Reinhold Environmental Ltd.

2007 NOx Round Table & Expo Presentation

February 5-6, 2007 in Cincinnati, OH

Workshop IV

New Tools for SCR: Interlayer Mixing and Determination of Catalyst Activity Insitu

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2007 Reinhold NOx Roundtable

Cincinnati, Ohio

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Topics

- Interlayer Mixing [1]
- Insitu Determination of Catalyst Activity [2]

(1) Funded by EPRI
(2) Funded by DOE/NETL, EPRI, Southern Company

Interlayer Mixing *

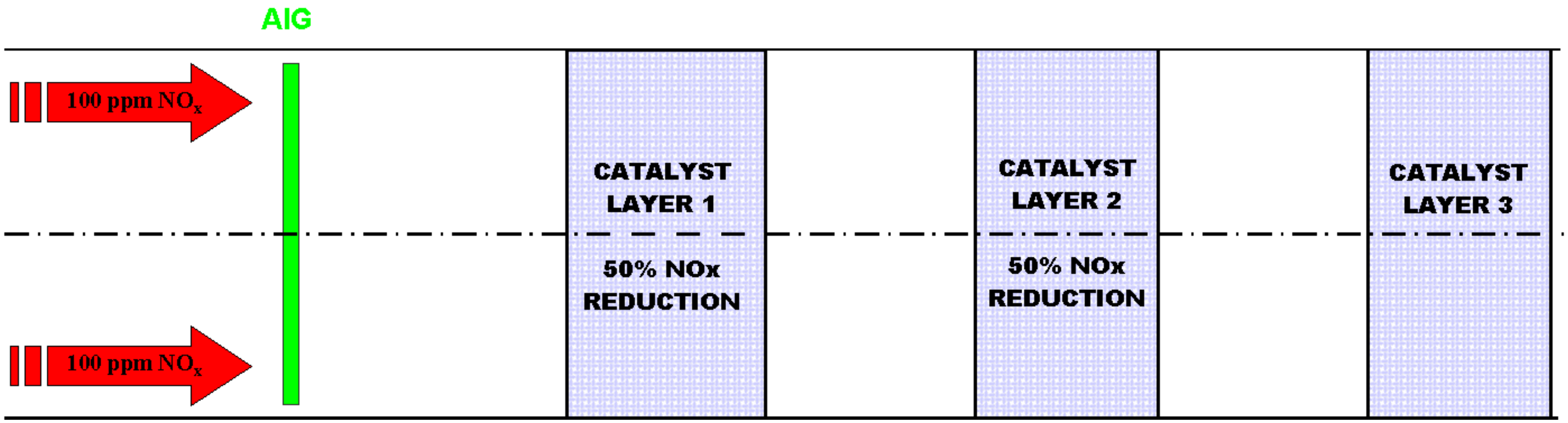
- Principal Investigators
  - FERCo: J. Muncy, D. Shore, T. Martz, L. Muzio
  - EPRI: D. Broske

* Funded by EPRI

What is Inter-Layer Mixing?

- *Use of devices to induce mixing between layers of catalyst in an SCR system*
- *Good NH_3/NO_x distribution uniformity of a "tuned" SCR exists only at the 1st catalyst layer*
  - *As the flow progresses though each layer, the NH_3/NO_x uniformity degrades*
- *Mixing between the catalyst layers will help re-distribute NH_3*
  - *Improving the uniformity to the next layer*
  - *Allows higher dNO_x with lower NH_3 slip*

Layer to Layer Changes in NH_3/NO_x Uniformity

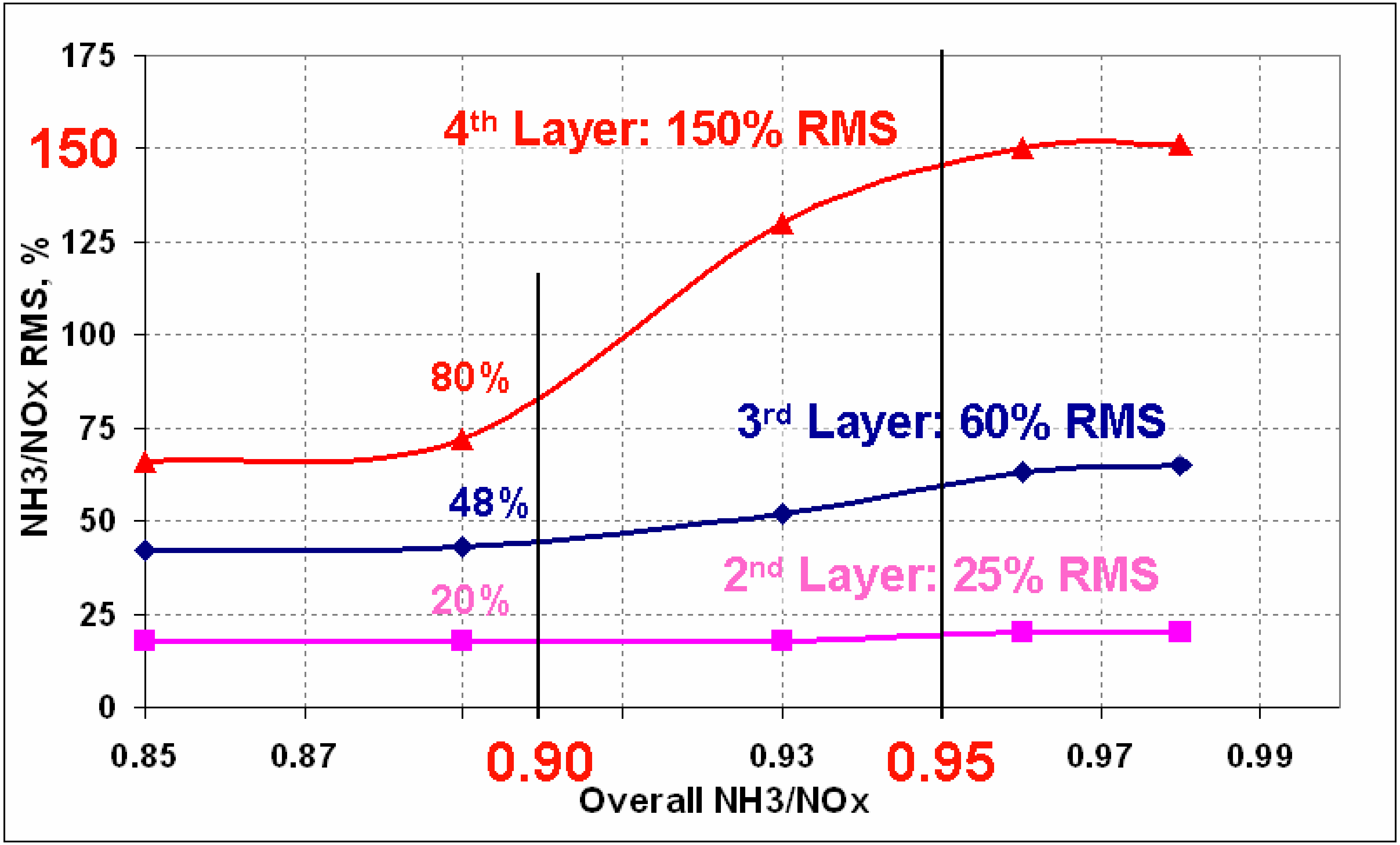


Inter-Layer Mixing Development

- Computer-based SCR Multilayer Process Model
  - How much can SCR performance be improved by inter-layer mixing?
  - What is the relationship between increased NOx reduction and the amount of inter-layer mixing?
  - Does the benefit depend on the number of catalyst layers?
  - Do all the layers need to be mixed?
- Physical Cold Flow Model
  - Are static or dynamic mixers more effective?
  - How much mixing can be achieved?
- Pilot Scale (planned for 2007)
  - Does interlayer mixing actually improve performance?
  - If so, by how much?
- Full Scale (planned for 2007)
  - What are the operational issues with the mixers in a full scale SCR reactor?

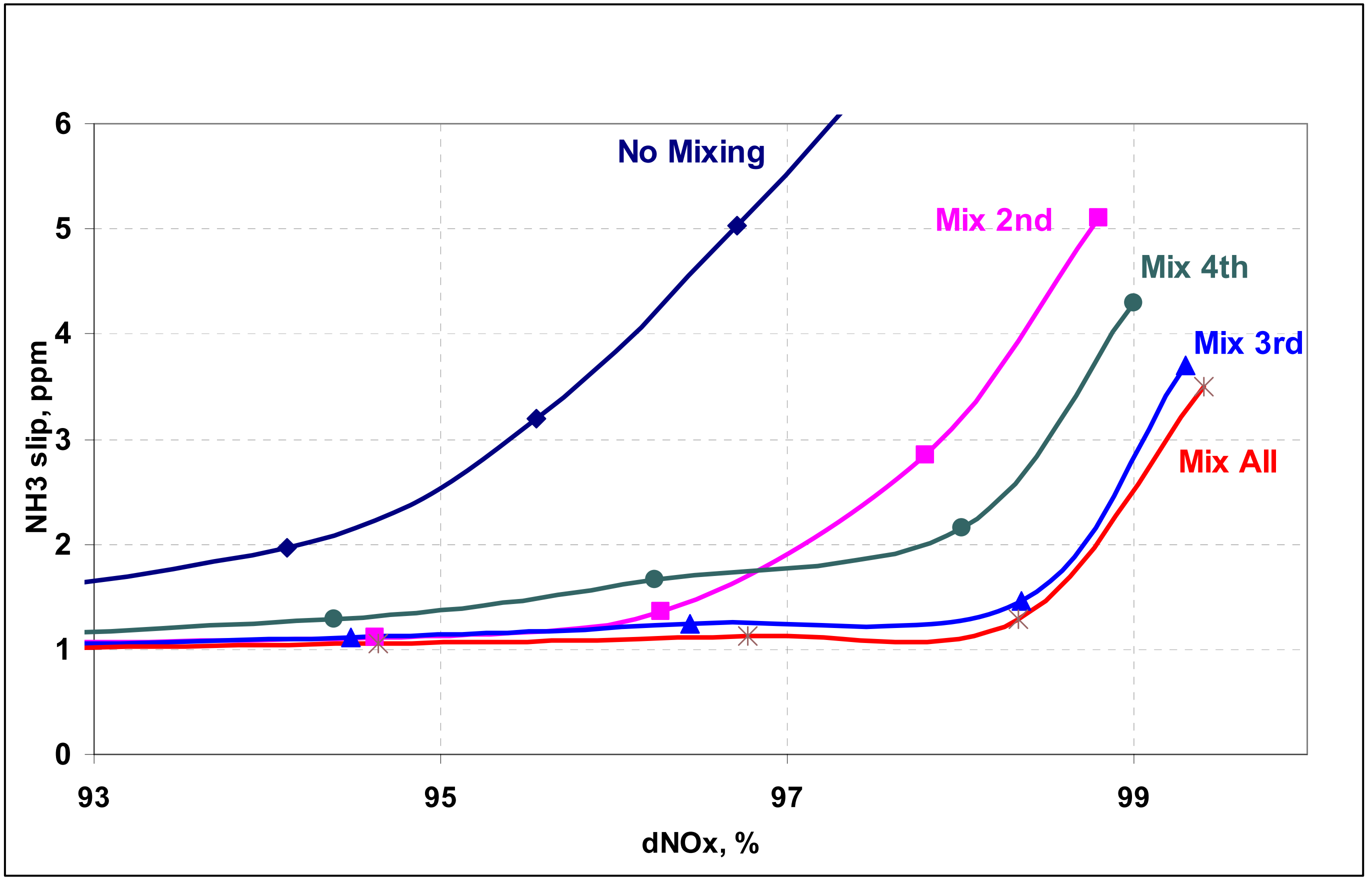
INTER-LAYER NON-UNIFORMITY

NH_3/NO_x distribution uniformity degrades through each layer



WHICH LAYERS TO MIX?

