REINHOLD ENVIRONMENTAL Ltd.

2015 NOx-Combustion Round Table & Expo Presentations

February 23 & 24, 2015, in Richmond, VA / Hosted by Dominion

2015 Reinhold NOx Conference
Part I – Perspectives on Hg Testing

February 24, 2015

www.jmsec.com

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Flashback to 2013 NOx Conference

- Mercury Oxidation over the SCR based on many conditions
- Mercury Oxidation can be transient – not only over the SCR but through the entire system
  - Age effects
  - Boiler/Fuel effects
  - Flow, Temperature, Flue gas variations
- NOx reaction and Hg reaction compete
- Mercury oxidation over SCR for some plants will naturally be very good, other plants may have to enhance mercury oxidation or use alternate mercury capture methods
- Lab testing protocol and subsequent correlation to field performance are not currently available - How far have we come in two years?

Intro

- The SCR industry is in need of guidance as it relates to the current status of mercury lab testing
- NOx testing has been performed via lab testing for decades, can the industry get there with mercury? Can all the SCR system owner's expectations be met?
- Objective: Present three perspectives on mercury lab testing/catalyst management
  - Part I – Johnson Matthey
  - Part II – Duke Energy and Steag
- Secondary objective for Part I – provide users more tools and guidance related to mercury oxidation

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Agenda

- Review the current state of the mercury lab testing
  - Third Party Testing Overview
  - Test Protocol Development
- Explore different mercury lab testing strategies
  - Comparing Catalysts
  - Representing Field Performance
  - Surveillance Testing
- Provide update and recommendations for SCR system owners

State of the Industry

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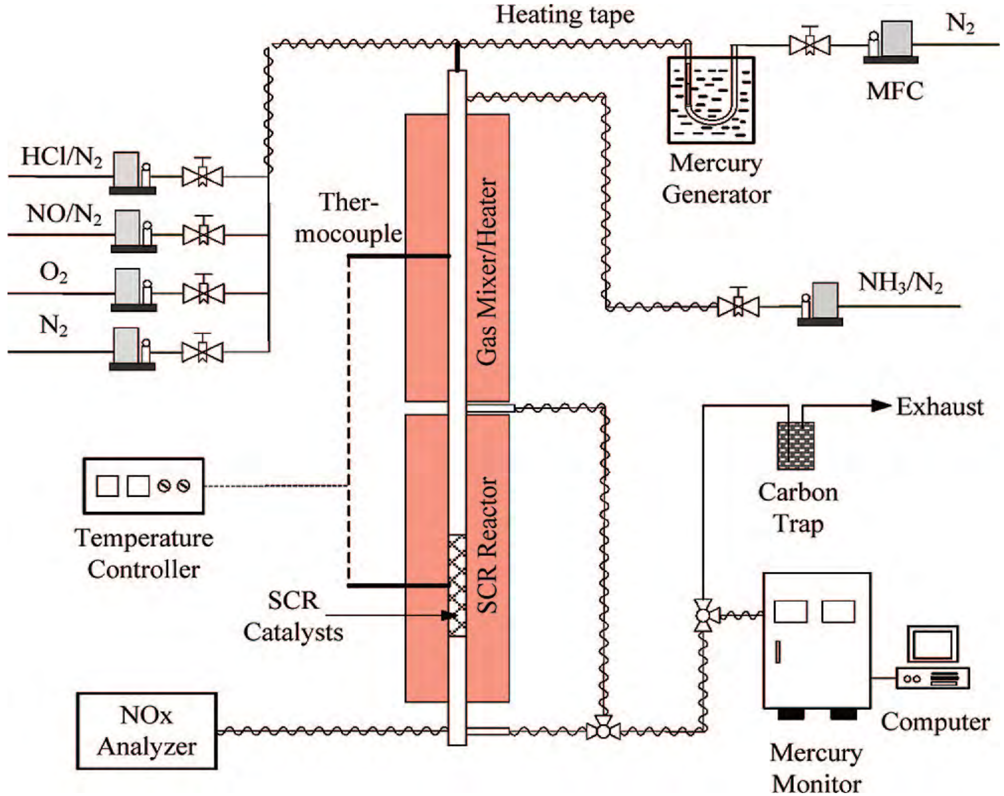
Hg Oxidation Lab Testing

