REINHOLD ENVIRONMENTAL Ltd.

2014 NOx-Combustion Round Table & Expo Presentations

February 10 & 11, 2014, in Charlotte, NC / Hosted by Duke Energy

SCR Catalyst Phosphorus Poisoning Prevention When Firing PRB Coal and Reducing Bromine Additive Required for Hg Control

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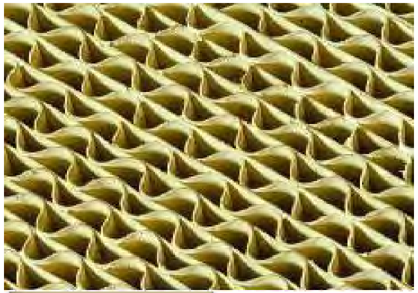
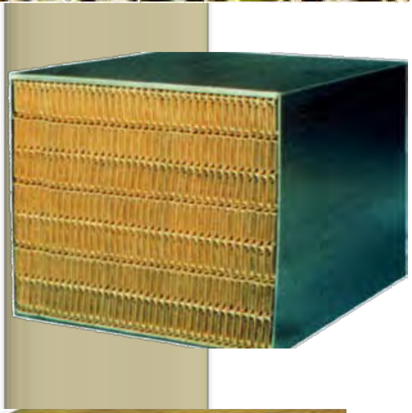
Presentation Agenda

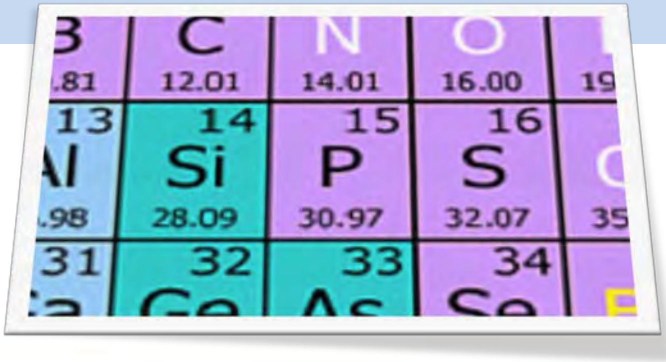
- Field test results of Mitagent for phosphorus mitigation
- Economic analysis of staged vs de-staged operation
- Bromine for mercury oxidation
- Pilot- & field-test results of Br reduction for Hg oxidation





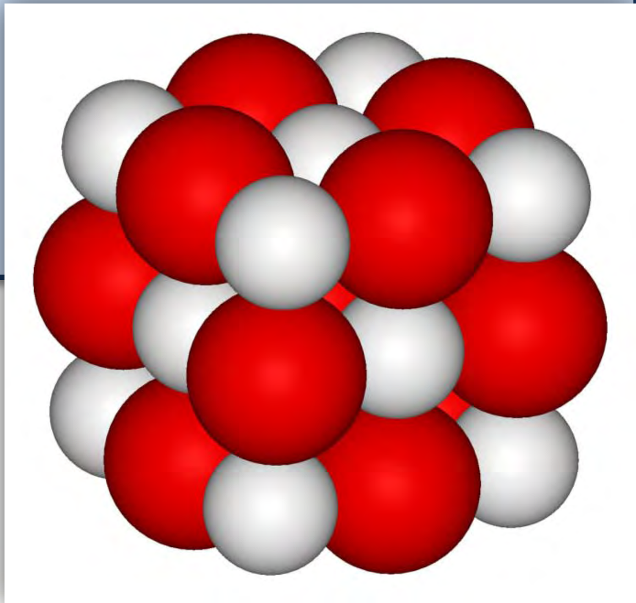
Deactivation of SCR Catalyst by Phosphorus

- Deactivation of catalyst by phosphorus commonly occurs when burning PRB coal
- Combustion conditions play major role in deactivation process
- Deactivation occurs more often under staged combustion conditions vs. un-staged combustion
- Poor combustion, regardless of type, also leads to deactivation of the catalyst by phosphorus
- Gas phase phosphorus level at the SCR inlet is an indicator of the amount of deactivation that will likely occur