- No difference between mixing only the 2nd or only the 3rd, up to 95%
- Mixing in only the third is better than only the 2nd, for greater than 96% reduction



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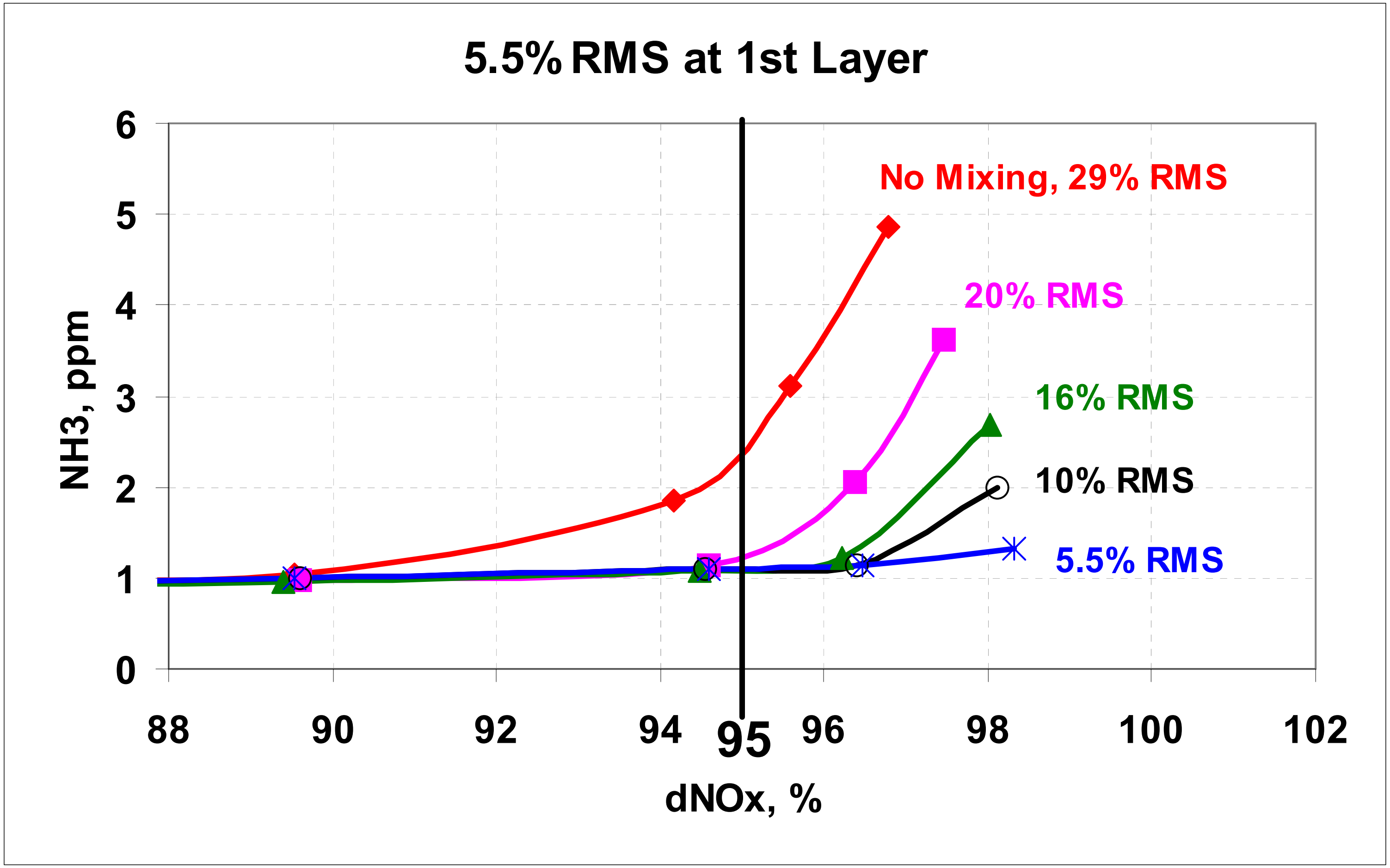
DETERMINING HOW MUCH TO MIX

(Mixing the 2nd Layer, 3 Layers Total)

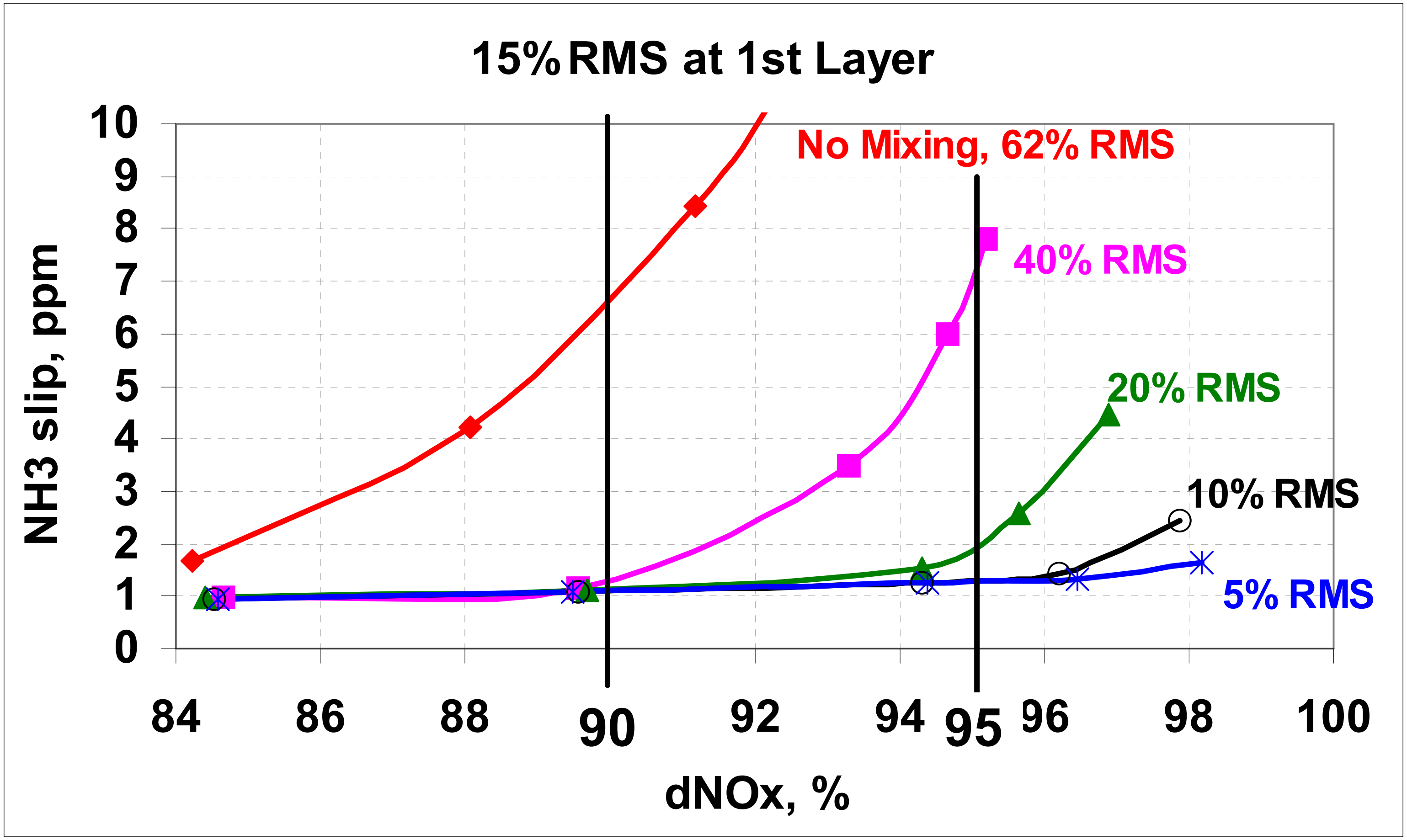
For 95% dNOx, only need to reduce NH_3/NO_x RMS from 29% to 20%



DETERMINING HOW MUCH TO MIX

(Mixing the 2nd Layer, 3 Layers Total)

Reducing NH_3/NO_x RMS from 62% to 40% would still be a significant improvement (increase dNO_x from 85% to 90%)

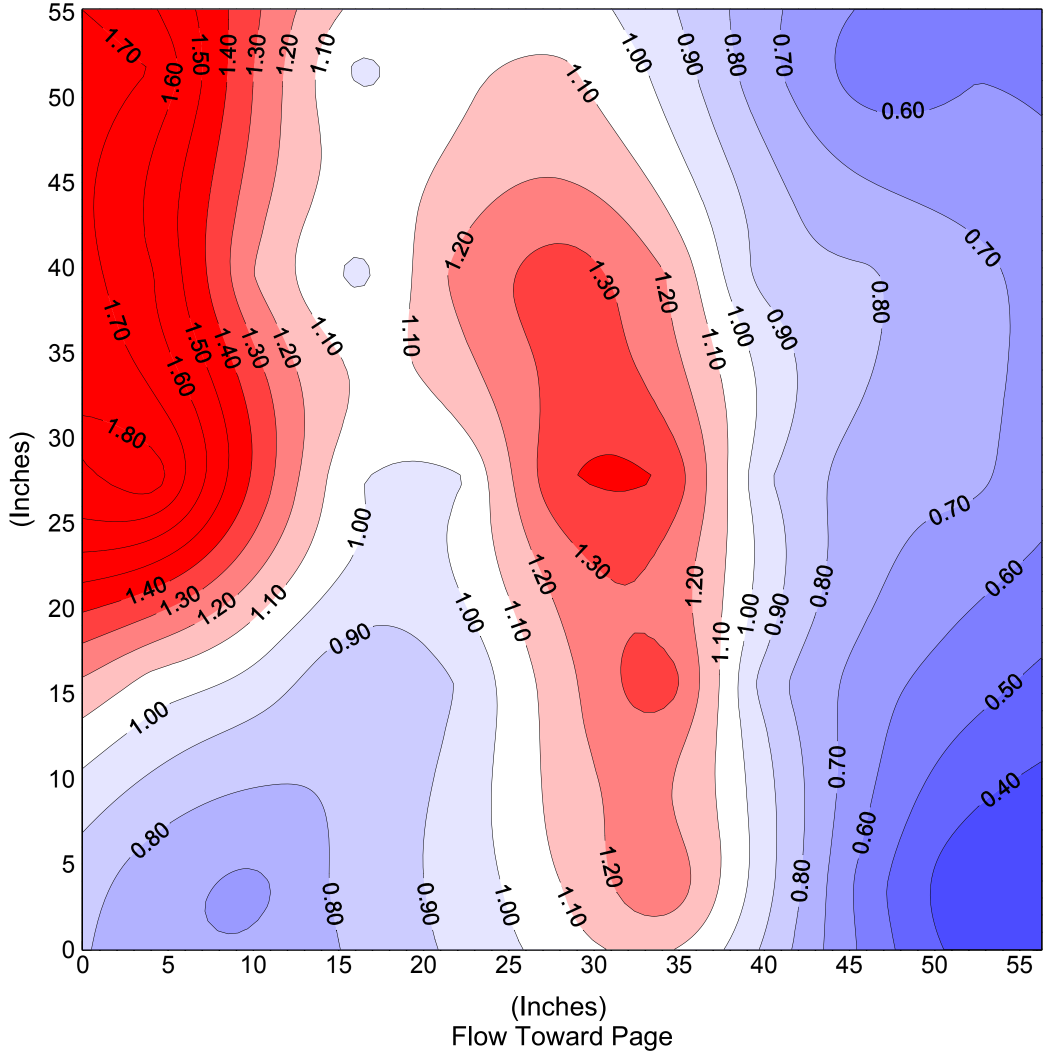


CAN THE REQUIRED MIXING BE ACHIEVED? COLD FLOW MODELING

- **Reviewed full-scale reactors to determine average catalyst spacing (6.8 feet)**
- **Reviewed actual NH_3/NO_x distributions to determine typical profile shape and average RMS**
  - **Inlet RMS: 3% - 5%**
  - **Outlet of 1st layer RMS (based on computer model): 22%-35%**
- **De-tuned the AIG of cold flow model to produce 30-35% RMS**

