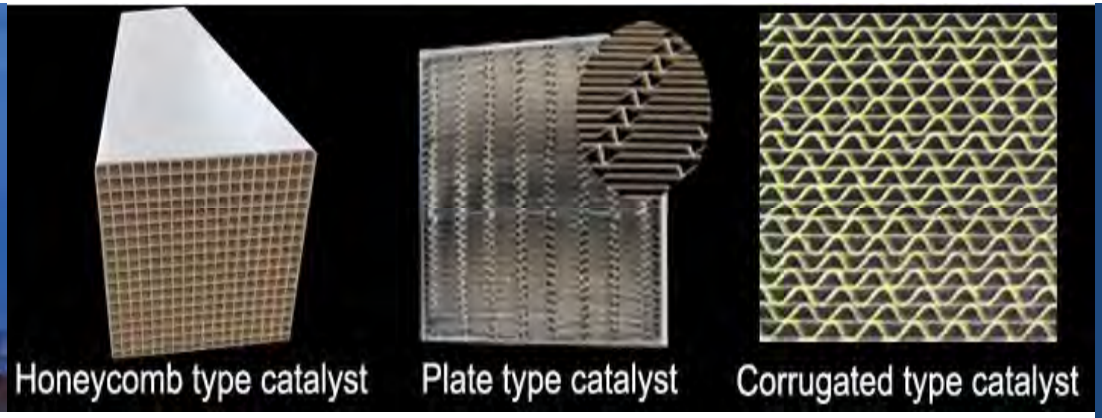
REINHOLD ENVIRONMENTAL Ltd.

2019 NOx-Combustion-CCR Round Table Presentation

February 11 & 12, 2019, in Salt Lake City, Utah / Hosted by PacifiCorp



SCR Catalyst Laboratory Testing: Results of EPRI's Round Robin Study & Revised Laboratory Testing Protocol

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Primary EPRI Studies - DeNOx

Bench Scale Testing for DeNOx and SO2 Conversion

Multi-Laboratory Comparative SCR Catalyst Testing for DeNOx Activity and SO2 Conversion: 2017 Testing Results (Round Robin Testing)

- Product Id: 3002010384
- Date Published: Feb 14, 2018

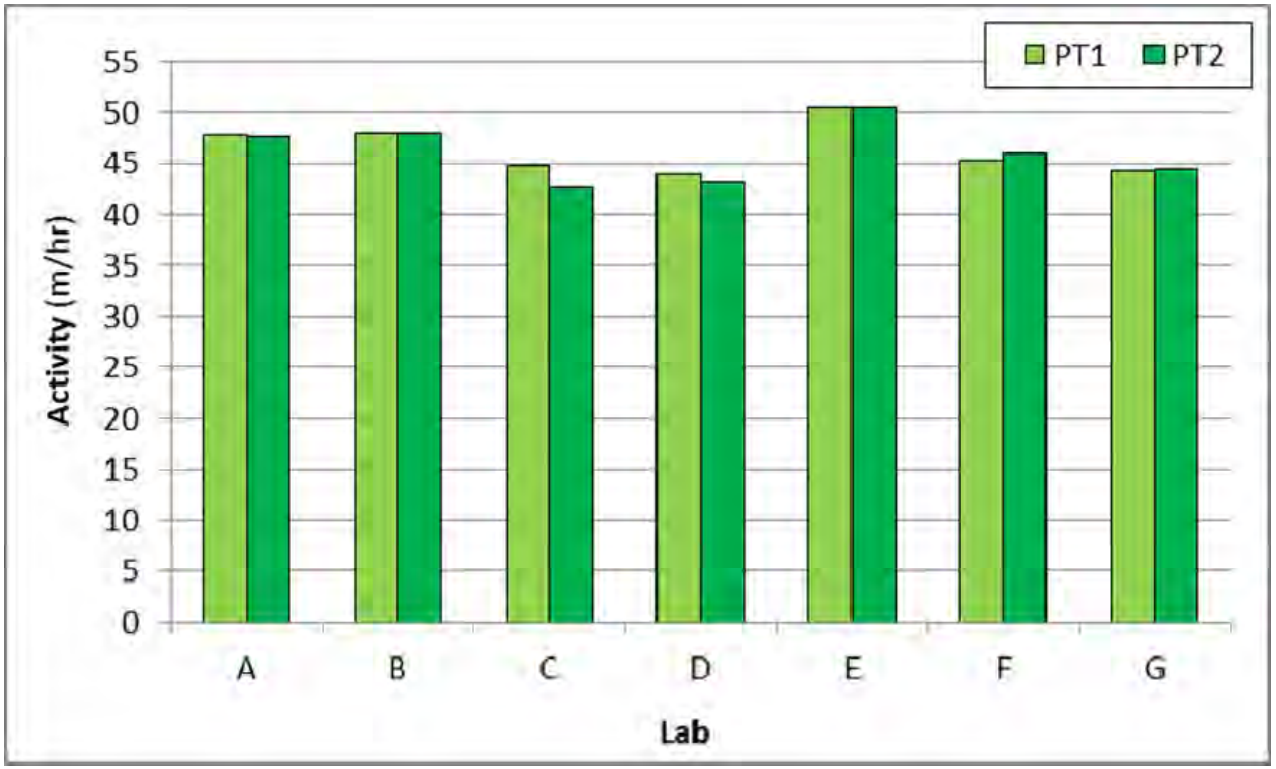
Laboratory Testing Protocol for Coal-Fired SCR Catalyst: 3rd Edition

