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WPCA

Babcock Power Inc.




The Future Of Coal Fired SCRs In A ~~Carbon Capture World~~

2011 WPCA IL

September 13, 2011

Babcock Power Inc.

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Introduction – Future Coal Plants

- Integrated Gasification Combined Cycle (IGCC), oxy-fuel combustion or post-combustion fuel gas CO_2 capture
  - With exception of purification of oxy-fuel derived flue gas, all will require AQCS systems
- Competing against gas turbines firing natural gas or coal synthesis gas
  - Achieve 2 to 5 ppm outlet NO_x
- What will it take to match this level with coal fired units?

Introduction – Present State Of Art

- Low NO_x burners with Selective Catalyst Reduction (SCR)
  - 90% to 92.5% NO_x reduction in SCR
  - 0.03 lb/MBtu (22 ppmvd) to 0.04 lbs./MBtu (29 ppmvd) outlet NO_x
  - 2 ppm ammonia slip
    - Effect on downstream equipment
    - Sale of flyash
      - Assuming a lack of economical method of removal of ammonia from flyash
    - Condensable PM

Necessary Input Values Of The MEA – Process

	PM [mg/Nm³] grs/scf lb/MMBtu	NO_X as NO_2 [mg/Nm3] ppm lb/MMBtu	SO_X as SO_2 [mg/Nm³] ppm lb/MMBtu
13. BImSchV (FRG 2004)	< 20 0.0012 0.0025	< 200 (solid fuel) 97.4 0.135	< 200 70 0.135
input values of the MEA - Process	< 15 0.00095 0.0020	< 30 (NO_2) 14.6 0.020	< 30 10.5 0.020

Daily average values for plants with thermal capacity of > 300 MW

NO_x Reduction Requirements

NO_x Reduction required to Meet 2 and 5 ppm Outlet NO_x

Coal Type		SCR NOx Reduction Wall-Fired Boiler	SCR NOx Reduction Tangential Fired Boiler
PRB-Lignite	Baseline NOx, ppm	180	130
	Overall Reactor Reduction	97.22%	96.15%
	Outlet NOx, ppm	5	5
	Overall Reactor Reduction	98.89%	98.46%
	Outlet NOx, ppm	2	2
Low - Medium Sulfur Coal	Baseline Nox	285	215
	Overall Reactor Reduction	98.25%	97.67%
	Outlet NOx, ppm	5	5
	Overall Reactor Reduction	99.30%	99.07%
	Outlet NOx, ppm	2	2
High Sulfur Coal	Baseline Nox	360	285
	Overall Reactor Reduction	98.61%	98.25%
	Outlet NOx, ppm	5	5
	Overall Reactor Reduction	99.44%	99.30%
	Outlet NOx, ppm	2	2

Source: "Advanced SCR Design Assessments for NO_x Less than 5 ppm", by R. Himes et. al.