Combustion Additive Development

- Investigation by B&W for binding gas phase phosphorus
- Evaluation of additive impact on boiler performance
- Technical feasibility of injection
- Short term testing
- Long term testing
- Multiple foreign & domestic patents pending

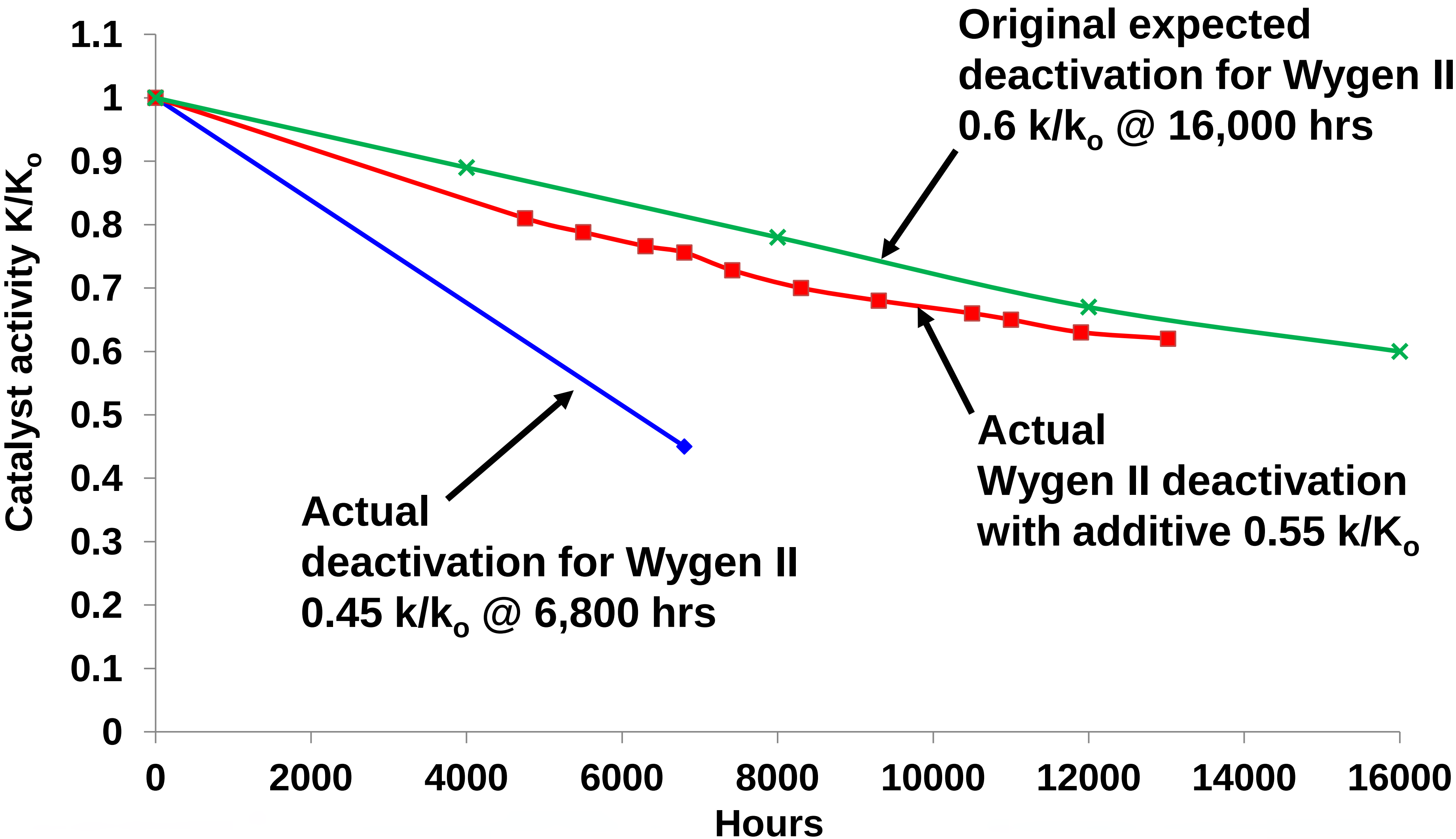


Additive Development – Long-Term Test Site

Wygen 2—100 MW unit with SCR, SDA, and baghouse

- ☑ **PRB coal (Wyodak mine)**
- ☑ **Staged combustion**
- ☑ **History of rapid catalyst deactivation due to phosphorus poisoning**

