

REINHOLD ENVIRONMENTAL Ltd.



2016 NO_x-Combustion-CCR Round Table Presentation

February 1 & 2, 2016, in Orlando, FL / Hosted by OUC

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Research and Consulting Engineers



2016 NO_x-Combustion-CCR Round Table

February 1-4, 2016 at Hyatt Regency Orlando Airport, Orlando, FL

SCR MERCURY OXIDATION

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EPRI Research Efforts

each designed to answer very practical questions related to SCR mercury oxidation

1. Guidelines for Speciated Mercury Field Measurements *including* Standard Test Method for Speciation Sorbent Traps
2. Long-Term Performance Tracking of OEM and Regenerated Catalysts
3. Field Interlayer Testing and Performance Tracking
4. Advanced Catalyst Performance
5. SCR Mercury Oxidation Modeling

Speciated Mercury Measurement Guidelines and Sorbent Trap Standard Test Method

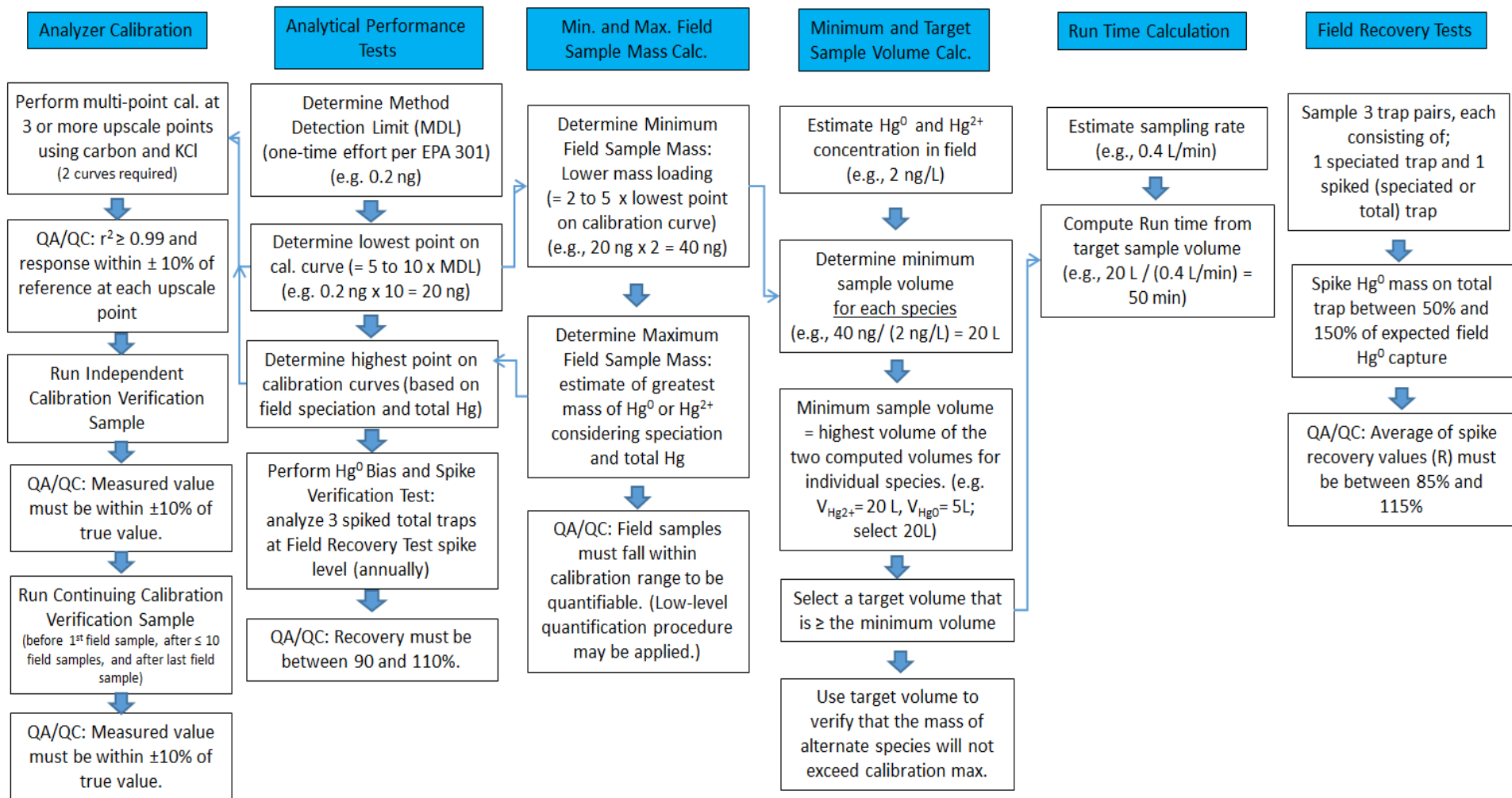
- 1) Comprehensive public* document covering current industry knowledge related to speciated mercury measurements, includes both speciation traps and continuous systems.
- 2) Fundamentals of mercury chemistry, factors affecting mercury speciation, and test method pros and cons.
- 3) Location-specific recommendations concerning applicability of test method, filtration requirements, potential interferences, etc.
- 4) QA/QC recommendations (includes *Speciation Trap Standard Test Method*, similar to EPA Method 30B).
- 5) Uncertainty Analysis for Speciation Traps

*See “*Guidelines for Speciated Mercury Field Measurement*,” Product ID: 3002006098.
<http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002006098>