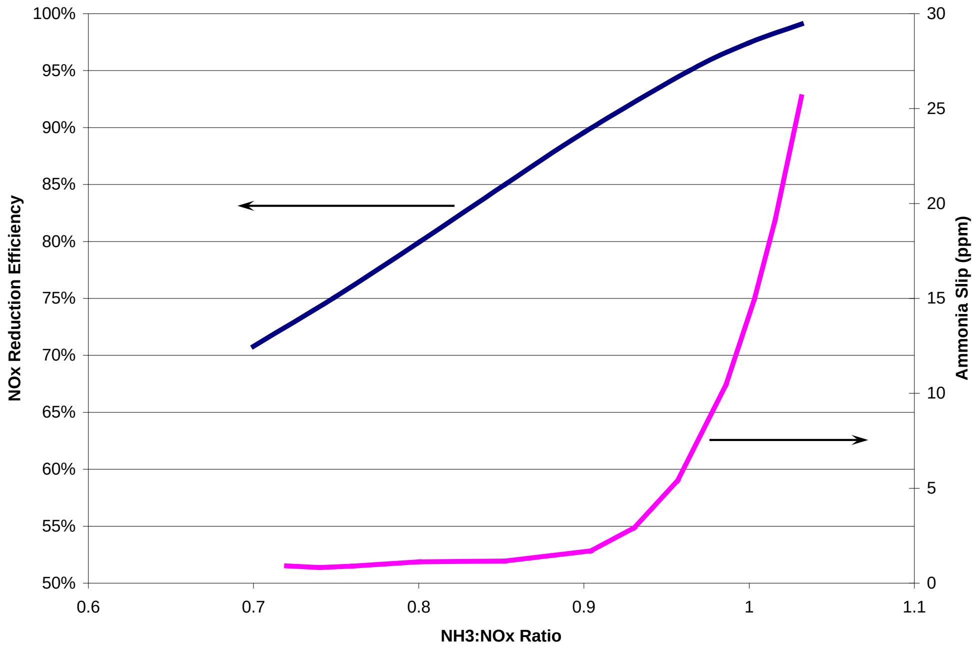
The 95% SCR

- More catalyst can only do so much
  - If NO_x is not there to react, NH_3 will slip through = “distribution induced slip”
- Higher removals through better mixing
  - The more uniform the NH_3/NO_x profile, the greater the catalyst performance and the lower the distribution induced slip
  - Maximum design NH_3/NO_x standard deviation to be 2 – 3 %
  - Current BPEI test data for NH_3/NO_x standard deviation are < 2%
    - Actual test results show 94.2% removal with NH3/NOx standard deviation of <2% yield undetectable slip for new catalyst

      (Based on catalyst design of 2 ppm slip – expected to be met)

Limitations On High NO_x Removal

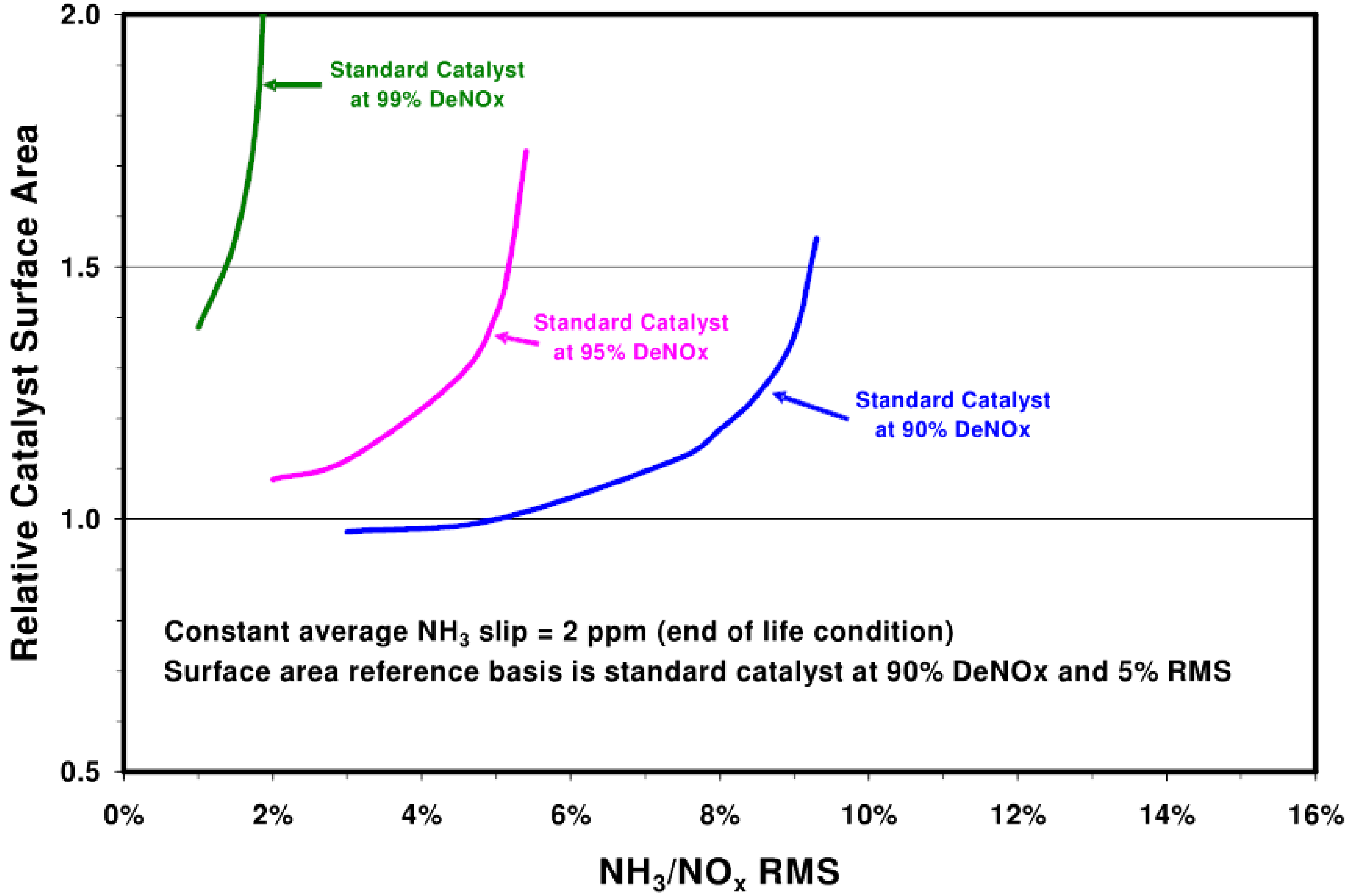
- Temperature, velocity, and NH_3/NO_x distribution
  - Key limitation is NH_3/NO_x distribution
  - NOx and ammonia become progressively more non-uniform as it passes down through catalyst layers



