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Using Dry Sorbent Injection to Meet the Utility MACT

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Overview

- Regulatory
- Options for Dry Sorbent Injection
- SO_3 and HCl removal rate examples
- Material Handling

Regulatory Reasons for Acid Gas Mitigation (Pre-MACT)

- Offset additional SO_3 generated from SCR installation

- Control blue plume at stack from Wet FGD addition
  - Appearance
  - Local concerns

Regulatory
Acid Gas Mitigation Outlook

- Consent decree on Acid gases
  - Specified amount at the stack
    - Limitations of Method 8A
- Particulate
  - 0.030 lb/MM Btu (filterable and condensable)
- HCl as acid gas surrogate
  - 0.002 lb/mmBTU (~3ppm)
- Consistency and OST of mitigation system will be critical

Regulatory
Options to meet requirements

- Fuel switch
- Equipment additions
  - Wet ESPs
- Dry scrubber
  - Unit size
  - Fuel

Dry Sorbent Injection

Many will opt for some form of alkaline injection to neutralize the acid gases

Regulatory
Most commonly selected options for DSI

- Hydrated lime
  - High BET surface area (> 20 m^2/g)
  - Fine particle size (D_{50} of 2-4 microns)

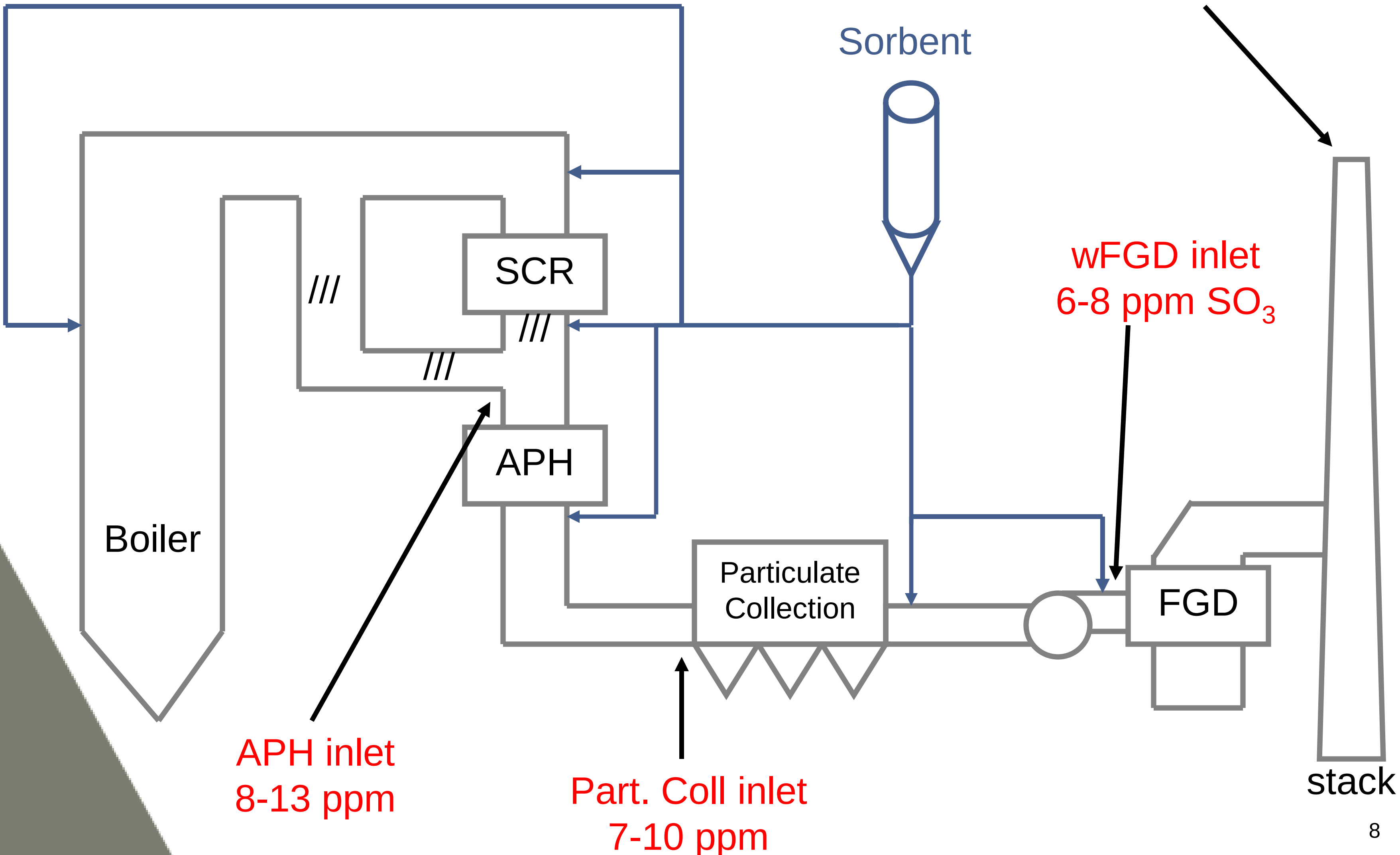
- Trona
  - Larger particle size (40-60 microns)
    - On site milling to 15-25 microns