COLD FLOW MODEL:
Normalized NH_3/NO_x Profile into Second Layer

Baseline 33% NH_3/NO_x RMS



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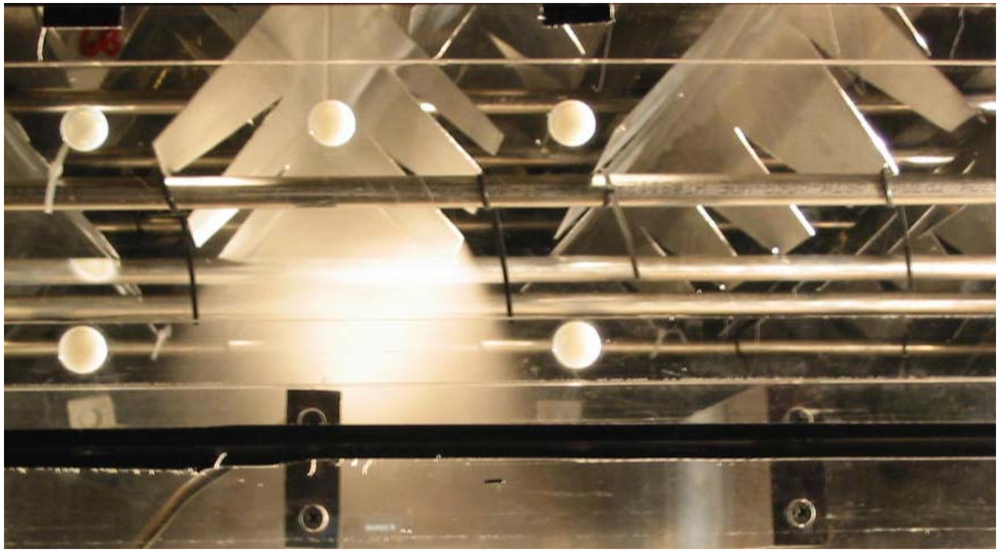
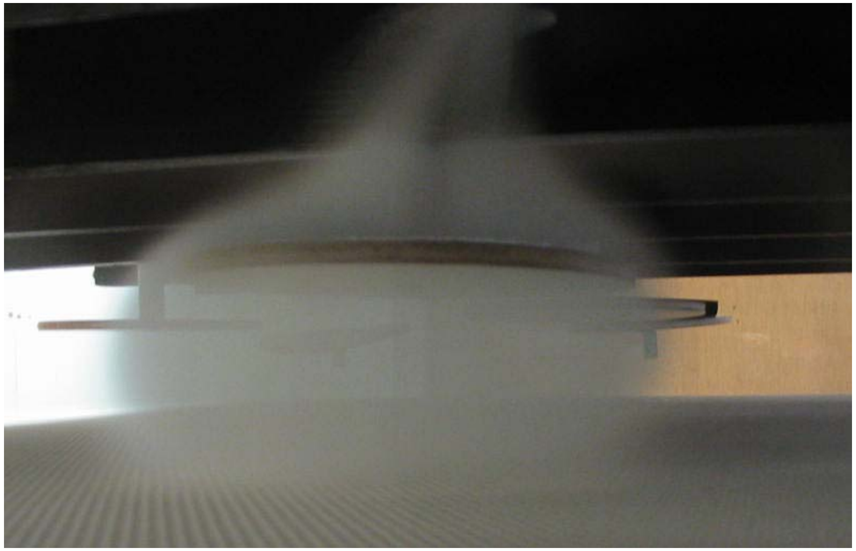
INTER-LAYER MIXING DEVICES

- Static Mixers
  - ✓ Bluff body discs and swirlers
  - ✓ High blockage – crossed slats
  - ✓ Inverted Sawtooth
- Dynamic Mixers
  - ✓ Wall Mounted Air Jets
  - ✓ Internal Air Amplifiers
- Combination of Static and Dynamic
- Other Parameters:
  - ✓ Mixing Distance
  - ✓ NH_3/NO_x Profile (RMS, Shape)