Source: "Enhanced Ammonia Distribution for Maximum SCR Performance", R. Sigling et. al.

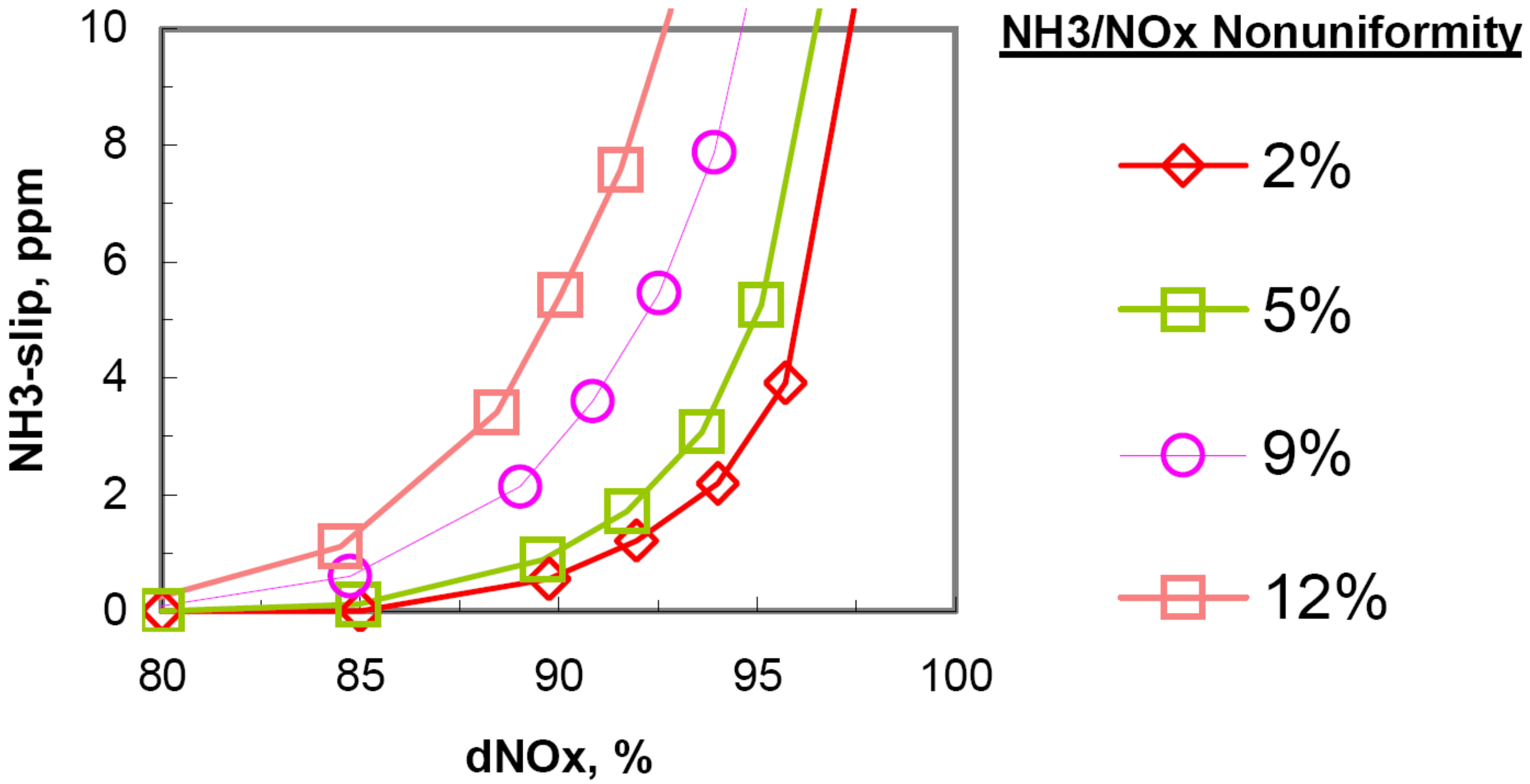
Effect Of Increasing NO_x Removal

Catalyst Volume - Distribution



