

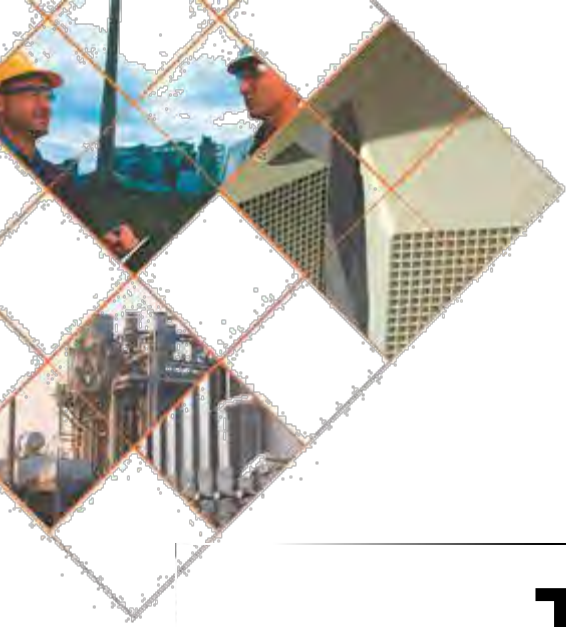
REINHOLD ENVIRONMENTAL Ltd.



**2015 NO<sub>x</sub>-Combustion Round Table  
& Expo Presentations**

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

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**CORMETECH**



# **The SCR Toolbox for Mercury Emission Management**

**Christopher Bertole**

Cormetech, Inc.

2015 Reinhold NOx-Combustion Round Table

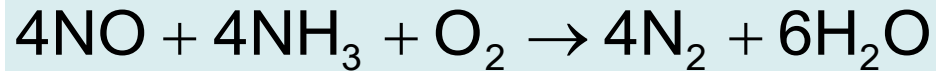
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- **Background**
  - The SCR's role in Hg control
  - Quantifying and testing SCR catalyst potential
- **Review the factors that affect the SCR catalyst potential for Hg oxidation**
  - Flue gas conditions
    - $\text{Hg}^0$ ,  $\text{Hg}^{2+}$ ,  $\text{O}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{NO}$ , Molar Ratio, Temperature,  $\text{CO}$ ,  $\text{SO}_2$
  - Halogens
    - $\text{HCl}$ ,  $\text{HBr}$ ,  $\text{HI}$
  - Catalyst
    - Traditional
    - Advanced

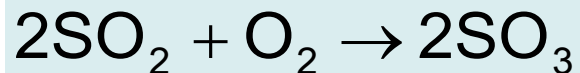
# SCR Catalyst Functionality



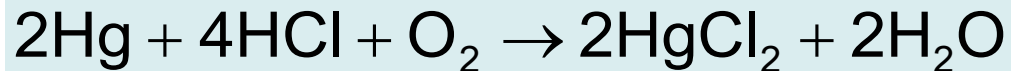
## □ Reduce NOx



## □ Minimize undesirable side reaction



## □ Oxidize elemental Hg



# SCR Hg Mass Balance



- **At the SCR inlet, Hg is present in three forms:**

$$\text{Hg}_{\text{in}}^{\text{total}} = \text{Hg}_{\text{in}}^0 + \text{Hg}_{\text{in}}^{2+} + \text{Hg}_{\text{in}}^{\text{particulate}}$$

*Particulate Hg is not affected by the SCR*

- **Hg mass balance across SCR (at steady state):**

$$\text{Hg}_{\text{in}}^0 + \text{Hg}_{\text{in}}^{2+} = \text{Hg}_{\text{out}}^0 + \text{Hg}_{\text{out}}^{2+} \quad 2\text{Hg} + 4\text{HCl} + \text{O}_2 \rightarrow 2\text{HgCl}_2 + 2\text{H}_2\text{O}$$

- **Quantify Hg oxidation by the SCR:**

$$\eta_{\text{HgOx}} = \frac{\text{Hg}_{\text{in}}^0 - \text{Hg}_{\text{out}}^0}{\text{Hg}_{\text{in}}^0}$$

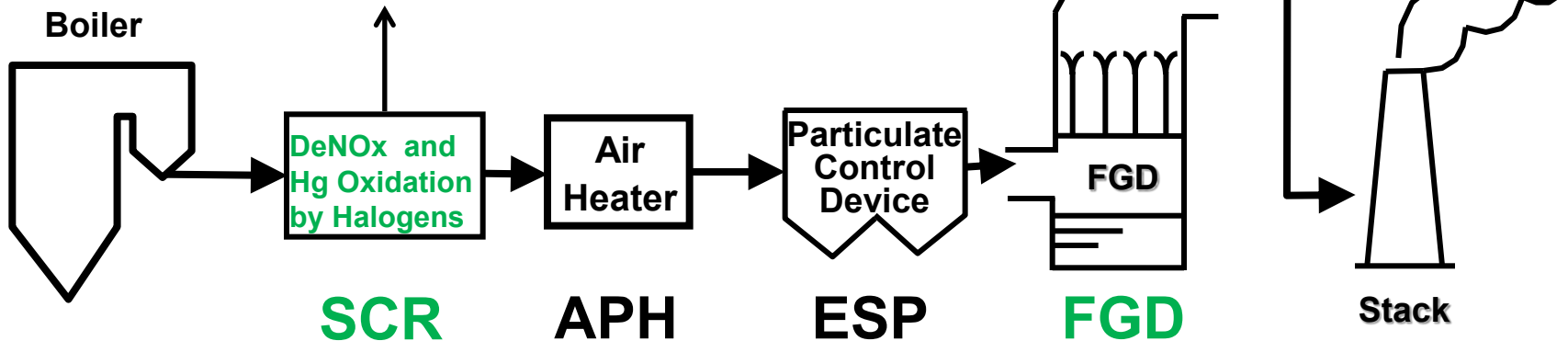
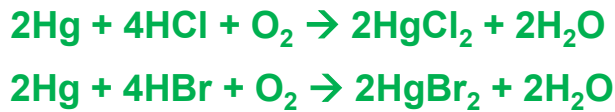
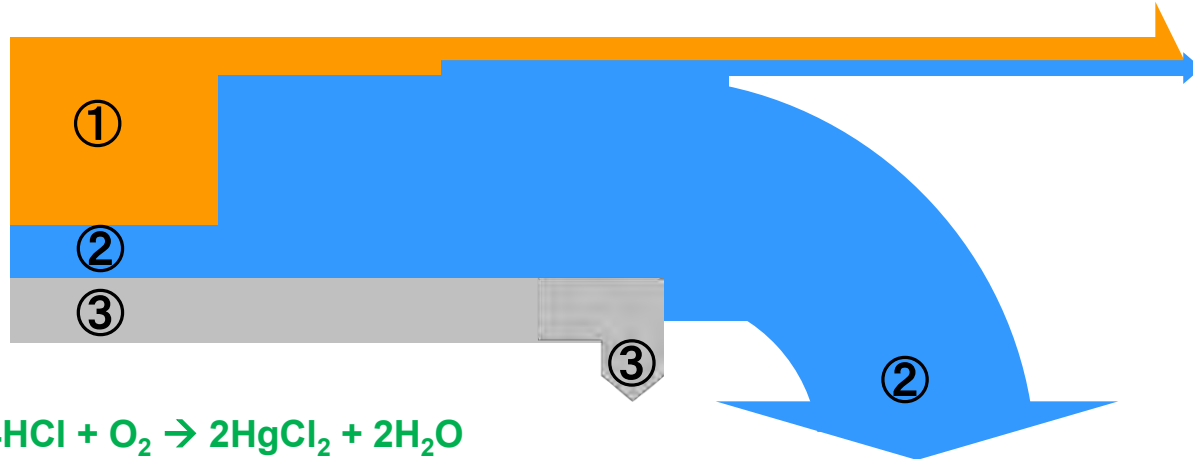
$$\% \text{ Oxidized} = \frac{\text{Hg}_{\text{out}}^{2+}}{\text{Hg}_{\text{out}}^0 + \text{Hg}_{\text{out}}^{2+}}$$

# The SCR's Role in Hg Removal



Oxidize Hg for Downstream Capture!

- ① Elemental
- ② Oxidized
- ③ Particulate



Water solubility values (g/l) at ~20°C:  
 Hg =  $5.6 \times 10^{-5}$ , HgO =  $5.3 \times 10^{-2}$ , HgCl<sub>2</sub> = 74

HgCl<sub>2</sub> removal

# Plant Hg Removal Strategy

Site Specific. Includes All or Some Components.

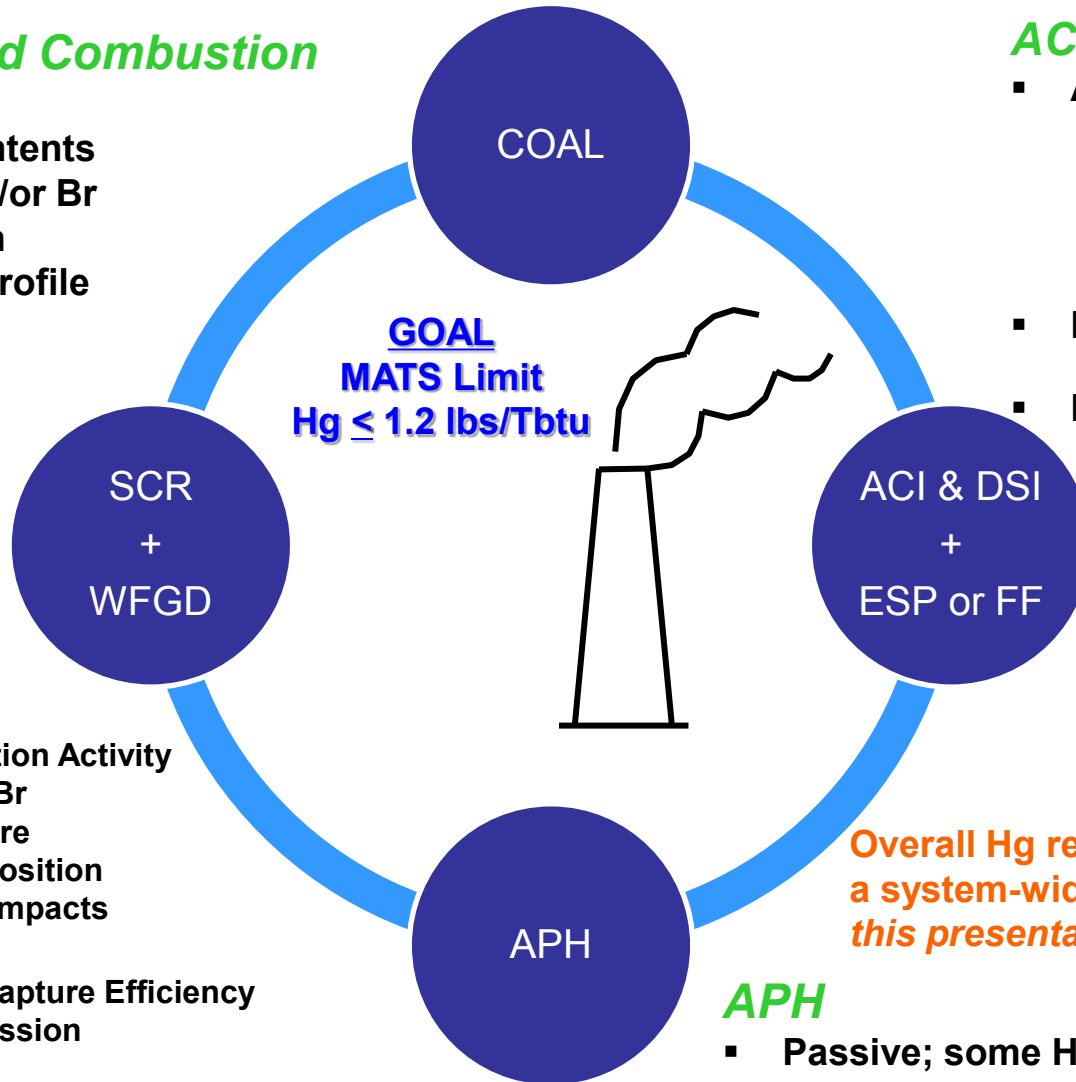


## Coal Type and Combustion

- Hg Content
- Cl and Br Contents
- Added Cl and/or Br
- LOI in Fly Ash
- Boiler Load Profile

## ACI & DSI + ESP or FF

- ACI:
  - Hg Capacity
  - Temperature
  - SO<sub>3</sub> Concentration
  - HCl and HBr
  - Sorbent Injection Rate
- DSI:
  - SO<sub>3</sub> Mitigation
- ESP or FF:
  - ACI, DSI Capture
  - Ash Capture (Hg on LOI)



## SCR + WFGD

- SCR:
  - Hg<sup>0</sup> Oxidation Activity
  - HCl and HBr
  - Temperature
  - Gas Composition
  - Seasonal Impacts
- WFGD:
  - Hg<sup>2+</sup> Net Capture Efficiency
  - Hg<sup>0</sup> Reemission

Overall Hg removal strategy requires a system-wide perspective. Focus of this presentation is on the SCR.

## APH

- Passive; some Hg Oxidation

# SCR Catalyst Potential



$$\frac{K}{AV} = \text{Catalyst Potential}$$

$$AV = \frac{\text{Gas Flow}}{\text{Total GSA}}$$

$$\frac{K}{AV} = \text{Catalyst Potential for } X\% \text{ DeNO}_x$$

$$\frac{K_{\text{HgO}_x}}{AV} = \text{Catalyst Potential for } Y\% \text{ Hg Oxidation}$$

$$\frac{K_{\text{SO}_2\text{O}_x}}{AV} = \text{Catalyst Potential for } Z\% \text{ SO}_2 \text{ Oxidation}$$

# SCR Catalyst Potential



$$\frac{K}{AV} = -\ln(1 - \eta_{\text{NO}_x})$$

## Activity, $K$ , depends on:

- Catalyst composition and age
- Flue gas conditions
  - Temperature
  - MR ( $\text{NH}_3$ ),  $\text{O}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{SO}_2$ ,  $\text{SO}_3$

$$\frac{K_{\text{HgO}_x}}{AV} = -\ln(1 - \eta_{\text{HgO}_x})$$

## Activity, $K_{\text{HgO}_x}$ , depends on:

- Catalyst composition and age
- Flue gas conditions
  - Temperature
  - MR ( $\text{NH}_3$ ),  $\text{O}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{SO}_2$ ,  $\text{SO}_3$
  - +HCl, HBr, HI, CO, HC

*$K_{\text{HgO}_x}$  is strongly condition dependent, but it's still a useful parameter!*

$$\frac{K_{\text{SO}_2\text{O}_x}}{AV} = -\ln(1 - \eta_{\text{SO}_2\text{O}_x})$$

## Activity, $K_{\text{SO}_2\text{O}_x}$ , depends on:

- Catalyst composition,  $\rho_{\text{bulk}}$  and age
- Flue gas conditions
  - Temperature
  - MR ( $\text{NH}_3$ ),  $\text{SO}_2$ ,  $\text{SO}_3$

# Measuring SCR Hg Oxidation

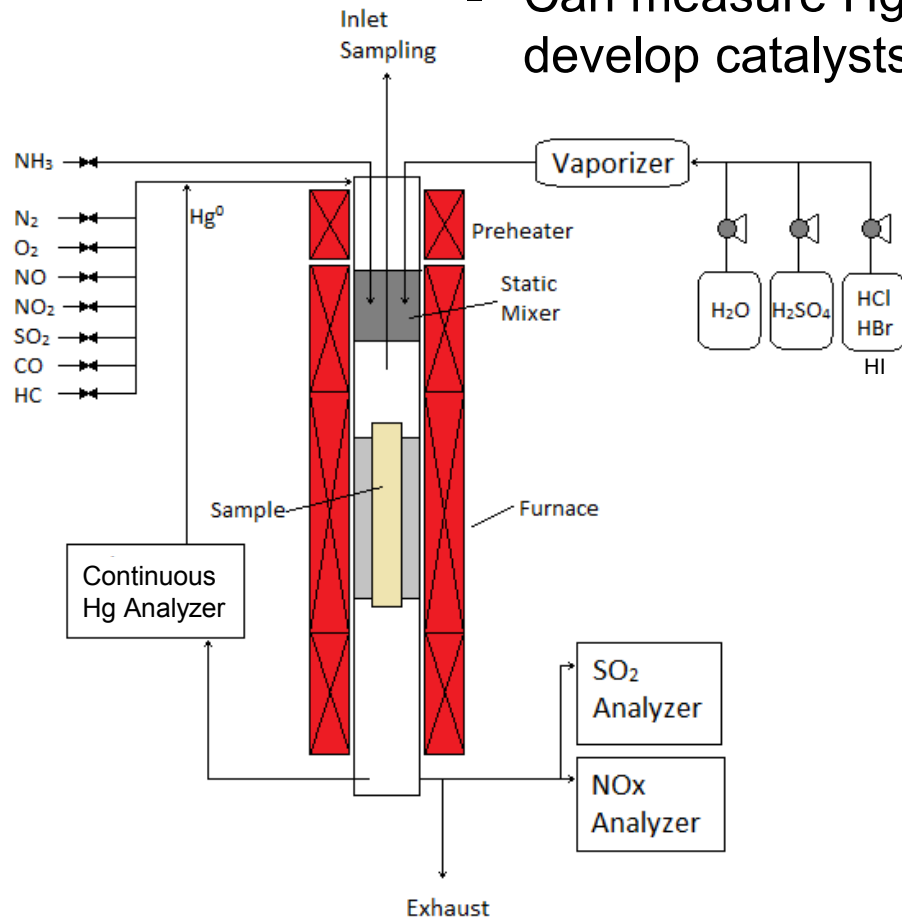


- **Measure Hg<sup>0</sup> and Hg<sup>2+</sup>**
  - CEMS
  - Sorbent traps
- **Lab-scale catalytic reactors**
  - Micro reactor
  - Bench reactor
- **Field (full scale reactor)**
  - SCR inlet and outlet measurements
    - Particulate challenge (high dust difficult to measure)
  - Stack measurements
    - Final system performance
    - SCR contribution combined

- *Each reactor type can be used to generate quality data.*
- *Each reactor type has it's own advantages and limitations.*
- **Micro is well-suited for parametric studies**
  - Automation can help rapidly test a large set of conditions
- **Bench is well-suited for field audit testing**
  - **Full size element**
    - Catalyst poisons not evenly distributed throughout log.
    - Micro may require multiple samples to fully characterize log.
  - **Multi-layer system test**
    - System and individual layer performance in a single test
    - Micro may need multiple step-wise tests using results of upper layers to set conditions for lower layers.
  - Aging times are similar to micro scale

# Micro Reactor

- Example shown is fully-automated for efficient data collection.
- Can measure Hg oxidation under a full range of conditions to develop catalysts and assist with management strategies.