Wygen II – Catalyst Performance



Observations

- With Mitagent injection, the rate of deactivation slowed significantly on a staged combustion unit
- No negative impact observed on furnace or any back-end equipment
- Worked well even with regenerated catalyst
- Universal applicability independent of catalyst type and pitch

Economic Analysis of Staged Vs De-staged Combustion

- It is claimed that de-staging a unit equipped with low-NO_X burners may mitigate the deactivation of catalyst by phosphorus poisoning
- Correlation between extent of de-staging and phosphorus poisoning is not yet proven with field measurements
- Cost comparison of staged combustion with additive and de-staged operation is needed

Economic Analysis of Staged vs De-staged Combustion

Parameter	Staged Operation	De-staged Operation
NOx @ Boiler Outlet	0.28 lb/Mbtu	0.35 lb/MBtu
Stack NOx	0.05 lb/Mbtu	0.05 lb/Mbtu
Phosphorus Poisoning Potential	Moderate to Severe w/o Additive Minimal with Additive based on proven results	Minimal * (not field proven)
No of Catalyst Layers	2	2
Catalyst Life	24,000 hrs	24,000 hrs
DeNOx	82.1 %	85.7 %
Ammonia Consumption	368 lb/hr	480 lb/hr
Additive Consumption	50 lb/hr	0.0 lb/hr
Total Cost * for 24,000 hour guarantee period	App $ 6,300,000	App $ 7,100,000

Economic Analysis of Staged vs De-staged Combustion

- **When evaluating anhydrous ammonia over a 20 year period**
  - **Cost savings of ~$7,100,000**
  - **NPV savings of ~3,500,000**
- **When evaluating urea solution over a 20 year period**
  - **Cost savings of ~$10,700,000**
  - **NPV savings of ~5,200,000**

How much benefit the additive system would provide is dependent on the specifics of the unit

These numbers include the cost of the additive system, and do not include some other benefits (most notably reduced consumables associated with lower ammonia demand and impacts to mercury control system)

Mercury Emissions Control

- Per MATs rule, Hg emissions will be controlled to 1.2 lb/TBtu (bituminous and subbituminous) and 4.0 lb/TBtu (lignite)
- Mercury oxidation and removal by FGDs is one method
- Activated Carbon Injection (ACI) is most widely used method
- Each method has advantages and disadvantages
- Mercury can be oxidized by SCR catalyst
- Ammonia slip negatively affects Hg oxidation by SCR
- In absence of SCR, mercury can be oxidized by halogen addition to the coal

Bromine Injection for Mercury Control

- **Br addition (as $CaBr_2$ solution) to the coal is very effective method to achieve mercury oxidation for all types of coal**
- **At combustion temperature, Br added to the coal forms HBr gas**
- **HBr does not directly participate in Hg oxidation**
- **HBr undergoes Deacon reaction to form Br_2 as follows**

$$4\,HBr + O_2 \rightarrow 2H_2O + 2Br_2$$

- **Br_2undergoes an oxidation reaction with Hg^0 to yield $HgBr_2$ otherwise known as mercury capture by halogen oxidation**
- **Br addition rate is substantially lower for units with an SCR as compared to units without an SCR**

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Bromine Injection for Mercury Control