- Product Id: 3002013048
- Date Published: Nov 14, 2018

Round-Robin Testing Highlights

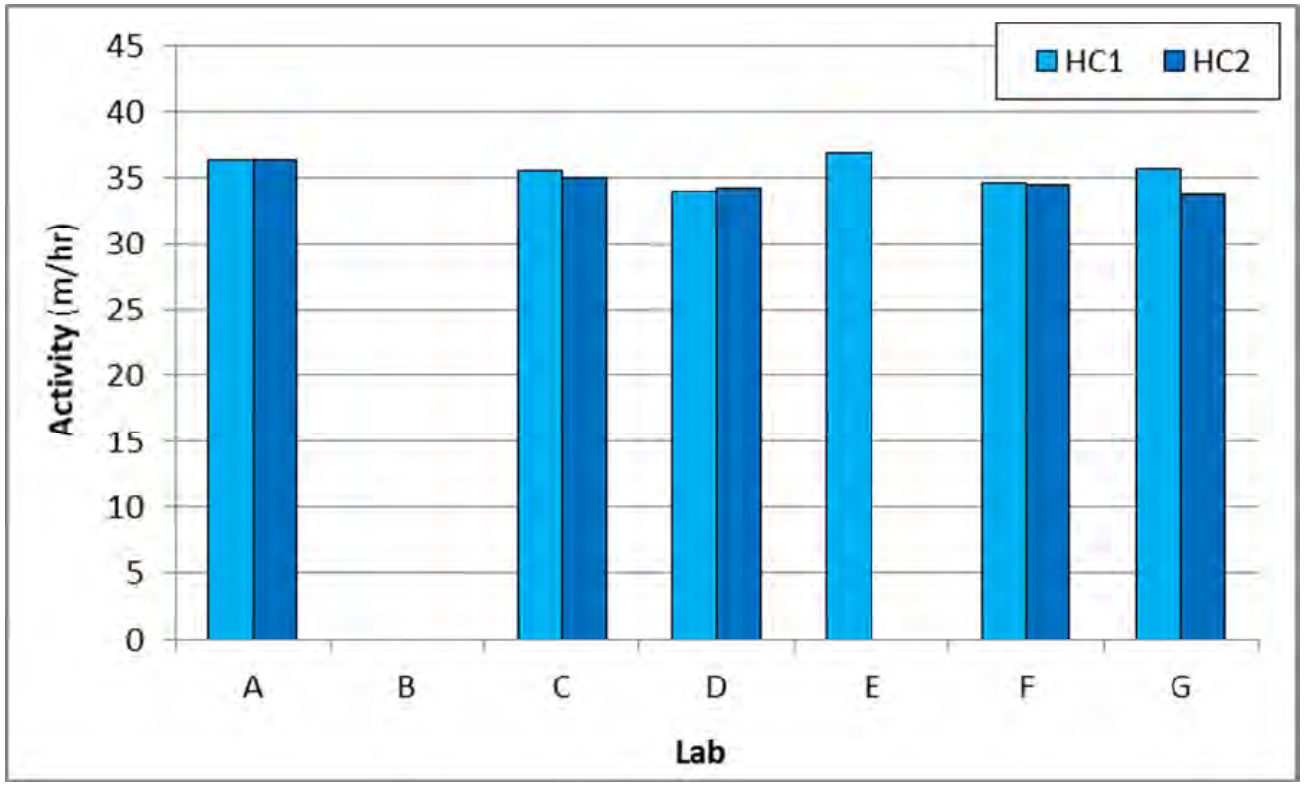
- 7 Bench-scale labs participated
- Tested 4 samples total, 2 each of identical honeycomb and plate
- Full length honeycomb (1,152 mm), Full length plate (single plate - 623mm)
- “Round-robin” approach, initiating lab re-tested at end of cycle