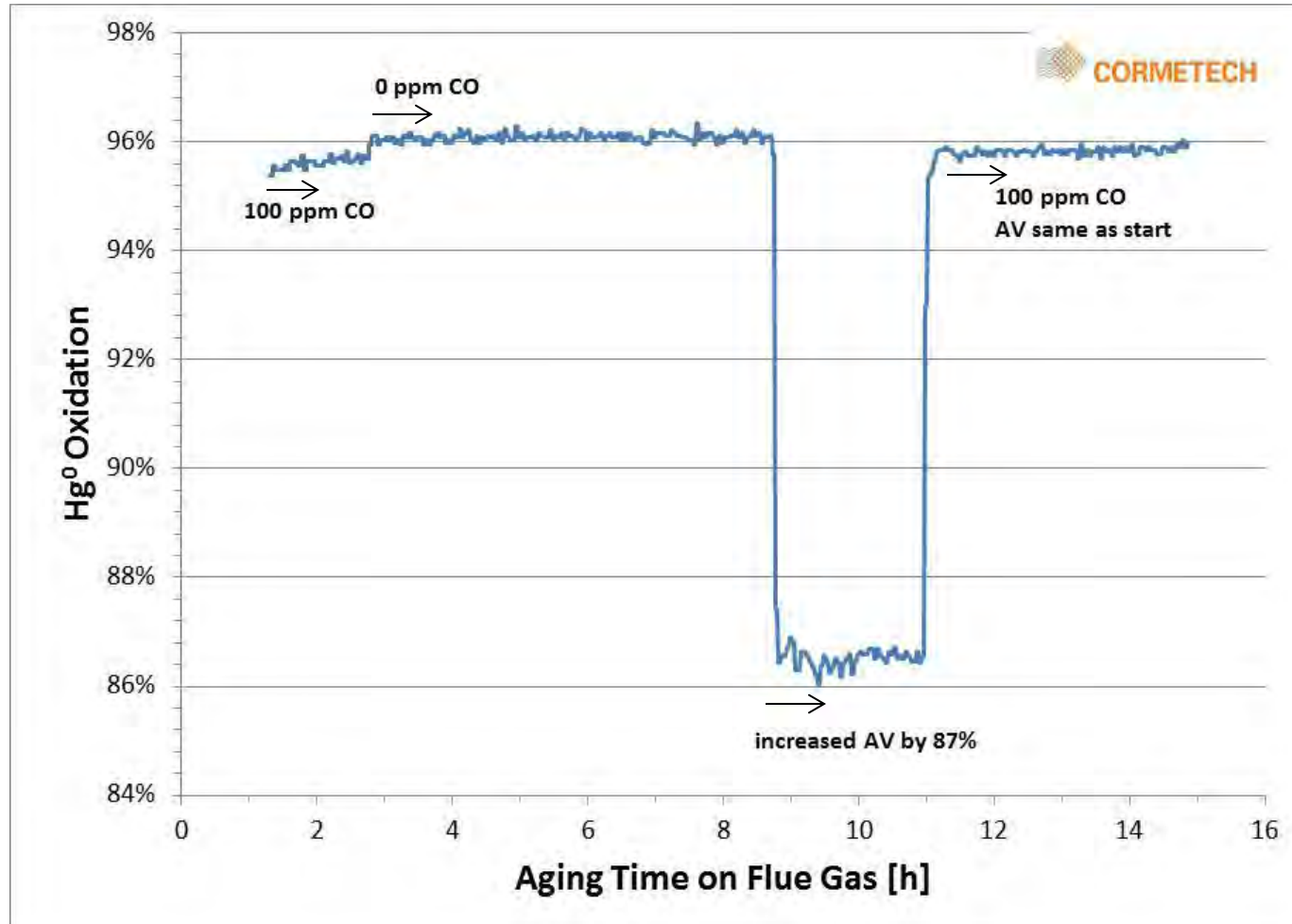


# Micro Reactor: Aging Times

## Fresh Catalyst



*Transients are typically short. Steady state for this test is achieved is < 1 hour.*



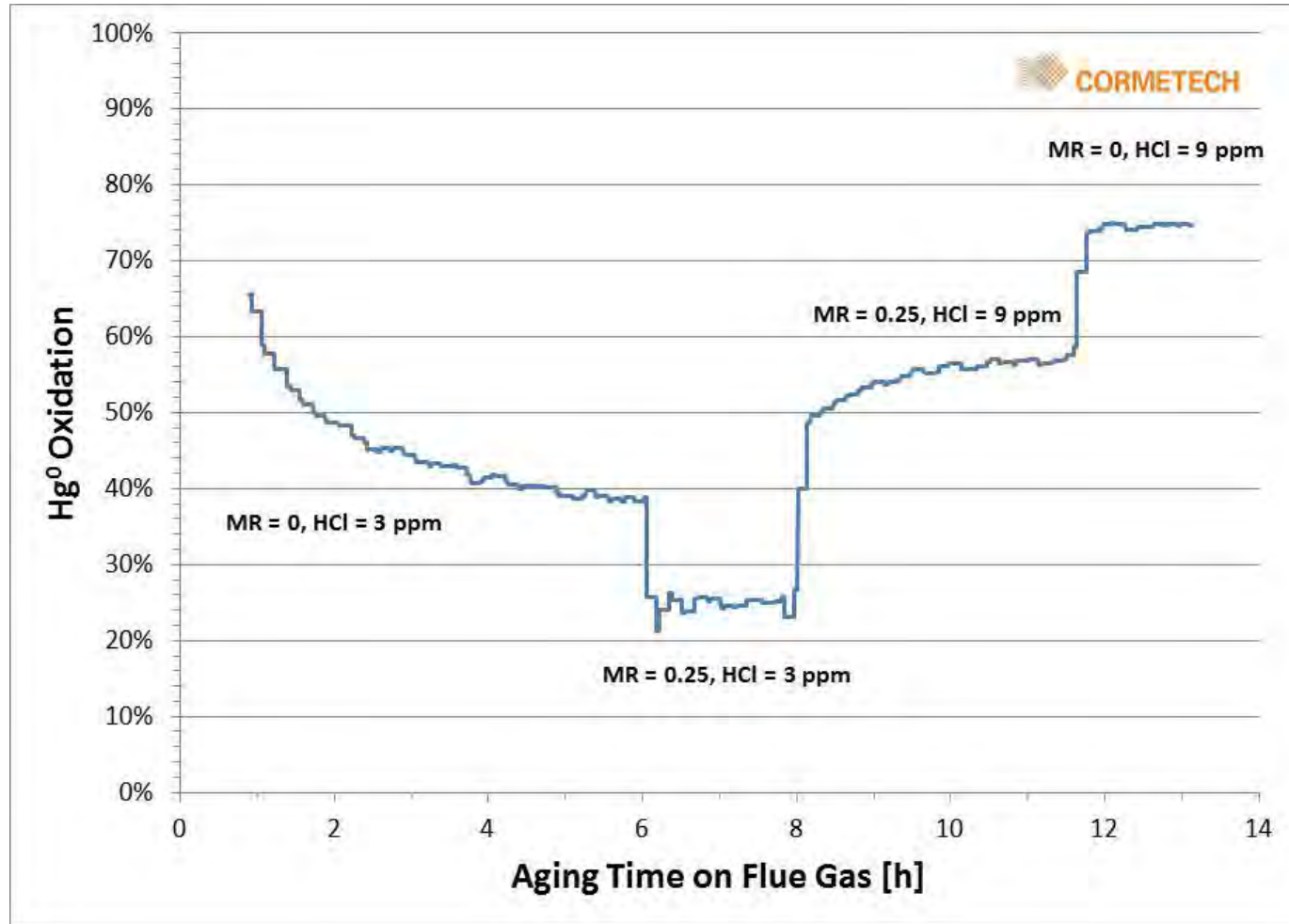
357°C, 5.4% O<sub>2</sub>, 9.7% H<sub>2</sub>O, 46 ppm HCl, 1450 ppm SO<sub>2</sub>, 15 ppm SO<sub>3</sub>, 0 or 100 ppm CO, 275 ppm NO, MR = 0

# Micro Reactor: Aging Times

## Fresh Catalyst



*Transients can be longer when HCl is < 10 ppm. Steady state for this series is achieved in < 5 hours.*



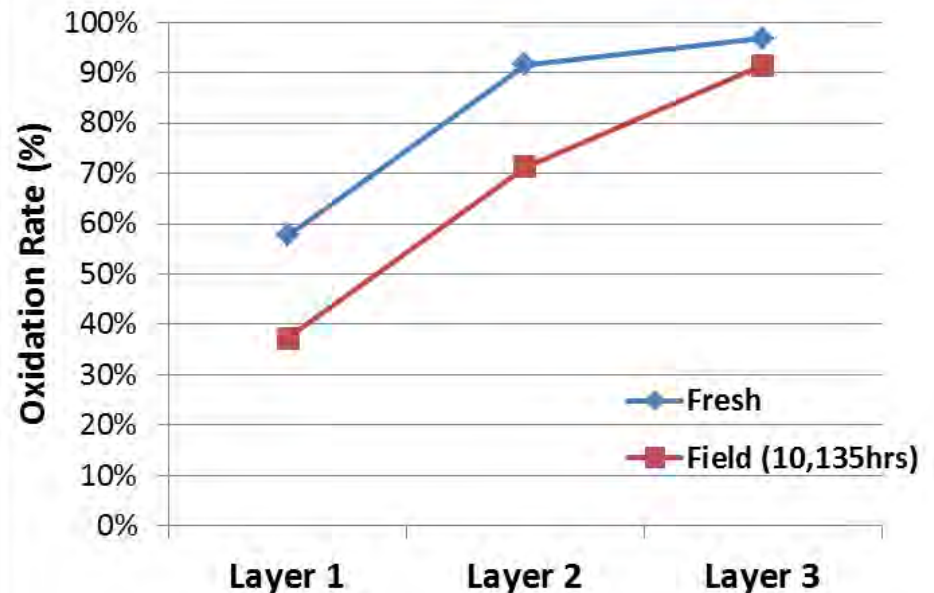
400°C, 3.3% O<sub>2</sub>, 11% H<sub>2</sub>O, 3 or 9 ppm HCl, 490 ppm SO<sub>2</sub>, 5 ppm SO<sub>3</sub>, 50 ppm CO, 375 ppm NO, MR = 0 or 0.25

# Bench Reactor

- Bench scale allows full-size element testing (single or multi-layer).
- Test fresh or deactivated catalyst.
- Inject HCl/HBr, O<sub>2</sub>, H<sub>2</sub>O, SO<sub>2</sub>, SO<sub>3</sub>, NO<sub>x</sub>, CO, HC.
- Full H<sub>2</sub>O concentration control

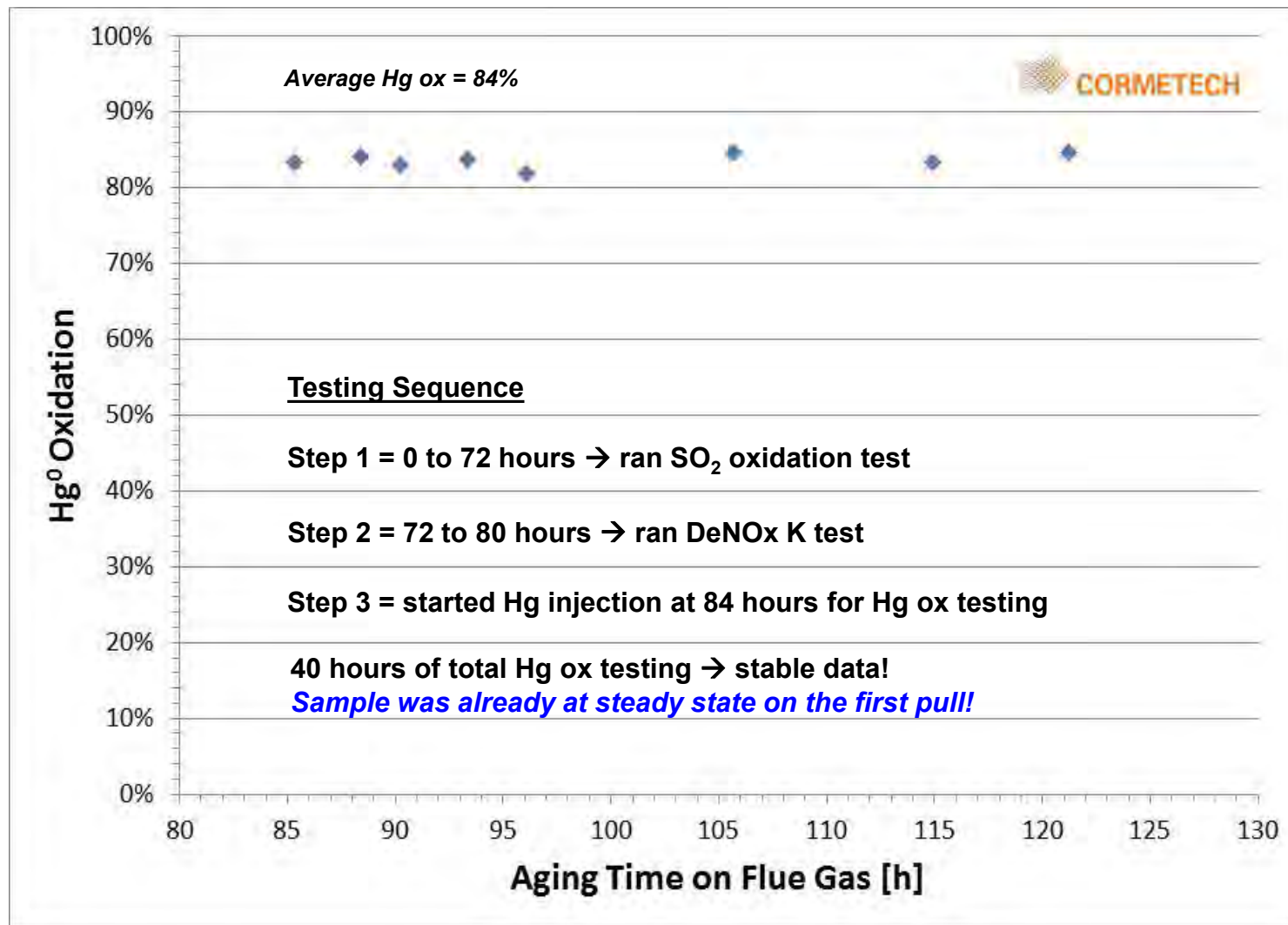


*Hg oxidation performance measured on bench reactor*



# Bench Reactor Data

## New Catalyst



371°C, 4.3% O<sub>2</sub>, 8.5% H<sub>2</sub>O, 58 ppm HCl, 850 ppm SO<sub>2</sub>, 9 ppm SO<sub>3</sub>, 100 ppm CO, 300 ppm NO, 11 ppm NH<sub>3</sub>

# Main Presentation Focus...



# Summary of Factor Impacts

## Positive Correlations













Factor	Hg Oxidation Correlation with Increasing Factor Value	Note
HCl	↑	Strong interdependence with T and concentration
HBr	↑	Strong interdependence with T and concentration
HI	↑	Strong interdependence with T and concentration
O <sub>2</sub>	↑	
Catalyst surface area	↑	Determined by layer length and Ap/pitch selection
Catalyst V <sub>2</sub> O <sub>5</sub>	↑	
Advanced catalysts	↑	Improve Hg ox at constant DeNO <sub>x</sub> and SO <sub>2</sub> ox
Hg <sup>0</sup>	○	No impact: kinetics are first order in Hg <sup>0</sup>

# Summary of Factor Impacts

## Negative Correlations



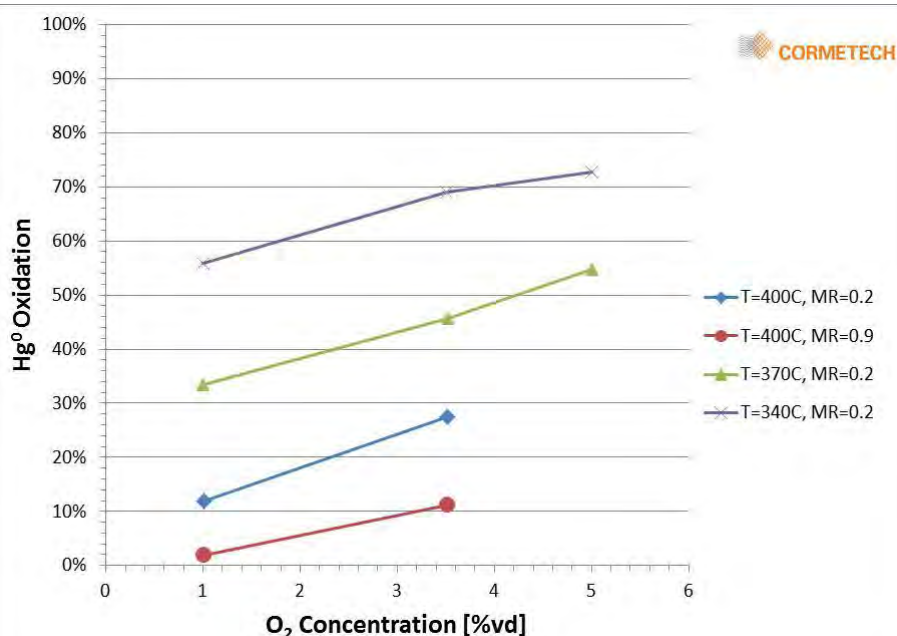
Factor	Hg Oxidation Correlation with Increasing Factor Value	Note
Hg <sup>2+</sup>		Impact depends on re-reduction activity
Temperature		Strong interdependence with HCl, HBr, NH <sub>3</sub> , catalyst
NH <sub>3</sub>		Strong interdependence with T, HCl, HBr, catalyst
NO		Impact is cross-correlated through NH <sub>3</sub>
H <sub>2</sub> O		
SO <sub>2</sub>		
SO <sub>3</sub>		
CO		Strong interdependence with T, HCl, HBr, catalyst
Hydrocarbons		
Catalyst Age		Strong interdependence with catalyst type

# Impact of O<sub>2</sub> and H<sub>2</sub>O

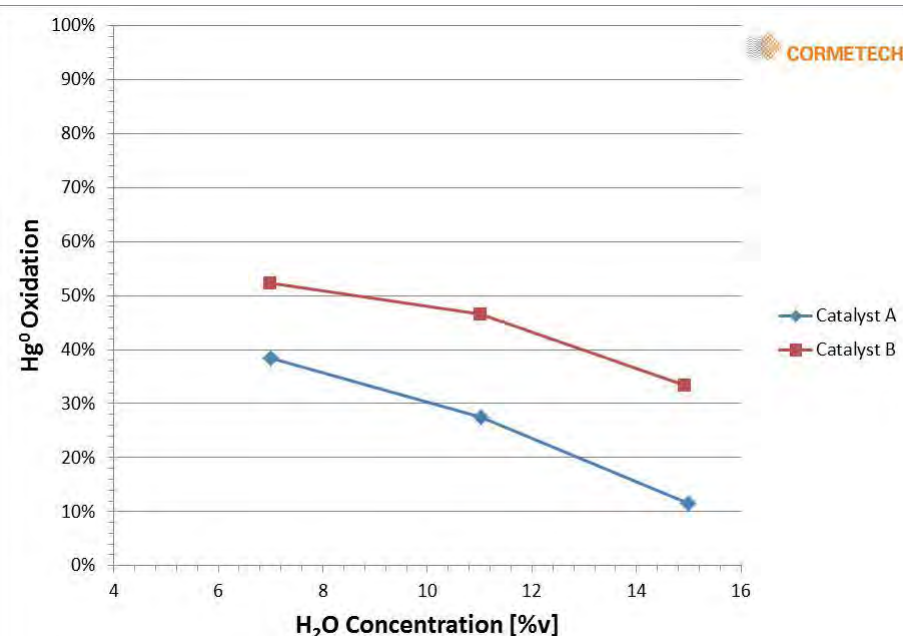
## Hg Oxidation Activity



O<sub>2</sub> and H<sub>2</sub>O both have a significant impact on Hg oxidation activity. In comparison, these parameters have a much smaller impact on DeNO<sub>x</sub> or SO<sub>2</sub> oxidation rates.