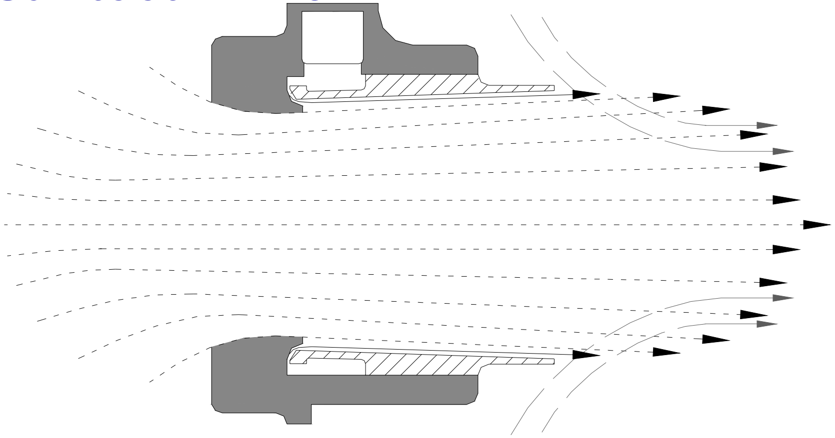
INTER-LAYER MIXING DEVICES



Sawtooth Mixer



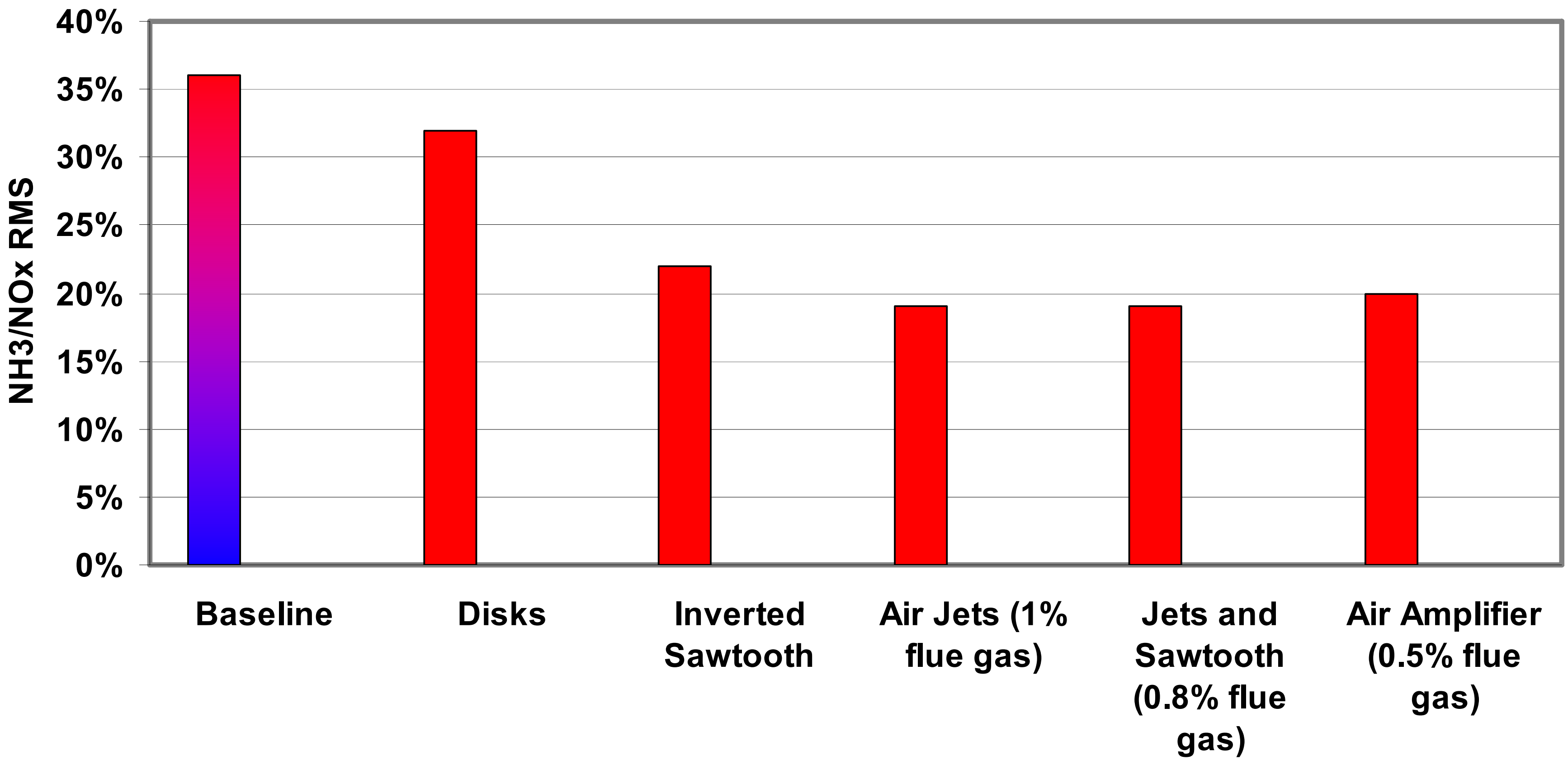
Disk with Smoke



Air Amplifier

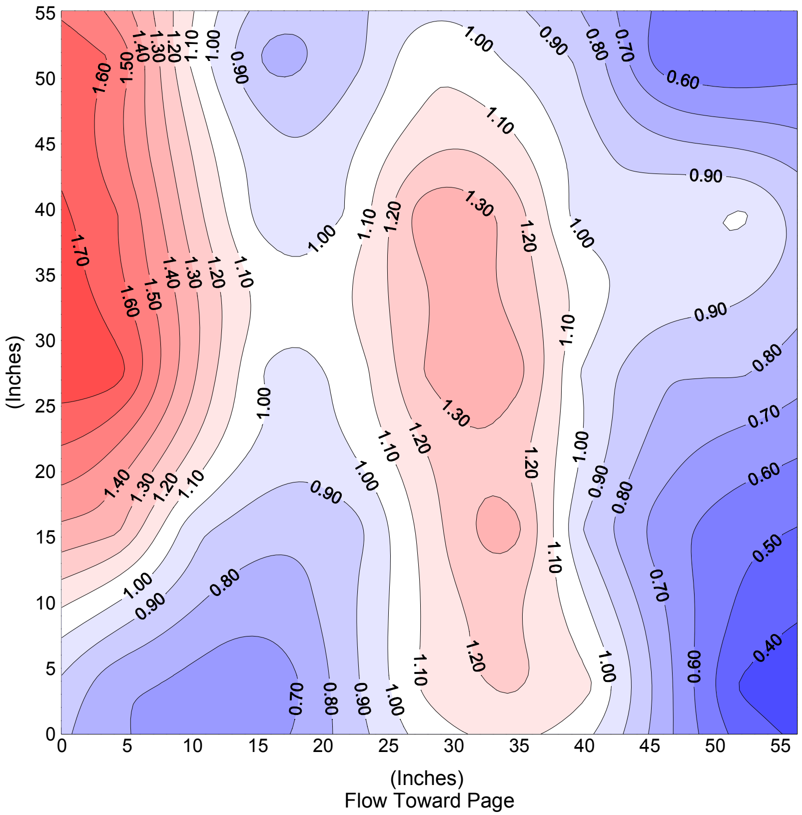
RESULTS

Air Amplifiers were most effective

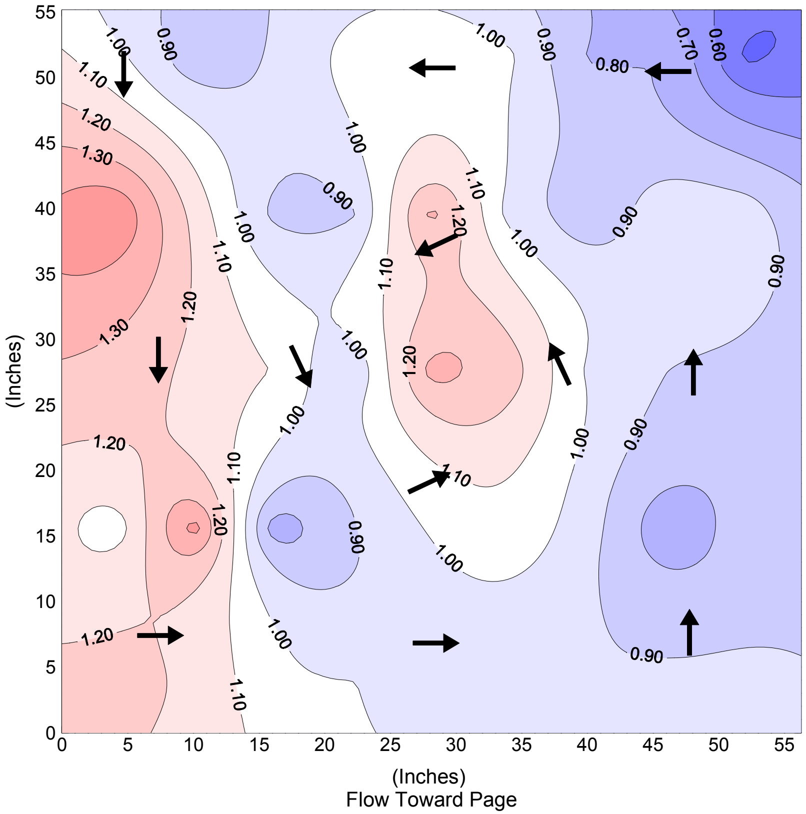


Inter-Layer Mixing

Air Amplifier Results



Normalized Baseline Tracer Gas Profile, Catalyst Layer #2 Inlet, RMS = 30%



Air Amplifiers: (denoted with arrows) RMS = 19%

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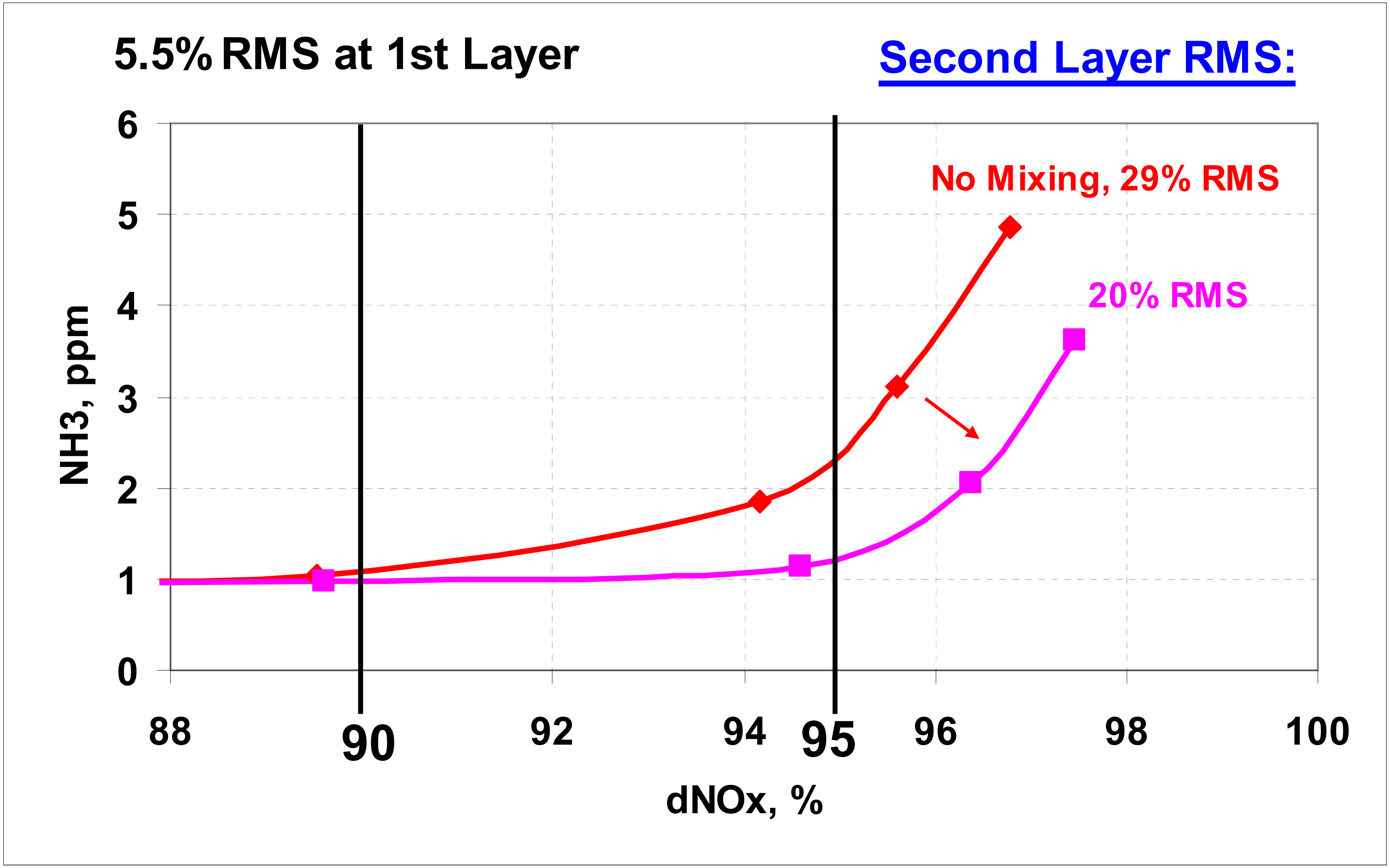
Air Amplifiers for Mixing

- **Air Amplifiers currently provide best results:**
  - ✓ Lower percentage of introduced air into flue gas
  - ✓ No associated pressure losses
  - ✓ Little/no expected ash deposition – under investigation
  - ✓ Can be turned off/down when not needed

- **Potential Issues:**
  - ✓ Plugging – maintain air flow, easy removal
  - ✓ Erosion – use better materials, replaceable
  - ✓ Catalyst Erosion – add a flow rectifier

SCR PERFORMANCE IMPROVMENTS

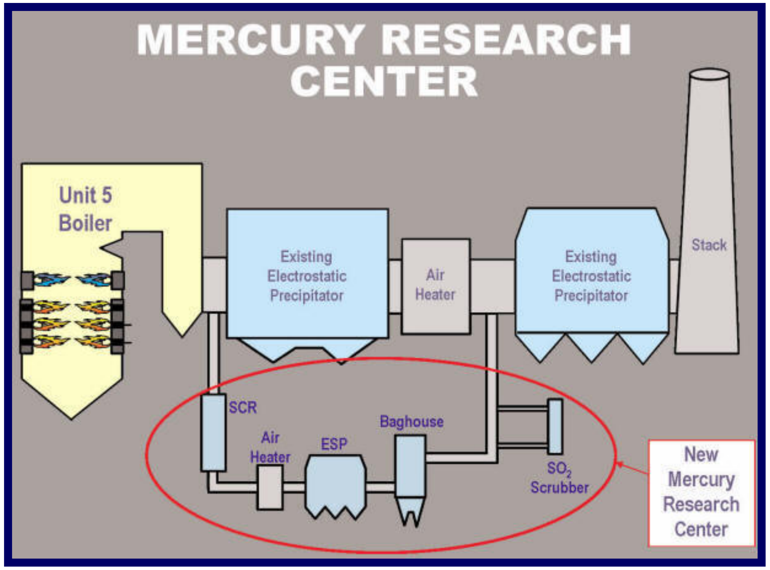
With 30% improvement, increase of dNOx from 90 to 95% at 1 ppm slip.



Inter-Layer Mixing

Pilot Scale Demo 2007

- **Mercury Research Center (MRC) at Gulf Power's Plant Crist (Pensacola, FL)**
- **Pilot Scale SCR Reactor**
  - ✓ **5 MW system**
  - ✓ **2 m x 2 m cross section**
  - ✓ **3 catalyst layers**
- **Test Plans:**
  - ✓ **Install 6-12 small scale amplifiers upstream of 2nd layer**
  - ✓ **Control NH_3/NO_x inlet distribution**
  - ✓ **Evaluate a series of mixer configurations**



Inter-Layer Mixing

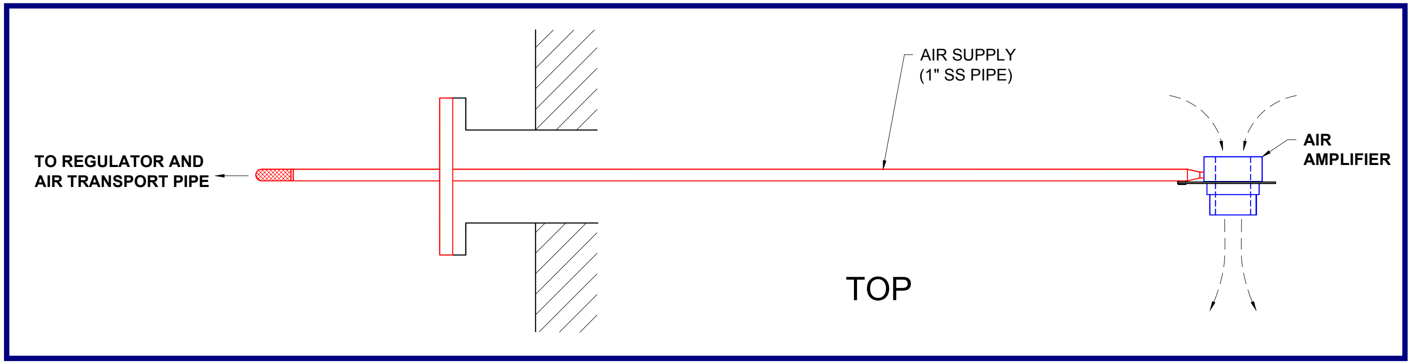
Full Scale Investigation of Mixer Erosion and Pluggage

- Georgia Power's Plant Bowen (Cartersville, GA)
- 2006: installed one full scale air amplifier to monitor erosion and plugging potential
- Amplifier located between 3rd and 4th catalyst layers
- No impact on SCR system
- Amplifier powered with approx 50 scfm at 80 psig during test period (expected about 1 month)
- No SCR performance data to be collected
- (SCR currently offline)

Inter-Layer Mixing:

Full Scale System

- **Design Basis:**
  - ✓ 500 MW unit with twin 36' x 36' SCR reactors
  - ✓ 10 air amplifiers per reactor (20 total)
- **Air Amplifiers:**
  - ✓ 5 inches max. dimension (require 8" port)
  - ✓ Weight: 9 lbs
  - ✓ Air Flow: 50 scfm at 80 psig (each)
    - ✓ *1000 scfm minimum for total system*
    - ✓ Total air flow is equivalent to about 0.1 to 0.2% of total flue gas flow rate
  - ✓ $1000 per air amplifier (stainless steel)
    - ✓ Support assembly should allow for easy removal/replacement



Inter-Layer Mixing:

Full Scale System

- **Compressed Air System:**
  - ✓ 1100 to 1600 cfm at 100 psig
  - ✓ 250-350 hp rotary screw compressor
  - ✓ $100-$300K depending on the compressor type and location
    - SCR platform (5 tons) vs. basement
    - Indoors vs. outdoors (ambient conditions)
    - Oil free?
    - Dryer Type (refrigerated vs. desiccant)
- **Piping Distribution System:**
  - ✓ Length/insulation depends on placement of compressor
  - ✓ Air manifold
  - ✓ Each air amplifier will require a filter, regulator, and (possibly) pressure taps (to measure flow)

Inter-Layer Mixing:
Cost Estimate for Full Scale Implementation

- **Initial Estimate:**
  - ✓ **Capital Cost: $300-$500K**
    - **Compressor, Piping, Amplifiers, Engineering, Installation**
  - ✓ **For a 500 MW unit → $0.60 to $1.00 per kW**
    - **Putting it in perspective: a complete SCR system retrofit costs $100-$150 per kW (on average)**
- **Average annual savings of $185K (ozone season) or $330K (annual operation)**
  - ✓ **Savings result from cost of NO_x credits**
    - **Yields 3-5% higher NO_x reduction**
  - ✓ **Incremental costs:**
    - **Minor increase in reagent costs (3-5%)**
    - **Cost of Compressor O&M**

In Situ Device for Real-Time Catalyst Deactivation Measurements*

- **Principal Investigators**
  - **FERCO:** R. Smith, L. Muzio
  - **Southern Company:** K. Harrison
  - **DOE/NETL:** C. Miller
  - **EPRI:** D. Broske

* Patent Pending

* Development Sponsored by:
  DOE/NETL
  EPRI
  Southern Company

In Situ Measurement of Catalyst Deactivation – Why?