- **Mercury oxidation in presence of an SCR catalyst occurs more efficiently**
- **For example, 30-40 ppm of Br addition to PRB coal typically produces high Hg oxidation in presence of SCR**
- **Without SCR, the addition rate of Br to the coal may be as high as 100-150 ppm to obtain similar performance**
- **Br addition may cause BoP impacts, i.e., back-pass fouling and cold-end air heater corrosion**
- **Br addition can also lead to Br discharge from plants with WFGDs, and the formation of Trihalomethanes (THMs) in lakes and streams**

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Mitagent Benefits for Br Injection

- **Pilot- and full-scale testing data show that Mitagent injection can reduce the Br injection rates for Hg oxidation by 50% to 60%**
- **Benefits of Br reduction include**
  - **Decrease in corrosion potential**
  - **Decrease in fouling potential**
  - **Decrease in THMs in water**
  - **Reduction in cost**

Refined Coal

- United States IRS Code Section 45
- Commercial Refined Coal Facilities
  - 40 Sites
    - Power and Industrial Boilers, Coal Dock
  - Coal Firing Configurations
    - PC (Wall, Tangential & Riley Turbo), Cyclone, Fluidized-bed, Stoker
  - AQCS Configurations
    - ESP, FF, SCR, WFGD, SDA, CDS
- Production
  - 150,000,000 tons to Date
- Coal Types
  - All Major Steam Coal Producing Basins

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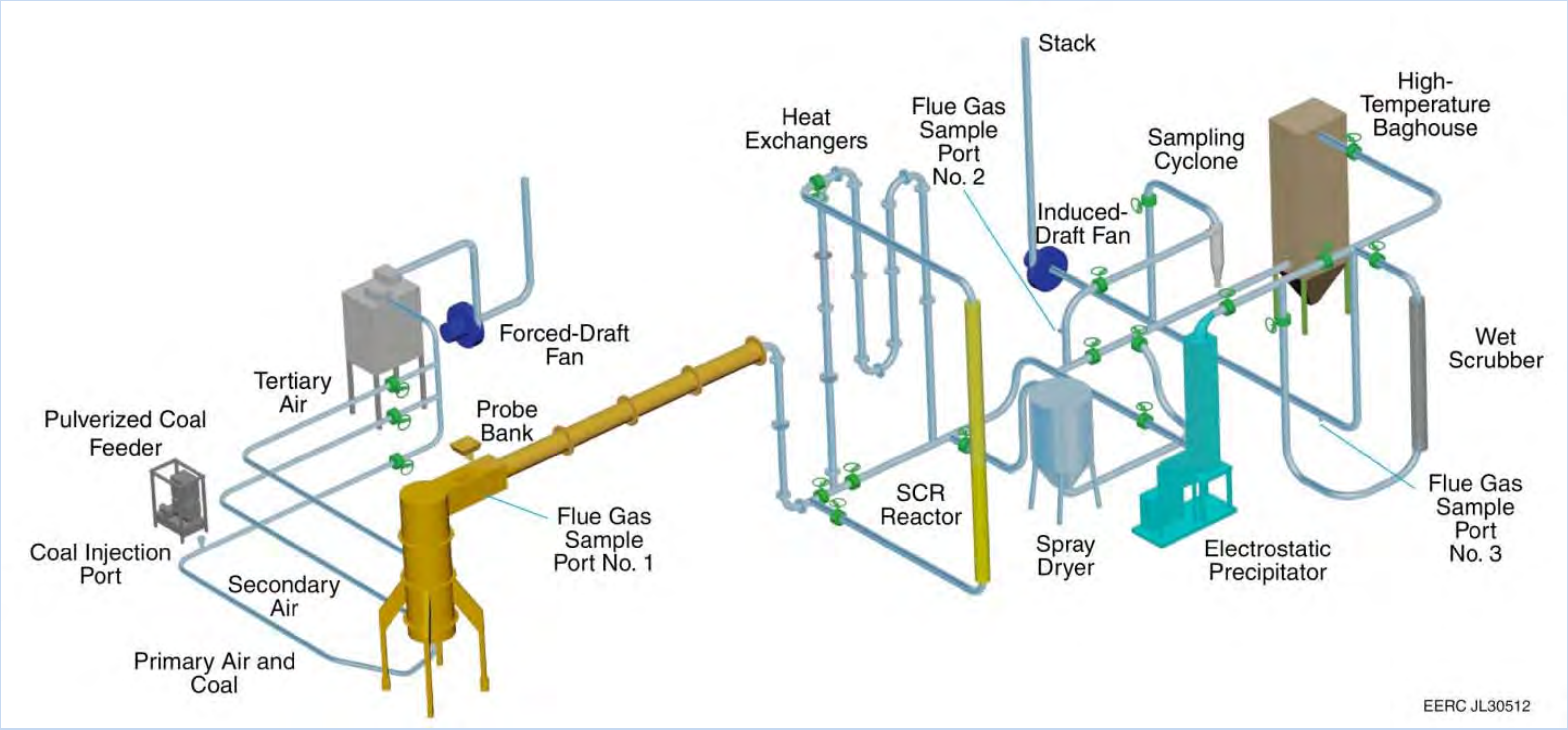
Pilot-scale Combustion Test Facility (CTF)