Questions to answer

- Where are you and where do you have to get with pollutants?
  - Potential side benefits of acid gas mitigation
- What will your injection system look like?
  - Expectations on Operations and Maintenance
- Implications of sorbent choice
  - Supply
  - Logistics
  - Ash

Removal - Consider working your way backwards
Example for SO_3 mitigation

Stack limit: 5 ppm maximum

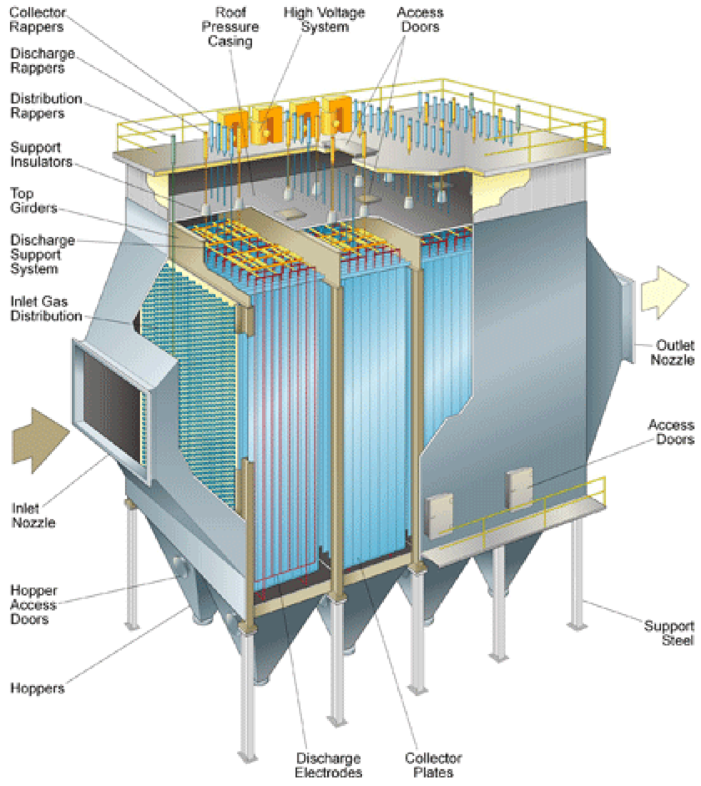


Removal
Consider additional benefits of early removal

- Pre-SCR
  - Minimum operating temperature
  - Reduce arsenic poisoning of catalyst (calcium)
- Pre-APH
  - Corrosion protection
  - ABS control
  - Heat rate
- Particulate collection
  - Corrosion
  - Operational
- Wet FGD
  - Corrosion
  - Effects of HCl on scrubber and wastewater treatment