11% H<sub>2</sub>O, 350 ppm NO, 0.2 Molar Ratio, 1000 ppm SO<sub>2</sub>,  
10 ppm SO<sub>3</sub>, 100 ppm CO, 11 ppm HCl



400°C, 3.5% O<sub>2</sub>, 350 ppm NO, 0.2 Molar Ratio, 1000 ppm SO<sub>2</sub>,  
10 ppm SO<sub>3</sub>, 100 ppm CO, 11 ppm HCl

# Impact of Hg<sup>0</sup>

## Hg Oxidation Activity



Steady state data reveal that the Hg oxidation reaction is 1<sup>st</sup> order in Hg<sup>0</sup> → Hg oxidation is constant with varied inlet Hg<sup>0</sup> concentration.

Inlet NH <sub>3</sub> /NO <sub>x</sub>	HCl [ppmvd]	Hg Oxidation with inlet Hg 21 µg/Nm <sup>3</sup>	Hg Oxidation with inlet Hg 11 µg/Nm <sup>3</sup>
0.2	11	28%	27%
0.9	11	11%	14%
0.2	56	81%	81%
0.9	56	58%	61%

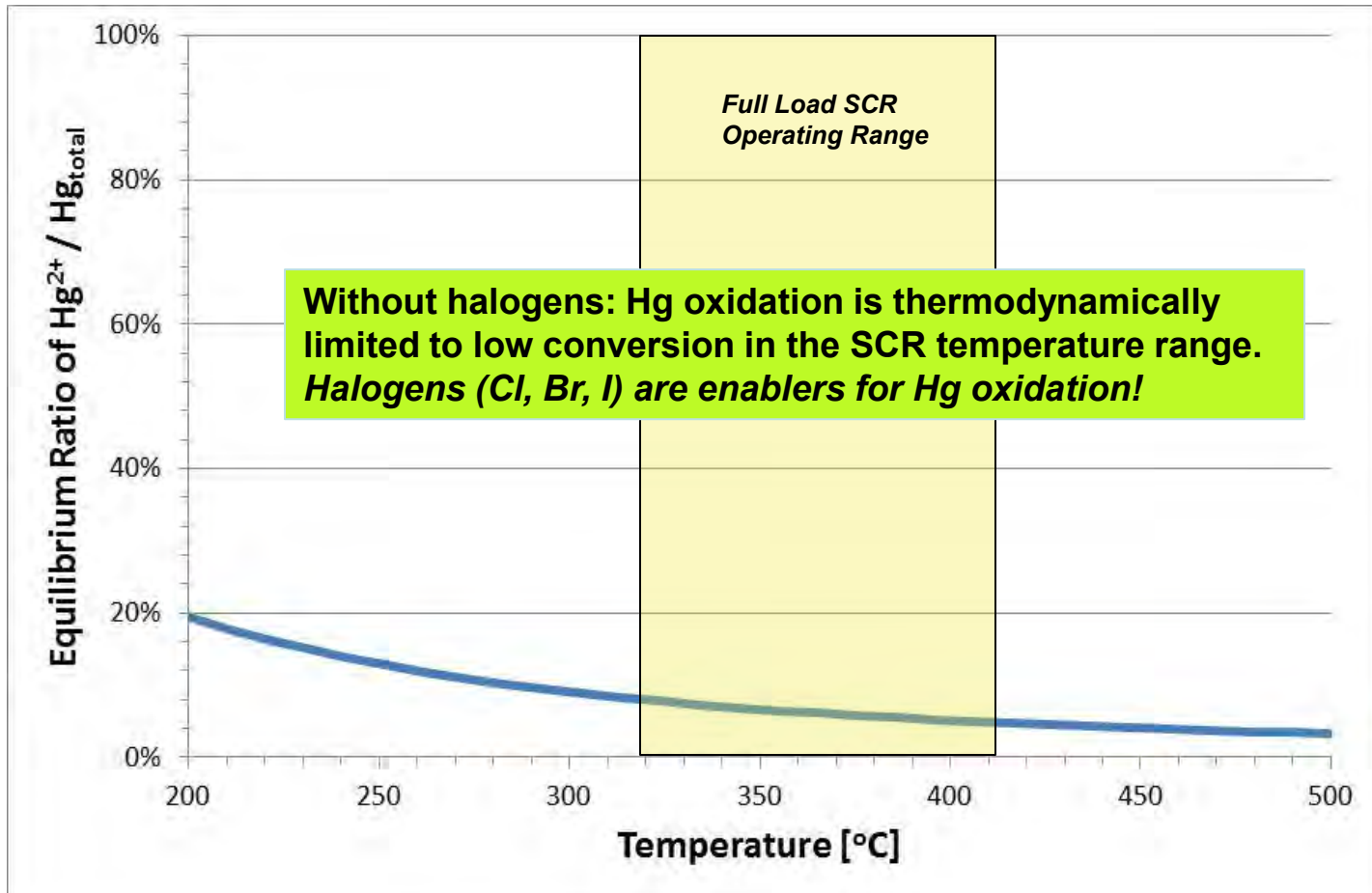
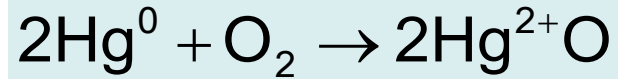
*400°C, 3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 350 ppm NO, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO*

The overall kinetic rate law, however, is more complex, and includes the kinetic effects of HCl and O<sub>2</sub>, and inhibition effects of H<sub>2</sub>O, NH<sub>3</sub>, CO and SO<sub>2</sub>.

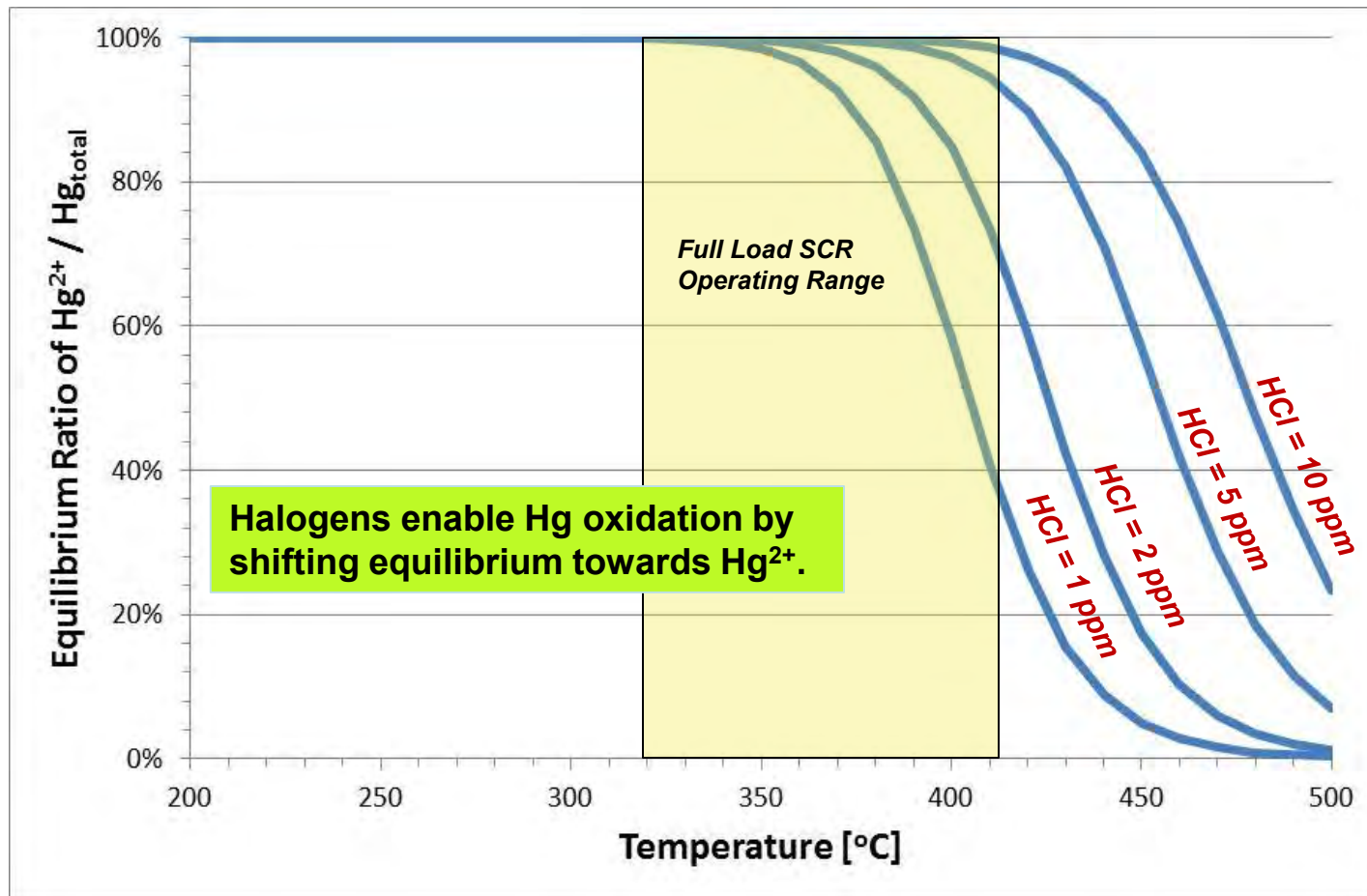
# Why are Halogens Needed?



*(No halogens included).*



# Why are Halogens Needed?

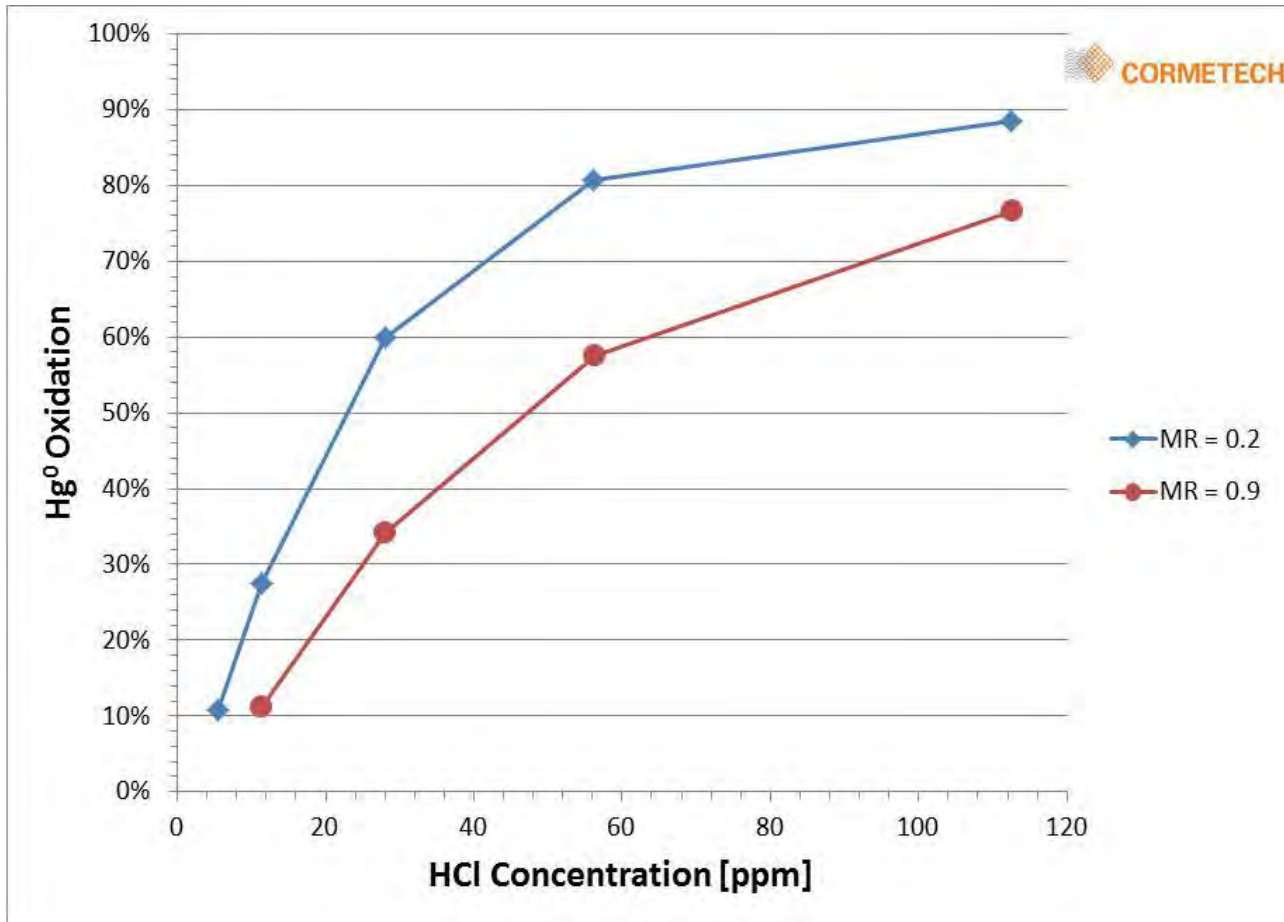


# Impact of HCl

## Hg<sup>0</sup> Oxidation Activity



The kinetic data are consistent with a mechanism where HCl adsorbs on the catalyst. NH<sub>3</sub> can significantly inhibit Hg oxidation activity.

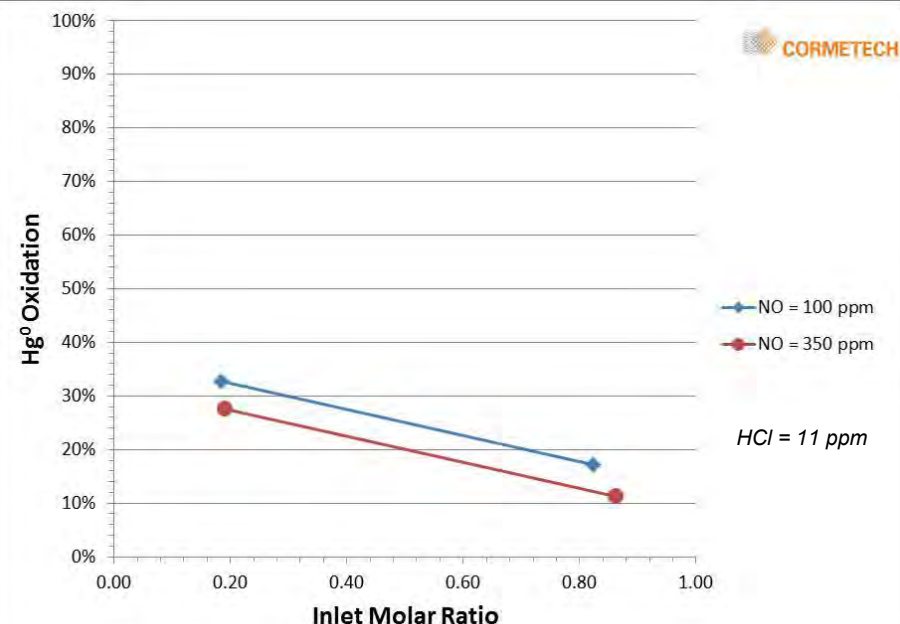
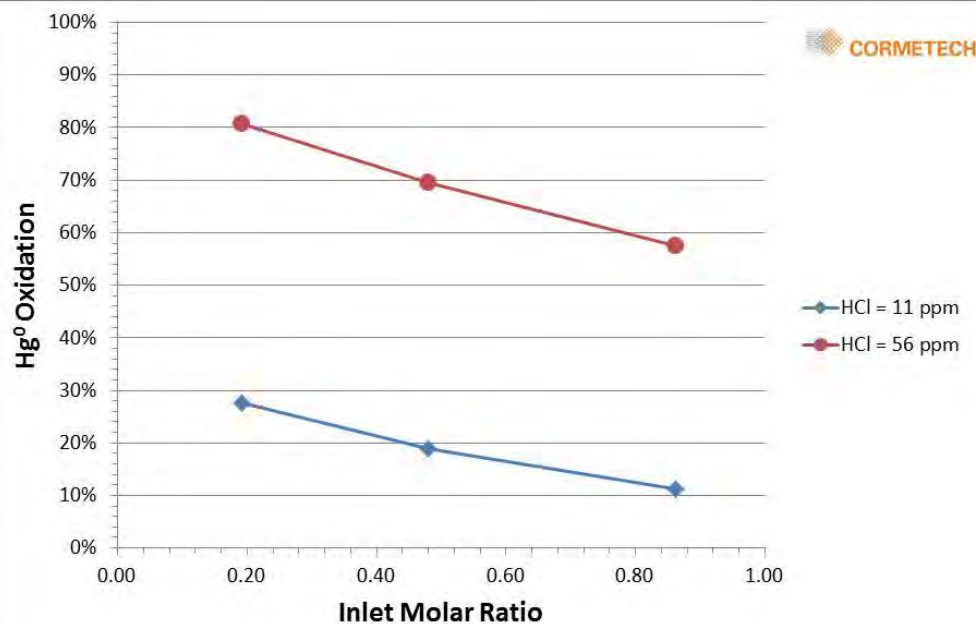


