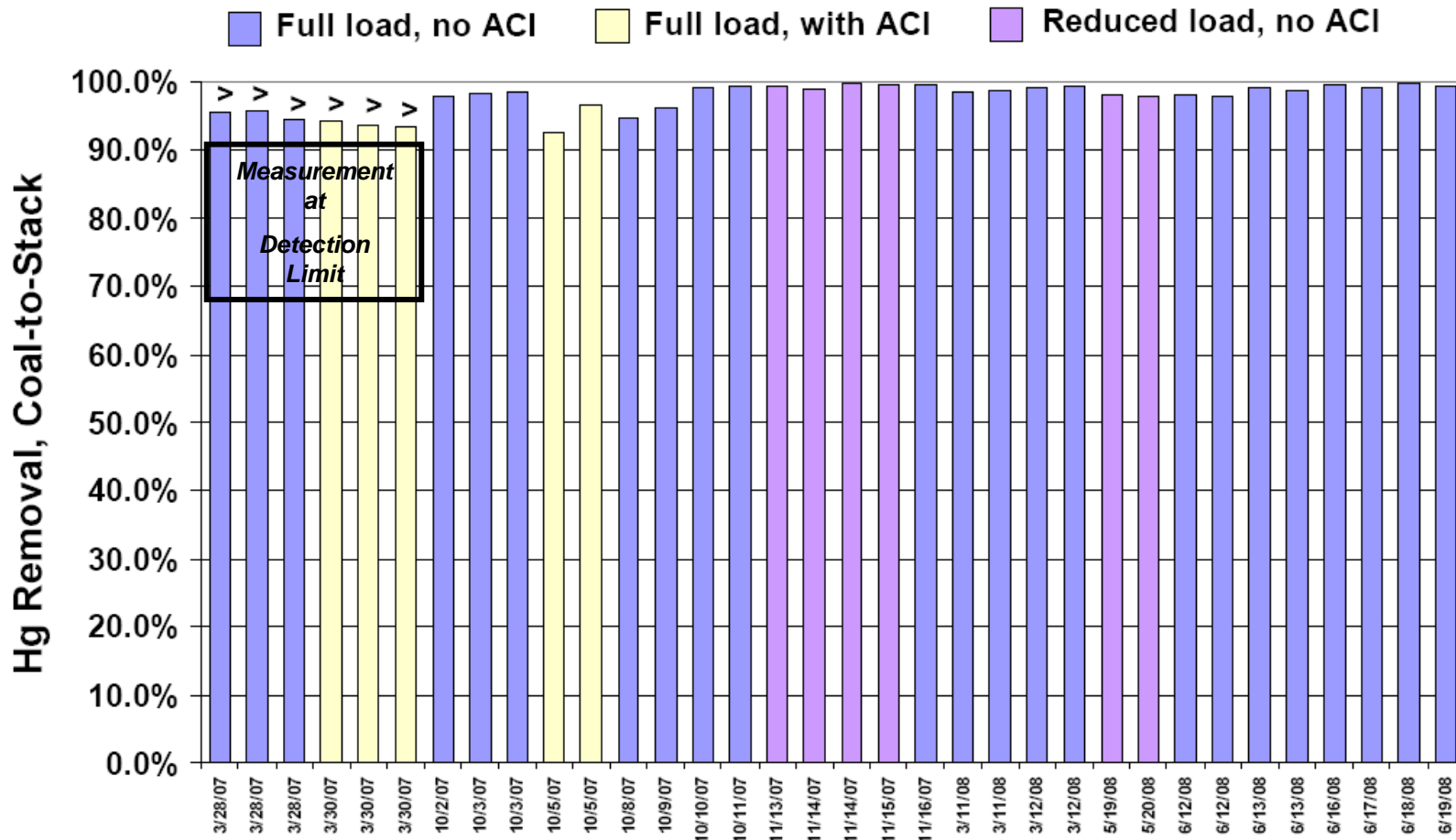
5. Performance

AES Greenidge Performance Data

- Lime Consumption
 - Guarantee 8,410 lb/hr
 - Test conditions 8,169 lb/hr
- Pressure Loss
 - Guarantee 17.3 iwc
 - Test conditions 16.1 iwc

5. Performance

AES Greenidge Mercury Removal Efficiency



Greenidge Multi-Pollutant Control Project Final Report
 DOE DE-FC26-06NT41426 April 2009

5. Performance

Turbosorp© CDS for a 87 MW boiler

- Exceeded 95% SO₂ Removal Guarantee for 3.3 lb/SO₂ coal
- Lime Consumption Below Guarantee
- Pressure Drop Below Guarantee
- Particulate Emission at 0.0023 lb/MMBtu Well Below 0.015 lb/MMBtu Guarantee
- Inlet SO₃ very low during test less than 1 ppm at stack (below guarantee)
- HCl: 98.8% removal
- HF below detection limits
- Opacity below 5%

5. Performance

Turbosorp© CDS for a 150 MW Boiler

- 96.8% SO₂ Removal for 2.1 lb SO₂/10⁶ Btu coal
- Lime Consumption Below Guarantee
- Pressure Drop and Power Consumption Below Guarantees
- Particulate Emission Well Below Guarantee
- Inlet SO₃ very low during test
- 96.7% Hg Removal without PAC injection

Outline

U.S. Emission Regulations

Dry Scrubbers

1. Circulating Dry Scrubber Features
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-

Summary

Summary

- CATR Driving Scrubber Retrofits
- Dry Scrubbers: SDA, CDS, FDA
 - SDA 1st Generation
Atomized Lime Slurry
 - CDS
Hydrated Lime + Water Injected Separately
High Recirculation Rate
- CDS Compared to SDA
 - No slurry handling
 - Higher solids recycle
 - Higher sulfur removal for higher sulfur fuels
 - Able to operate at lower approach temperature
 - Lower power consumption
 - Lower maintenance

Summary

- Turbosorp© CDS
 - AEE Licensor
 - Venturi (Single or Seven)
 - Turbulent Mixing and High Recirculation
 - Reactivation of Sorbent
 - Five Process Control Loops
 - Simple Startup and Shutdown
 - Modular Construction
 - > 20 Waste-to-Energy Systems
 - Thirteen Coal-Fired Systems (50 to 240 MW)
 - SO₂ removal up to 97%
 - Removes SO₃, HCl, HF, and Hg

Summary

- Performance
 - Exceeded SO₂ removal and below lime consumption guarantees
 - Exceeded SO₃ removal
 - Exceeded HCl removal
 - HF below detection limit
 - Below Pressure Drop & Power Consumption Guarantees
 - Well Below Particulate Emission Guarantee
 - High Mercury Removal with or without activated carbon injection

Summary

CDS Emissions Summary

	<u>Typical</u>
SO ₂	95 – 98 %
SO ₃	95 – 99 %
HCl	95 – 99 %
HF	95 – 99 %
Mercury	90 – 95 %
Coals up to 5 lbs SO ₂ /10 ⁶ Btu	

Thank you

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