- The in situ technique allows measurement of catalyst activity at any time the SCR is in operation
- For year-round operation, opportunities for physical catalyst sampling will be extended to 12 to 18 months
- The in situ technique can fill the information gap between laboratory analysis opportunities, thus providing a larger and more complete set of deactivation data from which to base catalyst management decisions
- The in situ technique should not be thought of as a replacement for laboratory analysis of catalyst samples, but as a companion measurement
- The in situ technique can monitor low load operation

Measuring Catalyst Activity

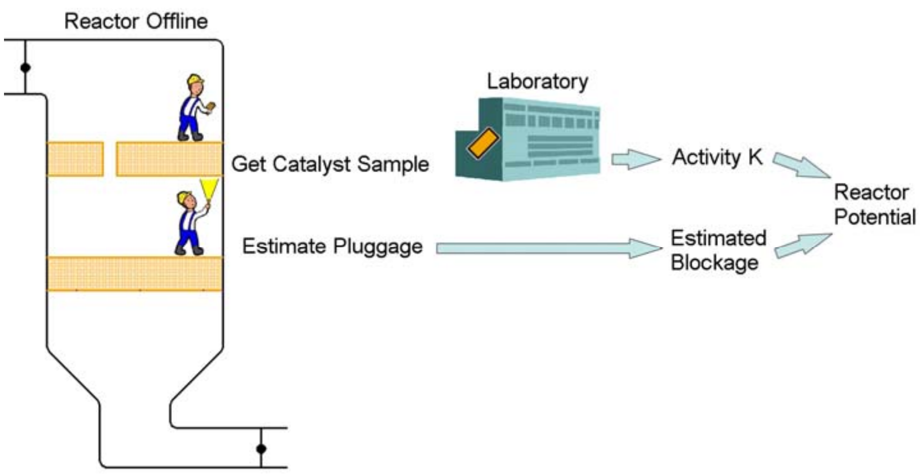
Laboratory:

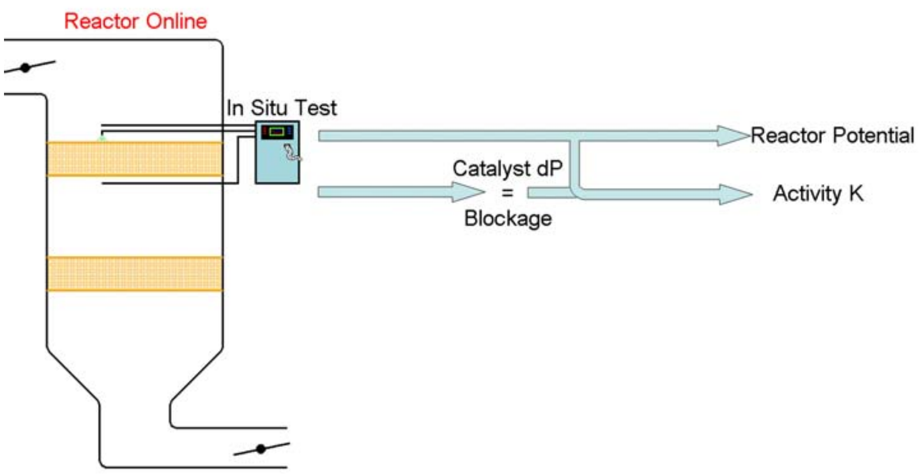
- Test Conditions:
  - A_{Vd} = Design Area Velocity
  - $NH_3/NO_x = 1$
- Measure:
  - ΔNO_x
- Calculate:
  - $K = -A_{Vd} \ln(1-\Delta NO_x)$
  - $RP = \frac{K}{A_{Vd}}(1-B)$

In Situ:

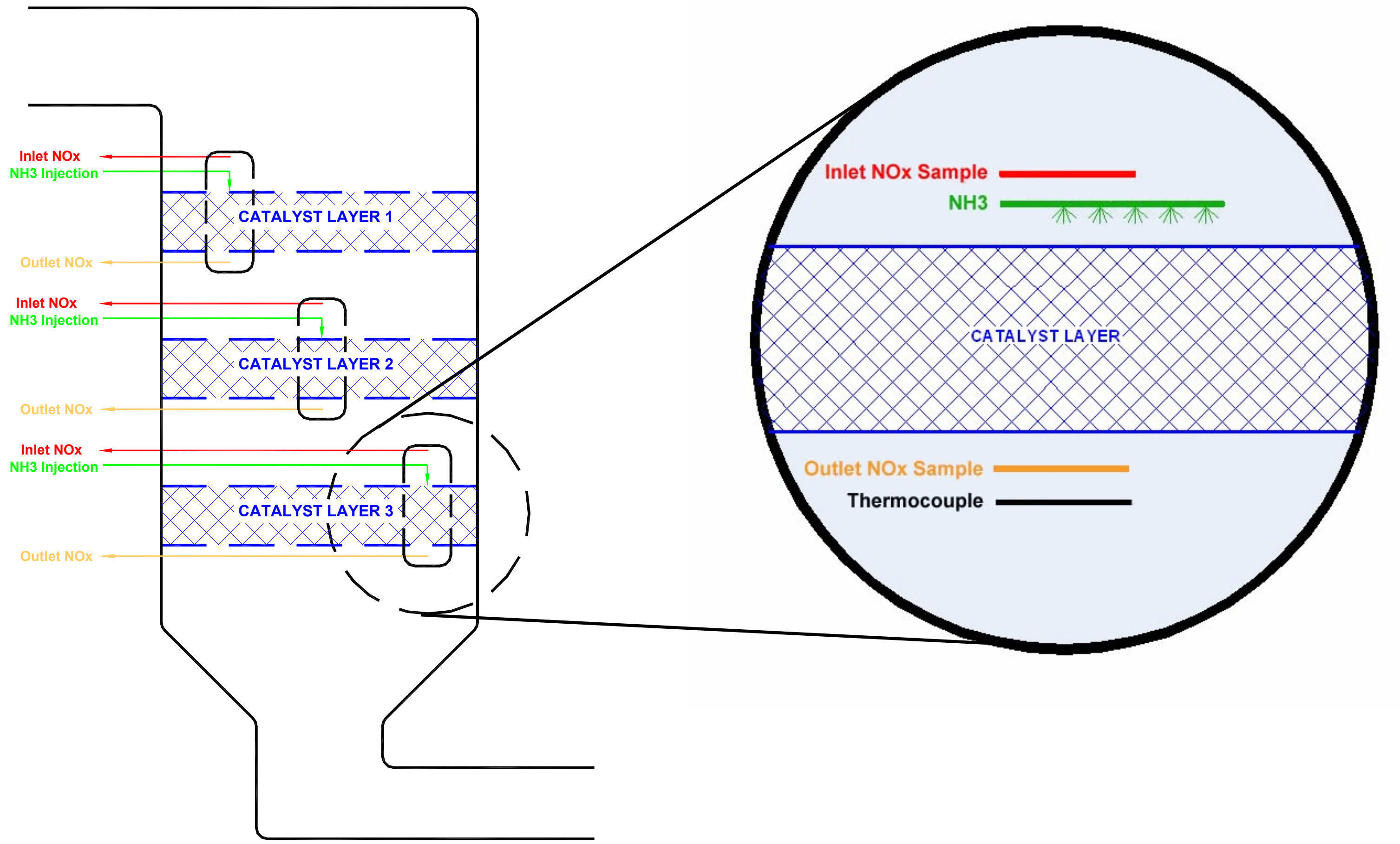
- Test Conditions:
  - $A_{V,FS}$ = Full-Scale Area Velocity
  - $NH_3/NO_x > 1$

  (NH_3 added only in test sections)
- Measure:
  - ΔNO_x
- Calculate:
  - $RP = K/A_{V,FS} = -\ln(1-\Delta NO_x)$