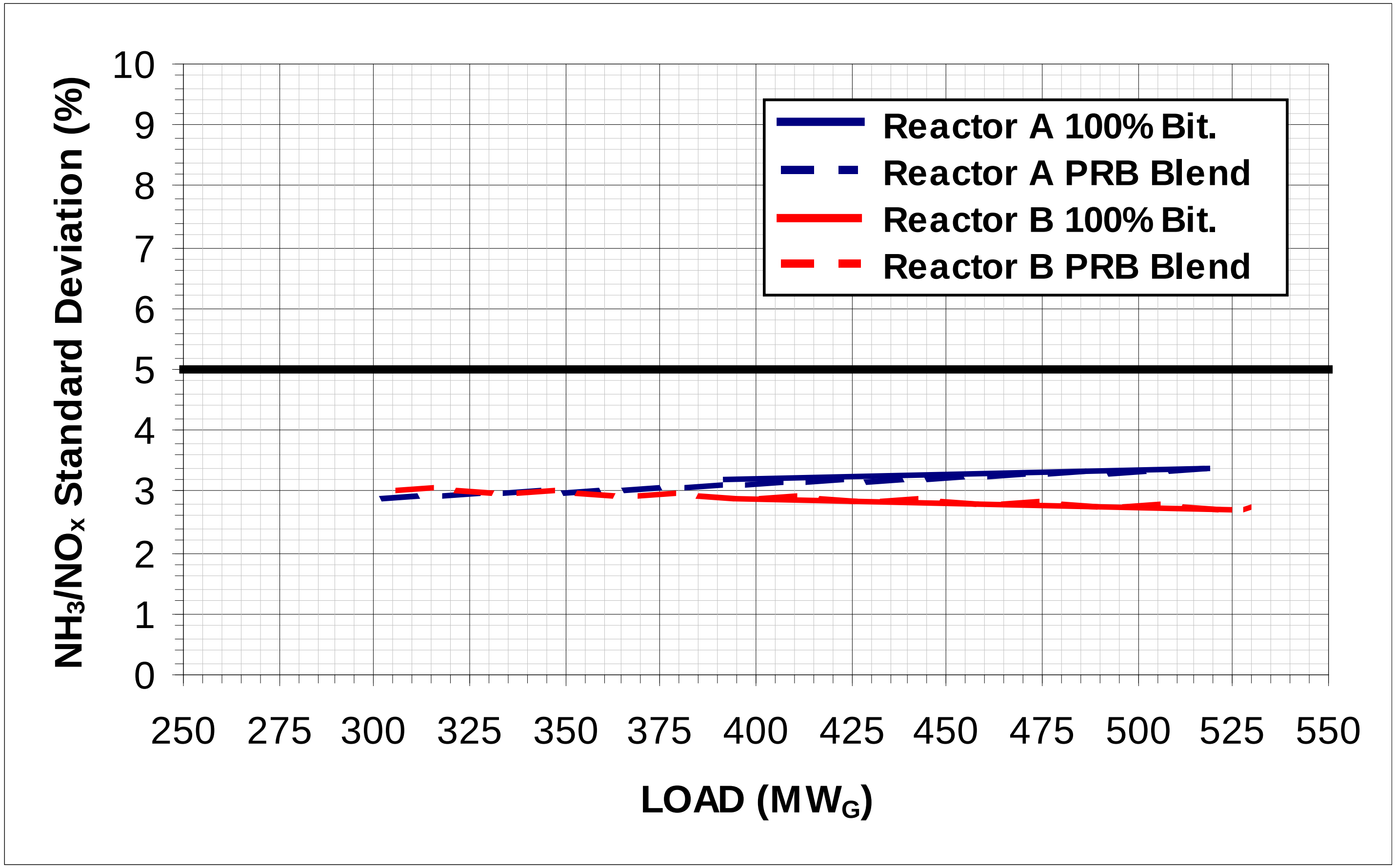
Source: "Selective Decomposition of Ammonia for Coal-fired Power Plant Selective Catalytic Reduction Application" by J. Bertole et. al.