ESPs - *"It depends…"*

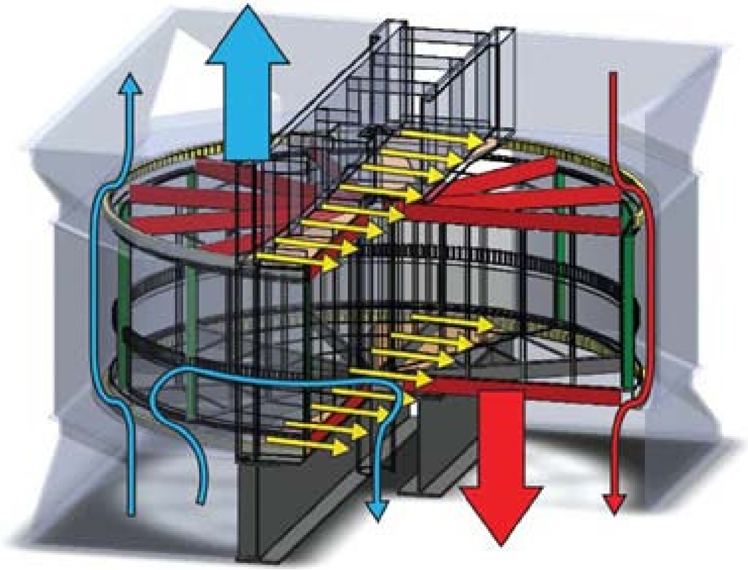
- Some SO_3 aids resistivity of ash
- Ash resistivity
  - Sodium reduces; Calcium increases
- Unit specific issues
  - Existing ash properties
  - ESP size and efficiency
    - Particulate loading with added sorbent
  - Residence time
    - Short -> more sorbent
      - Manage with split injection?
  - Best to test



Courtesy B&W

- Lodge Cottrell presentation from 2011 APC conference
  - Reinholdenvironmental.com library section

Air Preheater



Courtesy BreenES

Moving sorbent injection up in the process offers additional benefits:

- Better utilization of sorbent
  - Longer reaction time
- APH operation
  - Eliminate ABS buildup from ammonia slip
  - Flexibility on SCR operation
- Lower heat rate
  - Reduce acid dew point through APH

Using Sorbent Prior to APH

- Neutralization of SO_3 will occur at Pre-APH temperatures
- Sodium sorbents:
  - Byproducts and intermediates can form without temperature and concentration control
  - URS reported on Pre-SCR injection of SBS

APH after 8 week trial of PreAPH hydrate injection

- Calcium sorbents
  - No issues with reaction byproducts or intermediates
  - Multiple trials of Pre-APH since ’09
  - Utility – Pre-APH since 2010
    - ➢No issues reported

Hydrated Lime Data
Pre-APH removals from 2009 trial

- Injection of hydrate at SCR outlet
  - 2 sec residence time before first Breen probe (Pre-APH)
  - Post-APH Breen probe
- Took periods of stabilized operation of feed system and boiler
  - Varied from 1-24 hours
  - Averaged data from Breen probes
  - Hydrate feed rates varied
    - Stoich ratios from 3 to 6 mol Ca/mol SO_3
      - Unit load varied as well