- Potential use
  - Parametric studies
  - Catalyst screening
  - Catalyst surveillance
  - Guarantee testing
- Requirements of the test is dependent on the objective
- With currently available rigs, there are often volume to area scaling issues



Representative Lab schematic

Source: He et al. (2009)

Current Third Party Labs Operating

- Developed for commercial purposes
  - Southern Research Institute
    - Type - Micro
  - Steag
    - Type - Micro
  - Eon Germany
    - Type - Micro
- Developed for Research Purposes
  - IFK – various sizes, typically micro
  - EPRI (AECOM) – Semi Bench

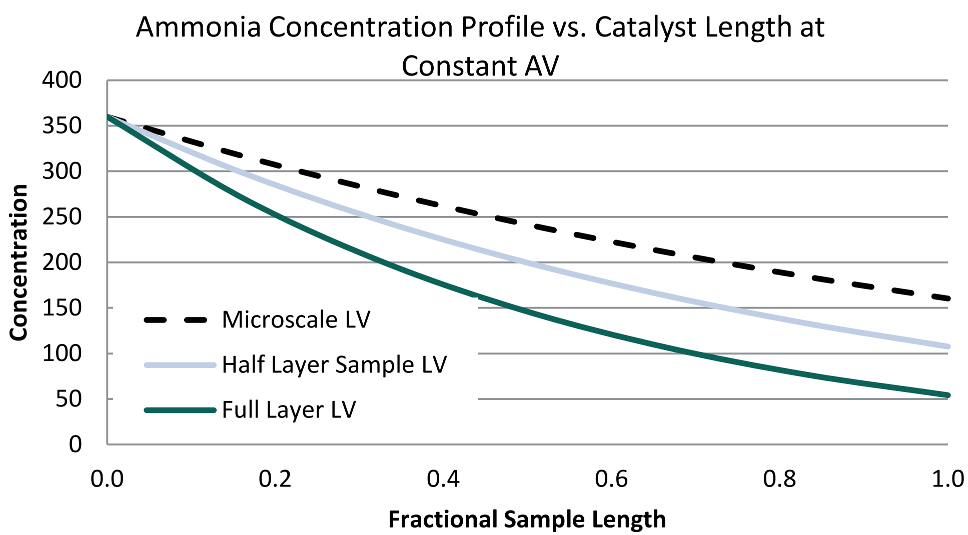
EPRI Definitions of lab types:

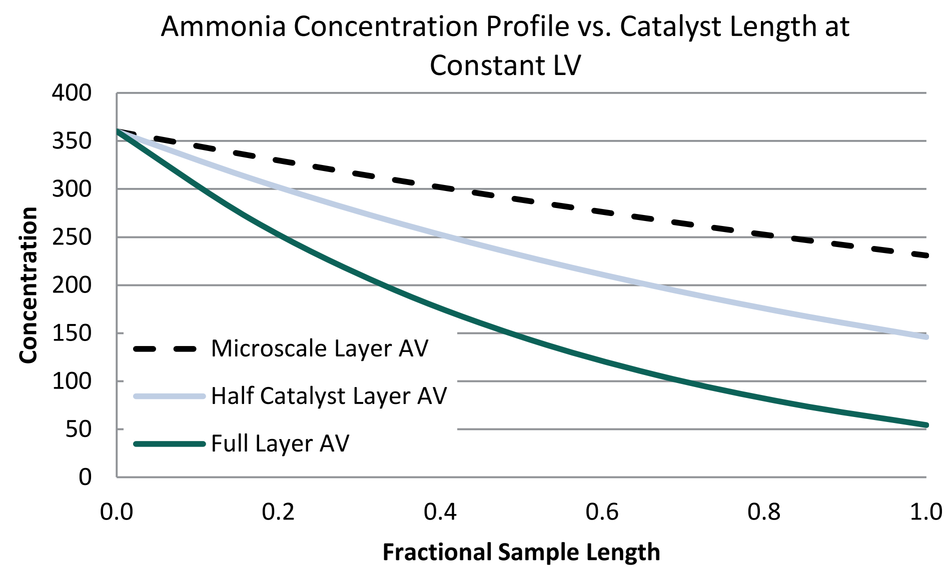
- Full Bench – 150 mm x 150 mm
  - Large scale apparatus capable of maintaining both AV and LV of the field catalyst
- Semi Bench
  - Mid scale apparatus capable of maintaining both AV and LV of the field catalyst
- Micro
  - Small scale apparatus not capable of maintaining both AV and LV of the field catalyst