400°C, 3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 350 ppm NO, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO; MR = Inlet Molar Ratio

# Impact of NH<sub>3</sub> and NO<sub>x</sub> Hg Oxidation Activity



**NH<sub>3</sub> can significantly inhibit Hg oxidation activity. Negative impact of higher inlet NO<sub>x</sub> is caused by higher inlet NH<sub>3</sub> (we tested at fixed molar ratio values).**



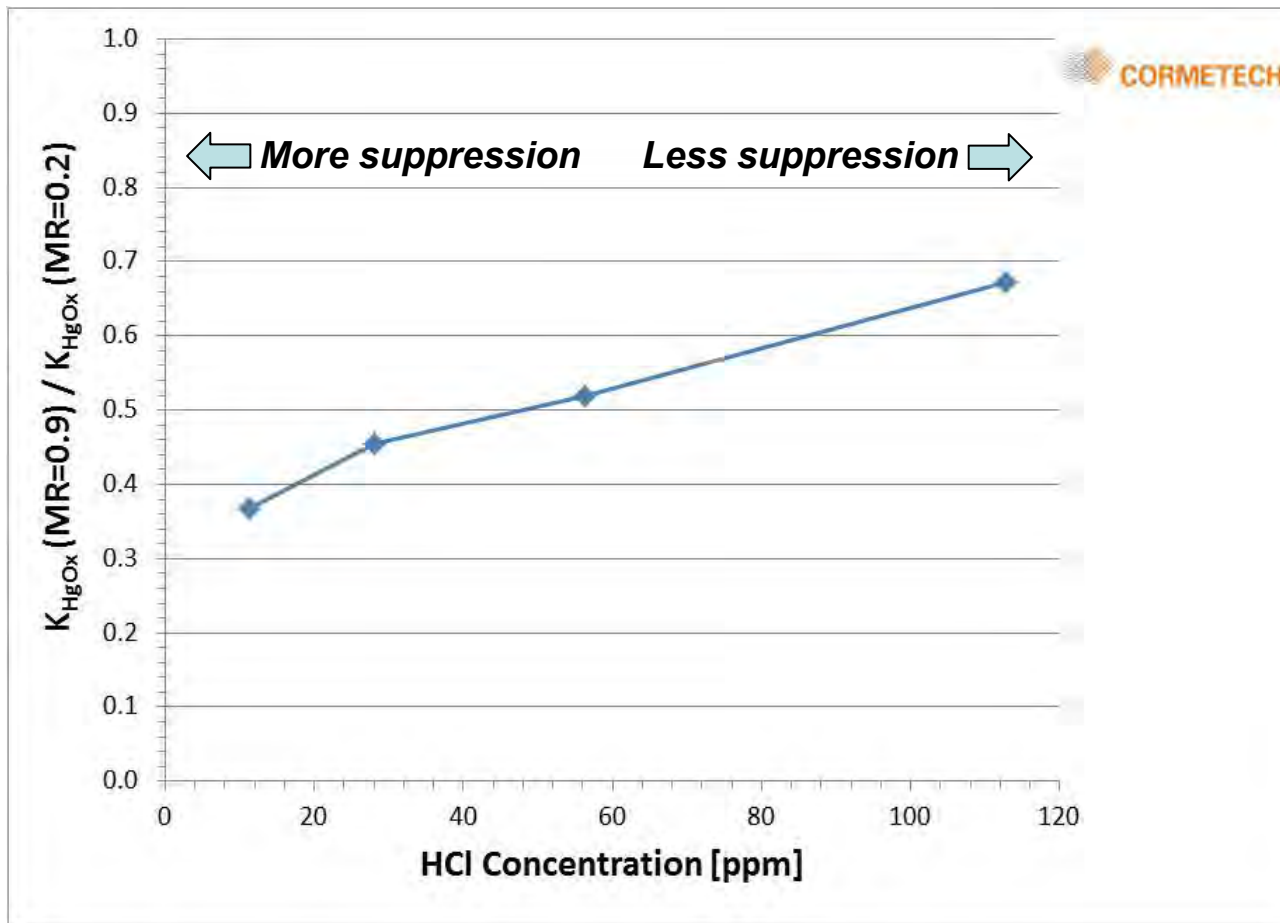
400°C, 3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 350 ppm NO, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO

# Impact of HCl on NH<sub>3</sub> Inhibition

## Hg Oxidation Activity



There is a strong Interdependence between the HCl concentration and the degree of NH<sub>3</sub> suppression of the Hg oxidation rate.



400°C, 3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 350 ppm NO, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO; MR = Inlet Molar Ratio

# Impact of HCl on NH<sub>3</sub> Inhibition

## First Layer vs. Lower Layer Performance



**Strong interdependence between the HCl content and the degree of NH<sub>3</sub> suppression of the Hg oxidation rate → one implication is that layer 1 catalyst can contribute more to overall Hg oxidation under higher HCl conditions!**

Single Layer Performance Example					
Position	Case	MR	HCl [ppm]	Layer Hg Ox	Hg Ox Delta Layer 1 vs. Lower Layer
Layer 1	Low HCl	0.9	28	36%	-27%
Lower Layer	Low HCl	0.2	28	63%	
Layer 1	High HCl	0.9	113	79%	-11%
Lower Layer	High HCl	0.2	113	90%	

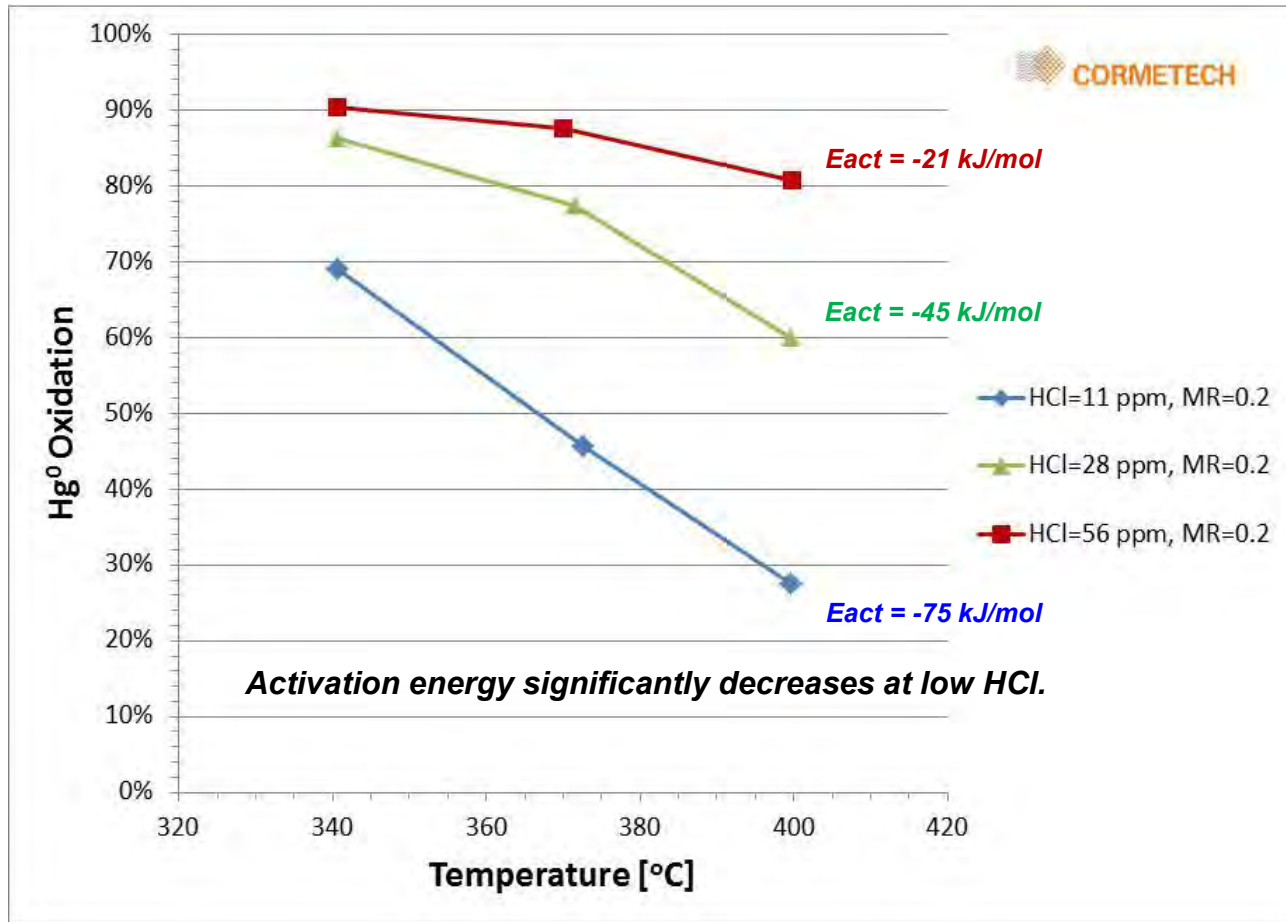
*400°C, 3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 350 ppm NO, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO; MR = Inlet Molar Ratio*

# Impact of Temperature (MR=0.2)



## Hg<sup>0</sup> Oxidation Activity

Listed activation energy values are for the overall Hg oxidation reaction. Values are negative because the rate decreases as temperature increases.



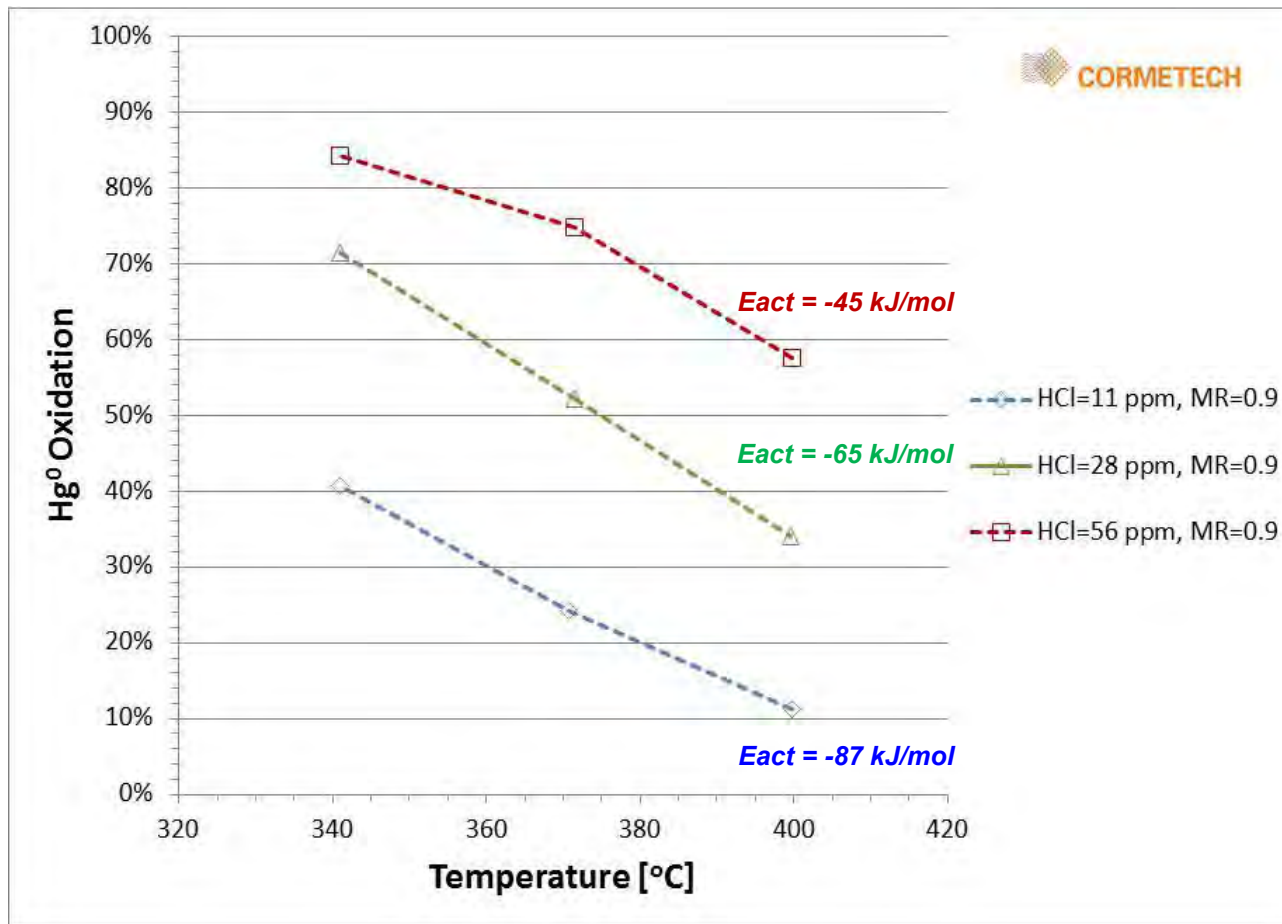
3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 350 ppm NO, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO; MR = Inlet Molar Ratio

# Impact of Temperature (MR=0.9)



## Hg<sup>0</sup> Oxidation Activity

With high inlet NH<sub>3</sub>, the activation energy decreases for constant HCl, which indicates that NH<sub>3</sub> inhibition can become more pronounced at high temperature.



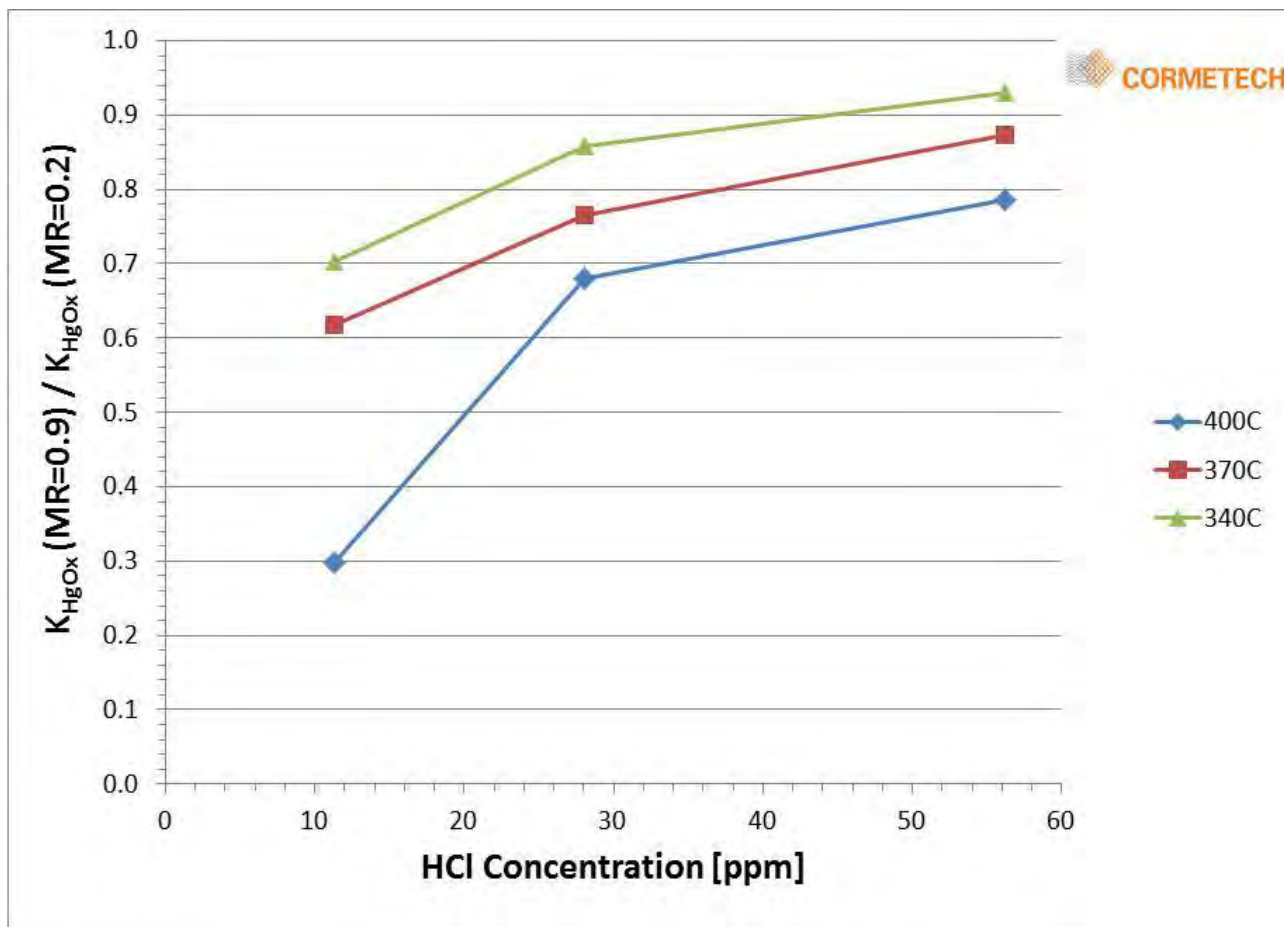
3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 350 ppm NO, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO; MR = Inlet Molar Ratio

# Impact of Temperature

## Hg Oxidation Activity



Increasing HCl can reduce the amount of NH<sub>3</sub> suppression across the temperature range.