Demonstrated Reductions Using In-line Breen Probes

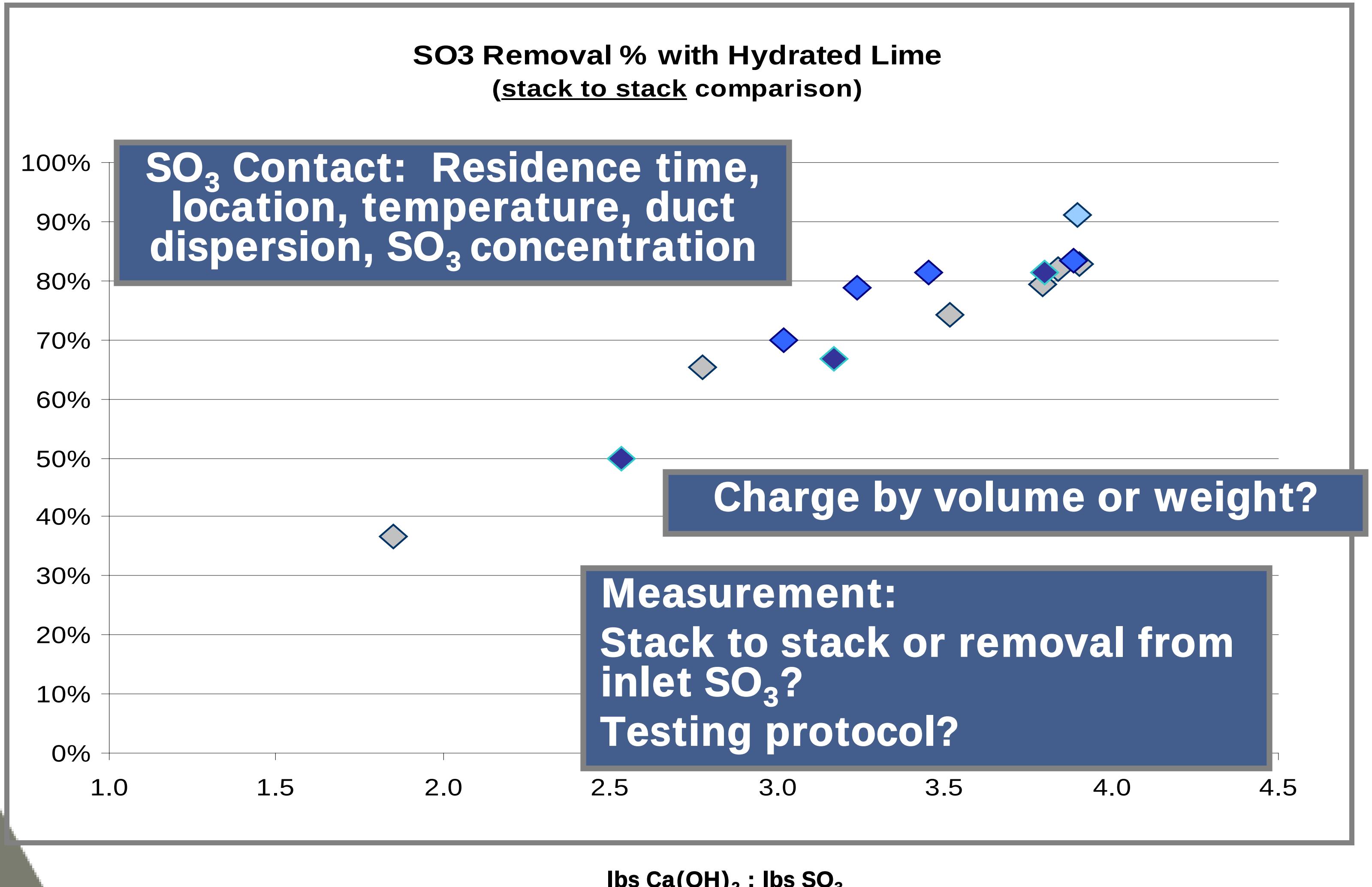
- Good reduction from injection point to Pre-APH measurement point
- In-flight capture results are very good

	SO_3 (ppm)		**% Reduction**		
	Pre-APH	Post-APH	Pre-APH	Thru APH	Overall In-flight
baseline	31.5	22.5	0%	28%	28%
With hydrate treatment	2.7	<1	>90%	<10%	>96%
	2.9	<1	>90%	<10%	>96%
	3.8	<1	>85%	<10%	>96%
	4.4	1.1	>85%	<10%	>96%
	3.2	<1	>90%	<10%	>96%

Removal Rates

Full Scale SO_3 Mitigation with Hydrated Lime

Stack to Stack Removal Rates



SO_3 Mitigation with Hydrated Lime Individual Examples

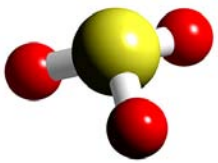
Plant	Location	SO_3 *APH*	SO_3 *Untreated Stack*	*mol Ca: mol SO_3*	*lb Ca: lb SO_3*	Removal *Stack*
550 MW	Pre-Wet FGD	20 ppm	12 ppm	4.2 : 1	3.9 : 1	92%
1300 MW	Pre-ESP	30 ppm	20 ppm	4.2 : 1	3.9 : 1	83%
704 MW 1150 MW	Post-ESP	35 ppm	21 ppm	3.8 : 1	3.5 : 1	83%