CTF Operating Conditions

- 560,000 Btu/hr
- 2100°F Furnace Exit Gas Temperature (FEGT)
- 3.5% XS Oxygen
- 18.5% Over-fire Air (OFA)
- ESP for Particulate Control
  - 300°F inlet temperature
- Other AQCS Equipment
  - Wet Scrubber, Dry Scrubber, SCR, FF Baghouse

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CTF Results – PRB Coal

Additives			Hg		NO_X	
MerSorb	S-Sorb	M15	Lb/Tbtu	% Reduced	Lb/MMBtu	% Reduced
0.0000	0.000	0.000	2.737	0	0.203	0
0.0200	0.300	0.000	1.088	60	0.156	23
0.0000	0.000	0.000	2.711	0	0.237	0
0.0200	0.200	0.050	1.383	49	0.186	22
0.0100	0.175	0.075	1.088	60	0.186	22
0.0075	0.175	0.075	1.515	44	0.177	25

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CTF Results – CAPP Coal

Additives			Hg		NO_x	
MerSorb	S-Sorb	M15	Lb/TBtu	% Reduced	Lb/MMBtu	% Reduced
0.000	0.0000	0.0000	0.494	0	0.318	0
0.025	0.3500	0.0000	0.275	44	0.241	24
0.000	0.0000	0.0000	0.113	0	0.363	0
0.010	0.3375	0.1125	0.040	64	0.282	22

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Mitagent Benefits for Br Injection

- **Testing at full scale unit burning PRB coal and only ESP**

Br Injection Rate ppm to coal	Mitagent Rate lb/hr to coal	% Oxidized Hg @ Stack (Method 30B)
0	0	38.0
70	0	46.5
100	0	62.5
40	25	56.0

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Full Scale Hg Testing Results – Unit 1

B&W/Chem Mod Blended Additive

- **B&W Mitagent (M_{15})**
- **ChemMod Refined Coal Additives (S-Sorb III + $CaBr_2$)**

- **Equivalent Hg oxidation with greater than 50% reduction in Br rate**
- **Baseline stack Hg emission was 1.9 lb/TBtu**
- **Stack Hg emission with the blend of B&W + Chem Mod additives was 0.6 lb/TBtu (without ACI)**
- **Hg removal was 63%**
- **Combined additive injection rate was not optimized; higher removals are possible**
- **Additive cost is 35%-50% of that of PAC at a similar performance level**