Impact Of RMS On NH_3 Slip



Source: FERCO Engineering

Mixing System Results



Effect Of Increasing NO_x Removal

- Rapid increase in catalyst volume
- Increase in cross-sectional area
  - Increased difficulty in achieving uniform distribution
- Increase the number of catalyst layers
  - More expensive catalyst management
    - Possible requirement to replace more than one layer at each outage
  - Increased pressure drop

NO_x Reduction With Two Reactors
90% NOx Removal In First SCR Reactor

Coal Type		SCR NOx Reduction Wall-Fired Boiler	SCR NOx Reduction Tangential Fired Boiler
PRB-Lignite	Baseline Inlet NOx, ppm	180	130
	NOx at Outlet of First Reactor, ppm	18	13
	Second Reactor Reduction	72.22%	61.54%
	Outlet NOx, ppm	5	5
	Second Reactor Reduction	88.89%	84.62%
	Outlet NOx, ppm	2	2
Low - Medium Sulfur Coal	Baseline Inlet NOx, ppm	285	215
	NOx at Outlet of First Reactor, ppm	28.5	21.5
	Second Reactor Reduction	82.46%	76.74%
	Outlet NOx	5	5
	Second Reactor Reduction	92.98%	90.70%
	Outlet Nox	2	2
High Sulfur Coal	Baseline Inlet NOx, ppm	360	285
	NOx at Outlet of First Reactor, ppm	36	28.5
	Second Reactor Reduction	86.11%	82.46%
	Outlet NOx	5	5
	Second Reactor Reduction	94.44%	92.98%
	Outlet NOx	2	2

Multi-Stage Mixing
Two Reactors In Series – Method A

- First reactor has low outlet ammonia slip
- Second reactor is preceded by second ammonia injection
- Advantages
  - Additional injection grid allows for more ‘tuning’ of second reactor
  - Conventional (but more challenging) ammonia control for both reactors
  - Some adjustment can be made on NO_x removal split between the two reactors
- Disadvantages
  - More expensive and complicated ammonia and control systems
  - Longer mixing length required for entrance to second reactor
  - Probably not possible to construct as a retrofit
  - Additional pressure drop from additional mixing and ductwork

Multi-Stage Mixing
Two Reactors In Series – Method B

- First reactor has high outlet ammonia slip
- Second reactor is preceded only by flue gas mixing
- Advantages
  - Less catalyst in first reactor
  - Less expensive / complicated ammonia system
  - Single conventional ammonia control system
- Disadvantages
  - No ammonia distribution tuning possible for second reactor
  - More challenging flue mixing required for second reactor
  - Probably not possible to construct as a retrofit
  - Additional pressure drop from additional mixing and ductwork

Advanced Catalyst Design
Ammonia Slip Destructive Catalyst

- NO_x catalyst followed by separate ammonia destructive catalyst
  - Minimize NO_x catalyst volume while maintaining low ammonia slip
  - Requires selective catalyst that minimizes SO_2 conversion
  - Requires selective catalyst that minimizes ammonia conversion back to NO_x
  - May require two catalyst management plans

Advanced Catalyst Design

Selective Destructive Of Ammonia (Cormetech)

- NO_x catalyst that selectively reduces areas of high ammonia to smooth out NH_3/NO_x

$$SO_3 + 2NH_3 + O_2 \rightarrow SO_2 + N_2 + 3H_2O$$

  - Special first catalyst layer
  - Minimizes catalyst volume
  - May require two catalyst management plans