Multiple In Situ Test Modules - General Approach

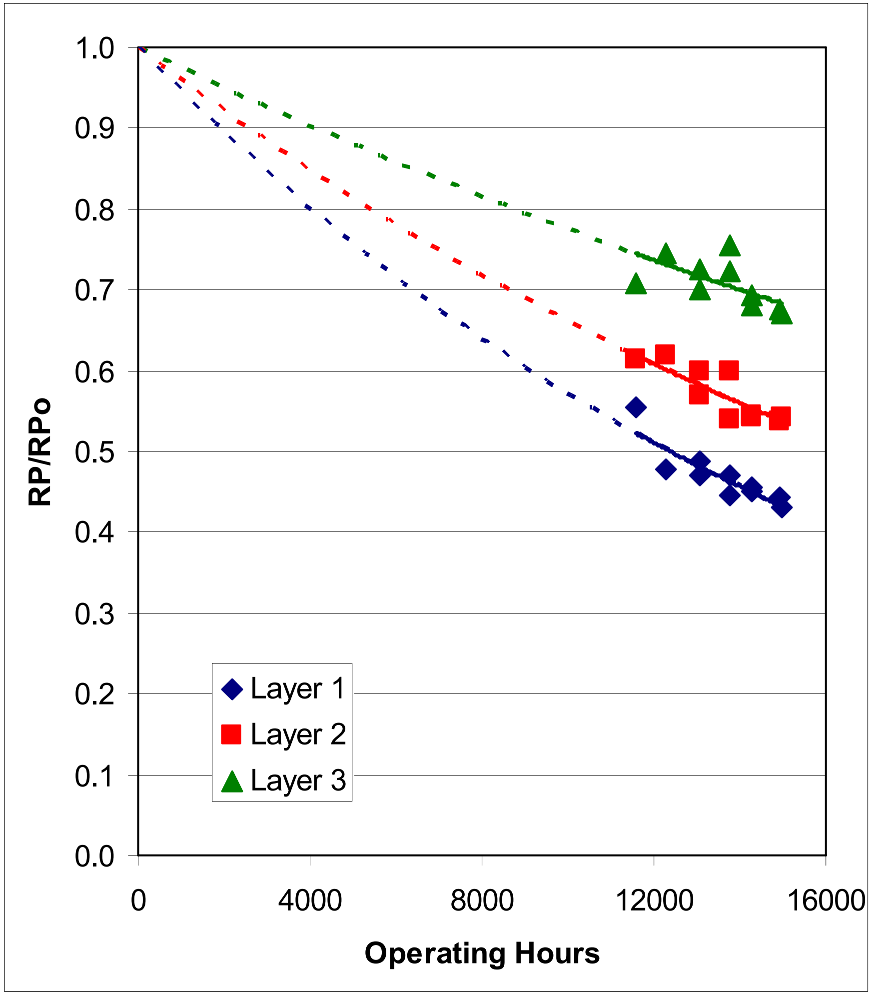


Demonstration Host Site Provided by Southern Company

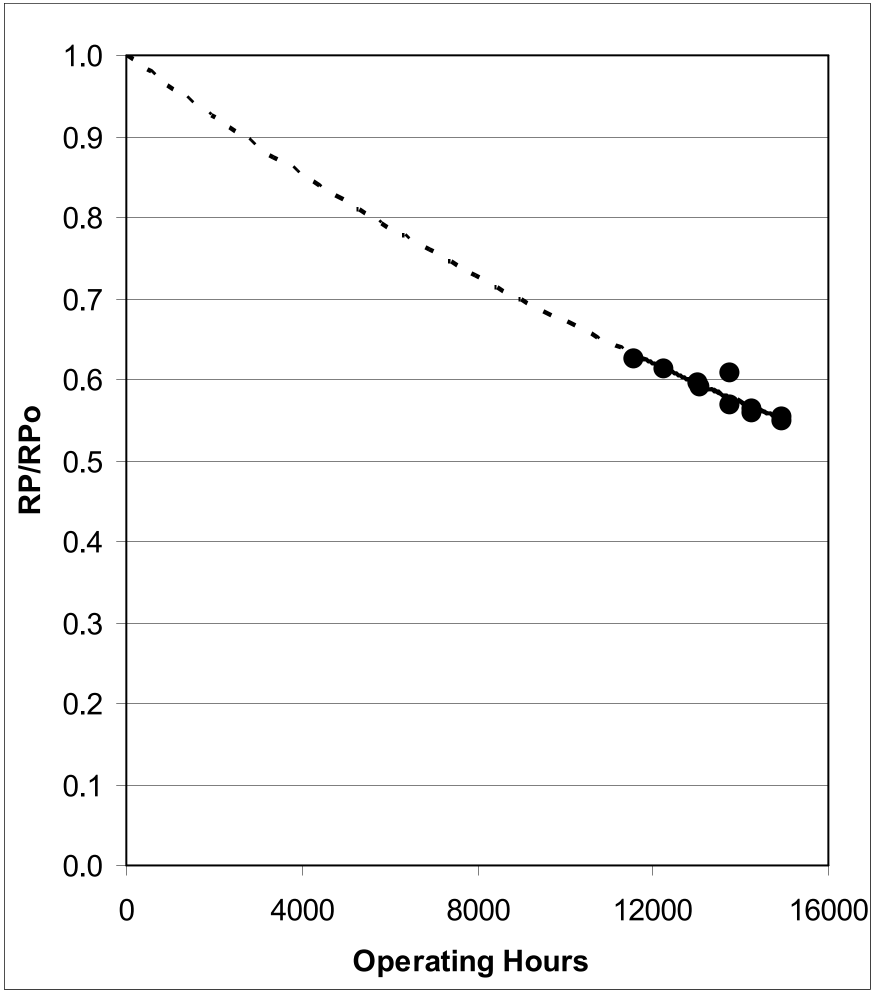
- Alabama Power Company's Gorgas Unit 10
  - 700 MW
  - Alabama bituminous coal
- SCR on-line May 2002
  - Seasonal operation
  - Two reactors
  - 3 + 1 configuration
  - Initial load: 3 layers honeycomb catalyst
  - Fourth layer plate catalyst added prior to 2006 ozone season

In Situ Reactor Potential Results - 2005

Individual Layers



Overall Reactor



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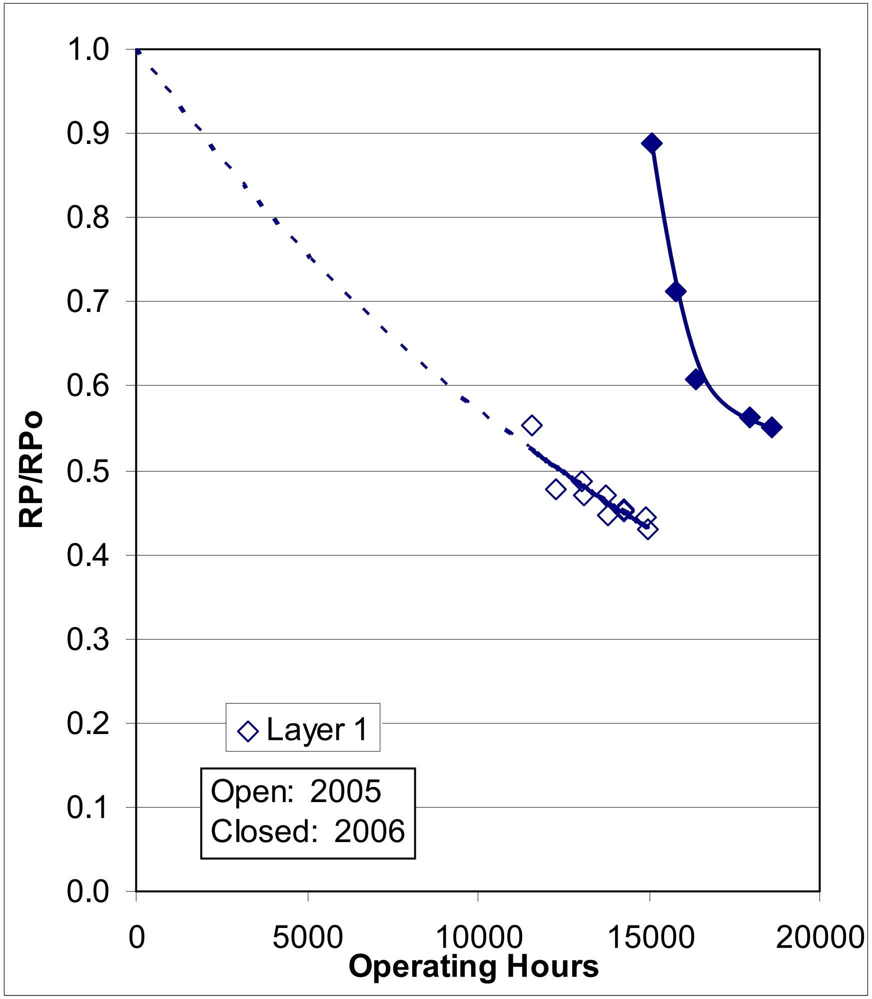
In Situ Reactor Potential Results – Layer 1

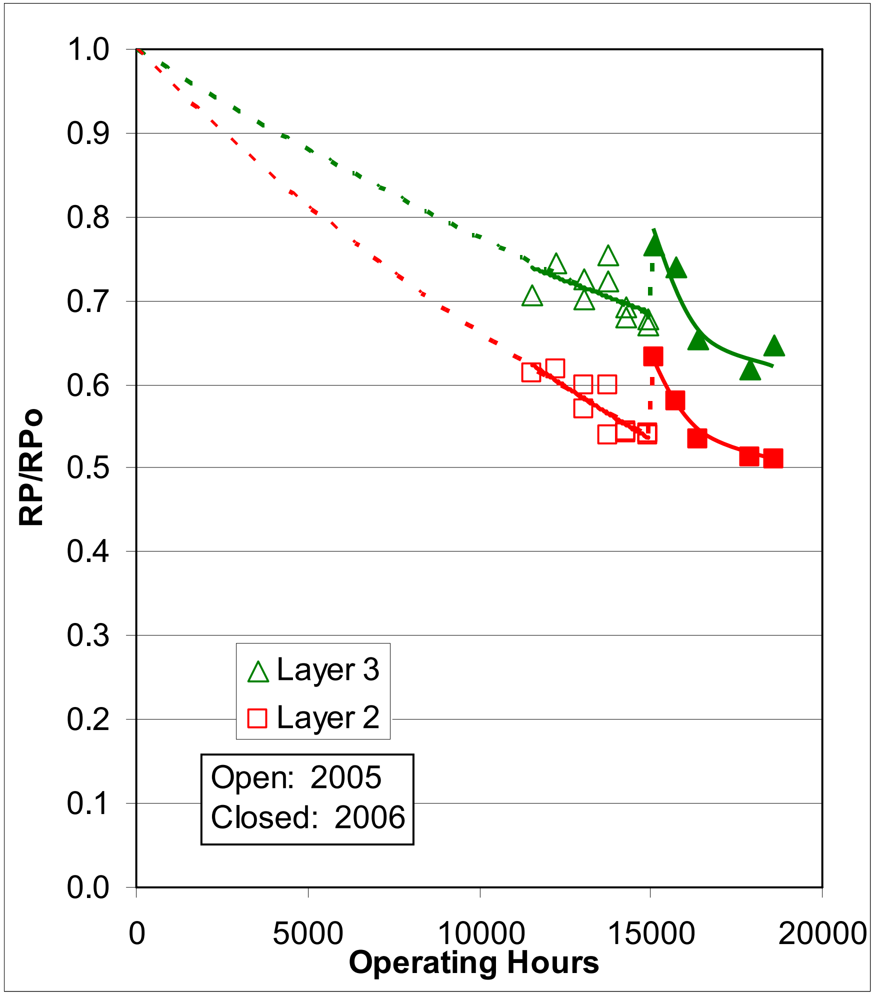
New Catalyst Material Installed before 2006 Ozone Season



- **Rapid decline early in 2006 season due to soot blower non-operation issues**
- **Boiler-side soot blowers for Layers 1, 2 and 3 OOS for 80 to 100 days through August**
- **Loss of reactor potential likely due to catalyst plugging, not true catalyst deactivation**

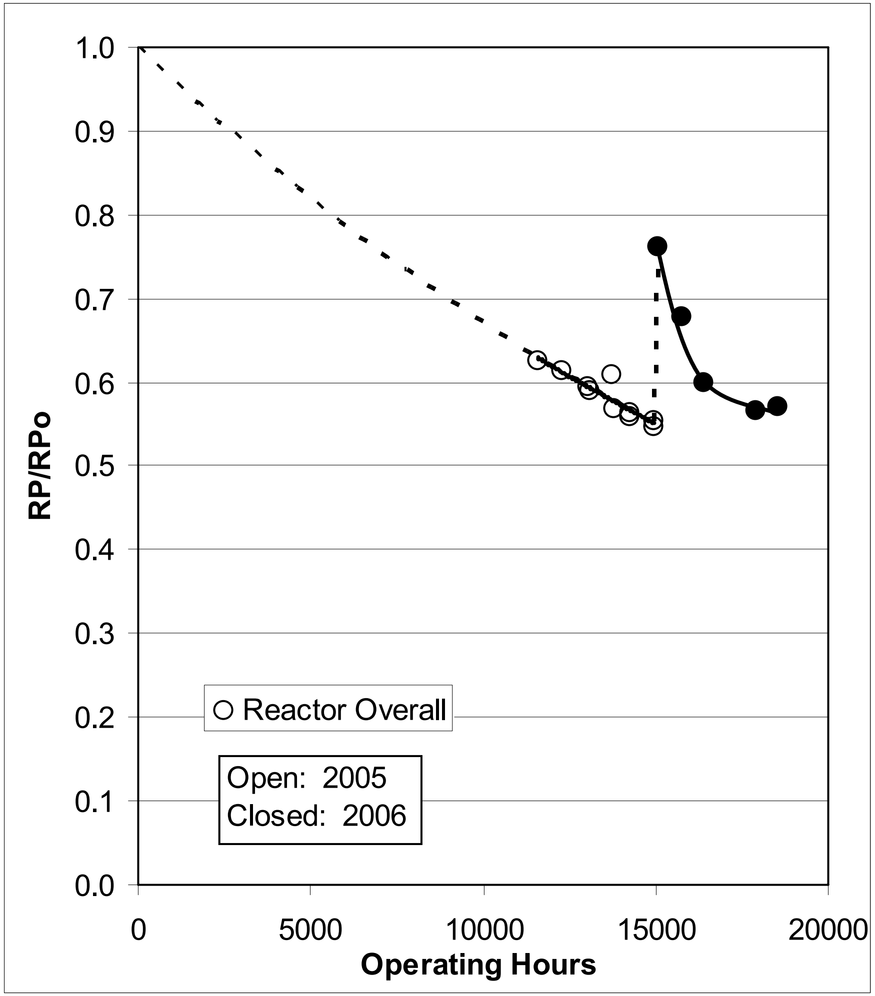
In Situ Reactor Potential Results - Layers 2 & 3