Relationship between AV, LV and Ammonia Profile

- Matching the ammonia profile in lab reactors can be difficult
  - Full layer area velocity (residence time) and linear velocity can not always be matched simultaneously
  - NOx activity dependent on linear velocity, not area velocity
  - Ammonia Profile dependent on area velocity and linear velocity
- Desired to have boundary conditions (inlet NH3 concentration and outlet NH3 concentration) as close to field as possible
- What about mass transfer if LV is different than the field?

Constant AV vs. Constant LV



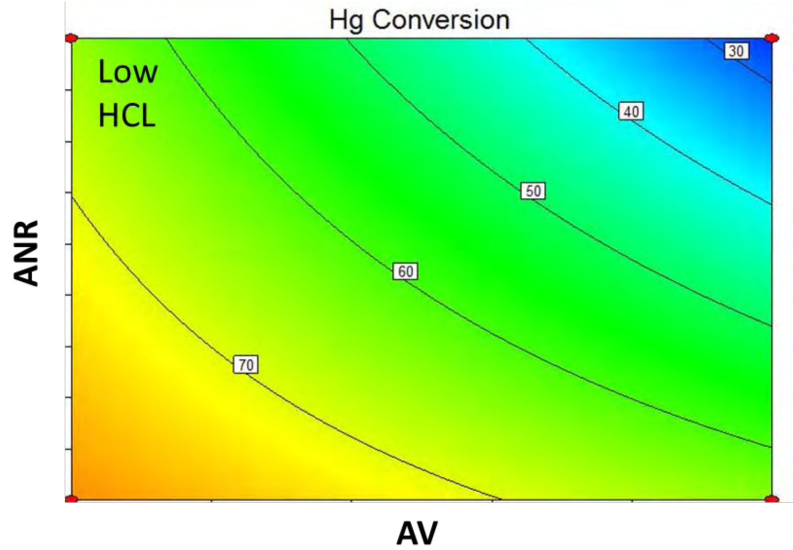


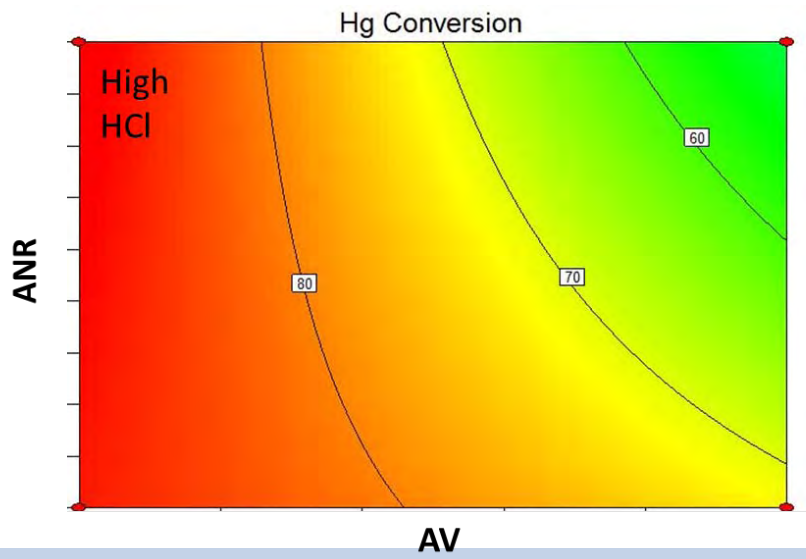
Possible Hg lab testing strategies

Correcting from micro to full layer

Test at field LV and correct for AV (or test at field AV and correct for LV) using known relationships