Speciation Trap Standard Test Method

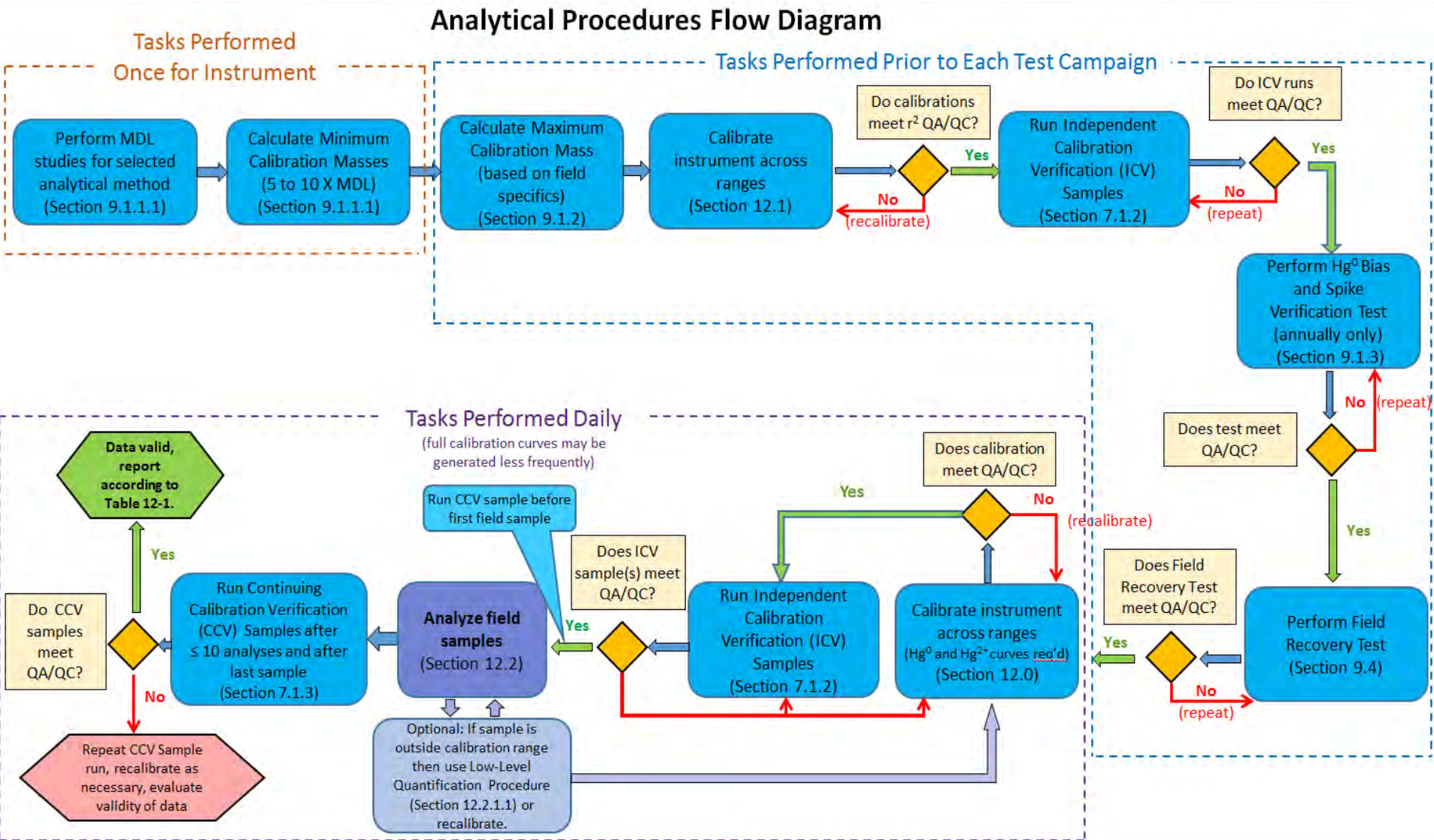
Calibration and QA/QC

Speciation Trap Calibration and QA/QC Tasks

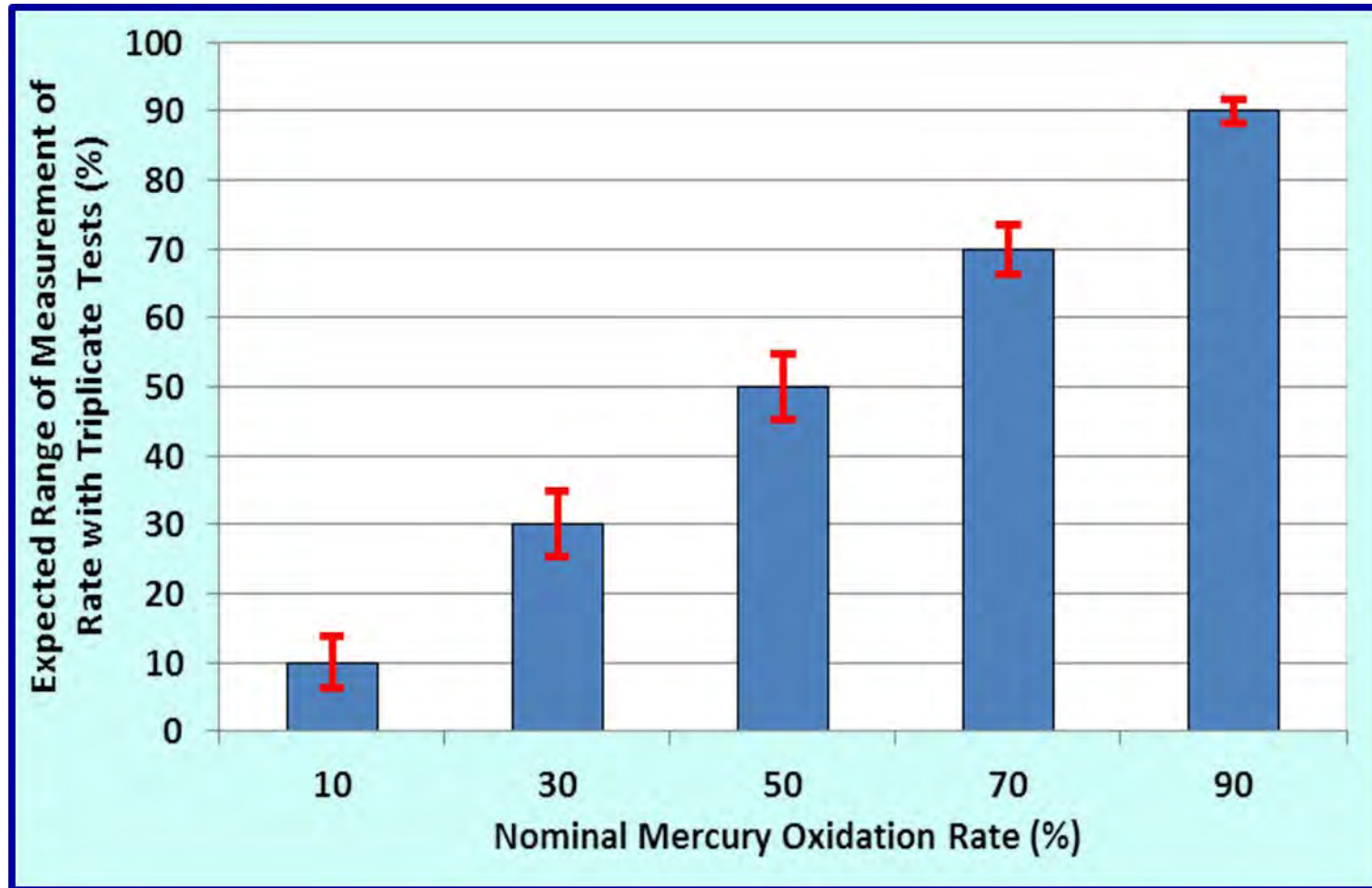


Speciation Trap Standard Test Method

Analytical Procedures Flow Diagram



Uncertainty Analysis: Expected Measurement Range as a Function of Mercury Oxidation Rate for Triplicate Paired Speciation Trap Runs



Uncertainty analysis indicates much less error using **relative basis** for mercury oxidation rate calculation

Absolute Basis:

$$\text{Mercury Oxidation Rate (\%)} = (\text{Hg}^0_{\text{in}} - \text{Hg}^0_{\text{out}}) / \text{Hg}^0_{\text{in}} * 100\%$$

Relative Basis:

$$\text{Mercury Oxidation Rate (\%)} = (\% \text{Hg}^0_{\text{in}} - \% \text{Hg}^0_{\text{out}}) / \% \text{Hg}^0_{\text{in}} * 100\%$$

- Variability in total Hg over time due to coal not attributed to speciation change.
- Stratification in total Hg not attributed to speciation change.
- Errors associated with sample volume, temperature, O₂ measurements, etc. eliminated.

Long-Term Tracking of OEM and Regenerated Catalysts

Questions

- 1) How does the initial performance of regenerated catalysts compare to that of OEM catalysts in terms of mercury oxidation?
- 2) How does catalyst deactivate over time for mercury oxidation, and how does this compare to deNO_x deactivation?