Same Catalyst Material for 2005 and 2006 Ozone Seasons



- **Rapid decline early in 2006 season due to soot blower non-operation issues**
- **RP at the start of 2006 is close to that at the start of 2005**

In Situ Reactor Potential Results – Overall Reactor

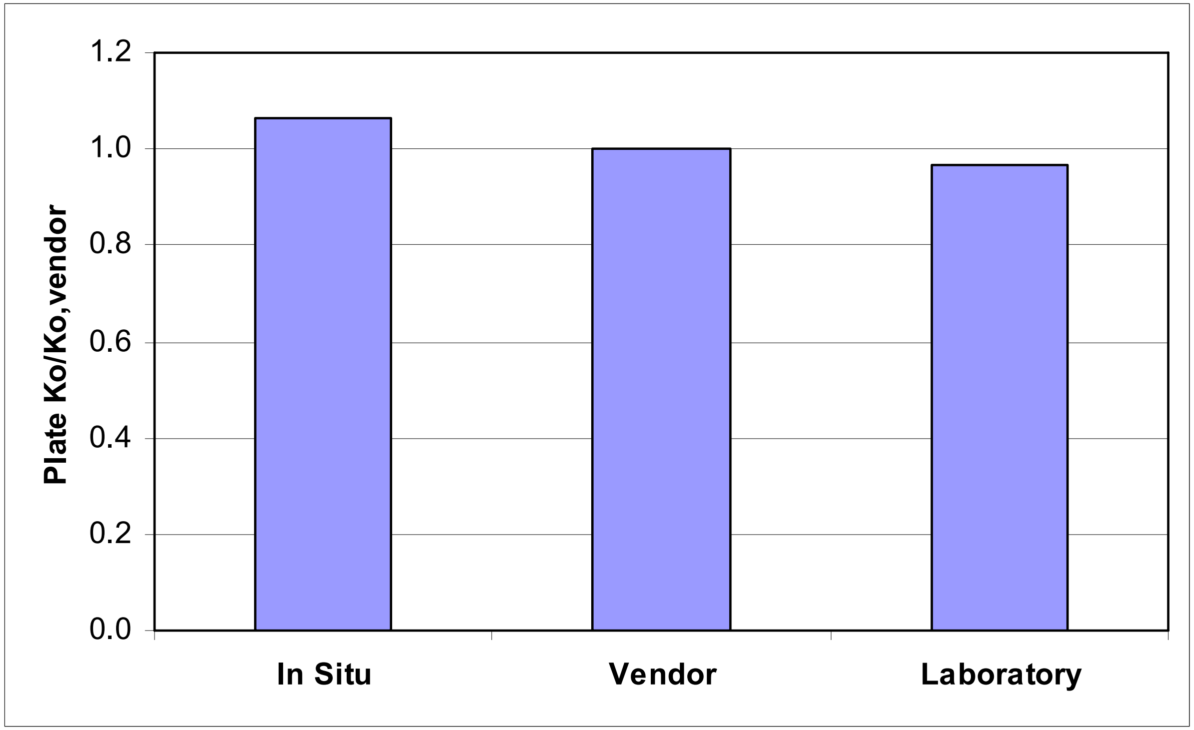


- **New layer 1 material and vacuuming of others resulted in 38% increase in overall RP**
- **Rate of 2006 RP decline after soot blower issues resolved is similar to rate seen throughout 2005**

Comparison of In Situ and Laboratory K Values

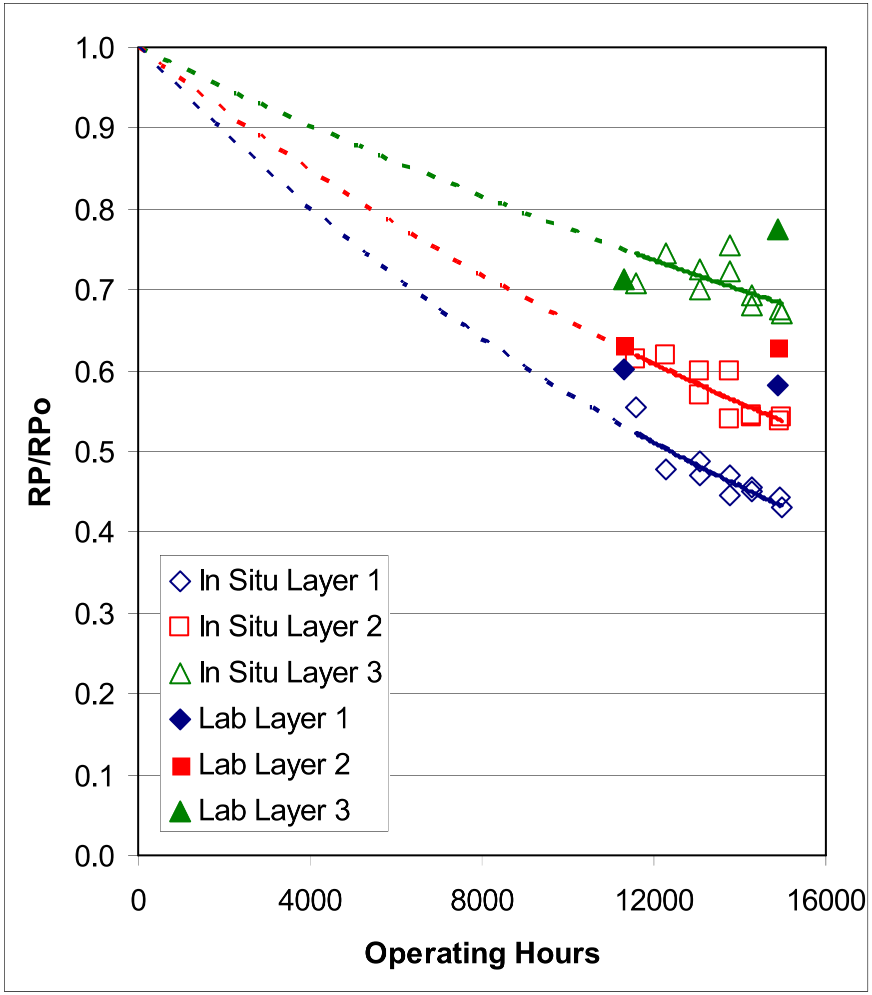
The validity of the relationship between "In Situ RP" and "Lab K" can be assessed by calculating K_0 for the new Layer 1 plate catalyst and comparing the value to the vendor's own value.

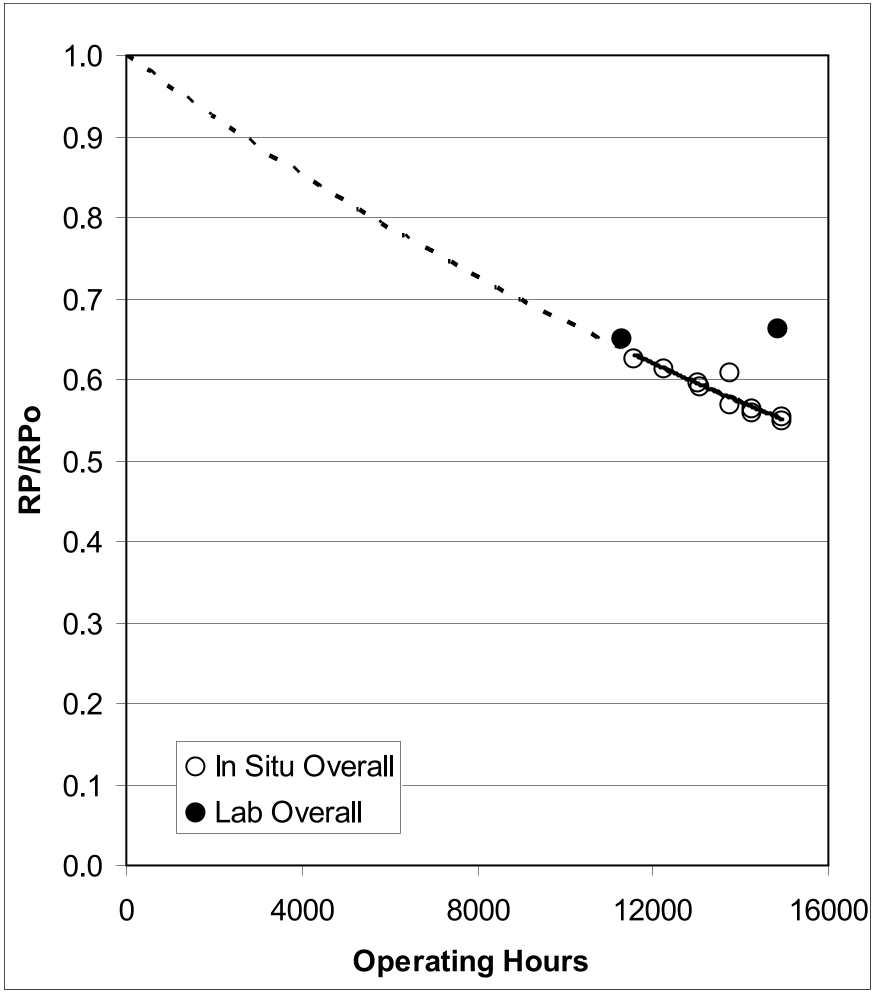
- K_0 for this material may be calculated from the first set of In-Situ Reactor Potential measurements performed in 2006
- $K_0 = \frac{RP_0 A_{V,cln}}{(1-B)}$



Comparison of 2005 Laboratory and In Situ RP Values

Laboratory Reactor Potential = $K(1\text{-}B)/A_{V,cln}$





Why do the In Situ and Laboratory RPs Differ?

Laboratory technique measures K at the design A_V

- **Estimated blockage needed to calculate RP may be in error**
- **Actual full-scale flue gas flow may differ from the design flow**

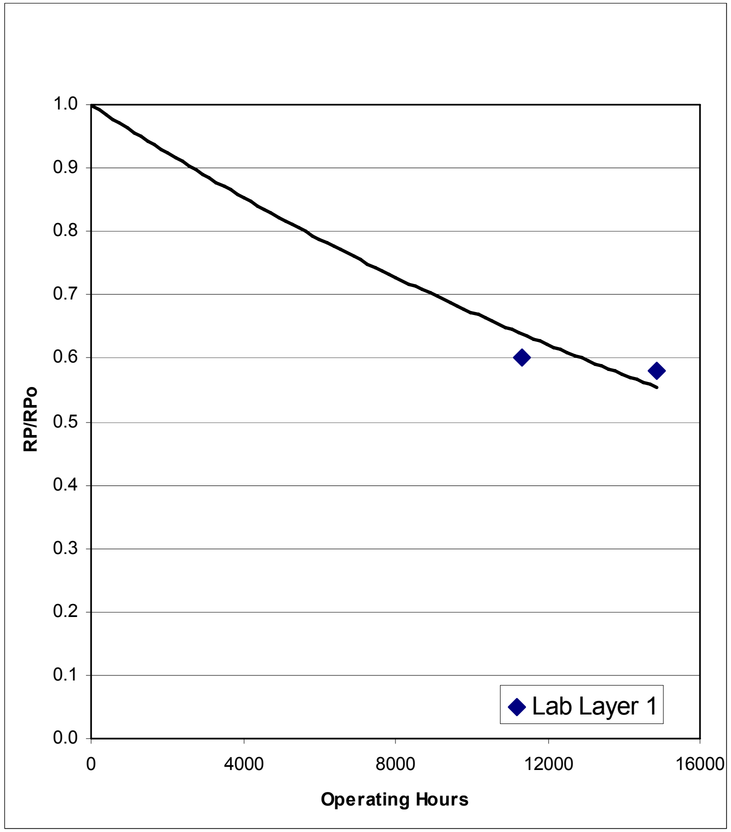
In Situ technique measures RP for the same piece of catalyst