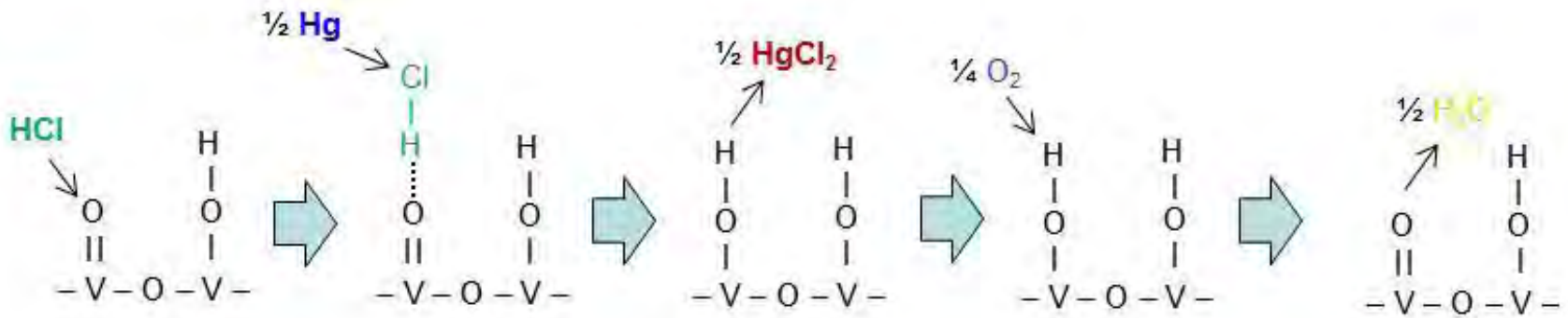
3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 350 ppm NO, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO; MR = Inlet Molar Ratio

# Reaction Mechanism

## Several Hypotheses in the Literature



One example: Eley – Rideal (HCl adsorbs, Hg reacts from gas phase)



Two other examples (both include Hg adsorption steps):

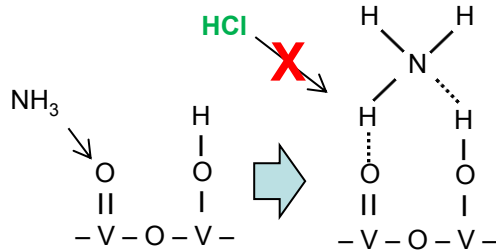
**Langmuir – Hinshelwood** (both HCl and Hg adsorb before reaction occurs)

**Mars – van Krevelen** (reaction of adsorbed Hg with lattice chloride)

# How NH<sub>3</sub> Inhibits Hg Oxidation



## 1. Competitive adsorption of HCl and NH<sub>3</sub>: (more significant at lower temperature)



*We verified that HgCl<sub>2</sub> reduction by NH<sub>3</sub> occurs by running experiments with 100% Hg<sup>2+</sup> injection and measuring the Hg<sup>0</sup> that formed.*

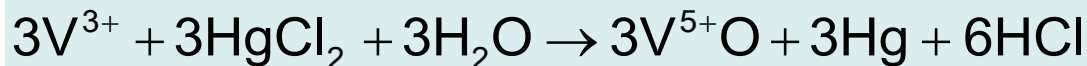
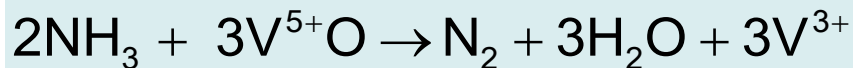
## 2. Re-reduction of HgCl<sub>2</sub> by NH<sub>3</sub>: (more significant at higher temperature)

	MR	Hg0 in	Hg2+ in	Hg0 out	Hg2+ out	Delta Hg0	Delta Hg2+	Hg Ox
with Hg2+ injection	0.0	0.0	19.7	1.7	18.0	1.7	-1.7	-9%
with Hg2+ injection	0.9	0.0	19.7	3.8	15.9	3.8	-3.8	-19%

400°C, 4% O<sub>2</sub>, 11% H<sub>2</sub>O, 350 ppm NO, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>



***What will happen on a more detailed level (simplified):***



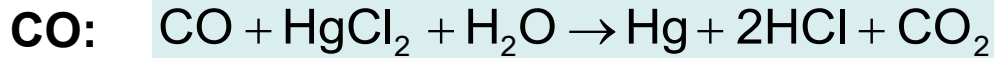
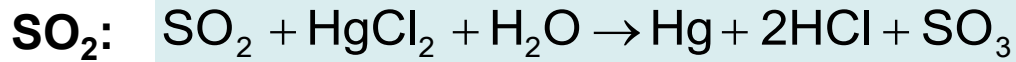
**Coal-type SCR has a low activity for NH<sub>3</sub> oxidation.**

# Impact of Reducing Agents

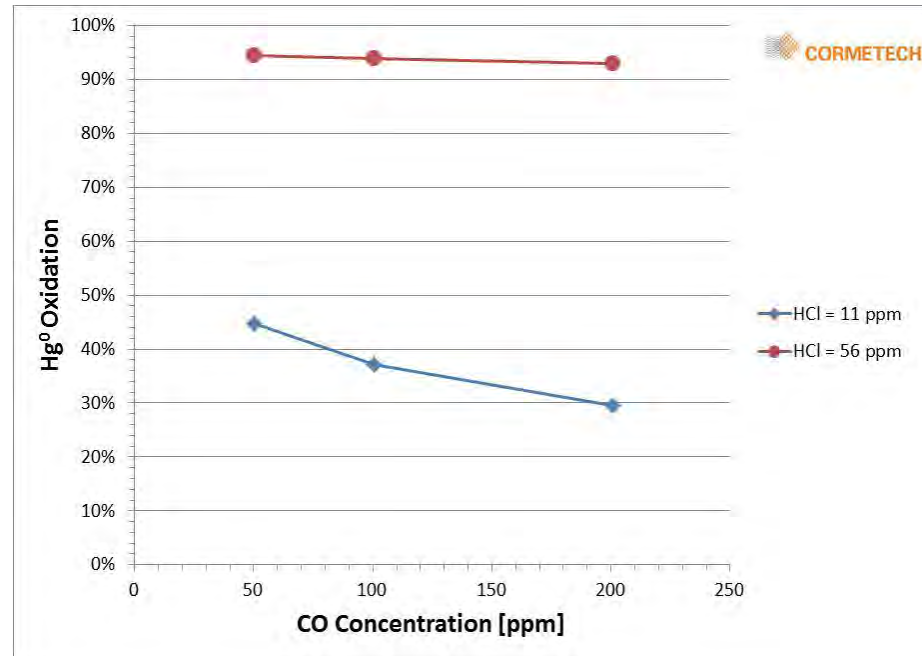
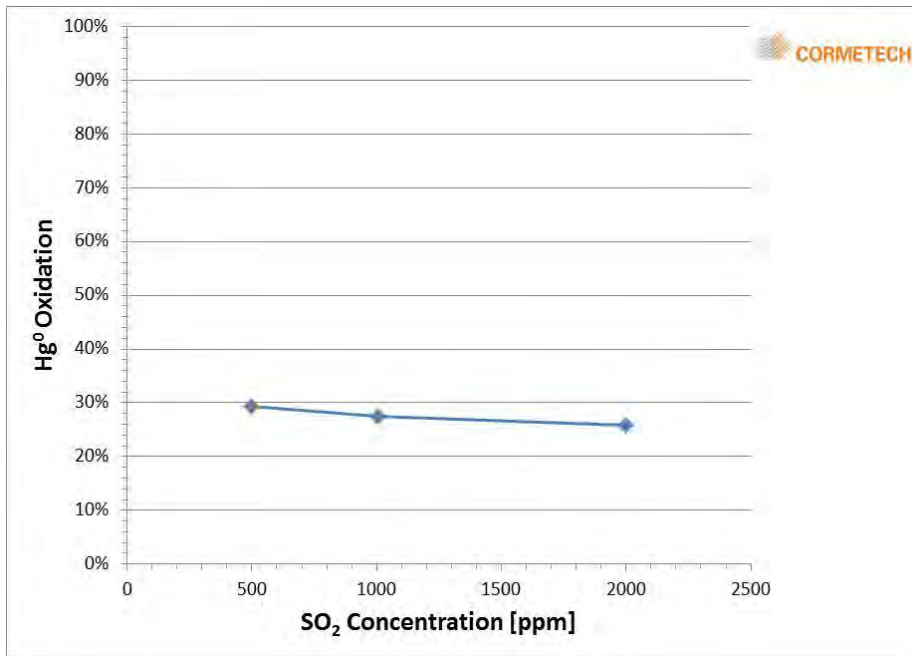
## Hg Oxidation Activity



In addition to NH<sub>3</sub>, there are additional flue gas species that can act as catalyst reducing agents and inhibit Hg oxidation by reduction of HgCl<sub>2</sub>.



*Hydrocarbons can oxidize over SCR catalyst and partially reduce V<sup>5+</sup> sites, but the hydrocarbon concentration in coal flue gas tends to be fairly low.*



400°C, 3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, HCl = 11 ppm or as specified, 350 ppm NO, 0.2 MR, SO<sub>2</sub> = 1000 ppm or as specified, SO<sub>3</sub> = 1% of SO<sub>2</sub>, CO = 100 ppm or as specified

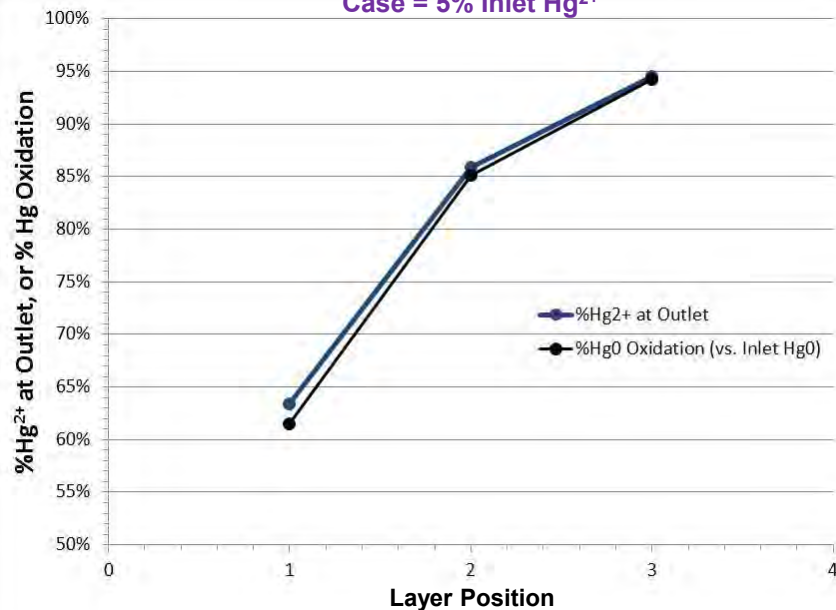
# Impact of Inlet Hg Speciation

## Model Simulation

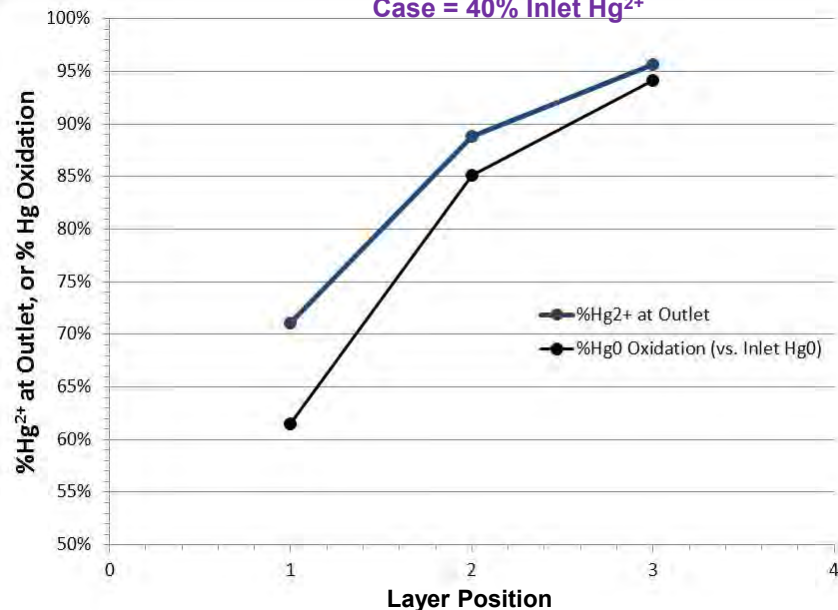


Hg oxidation reactivity held constant.  $\text{Hg}^{2+}$  reduction activity by  $\text{NH}_3$  set at 0 (inactive).

Case = 5% Inlet  $\text{Hg}^{2+}$



Case = 40% Inlet  $\text{Hg}^{2+}$



*In the limit where  $\text{Hg}^{2+}$  reverse reactions are inactive  $\rightarrow$  Hg oxidation is independent of inlet  $\text{Hg}^{2+}$  speciation, and the outlet % oxidized  $\text{Hg}^{2+}$  is effectively additive (= inlet  $\text{Hg}^{2+}$  + amount of  $\text{Hg}^0$  oxidized in the SCR)*

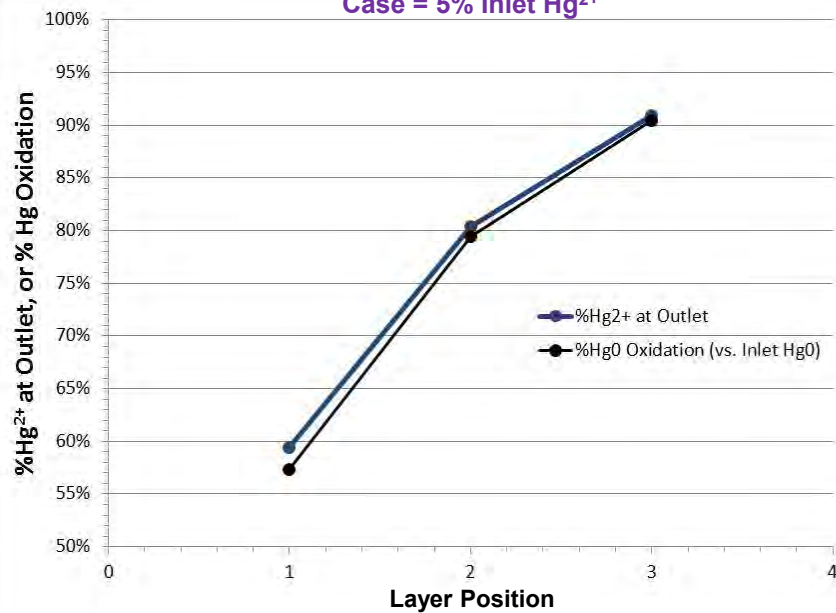
# Impact of Inlet Hg Speciation

## Model Simulation

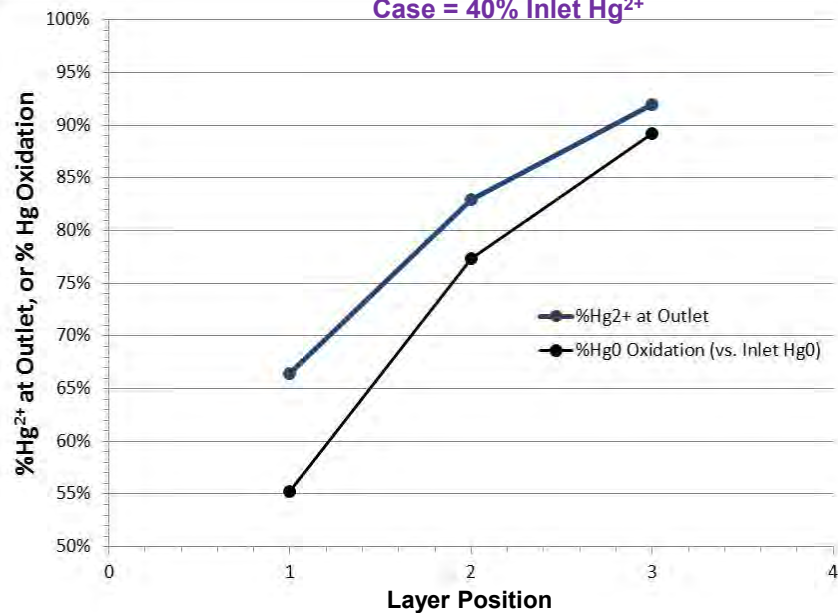


Hg oxidation reactivity held constant.  $\text{Hg}^{2+}$  reduction activity by  $\text{NH}_3$  set at a low value.

Case = 5% Inlet  $\text{Hg}^{2+}$



Case = 40% Inlet  $\text{Hg}^{2+}$



*Higher inlet  $\text{Hg}^{2+}$  decreases the effective Hg oxidation due to reverse reactions. Note that the outlet  $\text{Hg}^{2+}$  for the 40% inlet oxidized case is higher than the 5% inlet oxidized case.*

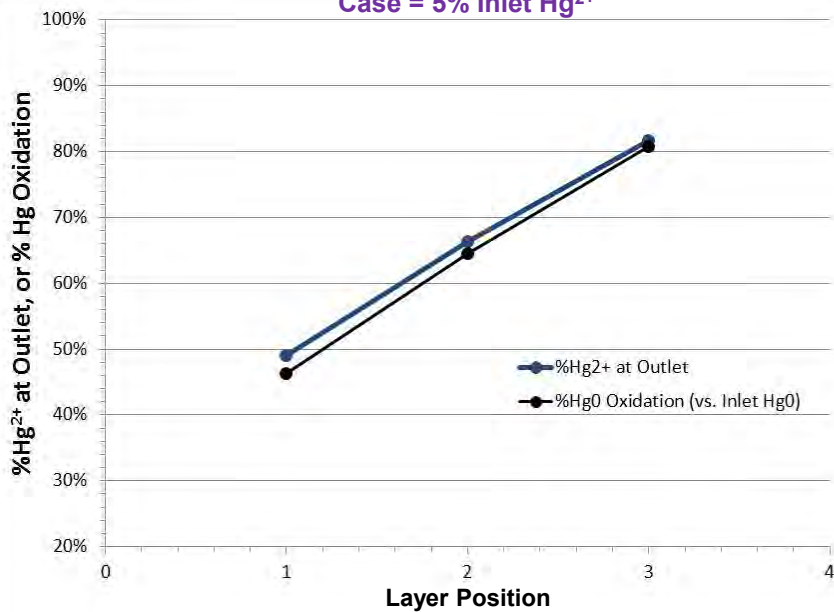
# Impact of Inlet Hg Speciation

## Model Simulation

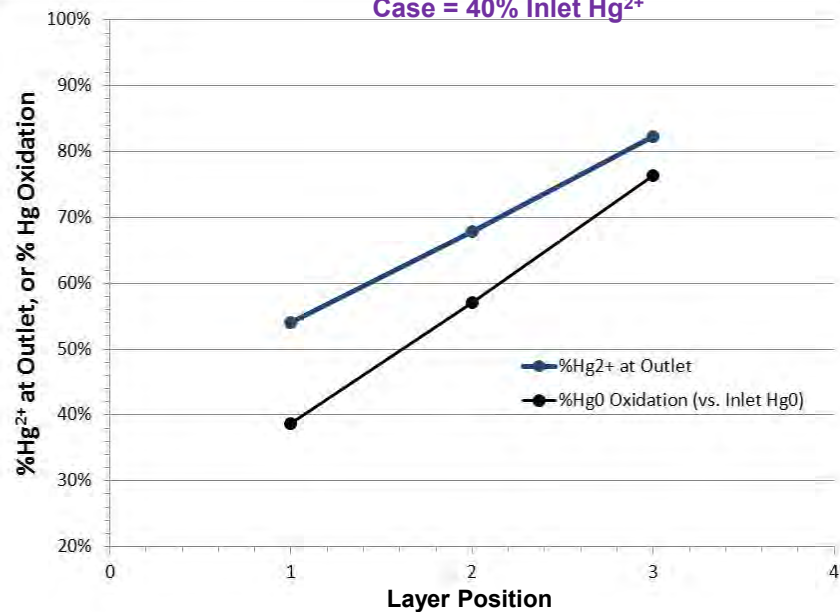


Hg oxidation reactivity held constant.  $\text{Hg}^{2+}$  reduction activity by  $\text{NH}_3$  further increased.