Case Study -
High Opacity with pre-ESP injection

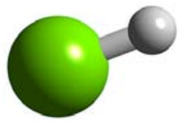
- Cold side ESP not capable of handling of sorbent injection / increased loading
  - Cyclone-fired boiler
    - ESP designed for ~20% fly ash
  - Sorbent injection increases ash by another 5%
    - Overwhelms ESP (since designed for low fly ash loading)
    - Opacity concerns
- Injected hydrated lime post ID fan, *after* the ESP
  - Achieved good removal of SO_3
  - Stack particulate emissions were not negatively affected

Load (MW)	NSR	Stack Particulate (lb/MMBtu)
1039	2.54	x
1030	4.75	0.40x

Baghouse Removal Data



- Midwestern Utility; med-high sulfur coal
- Injection post APH using temporary injection system
- Test runs measured at baghouse outlet



	Content, ppm		**Reduction**	
	SO_3	***HCl***	***SO_3***	***HCl***
baseline inlet	25	24	---	---
baghouse outlet	16	22.5	36%	<10%
lb Ca: lb SO_3				
2.15	4.9	21.9	80%	<10%
2.70	1.4	24.7	94%	<10%
3.24	<1	<1	98%	>98%

Reduced sorbent usages vs ESP

Lower emissions

Baghouse Follow-up Testing Mercury and HCl

- Hg Removal = ~ 40% removal from coal to Particulate Collection outlet (no carbon injection)
  - 3% LOI
  - Baseline (no hydrate injection, 2008): No Hg removal with 10% LOI
- HCl Removal (SCR outlet ~45 ppm Cl)
  - Under typical conditions of 3 – 4 Ca / S ratios, little HCl removal was detected
  - On over-injection conditions (mid-load, high Ca / S ratios), some HCl removal in flight was detected, about 20 – 30 %.
  - Similar to results from a Southern Co. test program at Mercury Research Center

Hydrated Lime for HCl Removal
Trial at Shawnee

Summary from report by Brian Williams (TVA) to PCUG, July 2011

Hydrated Lime Injection Demonstration Goals

- Low Cost HCl Control Desired to Avoid Expediting Scrubber Installation
- Hydrated Lime Injection Testing Program Chartered to:
  - Determine if Hydrated Lime Injection System can Achieve Proposed HAPs HCl Limits
  - Evaluate BOP Impacts on Baghouse and Ash Removal System if Lime Injection Reduces HCl Emissions
  - Evaluate Additional Total Particulate Margin Recovered from Reduced Condensable PM
    - Provides Filterable PM Margin to Allow Maximum Usable Bag Life (current bag life ~ 8 years per unit)
- **CHALLENGING TEST** – The Last Few PPMs Are The Hardest To Remove

Project Overview and Regulatory Drivers

Shawnee Plant Background

- Nine (9) 150-MW wall-fired units equipped with Baghouses
- Currently Burning up to 50% PRB Blended with Low Sulfur Colorado Coal
- Unit 6 Holds National Continuous Run Record of 1,093 days set in 2006

Emission	Proposed HAPs Limit	Shawnee U6-10 Stack Baseline (05/2011)
Total Particulate (lb/MMBTU)	0.03	0.016 Total 0.004 filterable 0.012 condensable
Mercury (lb/TBTU)	1.0	< 0.5
Acid Gas Surrogate - SO_2 **OR** HCl (lb/MMBTU)	0.2 SO_2 **OR** 0.002 HCl	0.63 SO_2 0.003 HCl