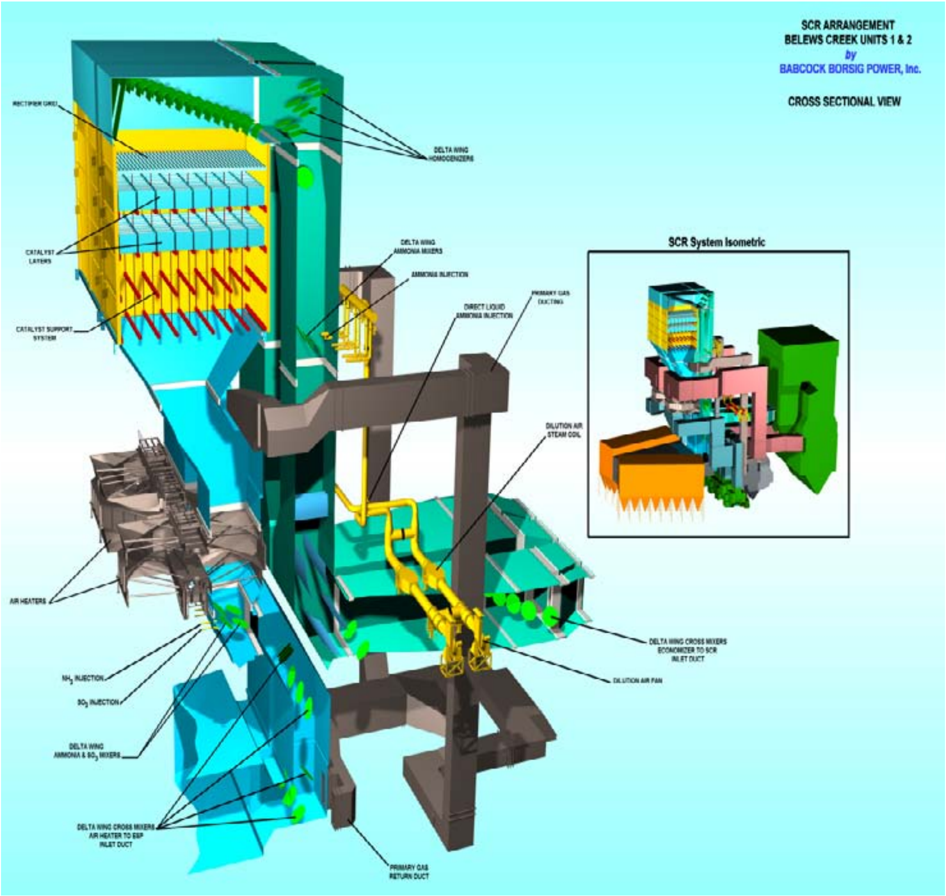
Increase SCR Performance Through Reliability Improvements

Operational Experience

- Increase reagent injection redundancy by tying Unit 1 & Unit 2 NH_3 injection systems together
- Aggressive equipment maintenance programs
- Continuous system condition monitoring
- On-line catalyst vacuuming and SAH water wash

Mixing System Improvements
Operational Experience

- In-house verification of ammonia injection as needed based upon changes in:
  - Reactor de-NO_x performance
  - Fuel quality
  - Ammonia-in-ash
  - SAH ΔP



Low Temperature SCR Operation
Operational Experience

- Real-time NH_3 MIT (Minimum Injection Temperature) calculated from measured flue-gas parameters using ABS dewpoint curves
- Increased SCR performance at low-load operation
- Eliminates catalyst recovery periods
- Reduces Secondary Air Heater (SAH) deposition