Approach

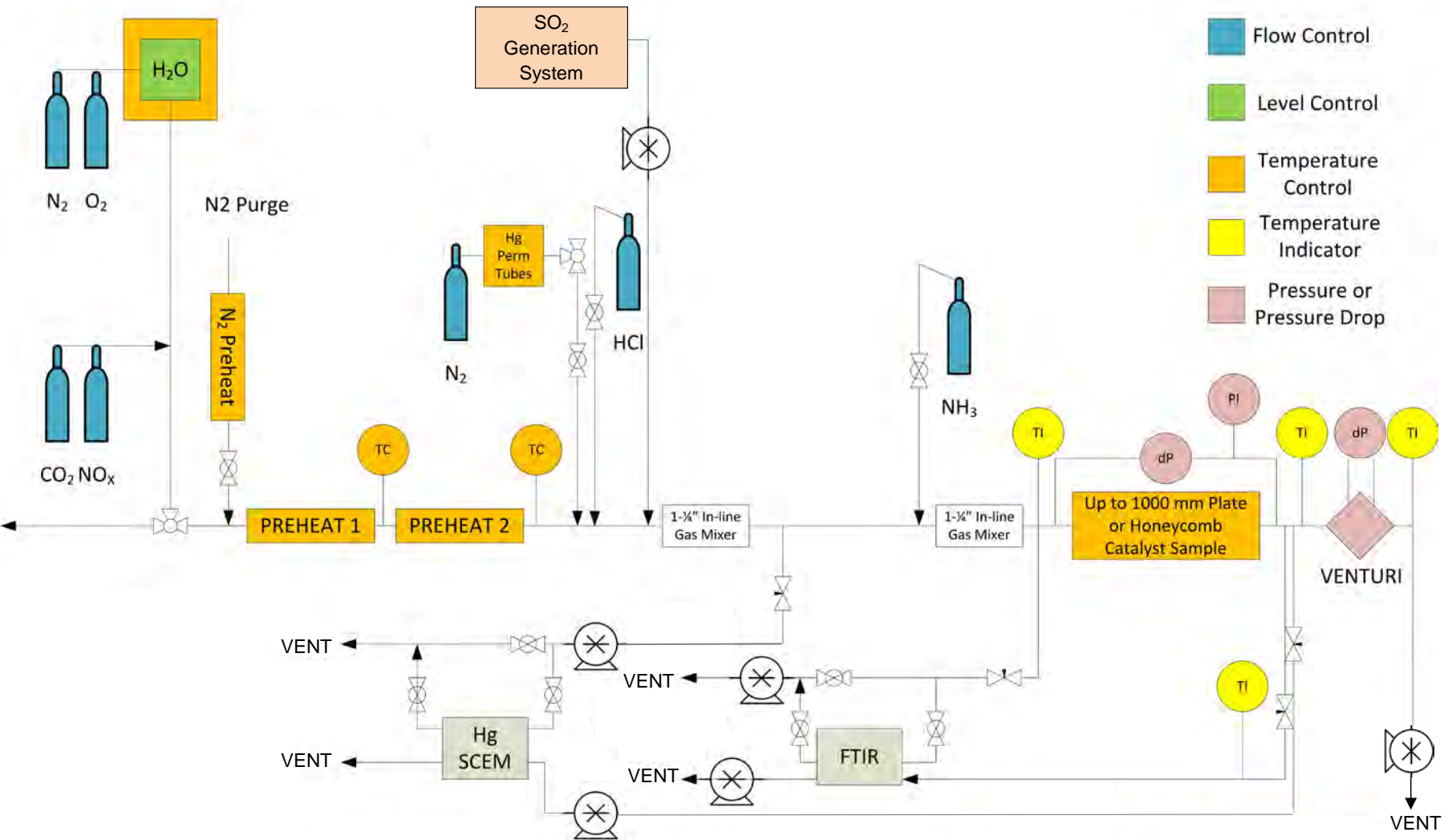
- 1) Install multiple samples of four different catalysts in full-scale unit;
 - a) Honeycomb fresh OEM
 - b) Honeycomb freshly regenerated
 - c) Plate fresh OEM
 - d) Plate freshly regenerated
- 2) Retrieve samples periodically and test in AECOM bench-scale facility for mercury oxidation and deNO_x activity

Coupon “blocks” ready for installation

roughly 4 elements of each catalyst type



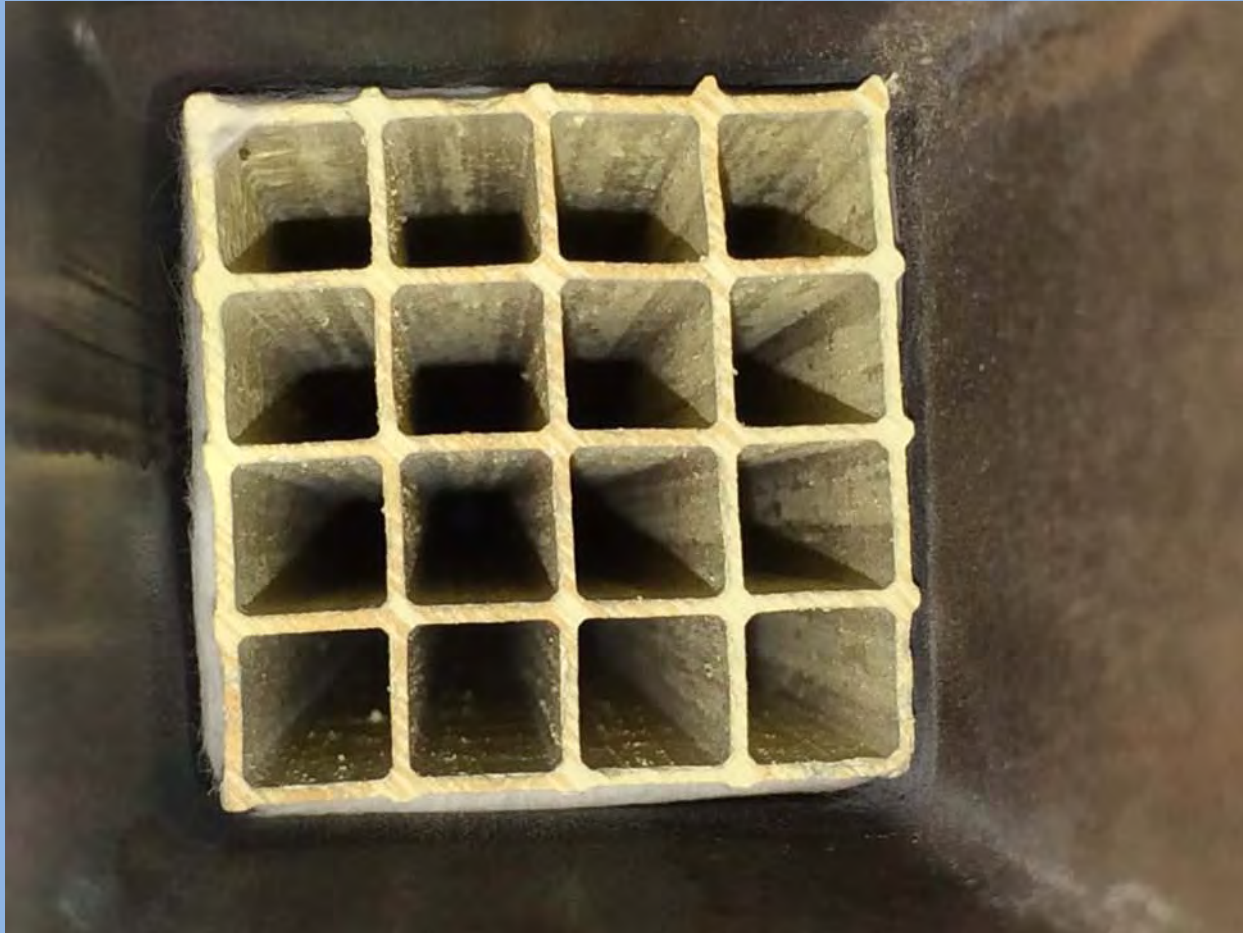
Laboratory Test Apparatus: AECOM Semi-Bench Facility in Austin, TX.