- Pros
    - Theoretically easier to implement
    - Less expensive
- Cons
    - Requires interpolations/extrapolations
    - No industry standard corrections available, does it depend on catalyst type/geometry?
- Further work required to implement
    - Corrections would have to be developed
    - Benchmarking versus full layer results required





Possible Hg lab testing strategies

Correcting from micro to full layer

Multiple tests for each layer

- Test maximum catalyst length at the field linear velocity
- Measure outlet ammonia, NOx and mercury values
- Change inlet setpoints to previous outlet values and repeat test
- Continue until full catalyst length was tested

- Pros
  - Better matching of ammonia profile
  - Provide value closer to expected field value
- Cons
  - More complex and expensive testing
  - Propagation of measurement errors possible
  - For micro reactors, matching field LV could provide low Hg oxidation numbers
- Further work required to implement – verify multiple tests provide same result as full layer test

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Protocol Development

- EPRI in final stages of releasing a Hg lab testing protocol
  - Current Target Release Date is March
- Objective – Develop a utilitarian protocol for the testing of SCR catalyst for mercury oxidation in the laboratory, considering multiple apparatus (Hinton, Martz, MEGA Proceedings 2014)
- Major steps made in regards to:
  - Quality control of rigs– allowable drift and deviation from target values defined
  - Requirements for catalyst equilibrium times
  - Standard test condition for mercury testing
- While a good first start, at least two open items:
  - Correlation to field performance
  - Catalyst surveillance testing strategies

Other EPRI Tasks related to Mercury

- Impact of operating conditions on mercury oxidation
- Full-Scale Interlayer speciation testing
- Long Term performance of OEM and regenerated catalysts
- Modeling of SCR mercury oxidation
- Database of SCR field and large pilot mercury oxidation performance

Lab Testing – Predicting Field Performance

- NOx reduction
  - Lab testing can be used to predict field performance
- SO_2 to SO_3 oxidation
  - Lab testing can not be used to predict field performance
    - Fly Ash adsorption of SO_3 in field
    - NH_3 reaction with SO_3 to form ABS
- Hg Oxidation
  - Applicability to field performance still being determined, no industry consensus
  - Trace oxidation species and ash effects will continue to prove difficult

Potential Options for Predicting Field Performance

- Option 1 – Test at standard condition, use correction curves/model
- Option 2 – Test at exact conditions for all flue gas species that are believe to impact Hg oxidation
  - Hg
  - NOx, NH_3
  - HCl, HBr
  - H_2O, CO, CO_2, O_2
  - SO_2, SO_3
- Option 3 – Test at a more limiting set of conditions, knowing that the result is conservative (similar to SO_2 oxidation testing)
  - Eliminate some of the harder species to handle, such as SO_3 and HBr
- All options will require some way to handle ash impact on Hg oxidation
- All options require more work to verify lab test results match field values

Catalyst management with Hg

- Hg activity/potential not analogous to NOx activity/potential
- Still possible to envelop all Hg oxidation rates with surveillance testing strategy