Optimal Control Strategy
Operational Experience

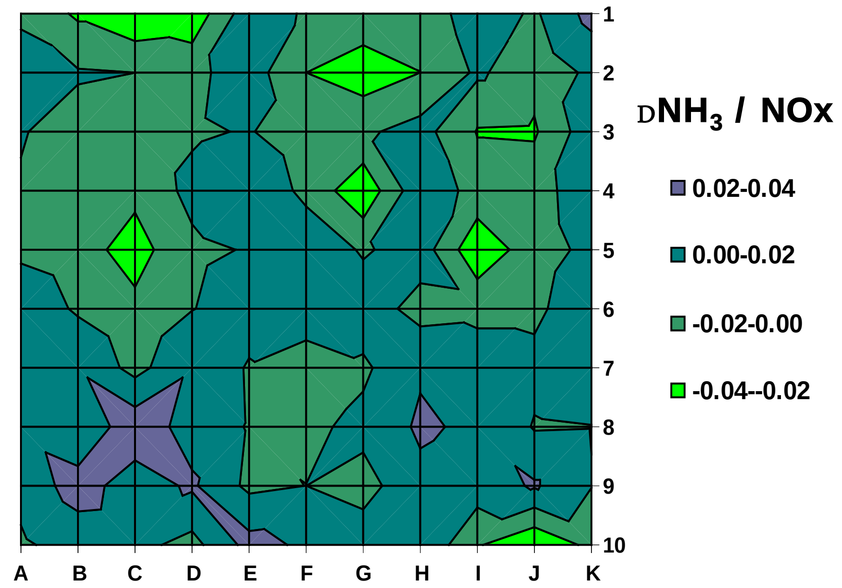
- Real-time ammonia injection flow control based upon:
  - SCR outlet NO_x vs. NO_x outlet setpoint
  - SCR outlet NH_3 slip
- Real-time MIT (Minimum Injection Temperature) Permissives and trips on each reactor
- Real-time catalyst ΔT monitoring
- Real-time ABS monitoring
- Parallel reactors are controlled independently

Improved Catalyst Inlet Ammonia-To-NO_x Ratio

- Increase mixing during initial design at cost of pressure loss
- Current designs have obtained less than 1 % RMS during testing
- Use mixing system design with active controls
- Designs must be reliable and able to alert operators

Design Of <2% RMS Mixing System

- Babcock Power studied the effect of individual mixings during model study
- Model study results verified with multiple field tests
- Mathematical optimization performed in model and field scale confirming design



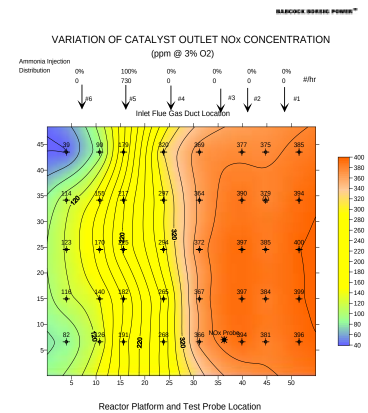
System Requirement For Enhanced Control

- Mixing system design is predictable and repeatable
- Model study accurately provides full scale injector influences
- One to one correspondence of NO_x measurement to injection point
- Furnace NO_x SCR inlet influence controlled

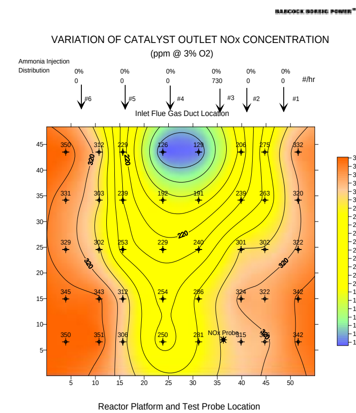
Valve Influence Test And Optimization Test

- Constant ammonia flow
- Test each valve individually
- Plot results for each valve
- Create influence coefficient matrix
- Computer optimization program
  - Linear equations
  - Ammonia flow constraints
- Review and adjust valves

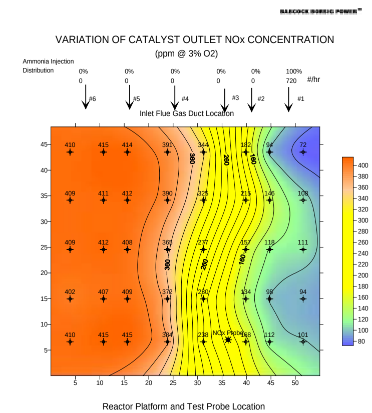
Injector Influence: Coal-Fired 400 MW SCR Reactor *



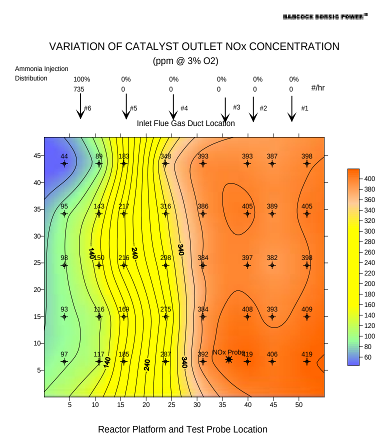
BBP Contract #: 100109 Project Name: AEP Unit: Big Sandy 2 Reactor: R1
Test: Big Sandy R1 071703 VI2 Valve 5 Test Date: 7/17/03 Test Start Time: 2052 Test End Time: 2106
Test Drescription: Full Load Valve Influence Test - Valve 5
Avg Outlet NOx ppm: 282 % Removal: 30 Std Deviation: 99.5