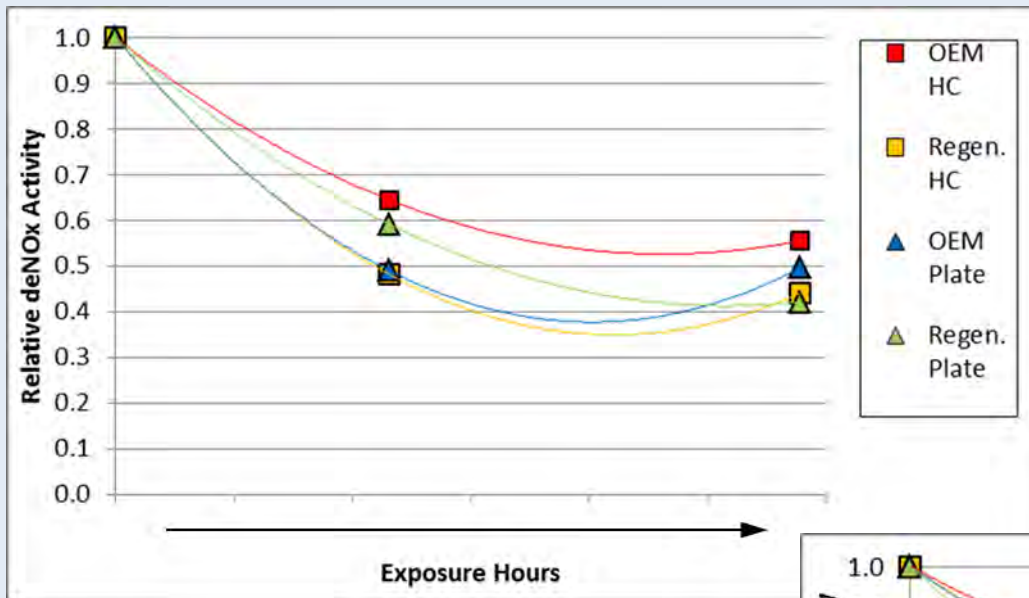
Laboratory Test Apparatus: Reactor details: three 12-inch heated reactor sections



Laboratory Test Apparatus: Honeycomb sample loaded in reactor

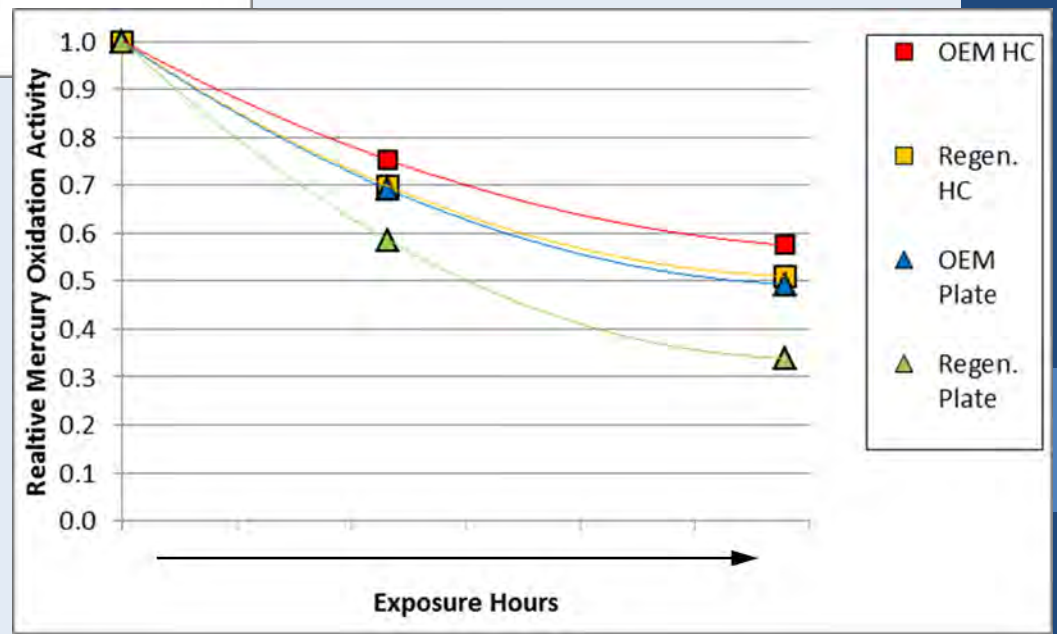


DeNOx and Mercury Deactivation



$$K_{Hg} = -AV * \ln \left(1 - \frac{Rate(\%)}{100} \right)$$

Caution: Data unique to the tested flue gas conditions (NH₃, HCl, etc.). Mercury data shown is without NH₃ present.



Public* version of lab testing protocol for mercury oxidation is available.

- **Covers critical issues associated with lab testing;**
- **Test apparatus design and performance requirements**
- **Equilibrium requirements (conditioning time)**
- **Test condition selection (including set of standard test conditions**
- **Sample preparation**
- **Reporting requirements and reference equations**

* See “*SCR Catalyst Mercury Oxidation Laboratory Testing Guideline – Industry Version.*”
Product ID: 3002005087.

<http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002005087>

Protocol Reference Test Conditions (Typical Eastern Bituminous Coal), Allowable Deviations, and Drift