$$K_{Hg} = -AV * ln(1 - \eta_{Hg})$$

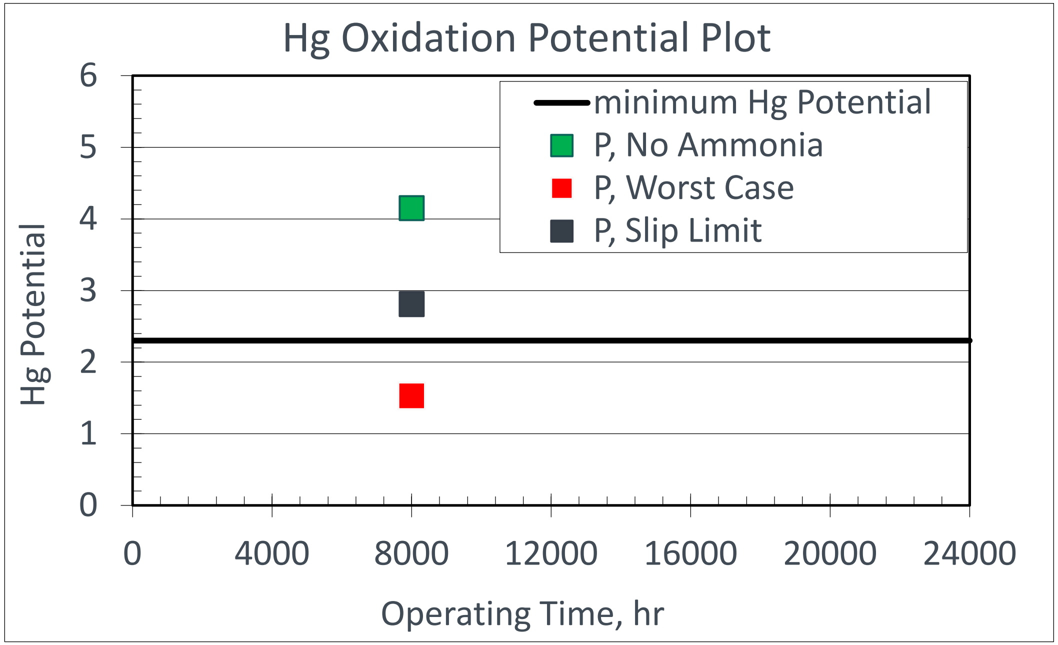
$$P_{Hg} = \frac{K_{Hg}}{AV}$$

$$P_{Hg,required} = -ln(1 - \eta_{Hg,required})$$

Surveillance testing example

- Assume 3 layers of same catalyst (age, type) for simplicity
- If only a simple envelop of the possible mercury oxidation rates is required, the follow strategy can be used
  - First, test all layers at the NH3/NOx levels seen at reactor inlet
  - Second, test all layers at the NH3/NOx = 0
- If more clarity is needed, use tested NOx activity values to determine layer by layer concentration profile
  - Determine mercury potential at this condition and compare with required potential

Calculations



At Inlet NOx and Ammonia

	AV	Hg Oxidation %	kHg	P
Layer 1	15	40	7.7	0.51
Layer 2	15	40	7.7	0.51
Layer 3	15	40	7.7	0.51
			Total	**1.53**

With No Ammonia

	AV	Hg Oxidation %	kHg	P
Layer 1	15	75	20.8	1.39
Layer 2	15	75	20.8	1.39
Layer 3	15	75	20.8	1.39
			Total	**4.17**

At Actual Conditions

	AV	Hg Oxidation %	kHg	P
Layer 1	15	40	7.7	0.51
Layer 2	15	60	13.7	0.92
Layer 3	15	75	20.8	1.39
			Total	**2.81**

SCR System Owner Guidance

Condition Development

When seeking mercury oxidation values from suppliers, be very specific with the conditions

- Absolute NOx and Ammonia values at the inlet to the layer(s)
- Absolute Cl, Br levels
- Lab value or field value
- Mercury oxidation definition

Leaving values up for interpretation can make comparisons between suppliers difficult

Aside - How to calculate HCl in flue gas:

$$HCl\ (ppmvw, actual\ O_2) = \frac{1000000 * \left[\frac{Cl\ in\ coal\ (wt\%)}{100} * fuel\ feed\ rate * \frac{HCl\ MW}{Cl\ MW}\right]}{Flue\ Gas\ Flow * density\ of\ HCl}$$

If Flue gas flow is in Nm^3/hr, fuel feed rate needs to be in kg/hr and density of HCl is 1.63 mg/Nm^3