Plate Catalyst Activity Test Results



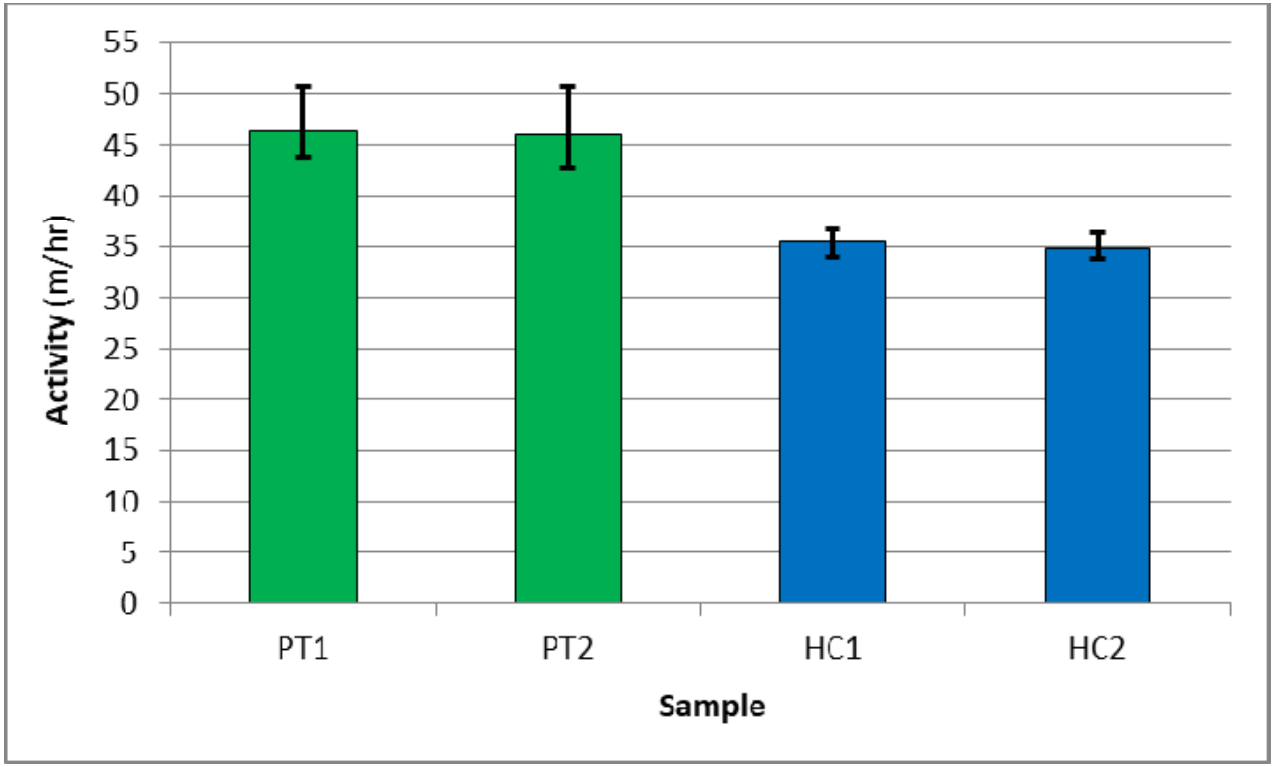
Parameter	Plate
DeNOx	75.4%
Average Activity	46.3 m/hr
Average Absolute Deviation	±3.66 m/hr
Average Relative Deviation	±7.92%
Average Absolute Standard Deviation	2.69 m/hr
Average Relative Standard Deviation	5.8%