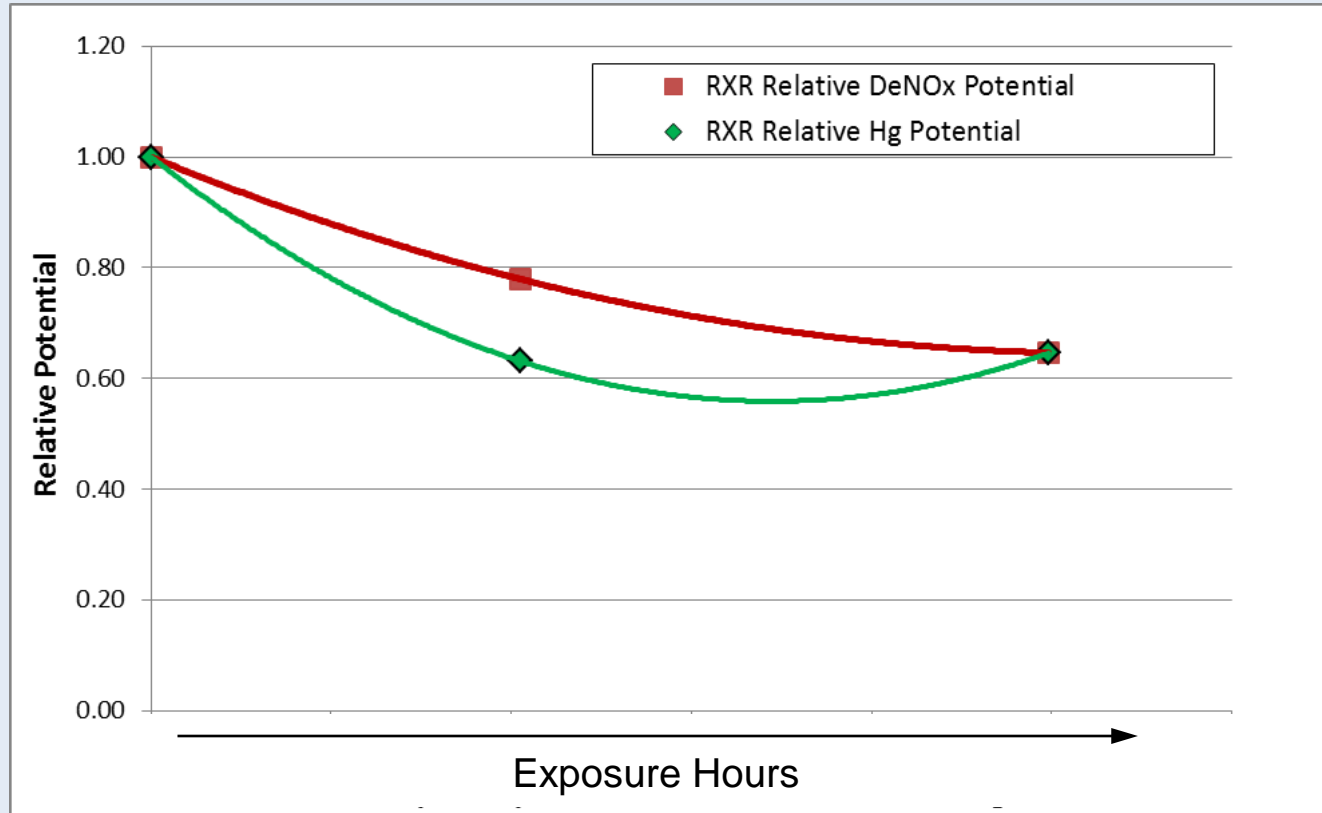
Parameter	Reference Test Condition Target Value	Allowable Deviation from Target ¹⁶	Allowable Drift ¹⁷
Temperature	700°F	± 10°F	± 5°F
AV ¹⁸	18.0 m/hr (STP)	± 0.5 m/hr	± 0.3 m/hr
O ₂	3.0% (dry)	± 0.5%, absolute	± 0.3%, absolute
H ₂ O	8.0% (actual, 3% O ₂)	± 2%, absolute	± 1%, absolute
CO ₂	0.0% or As-Generated	--	--
NO _x	0.0 ppmv	± 10% of value	± 5% of value
α (NH ₃ /NO _x ratio)	0.0	± 0.02 absolute	± 0.01 absolute
SO ₂	1,000 ppmv (dry, 3% O ₂)	± 10% of value	± 5% of value
SO ₃	0.0 ppmv	--	--
HCl	75 ppmv (dry, 3% O ₂)	± 10% of value	± 5% of value
HBr	0.0 ppmv	--	--
CO	0.0 ppmv	± 10% of value	± 5% of value
Hg ⁰	10-100 µg/m ³ (STP, dry, 3% O ₂)	± 10% of value	± 5% of value
Native Hg ²⁺ (reactor Inlet)	Less than 7% of total mercury	--	--
Added Hg ²⁺ (reactor Inlet)	0.0 µg/m ³	± 10% (as proportion of Hg ^T) absolute	± 5% (as proportion of Hg ^T) absolute

Field Interlayer Testing and Performance Tracking

- 1) Several full-scale test campaigns primarily using speciation traps.
- 2) Tests examined various interest areas including;
 - Interlayer performance (NH_3 effect)
 - Aging effects (yearly repeat testing)
 - Effect of operational changes
 - Testing methodology (filtration approach, etc.)
 - APH/ESP speciation

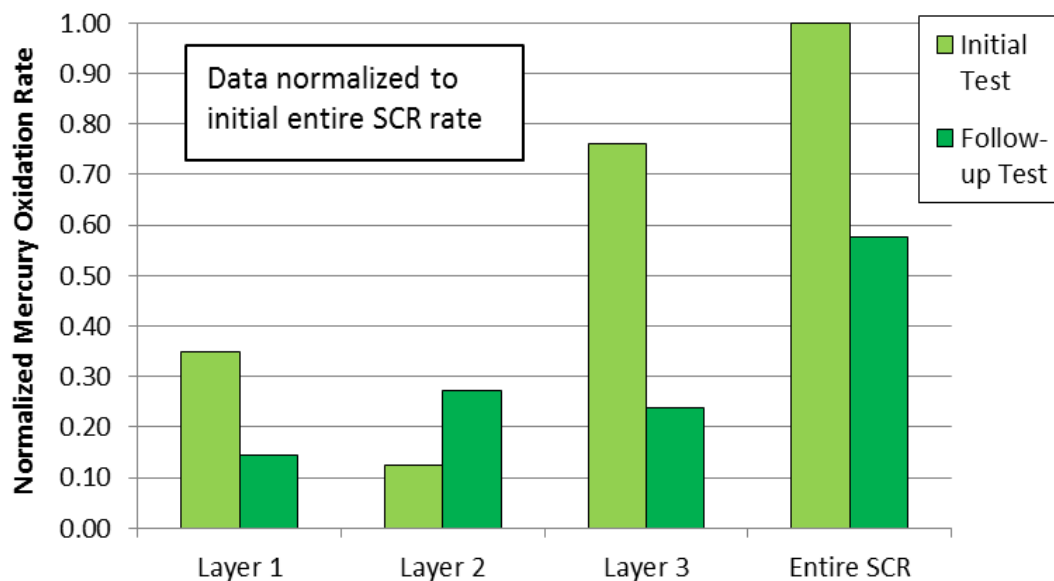
Case 1: Large eastern bituminous unit, with high deactivation rate

(same unit as host unit for long-term tracking samples described above)

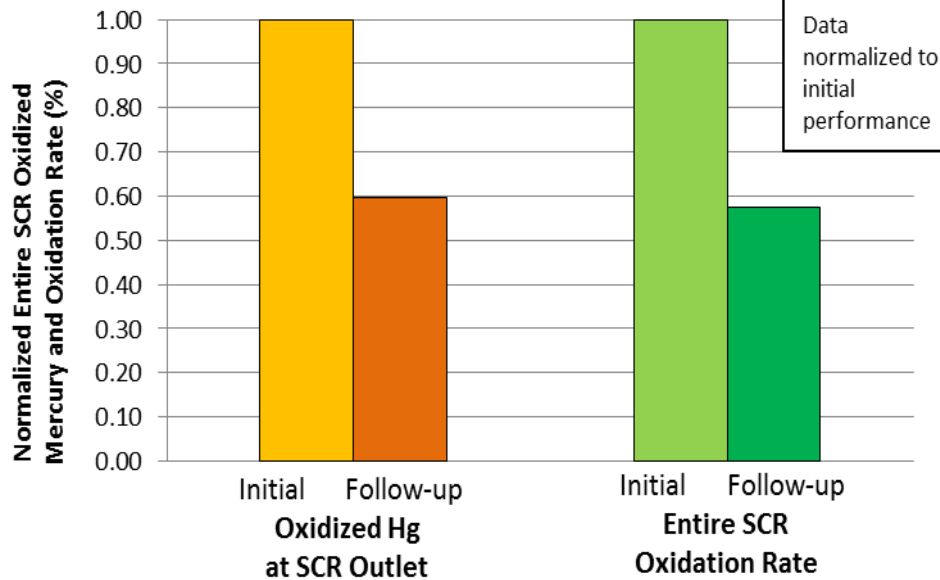


Data for entire RXR, data indicates that the decline in the mercury oxidation potential is similar to that for deNOx potential under real-world operating conditions.