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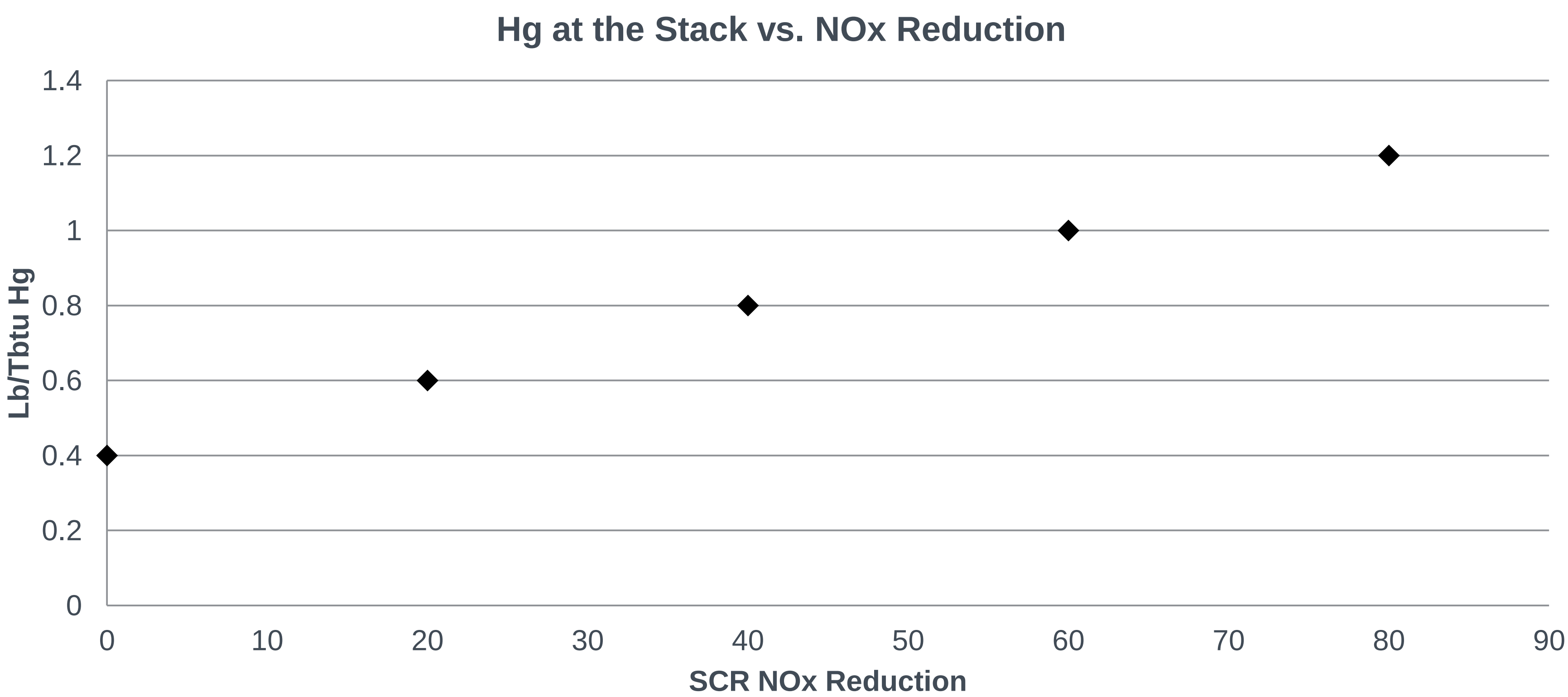
Why is condition development important?

Parameter	Test 1	Test 2	Test 3	Test 4
Temperature	700 F	700 F	700 F	700 F
NH3 (ppm)	100	100	20	20
NOx (ppm)	300	300	60	60
HCl (ppm)	30	35	30	35
SO_2 (ppm)	1500	1500	1500	1500

All other parameters constant, can see more than a 20% absolute Hg mercury oxidation difference between the high and low result

Operational advice to maximize Hg Oxidation



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Future Needs and Takeaways

- Round Robin Testing of all existing labs needed
- Industry agreed path forward on required for:
  - Surveillance testing strategy
  - Predicting field performance
  - Matching full layer ammonia profile
- Matching third party lab's capability with SCR owners expectations needed
- Catalyst suppliers' numbers can be more easily compared if testing conditions are explicitly provided