Case = 5% Inlet  $\text{Hg}^{2+}$



Case = 40% Inlet  $\text{Hg}^{2+}$



*Higher inlet  $\text{Hg}^{2+}$  decreases the effective Hg oxidation due to reverse reactions. Note that the outlet  $\text{Hg}^{2+}$  for the 40% inlet oxidized case is still higher than the 5% inlet oxidized case (but the difference is becoming smaller).*

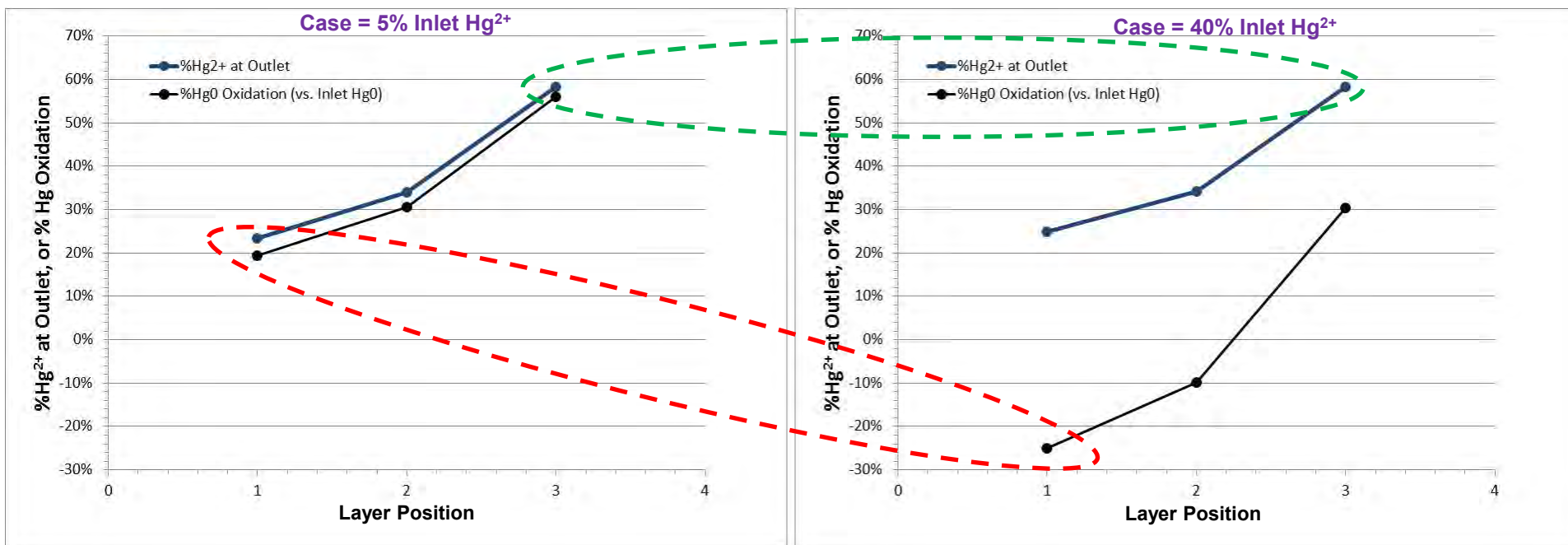
# Impact of Inlet Hg Speciation

## Model Simulation



Hg oxidation reactivity held constant.  $\text{Hg}^{2+}$  reduction activity by  $\text{NH}_3$  increased again.

*In the limit where reverse reactions are dominant, the %outlet  $\text{Hg}^{2+}$  achieved is independent of the %inlet  $\text{Hg}^{2+}$ .*



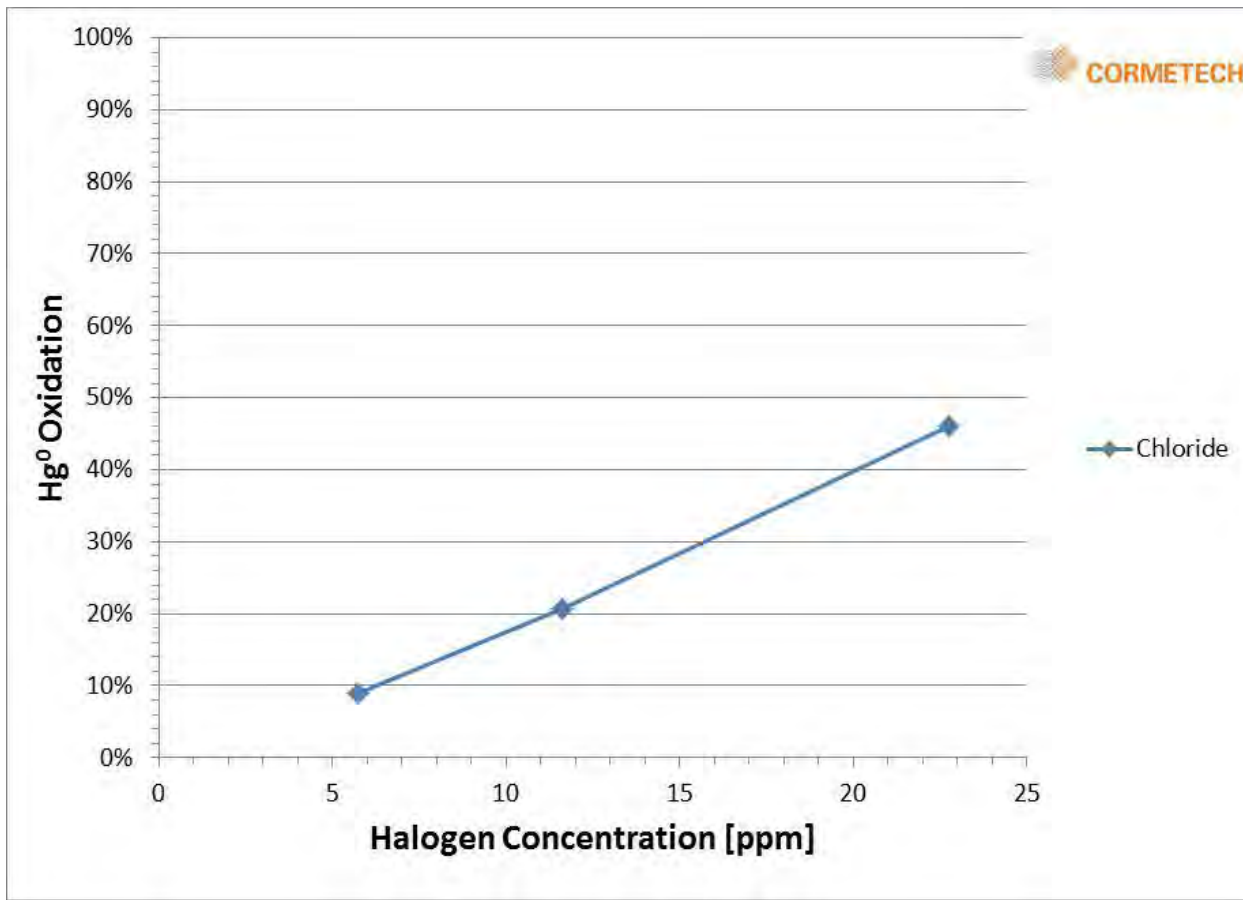
*In the limit where reverse reactions are dominant, Hg oxidation of top layers can become negative for high %inlet  $\text{Hg}^{2+}$ .*

# Halogens: Cl vs. Br vs. I

## Hg<sup>0</sup> Oxidation Activity



**Baseline with chloride only. Challenging Hg oxidation condition.**



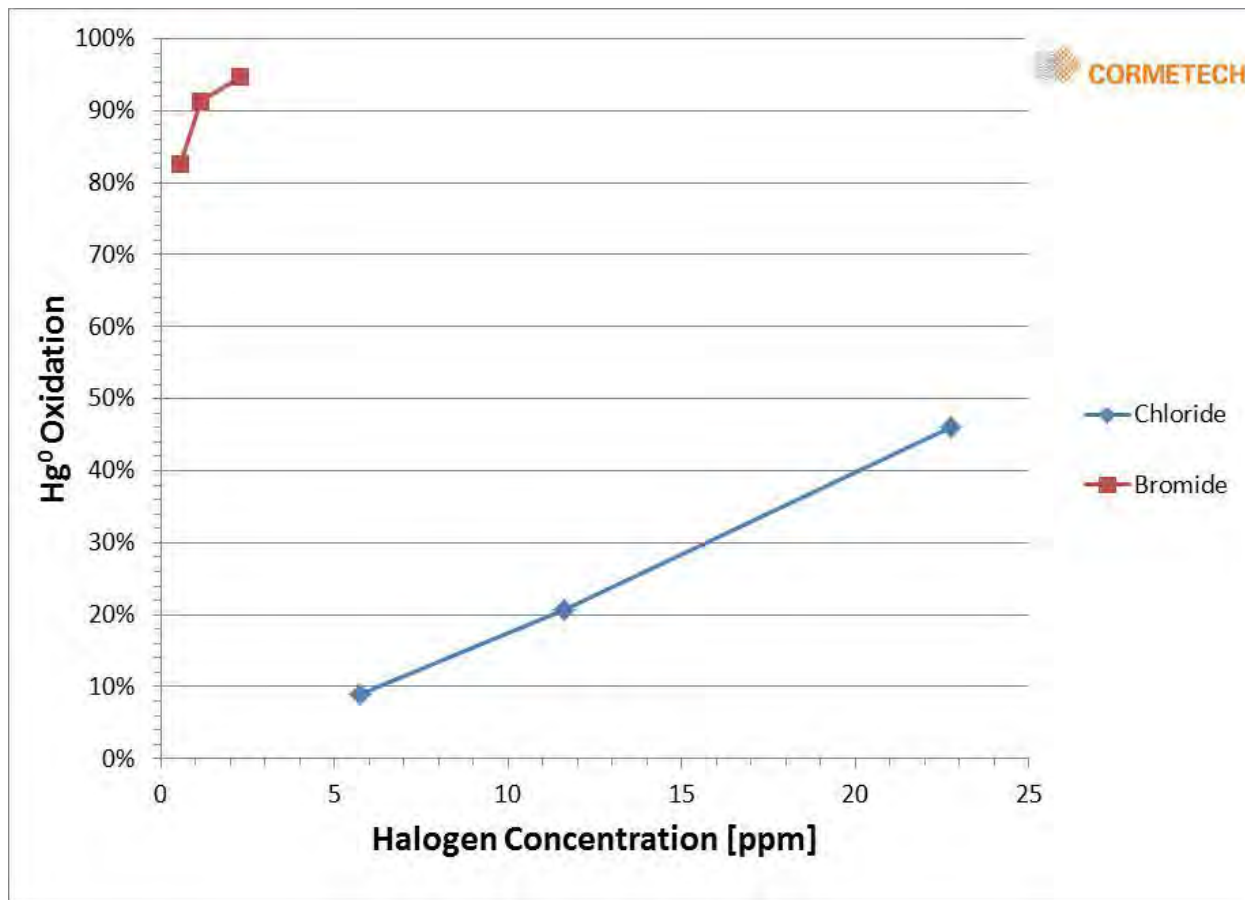
*400°C, 350 ppm NO, 0.9 MR, 3.5% O<sub>2</sub>, 12% H<sub>2</sub>O, 1000 ppm SO<sub>2</sub>, 11 ppm SO<sub>3</sub>, 100 ppm CO.*

# Halogens: Cl vs. Br vs. I

## Hg<sup>0</sup> Oxidation Activity



**Bromide is much more effective than chloride for Hg oxidation.**



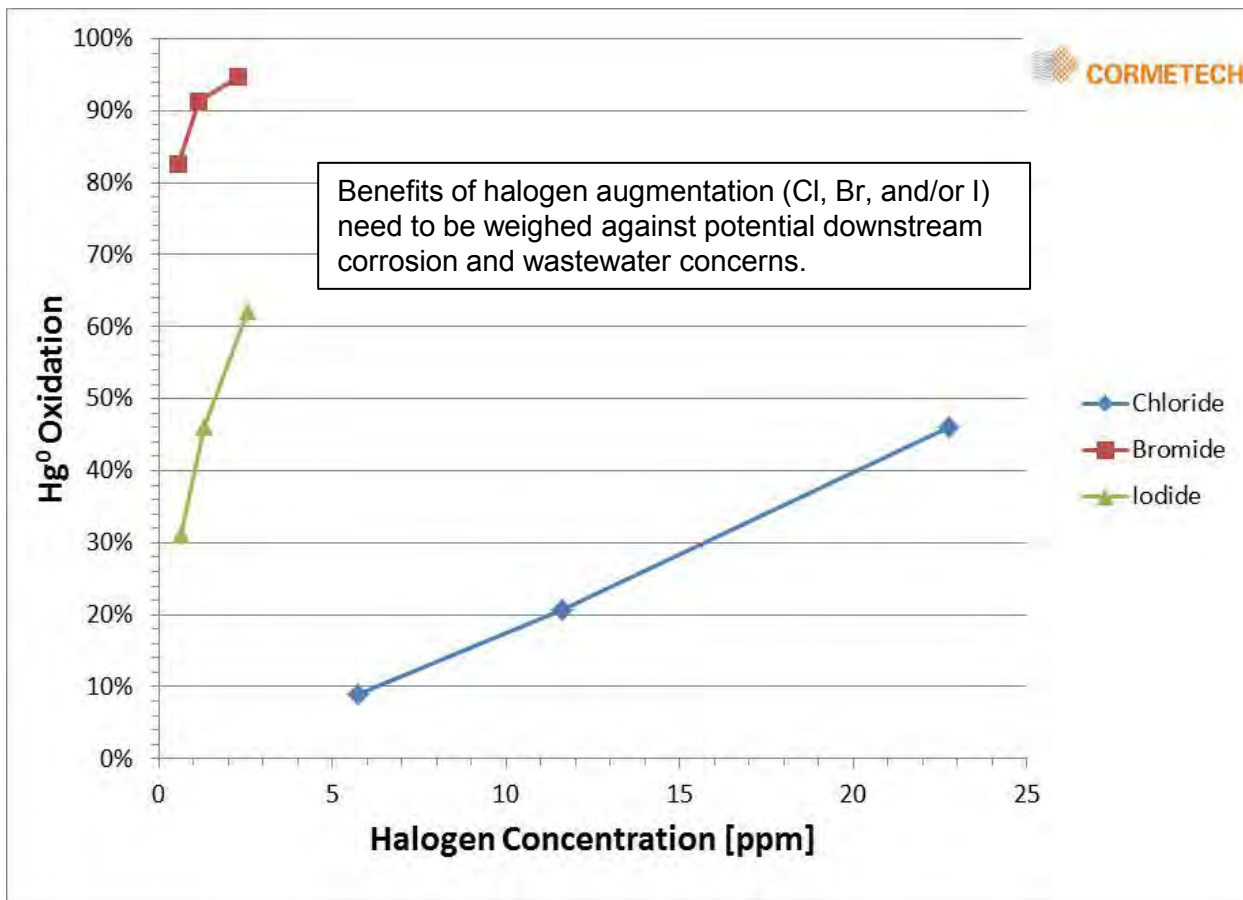
*400°C, 350 ppm NO, 0.9 MR, 3.5% O<sub>2</sub>, 12% H<sub>2</sub>O, 1000 ppm SO<sub>2</sub>, 11 ppm SO<sub>3</sub>, 100 ppm CO.*

# Halogens: Cl vs. Br vs. I

## Hg<sup>0</sup> Oxidation Activity



Rank of halogen effectiveness for Hg oxidation: Br > I > Cl.