Emissions Control

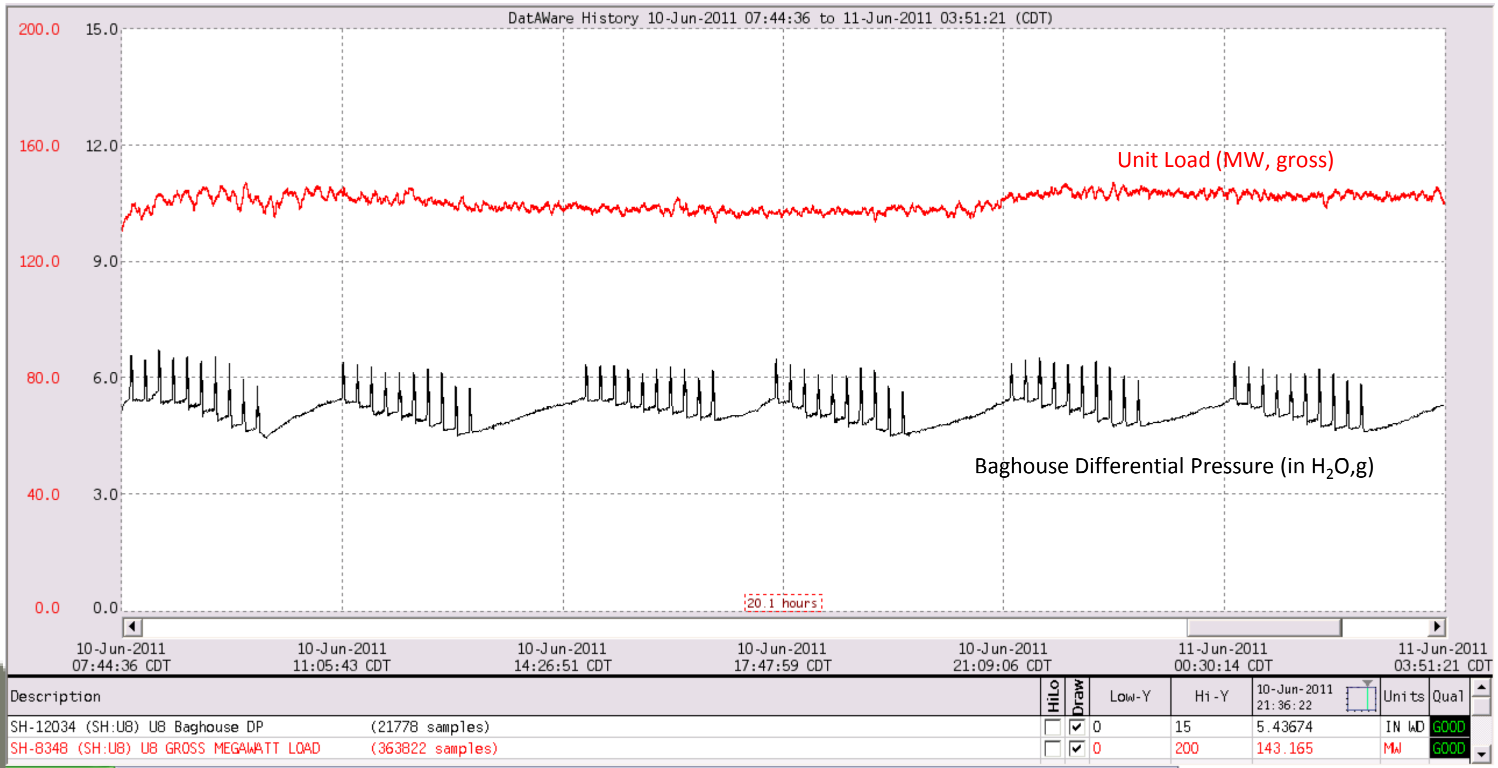
- HCl controlled, especially after one day seasoning of baghouse
- No balance of plant impacts in baghouse operations
- Particulate emissions reduced by 44%

Hydrate Injection Rate	HCl (lb/MMBTU)	HF (lb/MMBTU)	H_2SO_4 (ppmvd)
0 lb/hr - Baseline	**0.0030**	**0.0045**	**1.3**
350 lb/hr	**0.0005**	**0.0006**	**0.37**
350 lb/hr	**0.0007**	**0.0007**	**0.35**
300 lb/hr	**0.0008**	**0.0006**	**0.35**