Honeycomb Catalyst Activity Test Results



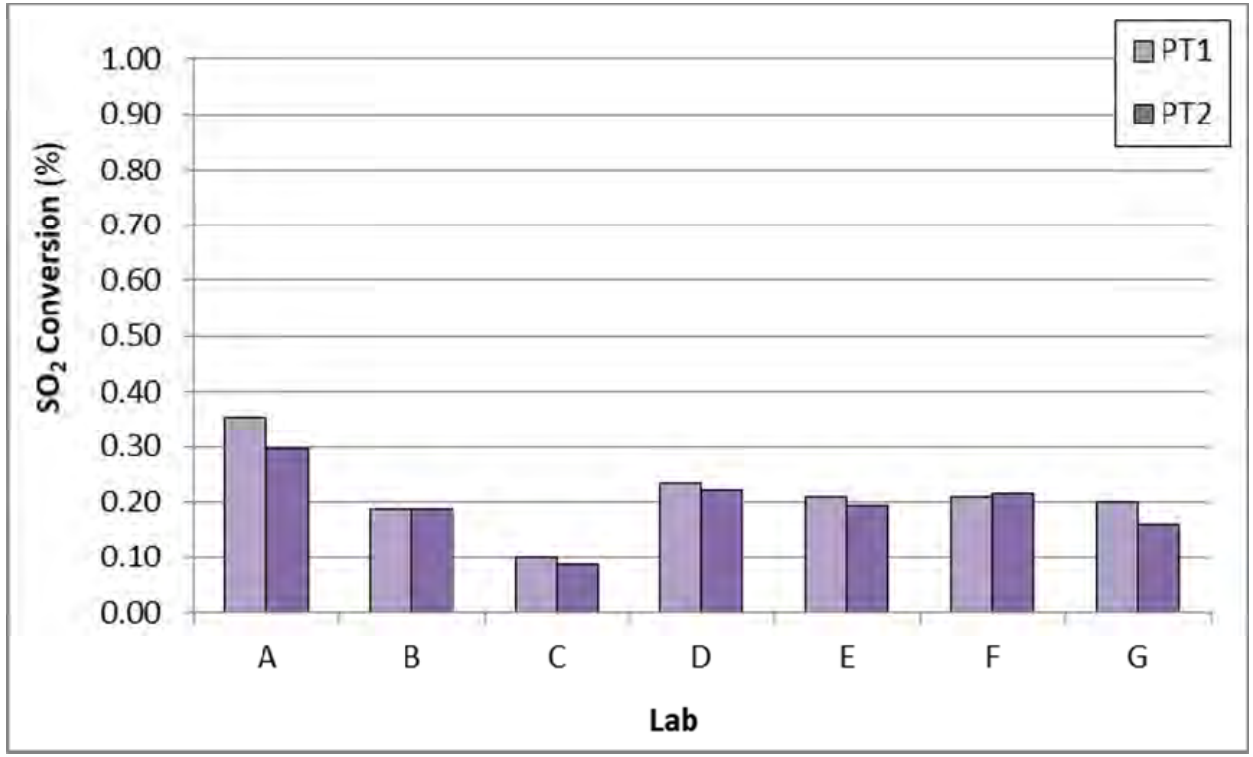
Parameter	Honeycomb
DeNOx	91.0%
Average Activity	35.1 m/hr
Average Absolute Deviation	±1.37 m/hr
Average Relative Deviation	±3.90%
Average Absolute Standard Deviation	1.03 m/hr
Average Relative Standard Deviation	2.9%