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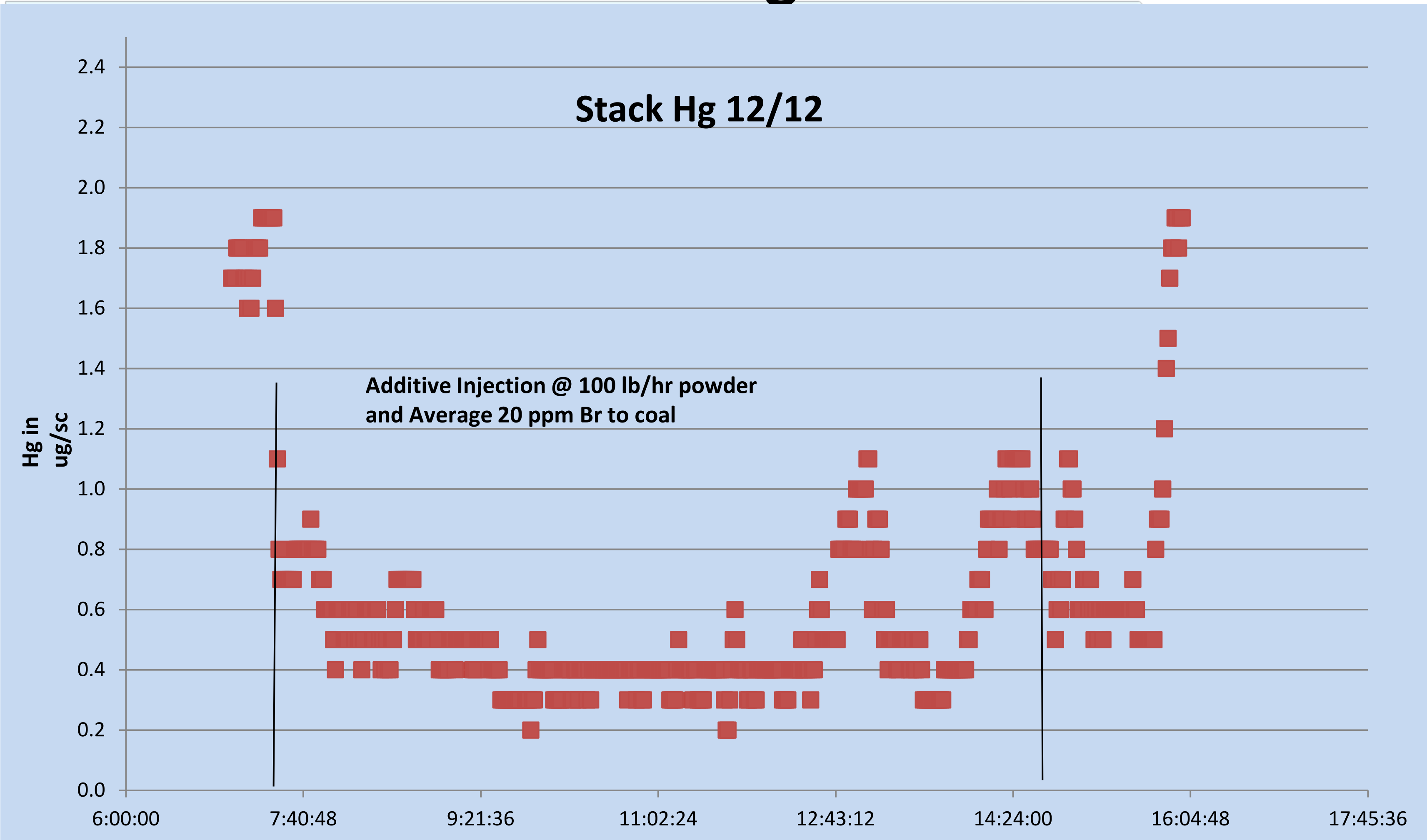
Full Scale Testing Results



Full Scale Testing Results Unit 2

- Unit 2 burns PRB coal and is equipped with SCR+CDS+FF
- Br addition rate was 40 ppm of coal with powder additives at 100 lb/hr
- Baseline stack Hg emission was 2.6 lb/TBtu (10-hr average)
- Stack Hg emission with additive blend was 0.7 lb/TBtu (10-hr average) without ACI resulting
- Hg removal was 73%

Benefits of B&W & ChemMod Blended Additive

- Lower cost of Hg control
- Not affected by SO_3
- No negative impact on ash sales
- No carbon accumulation in ash for CDS units
- Lower Br concentration in WFGD
- Removes Se, As, Pb and other heavy metals