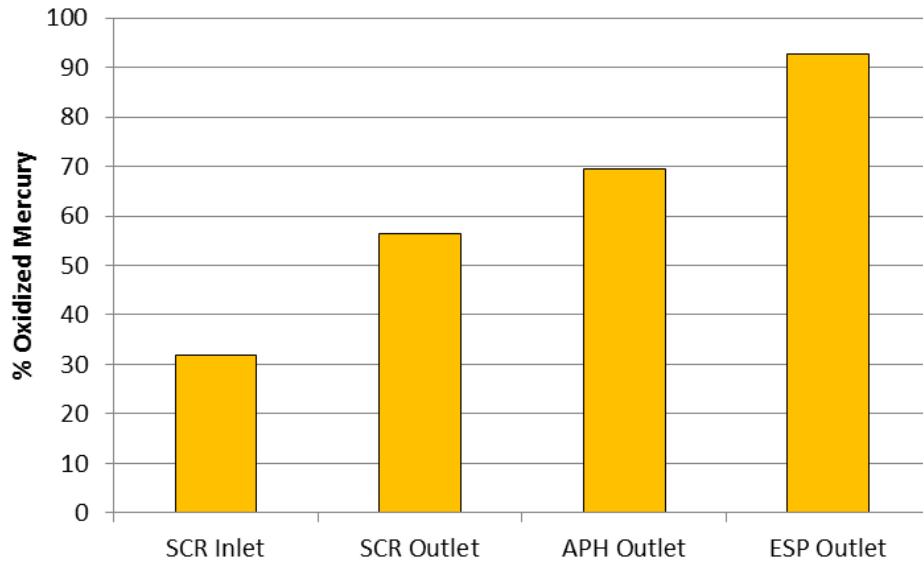
Case 2: Large PRB Unit



Demonstrates decline in mercury oxidation capability for PRB fuel, comparison to deNO_x deactivation forthcoming.

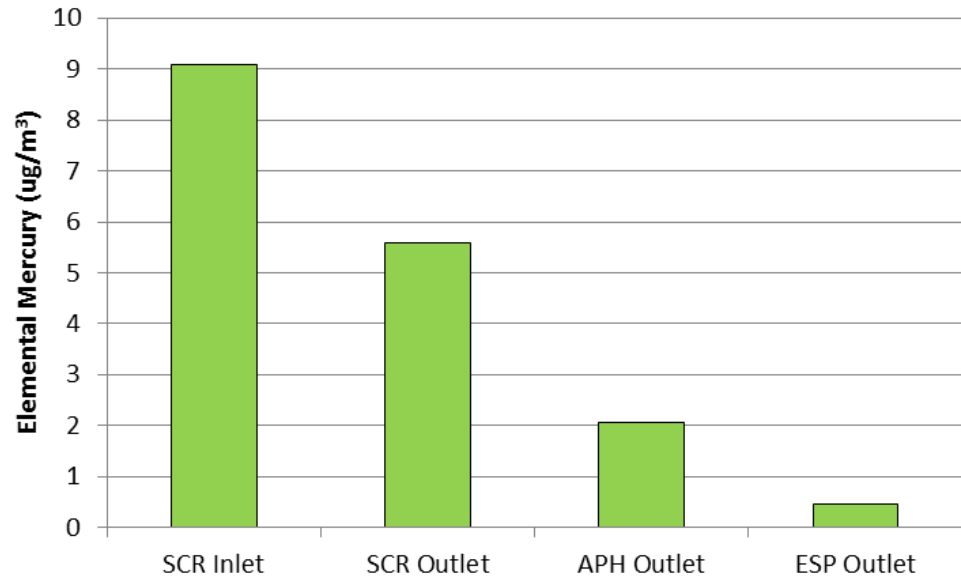


Case 3: Large eastern bituminous unit

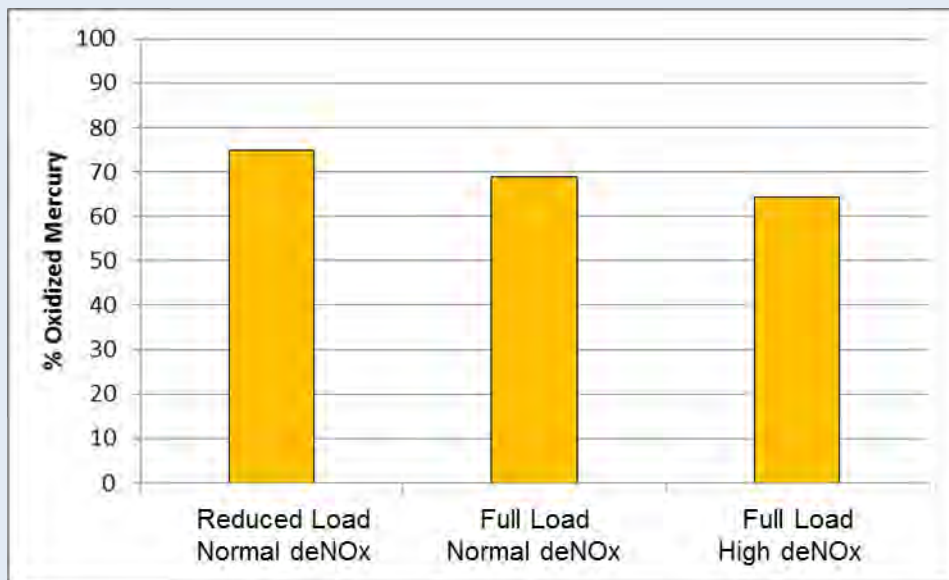


Remember: These are gas-phase measurements. At the APH outlet and ESP outlet, there may have been significant mercury partitioning to the ash.

Absolute gas-phase elemental mercury concentrations show a more complete picture when significant mercury capture may occur.



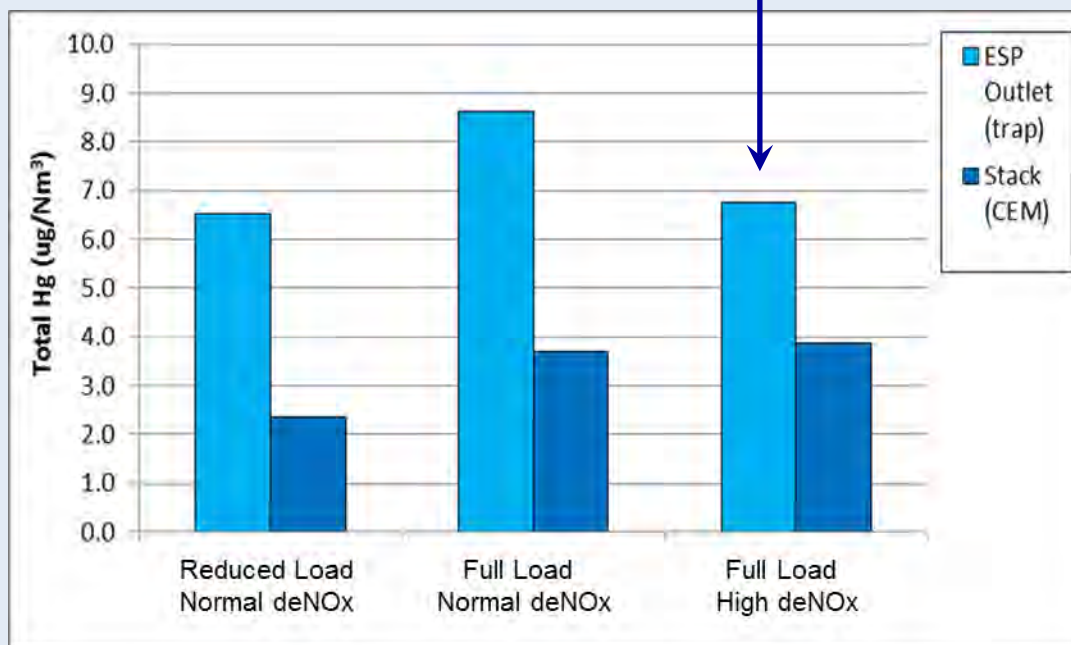
Case 3: Boiler operating condition effects