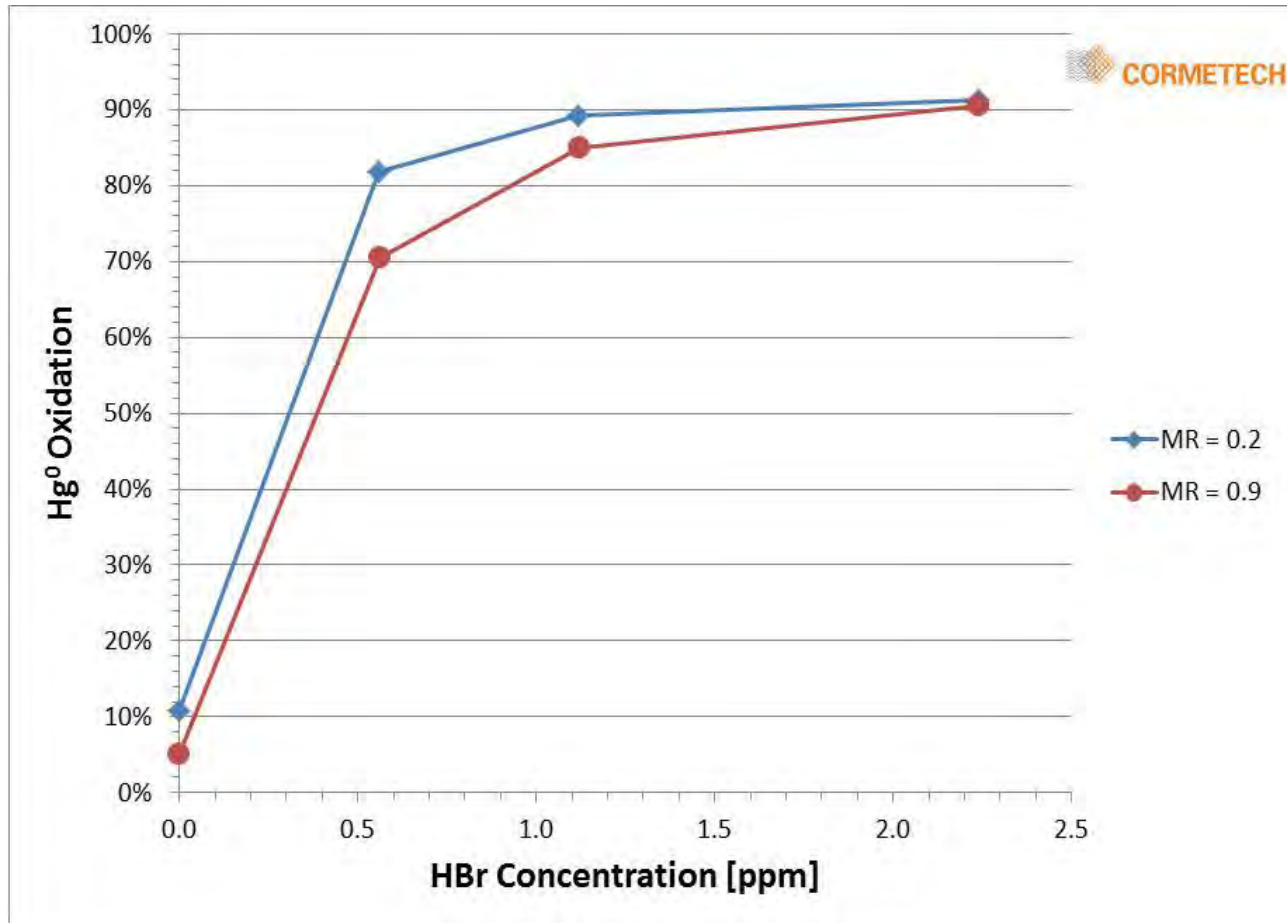


400°C, 350 ppm NO, 0.9 MR, 3.5% O<sub>2</sub>, 12% H<sub>2</sub>O, 1000 ppm SO<sub>2</sub>, 11 ppm SO<sub>3</sub>, 100 ppm CO.

# HBr Impact on NH<sub>3</sub> Inhibition



Testing data set at MR = 0.2 and MR = 0.9.

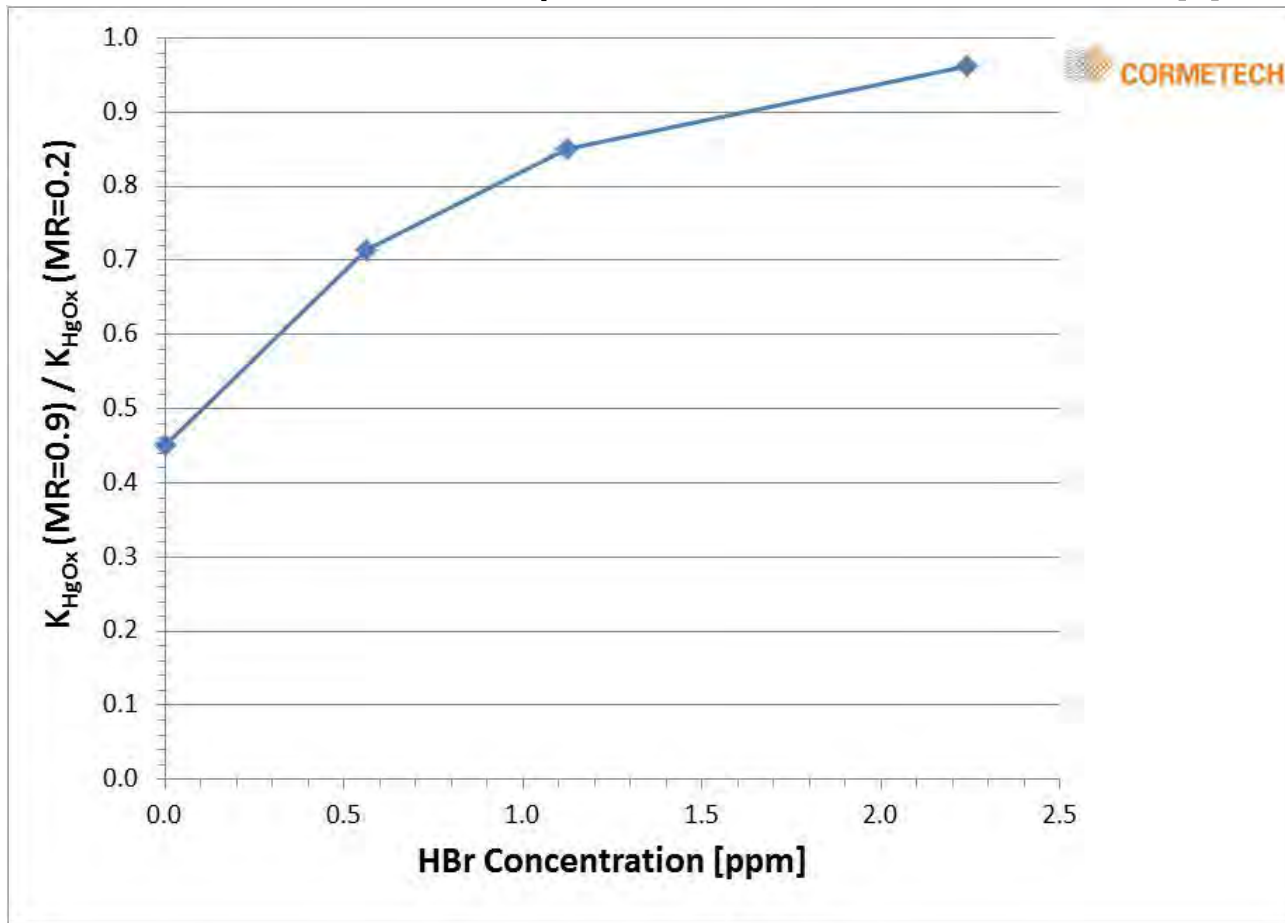


400°C, 3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO, HCl = 5 ppm; MR = Inlet Molar Ratio

# HBr Impact on NH<sub>3</sub> Inhibition



The catalyst's Hg oxidation activity is much less sensitive to NH<sub>3</sub> at high HBr concentration (almost no inhibition at 2 ppm HBr).



400°C, 3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO, HCl = 5 ppm; MR = Inlet Molar Ratio

# Impact of HBr on NH<sub>3</sub> Inhibition

## First Layer vs. Lower Layer Performance



**Strong interdependence between the HBr content and the degree of NH<sub>3</sub> suppression of Hg ox rate → as with higher HCl, the layer 1 catalyst will contribute more to overall Hg oxidation with HBr injection!**

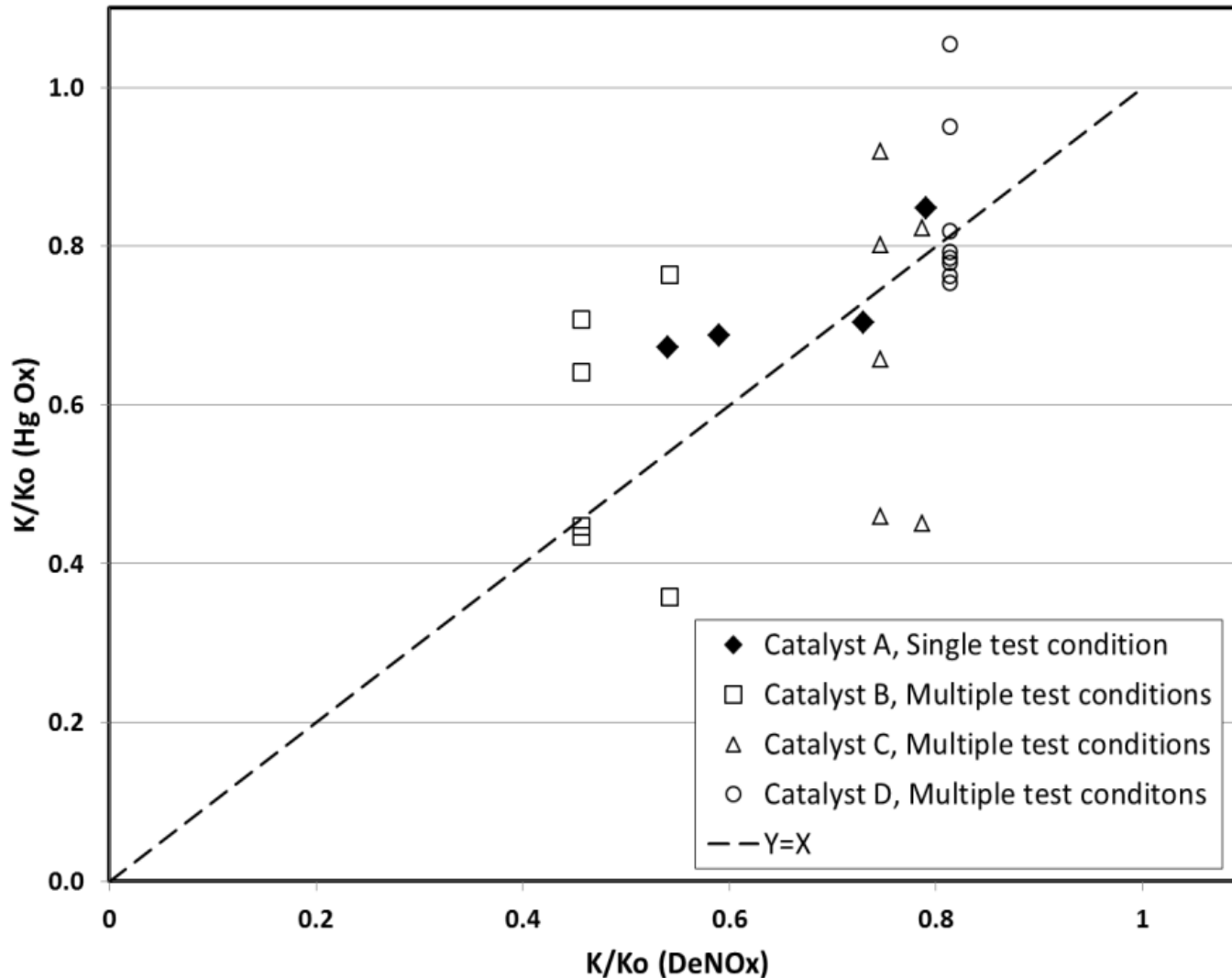
Single Layer Performance Example						
Position	Case	MR	HCl [ppm]	HBr [ppm]	Layer Hg Ox	Hg Ox Delta Layer 1 vs. Lower Layer
Layer 1	no HBr	0.9	6	0	5%	-6%
Lower Layer	no HBr	0.2	6	0	12%	
Layer 1	HBr = 1	0.9	6	1	87%	-4%
Lower Layer	HBr = 1	0.2	6	1	91%	
Layer 1	HBr = 2	0.9	6	2	92%	-1%
Lower Layer	HBr = 2	0.2	6	2	93%	

*400°C, 3.5% O<sub>2</sub>, 11% H<sub>2</sub>O, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO, HCl = 5 ppm; MR = Inlet Molar Ratio*

- **Including Hg is analogous to DeNOx...**
  - *With the caveats for  $K_{HgOx}$  previously outlined*
- **DeNOx or Hg oxidation establishes the design minimum volume**
  - *Depends on the relative catalyst potential and performance requirements for each reaction*
- **Considerations**
  - Layer auditing (lab reactor testing)
  - Catalyst action selection (traditional, regen, advanced)
  - Halogen augmentation potential

# Catalyst Deactivation

## Correlation with DeNOx Deactivation



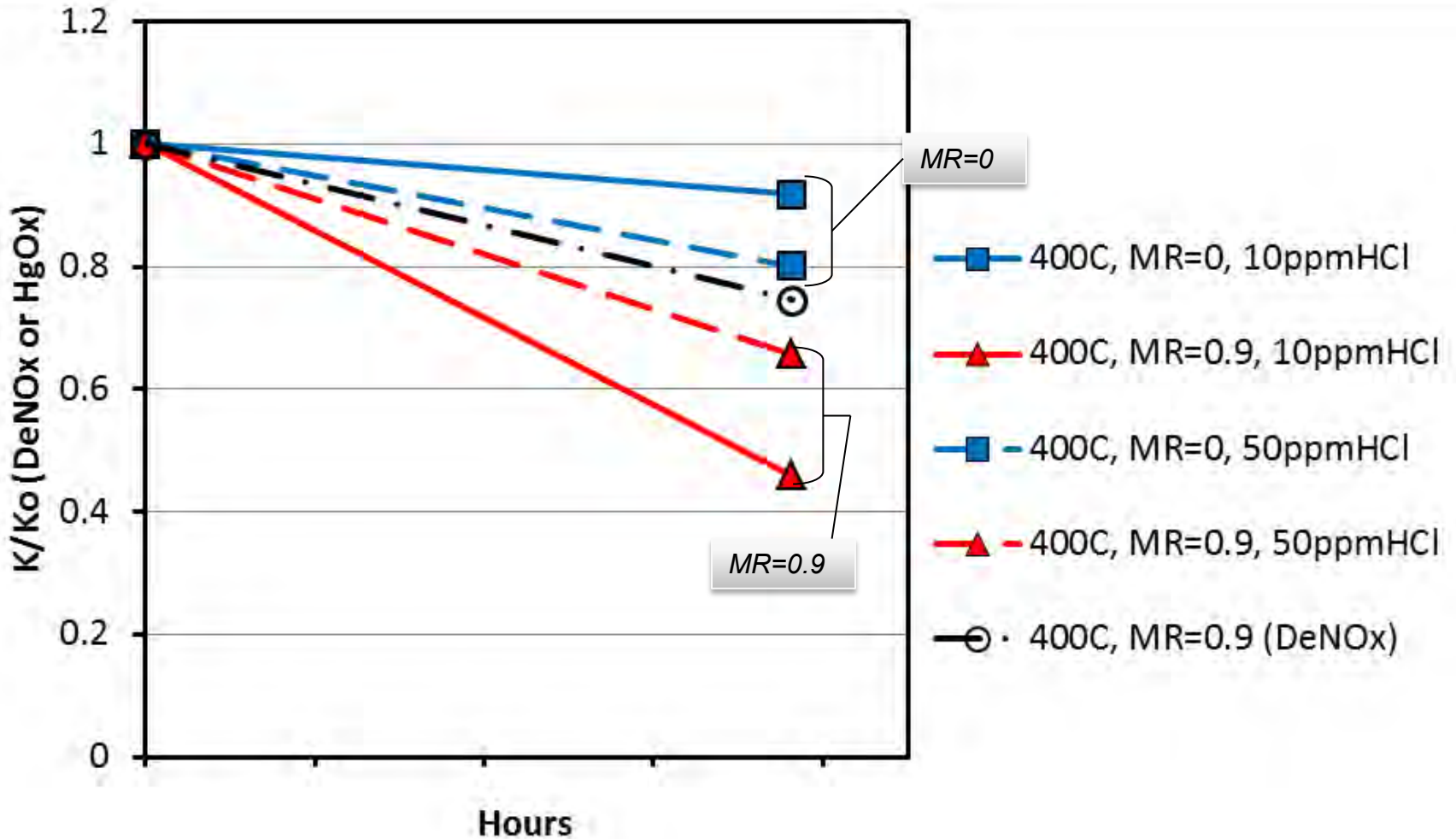
*Hg oxidation deactivation generally correlates with DeNOx deactivation.*

*The extent of deactivation for the two reactions may not be equivalent:*

*K/Ko (Hg Ox) is sensitive to operating conditions (especially NH<sub>3</sub>, HCl, temperature, and catalyst type).*