- **Laboratory uses a different piece for each test**
- **Possible variations in K across the catalyst layer**

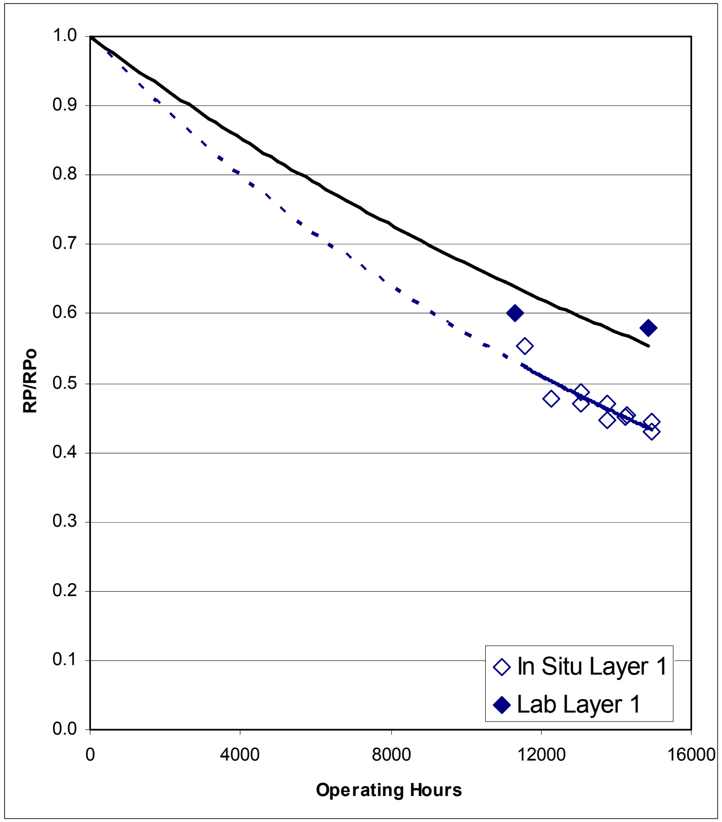
Operating Hours	K/K_0 Layer 1	K/K_0 Layer 2	K/K_0 Layer 3
11317 (end 2004)	0.71	0.75	0.79
14870 (end 2005)	0.80	0.78	0.90

Larger Data Set Means More Accurate Predictions: Layer 1

Lab Predictions

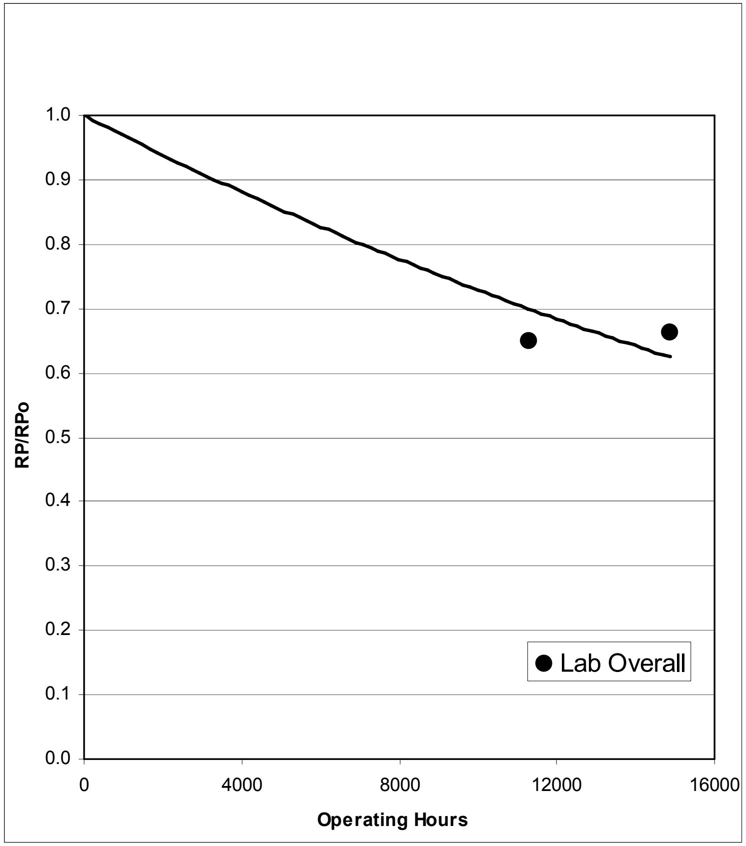


Insitu Predictions

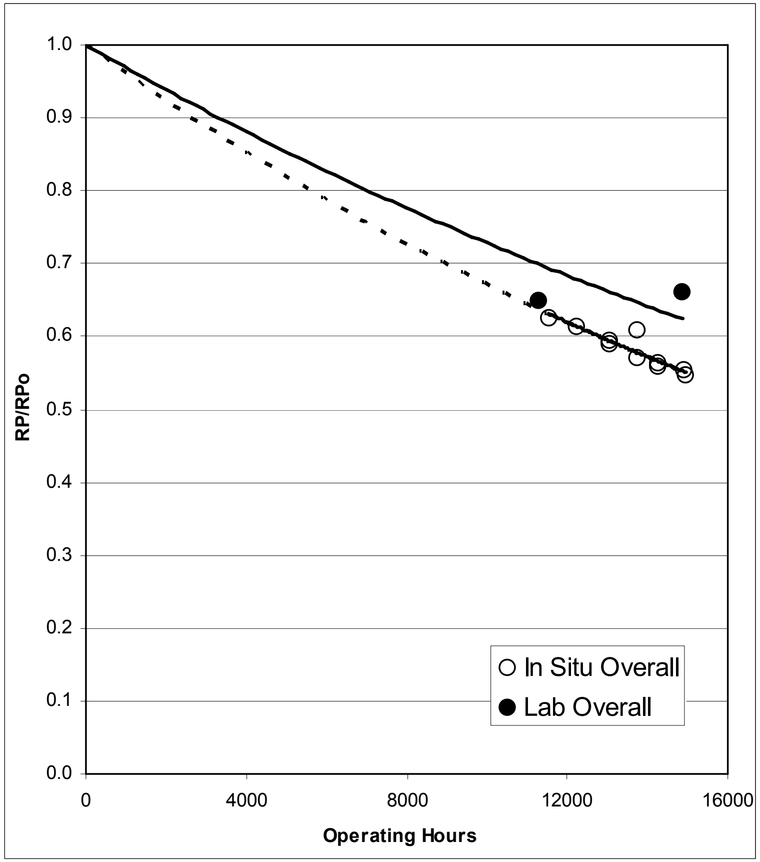


Larger Data Set Means More Accurate Predictions: Overall Reactor

Lab Predictions



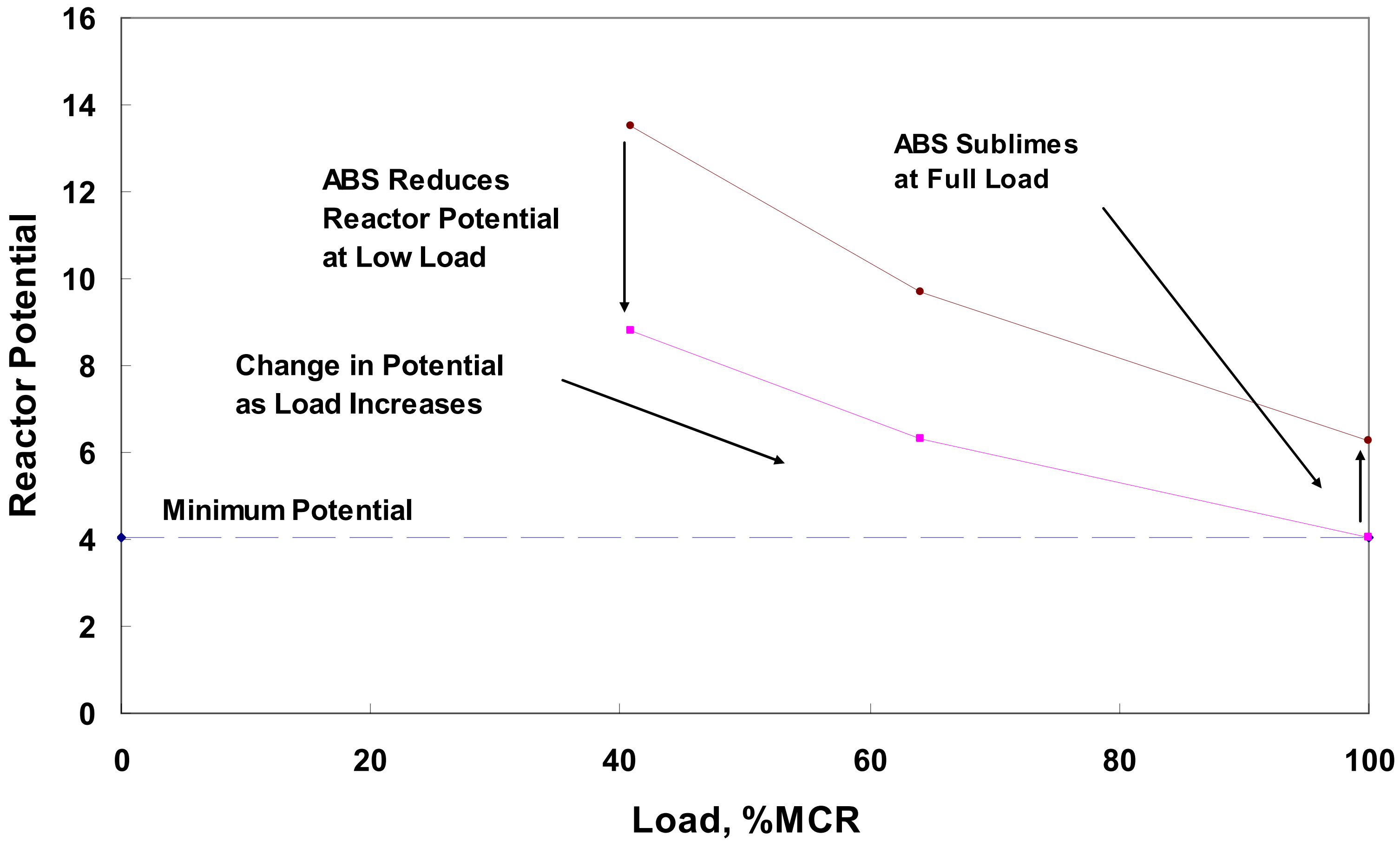
Insitu Predictions



Additional Benefit: Low-Load Operation

- At temperatures below MOT:
  - ABS formation
  - Loss of catalyst surface area
  - Reduction in catalyst activity
- At full-load operating conditions, ABS will sublime, leading to a restoration of catalyst activity
- The extent of catalyst activity recovery will be a function of temperature and cycle duration
- In Situ deactivation measurements would allow the real-time tracking of catalyst activity reduction and restoration

ABS Accumulation Decreases Reactor Potential



Summary

- In situ system provided:
  - Real-time tracking of reactor potential
  - Tracking of each catalyst layer independently
  - Larger deactivation data set (not limited to outages)
- 2006 RP data clearly showed the effect of soot blowers being out of service early in the season
- Results indicate RP decrease for Layers 2 and 3 in 2005 may be primarily due to catalyst plugging, not deactivation
- The in situ technique should not be thought of as a replacement for laboratory analysis of catalyst samples, but as a companion measurement
- The insitu device can track Reactor Potential while operating below the "Minimum Operating Temperature"

Commercial System – Available 2007