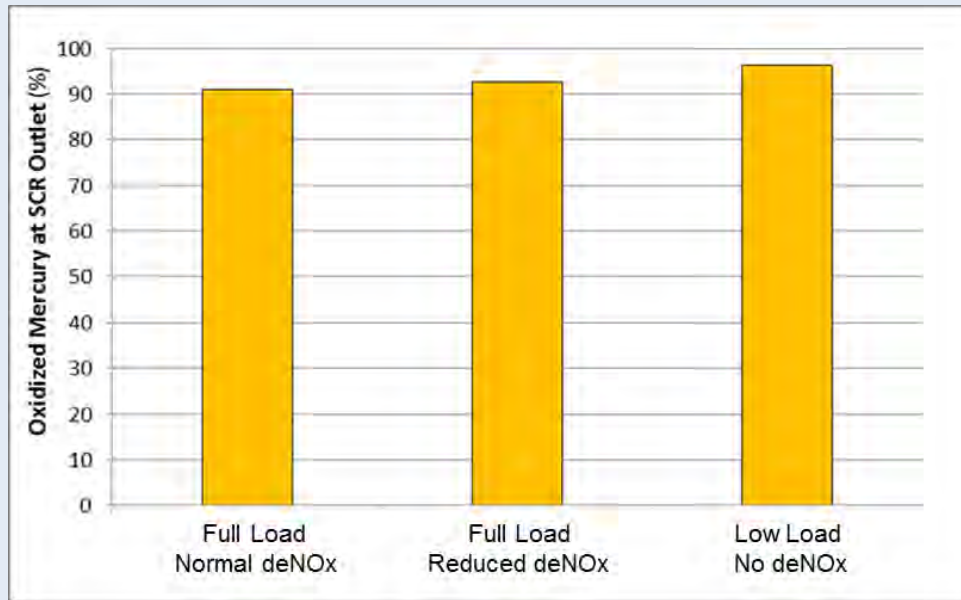
SCR outlet data follows expected trend as a function of load and deNOx setpoint.

Does the extra NH₃ help to improve ESP capture, but does not improve overall capture at the stack?

Note: variation in conditions were small, i.e. relatively small turndown in load, and small increase in deNOx.



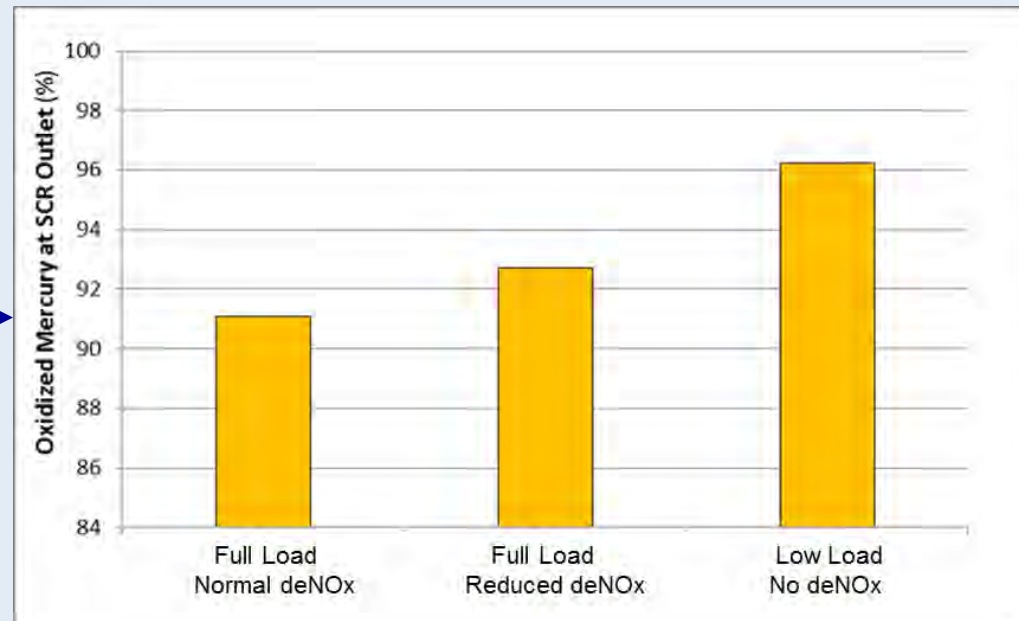
Case 4: Eastern bituminous boiler – operating condition effects



Differences seem small on absolute scale.

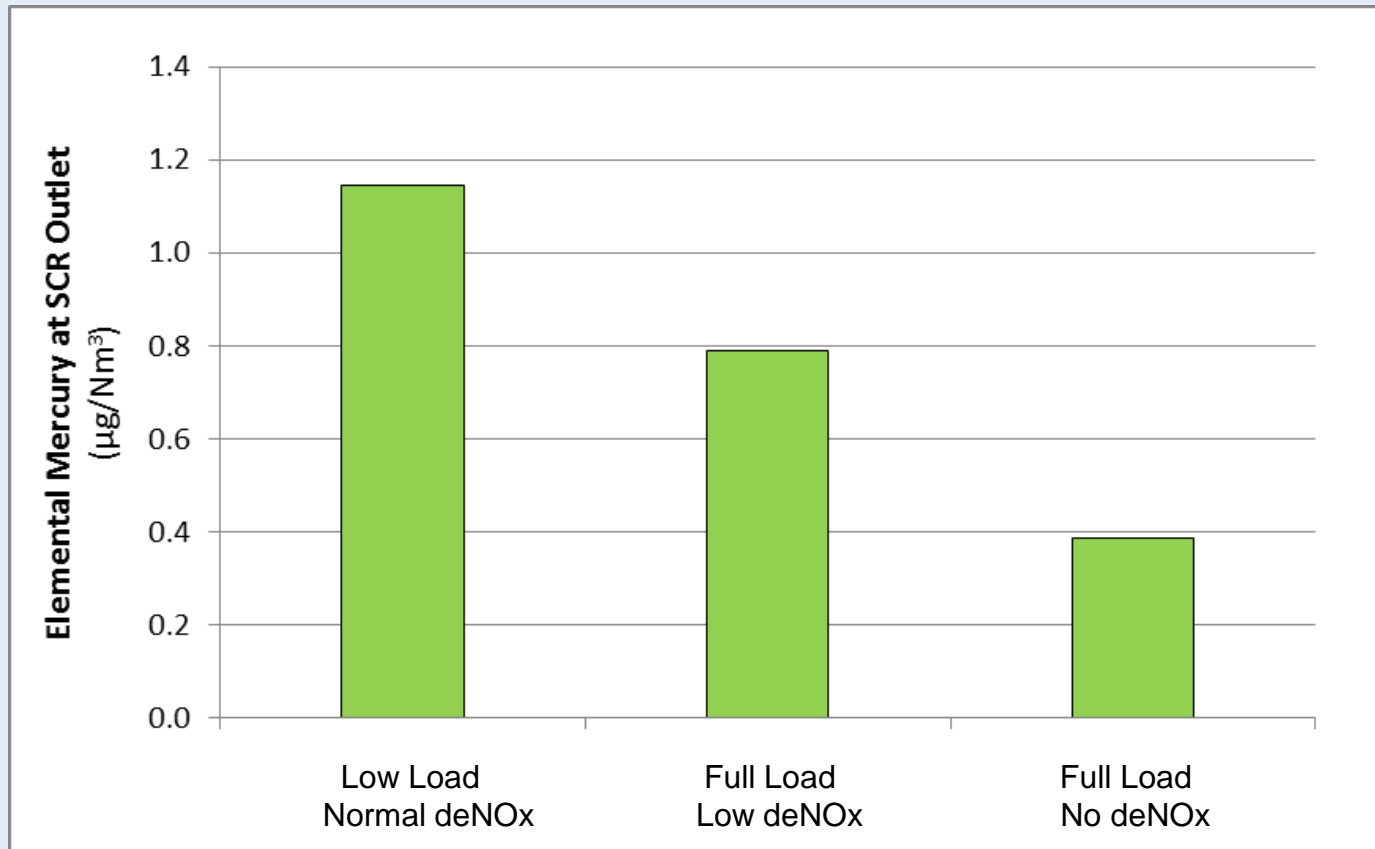


Differences more impressive on expanded scale.