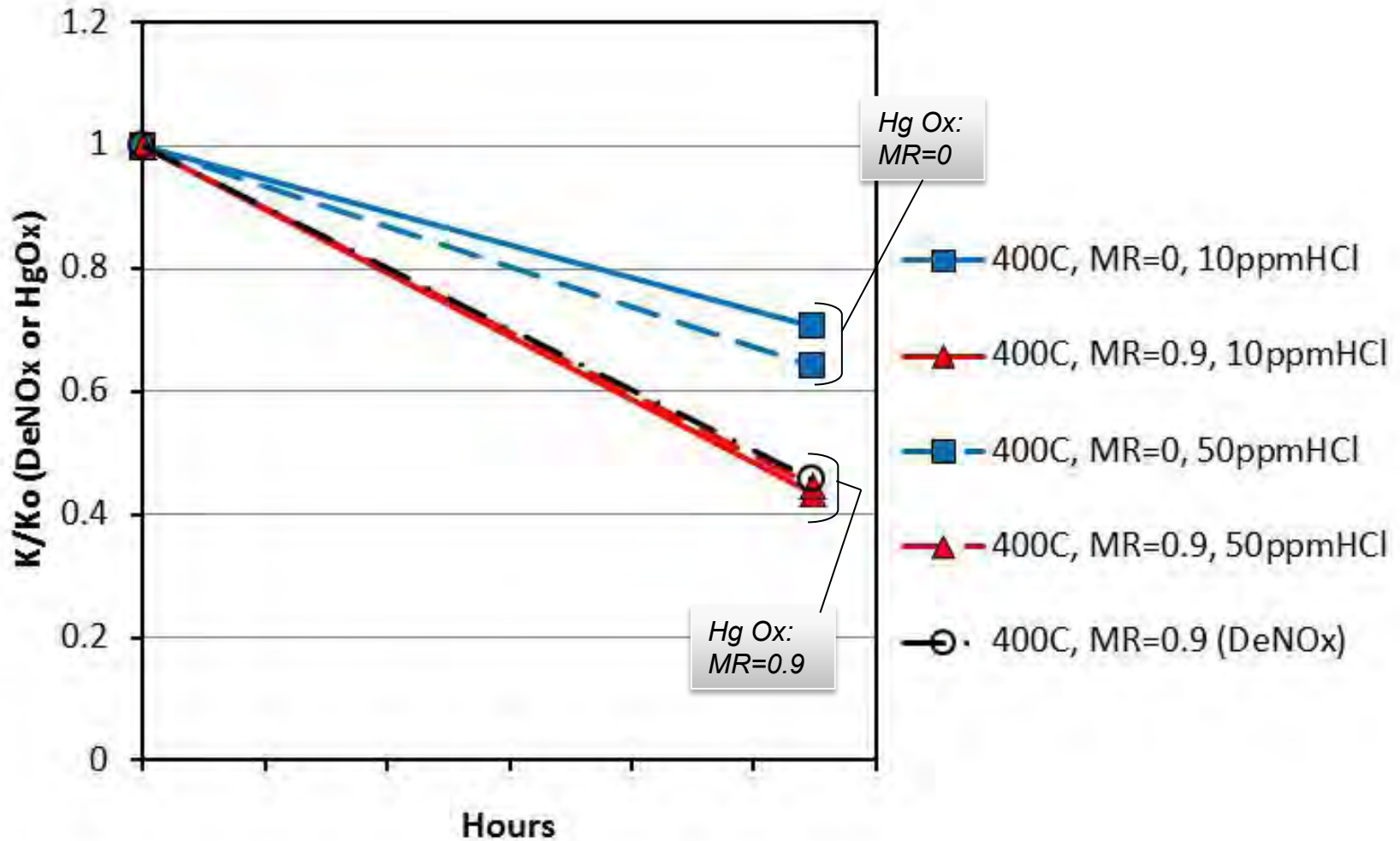
# Catalyst Deactivation

## PRB-Firing Unit Example (Ca, P)



# Catalyst Deactivation

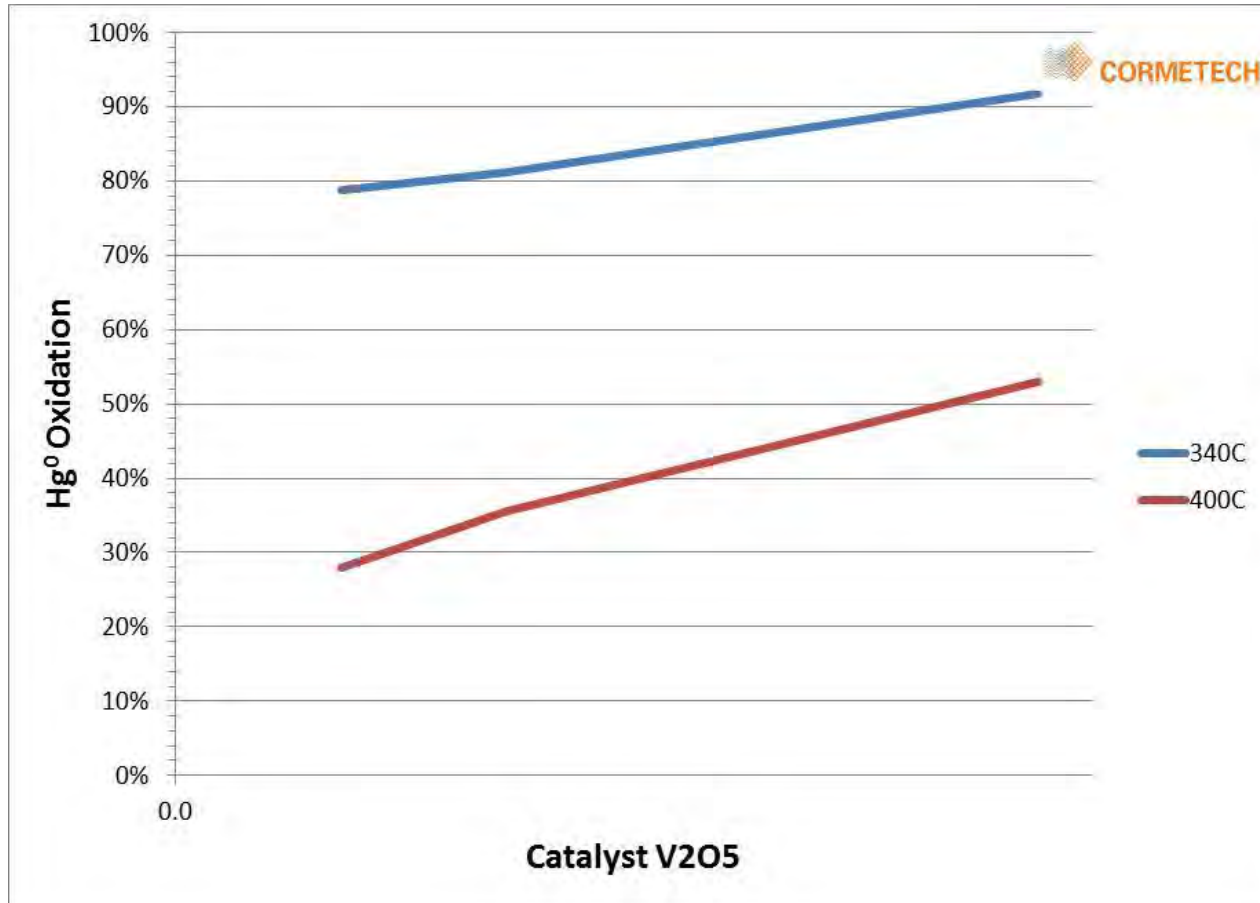
## Bituminous-Firing Unit Example (As)



# Impact of Catalyst $V_2O_5$ Content



Higher  $V_2O_5$  improves Hg oxidation and DeNOx, but it must be balanced relative to  $SO_2$  oxidation constraints (e.g., PRB vs. bituminous,  $SO_3$  mitigation).

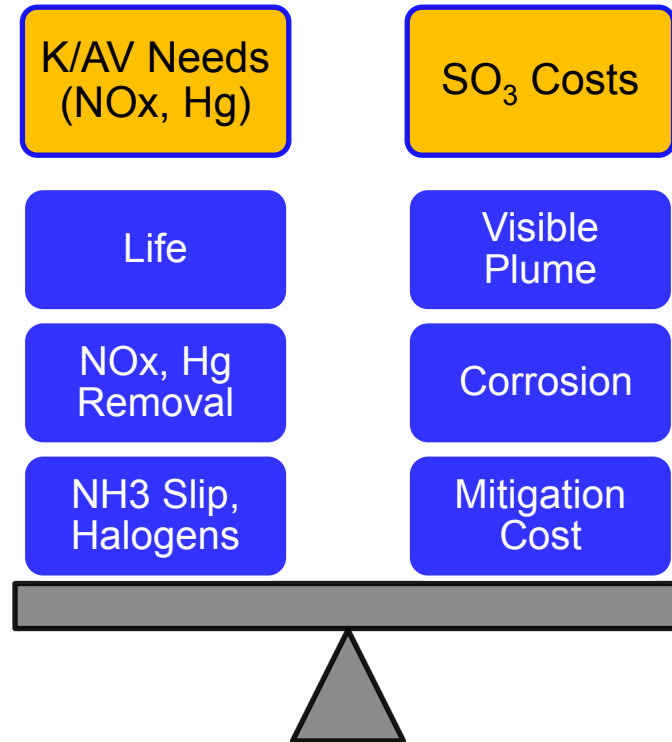


400°C, 3.5%  $O_2$ , 11%  $H_2O$ , 1000 ppm  $SO_2$ , 10 ppm  $SO_3$ , 100 ppm  $CO$ ,  $HCl = 11$  ppm;  $MR = 0$

# SCR Catalyst: Design Approach

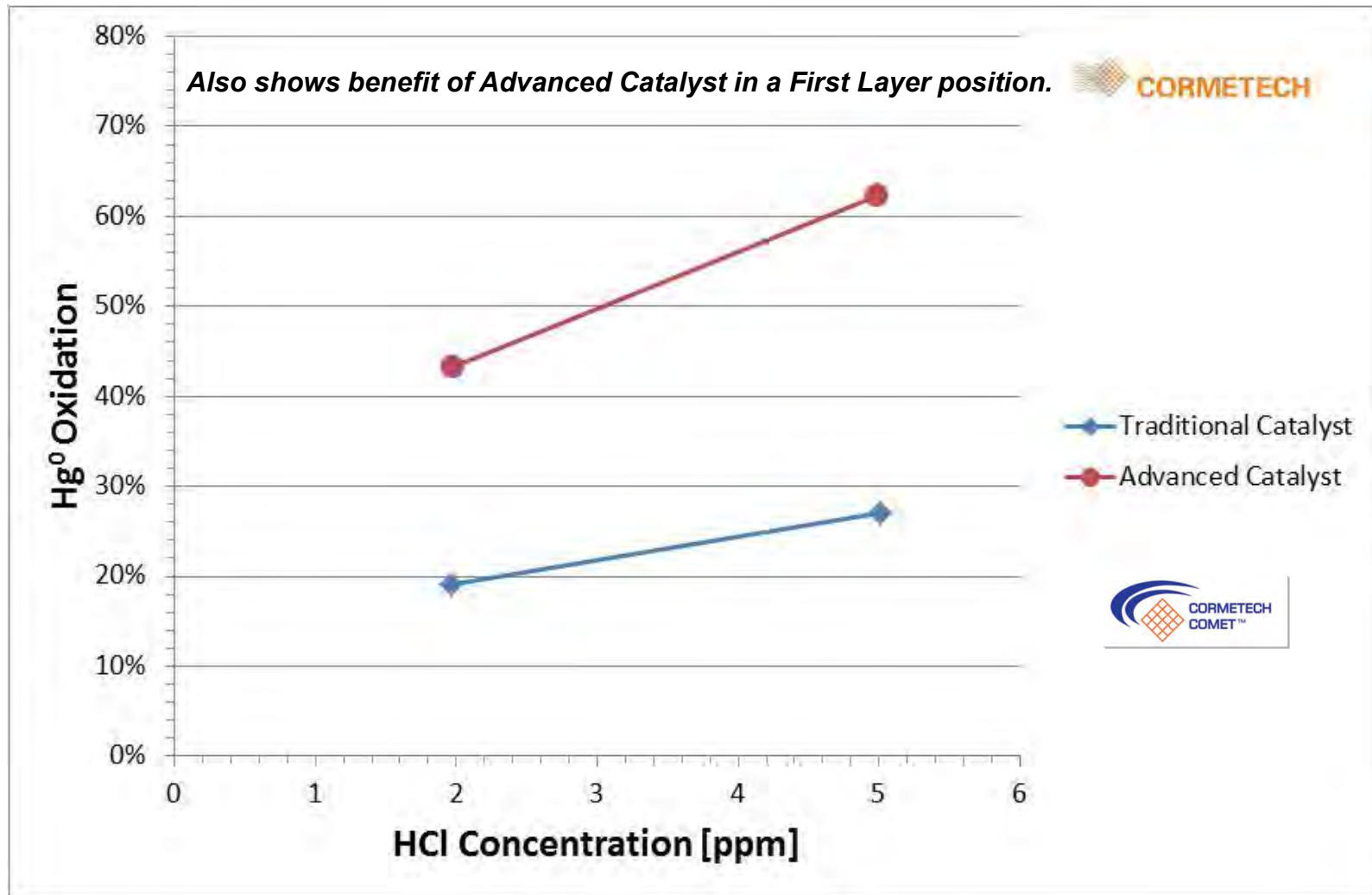


SCR catalyst is formulated to achieve DeNO<sub>x</sub> and Hg oxidation requirements, while meeting SO<sub>2</sub> oxidation constraints. Either DeNO<sub>x</sub> or Hg oxidation will be controlling for catalyst volume; the other will have excess potential.



- **For challenging conditions, such as...**
  - Lower HCl, and/or
  - Higher temperature, and/or
  - Higher concentration of reducing agents (NH<sub>3</sub>, CO, SO<sub>2</sub>)
- **...we can modify catalyst formulation and processing to improve Hg oxidation relative to DeNOx and SO<sub>2</sub> oxidation**

# Advanced Catalyst: Low HCl



370°C, 250 ppm NO, 0.9 MR, 4% O<sub>2</sub>, 14% H<sub>2</sub>O, 400 ppm SO<sub>2</sub>, 4 ppm SO<sub>3</sub>, 100 ppm CO

# Advanced Catalyst: NH<sub>3</sub> Impact

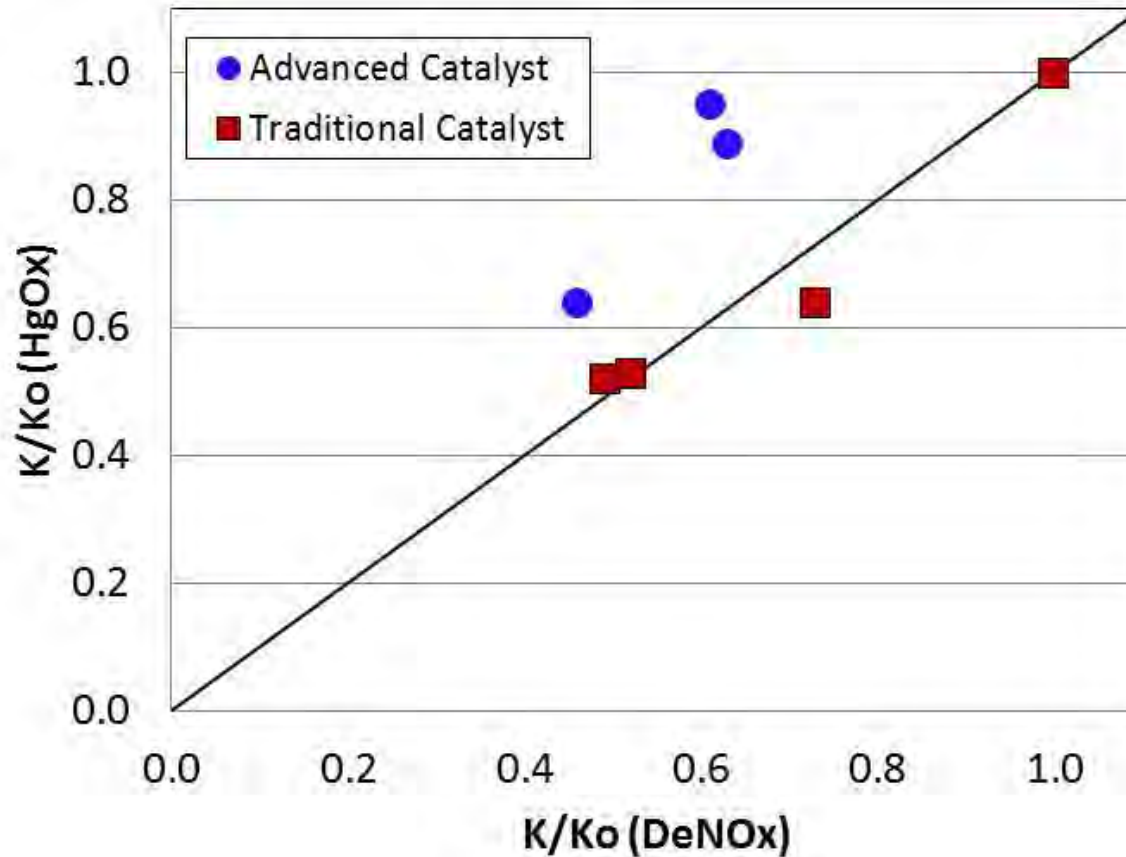


**Advanced Catalyst also has a performance benefit in the First Layer position for higher HCl cases.**

Single Layer Performance Example					
Position	Case	MR	HCl [ppm]	Layer Hg Ox	Hg Ox Delta Advanced vs. Traditional
Layer 1	Traditional Catalyst	1.0	58	53%	
Layer 1	Advanced Catalyst	1.0	58	72%	18%

*371°C, 305 ppm NO, 1.0 MR, 4.3% O<sub>2</sub>, 8.5% H<sub>2</sub>O, 850 ppm SO<sub>2</sub>, 8 ppm SO<sub>3</sub>, 100 ppm CO.*

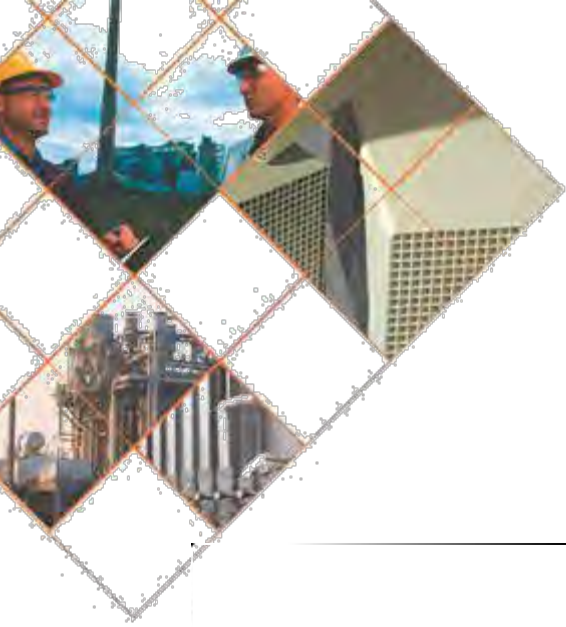
# Advanced Catalyst: K/Ko



*400°C, 350 ppm NO, 0.9 MR, 3.5% O<sub>2</sub>, 12% H<sub>2</sub>O, 1000 ppm SO<sub>2</sub>, 10 ppm SO<sub>3</sub>, 100 ppm CO, 56 ppm HCl*

- **SCR Hg oxidation is influenced by multiple factors**
  - Layer dependency
  - More factors in setting design conditions
  - Interdependencies between factors
  - Impacts of catalyst type & formulation

***Understand these factors and incorporate them into the design process to optimize the SCR for Hg oxidation, maintain NO<sub>x</sub> reduction and manage SO<sub>2</sub> oxidation.***



**CORMETECH**



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**Thank You!**

**Questions?**

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**Christopher Bertole**

Cormetech, Inc.

2015 Reinhold NOx-Combustion Round Table

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