Activity Test Results Summary



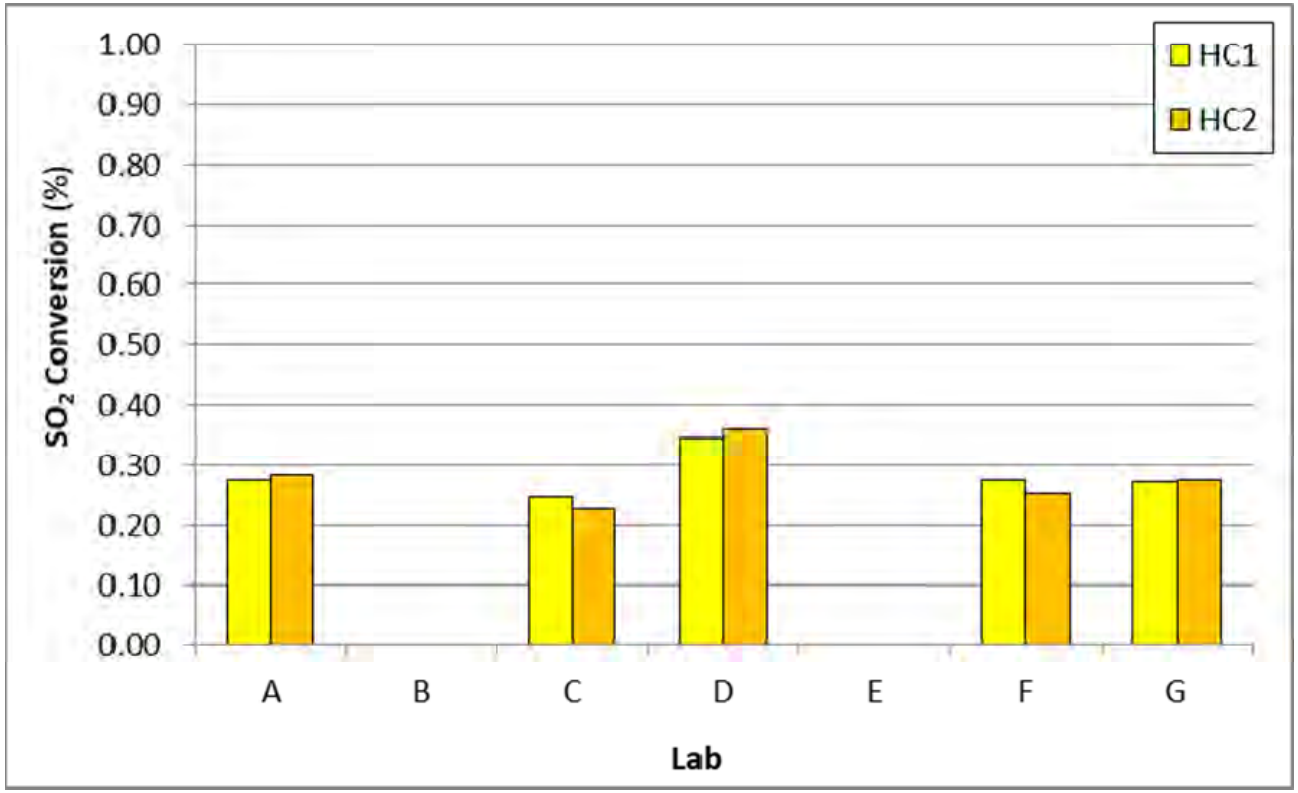
Parameter	Plate	Honeycomb
DeNOx	75.4%	91.0%
Average Activity	46.3 m/hr	35.1 m/hr
Average Absolute Deviation	±3.66 m/hr	±1.37 m/hr
Average Relative Deviation	±7.92%	±3.90%
Average Absolute Standard Deviation	2.69 m/hr	1.03 m/hr
Average Relative Standard Deviation	5.8%	2.9%