Case 4: Elemental mercury at SCR outlet

Differences become clear when looking at elemental mercury on an absolute basis – good way to assess data when considering potential emissions with a wet scrubber in place.



Advanced Catalyst Performance

- 1) Advanced catalysts that improve mercury oxidation are attractive to the industry - it's in everyone's best interest that they succeed. Cooperative effort between multiple catalyst suppliers and industry.

- 2) Several questions need to be answered;
 - **What is the performance differential under various flue gas conditions?**
 - **When is it advantageous to use advanced catalyst in light of the unit's overall mercury control approach?**
 - **How should advanced catalysts be managed?**
 - **What needs to be changed in the current models to incorporate the use of advanced catalysts?**

Advanced Catalyst Testing Approaches

Laboratory

- Good for fundamental performance differences
- Parametric testing easy
- Deviates from actual field conditions (no fly ash, etc.)
- Can be expensive

Full Scale

- Real-world comparison
- Limited opportunities – major utility investment
- Generally limited to one fuel and one set of catalysts

Pilot Scale

- Representative of full-scale conditions
- Testing of multiple catalysts possible
- Parametric testing possible
- Relatively easily tested on multiple units/fuels
- Cost effective

Pilot-Scale Facilities Currently Being Utilized for Advanced Catalyst Testing

- 1) Conventional Pilot Facility
 - **Dual reactor, permanently installed pilot plant**
 - **Can accommodate 4 standard size elements per reactor**
 - **PRB-fired boiler.**

- 2) EPRI's Portable Catalyst Test Facility (PCTF)
 - **Designed specifically for comparative catalyst testing**
 - **Capabilities for independent temperature control, NH₃ injection, flow rate adjustment, bromine injecting, etc. making parametric testing easy**
 - **Easy transport and erection maximizing potential host sites**
 - **Extremely good operational control – critical for comparative testing.**

PCTF As-Installed During Test



- 2 reactors capable of independent operation (single reactor can be installed)
- Each can accommodate a single standard element of 150mm x 150mm x 1,400mm (max.)

PCTF Reactor Section with Plate Catalyst Element Installed



SCR Mercury Oxidation Modeling

- 1) Models act as clearing house for learned information – compiles data into a useable format.
- 2) Developed 2 interactive excel-based models based on available information and data.
 - a. **Effect of operating condition changes**
 - b. **Effect of routine catalyst aging and catalyst management**
- 3) Use calculation “modules” to determine the various effects. Underlying information based on lab data (from EPRI and industry), and field data (tuning).
- 4) Planned integration in EPRI’s “CatReact” model.

Effect of Operating Condition Change - Inputs

MERCURY OXIDATION BENCHMARK DATAPOINT

COAL DATA		
Parameter	Value	Units
Coal Chlorine	8	ppmw (dry basis)
Coal Sulfur	0.70%	% (dry basis)
Coal Ash Content	10.00%	% (dry basis)

UNIT OPERATIONAL DATA		
Parameter	Value	Units
Full Load Capacity	500	MW
Actual Load	500	MW
Flue Gas Moisture	9.0%	%
Flue Gas CO Concentration	50	ppmvd

SCR OPERATIONAL DATA		
Parameter	Value	Units
Temperature	700	°F
Average O ₂	3.0%	%, dry
DeNOx Setpoint	90.0%	%, (dry basis)
Inlet NOx	375	ppmvd at 3% O ₂
Ammonia Slip (approx.)	2	ppmvd at 3% O ₂

FULL LOAD CATALYST DENOX POTENTIAL	
Layer	DeNOx Potential
1	0.80
2	0.80
3	0.80
4	0.80

MERCURY DATA		
Parameter	Value	Units
SCR Inlet % Oxidized Mercury	5.0%	%
SCR Outlet % Oxidized Mercury	40.0%	%

NEW OPERATIONAL CONDITIONS FOR MERCURY OXIDATION PERFORMANCE PREDICTION

COAL DATA		
Parameter	Value	Units
Coal Chlorine	8	ppmw (dry basis)
Coal Sulfur	0.70%	% (dry basis)
Coal Ash Content	10.00%	% (dry basis)

UNIT OPERATIONAL DATA		
Parameter	Value	Units
Actual Load	500	MW
Flue Gas Moisture	9.0%	%
Flue Gas CO Concentration	5000	ppmvd

SCR OPERATIONAL DATA		
Parameter	Value	Units
Temperature	700	°F
Average O ₂	3.0%	%, (dry basis)
DeNOx Setpoint	90.0%	%
Inlet NOx	375	ppmvd at 3% O ₂
Ammonia Slip (approx.)	2	ppmvd at 3% O ₂

Output
 SCR Outlet %
 Oxidized Hg
 40% → 12%

Effect of Catalyst Aging

MERCURY OXIDATION BENCHMARK DATAPOINT

COAL DATA		
Parameter	Value	Units
Coal Chlorine	20	ppmw (dry basis)
Coal Sulfur	1.00%	% (dry basis)
Coal Ash Content	10.00%	% (dry basis)

UNIT OPERATIONAL DATA		
Parameter	Value	Units
Full Load Capacity	500	MW
Actual Load	500	MW
Flue Gas Moisture	9.0%	%
Flue Gas CO Concentration	50	ppmvd

SCR OPERATIONAL DATA		
Parameter	Value	Units
Temperature	700	°F
Average O ₂	3.0%	%, dry
DeNOx Setpoint	90.0%	%, (dry basis)
Inlet NOx	375	ppmvd at 3% O ₂
Ammonia Slip (approx.)	2	ppmvd at 3% O ₂

FULL LOAD CATALYST DENOX POTENTIAL	
Layer	DeNOx Potential
1	1.00
2	1.00
3	1.00
4	1.00

MERCURY DATA		
Parameter	Value	Units
SCR Inlet % Oxidized Mercury	10.0%	%
SCR Outlet % Oxidized Mercury	90.0%	%

NEW CATALYST STATUS

FULL LOAD CATALYST DENOX POTENTIAL	
Layer	DeNOx Potential
1	0.40
2	0.50
3	0.70
4	0.70

Output

SCR Outlet %
Oxidized Hg

90% → 64%

CONCLUSIONS

More tools are now available for assessing mercury oxidation of catalysts, from both a facility standpoint, and a measurement standpoint.

Current projects are making quick headway in very targeted areas, allowing for mercury oxidation behavior of the SCR, and flue gas train in general, to be better understood.

Integration of the learned mercury behavior information into overall plant operations and compliance strategies is still needed.



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