Objective 2 - Balance of Plant Impacts

Baghouse and Ash System Performance – No Issues Identified

- Full Pressure Loss Recovery Achieved (~4.4 in H_2O,g)
- The DP Cleaning Cycle Dwell Time Shortened (~ 2hrs to ~1.5 hrs) as expected
- No Ash Handling System Impacts (Hoppers Pulling Empty)



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Conclusions and Path Forward

- Shawnee can achieve compliance with proposed HAPs regulations via a low cost hydrated lime injection system
  - Postpones unit idling/retirement or FGD installation.

- Hydrated Lime System
  - Can later be used with SCR installation to mitigate SO_3
  - Consider longer term (~2 month) demonstration on temporary system with HCl CEMS
    - Longer-term BOP issues
    - Process variability to minimize project and operational risk.

- Consider Clean Air Strategy changes at other sites slated for dry scrubbers.

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Material Handling

Dense vs. Dilute Phase Conveying

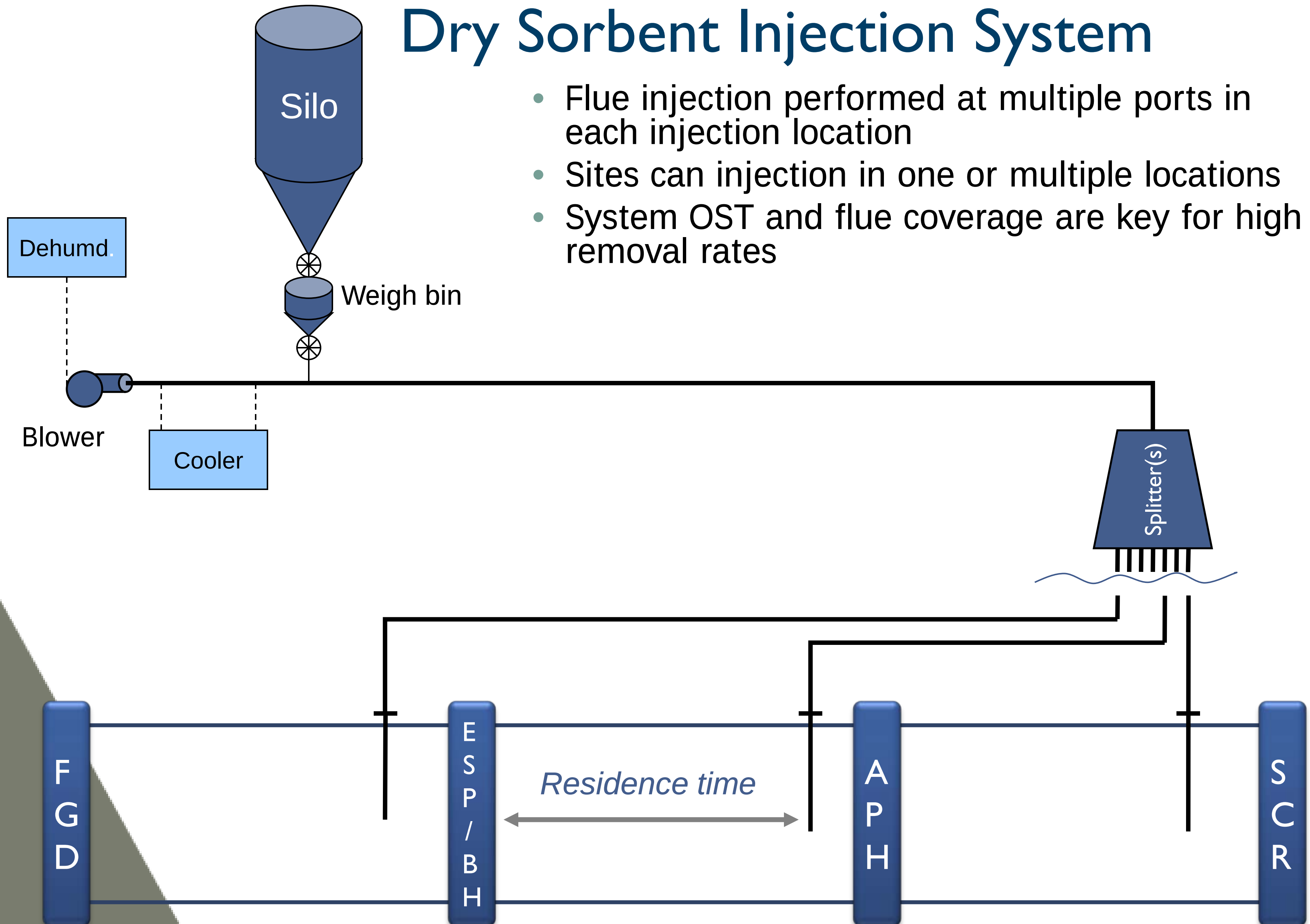
- Dense Phase Conveying
  - Material:Air of 99 to 6.2 (two phase) or 1,239 to 62 (piston) lbs material/lb of air
  - Truck Unloading