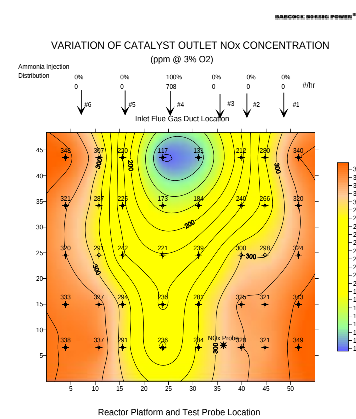
BBP Contract #: 100109 Project Name: AEP Unit: Big Sandy 2 Reactor: R1
Test: Big Sandy R1 071703 VI2 Valve 3 Test Date: 7/17/03 Test Start Time: 2233 Test End Time: 2247
Test Drescription: Full Load Valve Influence Test - Valve 3
Avg Outlet NOx ppm: 284 % Removal: 29 Std Deviation: 50.2



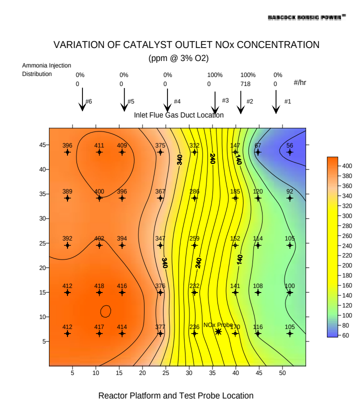
BBP Contract #: 100109 Project Name: AEP Unit: Big Sandy 2 Reactor: R1
Test: Big Sandy R1 071703 VI2 Valve 1 Test Date: 7/17/03 Test Start Time: 2144 Test End Time: 2200
Test Drescription: Full Load - Valve Influence Test Valve #1
Avg Outlet NOx ppm: 285 % Removal: 29 Std Deviation: 115.4



BBP Contract #: 100109 Project Name: AEP Unit: Big Sandy 2 Reactor: R1
Test: Big Sandy R1 071703 VI2Valve 6 Test Date: 7/17/03 Test Start Time: 2117 Test End Time: 2131
Test Drescription: Full Load Vlave Influence Test - Valve 6
Avg Outlet NOx ppm: 287 % Removal: 28 Std Deviation: 113.2



BBP Contract #: 100109 Project Name: AEP Unit: Big Sandy 2 Reactor: R1
Test: Big Sandy R1 071703 VI2 Valve 4 Test Date: 7/17/03 Test Start Time: 2255 Test End Time: 2309
Test Drescription: FullLoad Valve Influence Test - Valve 4
Avg Outlet NOx ppm: 279 % Removal: 30 Std Deviation: 49



BBP Contract #: 100109 Project Name: AEP Unit: Big Sandy 2 Reactor: R1
Test: Big Sandy R1 0711703 VI2 Valve 2Test Date: 7/17/03 Test Start Time: 2211 Test End Time: 2225
Test Drescription: Full Load Valve Influence Test - Valve 2
Avg Outlet NOx ppm: 276 % Removal: 31 Std Deviation: 107.2

*** Benes & Erickson, Electric Power 2005**

Automatic Control – Example

- 180 MW gas fired single unit
- Poor ammonia flow control at non-design low injection rates
- Solution enhanced ammonia control
  - Limited number of NH3 injectors
  - Clearly defined influence fields
  - Modified with additional outlet NO_x meter for two feedback loops
- Installed in summer 2005
- Extended time between injection point ‘tune ups’

Automatic Control – Example

Summary

Meeting 2 – 5 ppm Outlet NO_x

- Outlet Values can be met with multiple reactors but at substantial cost
- Alternate catalyst technologies can meet this level of performance but are under development
- Outlet NO_x levels of 2 – 5 ppm are achievable with additional mixing and controls

Babcock Power would like to thank Wayne Whitaker, Duke Energy, for his contribution to and support of this work

Thank You

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