Plate Catalyst SO_2 Conversion Test Results



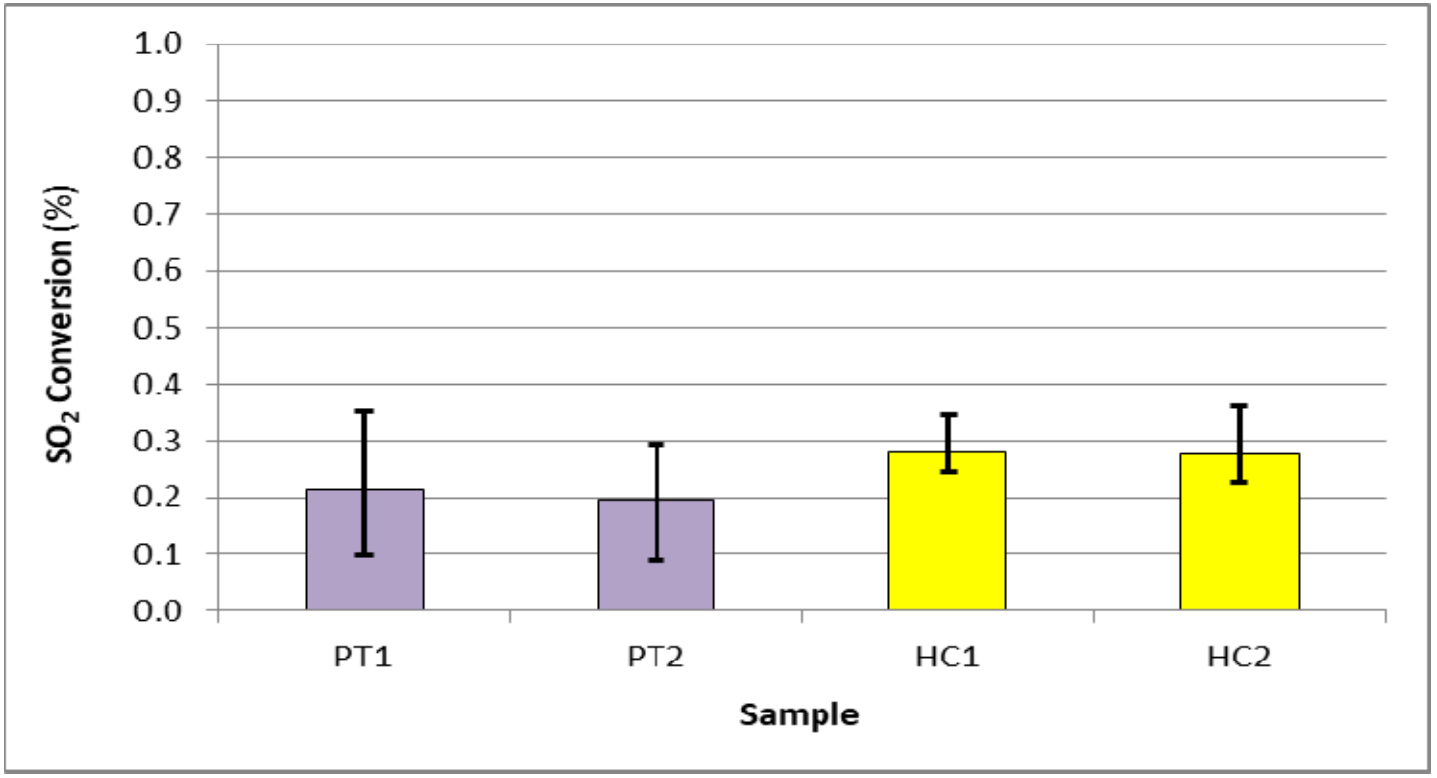
Parameter	Plate
Average SO_2 Conversion	0.20%
Average Absolute Deviation	±0.12%
Average Relative Deviation	±56.78%
Average Absolute Standard Deviation	0.07%
Average Relative Standard Deviation	34%

Honeycomb Catalyst SO_2 Conversion Test Results



Parameter	Honeycomb
Average SO_2 Conversion	0.28%
Average Absolute Deviation	±0.06%
Average Relative Deviation	±21.20%
Average Absolute Standard Deviation	0.04%
Average Relative Standard Deviation	16%