- Dilute Phase Conveying
  - Material:Air 6.2 to 0.10 lbs material/lb of air
  - Pneumatic Injection Systems

Source: Solt, P. E., Pneumatic Points to Ponder, Powder and Bulk Engineering

Dry Sorbent Injection System

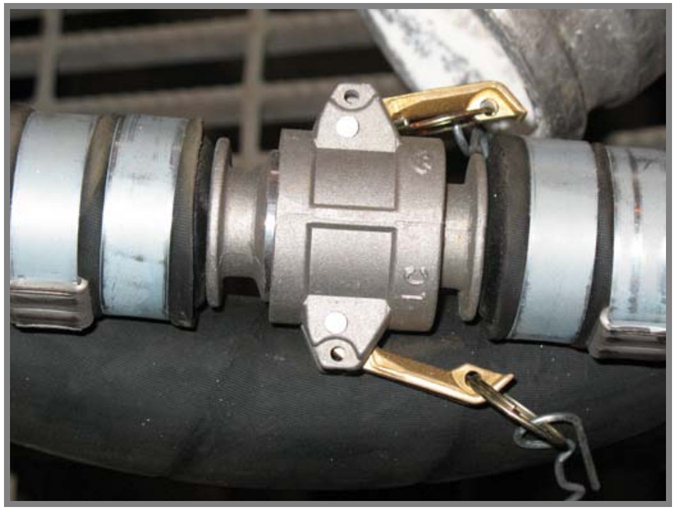
- Flue injection performed at multiple ports in each injection location
- Sites can injection in one or multiple locations
- System OST and flue coverage are key for high removal rates



System Installation

- Wet air
  - Conveying
  - Rotary Airlock seals
- Piping joints
  - Shelf
- Field modifications
  - Added bends

J. Wilson, DHUG, 2010



J. Wilson, DHUG, 2010

Design Challenges – Understanding Air Dilute Phase Systems

- Flue coverage
  - High # of injection lances
- Two sorbent option
  - Different properties and system requirements
- Alternate fuels
  - Oversized equipment
- Inflexible equipment
  - Single speed blowers
- Conveying distance and pathway
  - # of bends require increased air

Questions

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Possible Explanations for Reduced PM Measured During Hydrated Lime Testing

- Triboelectric theory (Observed at Widows Creek, etc.)
  - Friction causes particles to become charged
  - One material positively charged, other material negatively charged
  - Fly ash (alumina and silica oxides) are typically negative
  - Hydrated lime, pneumatically conveyed, should be positive
  - Opposite charges attract, agglomerating fine particulate
- Measurement of Condensables on Particulate Filters (at Paradise)
  - Prescribed filter bake times do not eliminate all acid condensables
  - Baseline PMs include high acid concentrations
  - Hydrated lime injection PMs reduce acid on filters, lowering PMs
- Combination of the above and other unknown effects