SO_2 Conversion Test Results Summary



Parameter	Plate	Honeycomb
Average SO_2 Conversion	0.20%	0.28%
Average Absolute Deviation	±0.12%	±0.06%
Average Relative Deviation	±56.78%	±21.20%
Average Absolute Standard Deviation	0.07%	0.04%
Average Relative Standard Deviation	34%	16%

Revised Protocol Highlights

- 10 years since last protocol was issued: time to update to ensure consistency with current practice and best available test methods
- Expansion of the scope to include semi-bench facilities
- Adjustments to the required target and maximum drift accuracy of test conditions for both activity and SO_2 oxidation measurements
- Addition of detailed test sample assembly procedures for plate-type catalysts
- Detailed discussions related to the setting of the NH_3/NOx ratio, including general approaches
- Error analyses for both deNOx and SO_2 oxidation measurements
- Reporting templates for deNOx activity and SO_2 oxidation measurement data.

Activity Test Conditions

Table 3-2
Activity Test Conditions

Parameter	Target	Allowed Deviation from Target	Required Measurement Accuracy	Maximum Drift During Testing
Temperature	Representative field condition	± 5 °F (±2.8 °C)	± 3 °F (±1.7 °C)	± 5 °F (±2.8 °C)
Linear Velocity	Representative field condition	± 10%	± 2% of value	± 5% of value
O_2	Representative field condition	± 0.2% absolute	± 0.1% absolute	± 0.1% absolute
H_2O	Representative field condition or as-generated	NA	± 1% absolute	± 1% absolute
CO_2	As-generated	NA	NA	NA
NO_x (inlet)	Representative field condition	± 10%	± 1% of value	± 1% of value
NO_x (outlet)	NA	NA	± 1% of value	NA[25]
SO_2	Representative field condition	± 1%	± 1% of value	± 0.5% of value
SO_3	None added	NA	NA	NA
NH_3/NOx ratio	1.01	±0.01 absolute	±0.01 absolute	±0.01 absolute
N_2	Balance	NA	NA	NA

SO_2 Conversion Test Conditions

Table 4-2
SO_2 Oxidation Test Conditions

Parameter	Target	Allowed Deviation from Target	Required Measurement Accuracy	Maximum Drift During Testing
Temperature	Representative field condition	± 5 °F (± 2.8°C)	± 3 °F (± 1.7 °C)	5 °F (± 2.8 °C)
Linear Velocity§	Representative field condition	± 10%	± 2% of value	± 5% of value
O_2	Representative field condition	± 0.2% absolute	± 0.1% absolute	± 0.1% absolute
H_2O	Representative field condition or as-generated	NA	± 1% absolute	± 1% absolute
CO_2	As-generated	NA	NA	NA
NO_x Inlet	Representative field condition	± 10%	± 1% of value	± 1% of value
SO_2	Representative field condition	± 1%	± 1% of value	± 0.5% of value
SO_3 Inlet	None added	NA	± 0.2 ppmv	± 0.2 ppmv
SO_3 Outlet	NA	NA	± 0.2 ppmv	± 0.2 ppmv
NH_3/NO_x ratio	0	NA	NA	NA
N_2	Balance	NA	NA	NA

Hypothetical True Values for Error Analyses

Table A-1
Hypothetical Test Samples – True Values for Test Conditions and Results

Parameter	Honeycomb	Plate
Sample Length (mm)	1,000	500
Pitch (mm)	7.10	
Wall Thickness (mm)	0.71	
Geometry	Cell Opening: 6.39 mm	Plate Width: 150 mm
Sample Cross-Section (mm x mm)	150 x 150	
LV (m/s at actual temp, 1 atm.)	6.00	
AV (m/hr)	18.0	36.0
NH_3/NOx Ratio	1.01 (activity) 0.0 (SO_2 oxidation)	
deNOx	89.16%	67.08%
Activity (m/s)	40.0	
SO_2 Oxidation (%, full layer)	0.35	
Inlet NOx (ppmvd at actual O_2)	250.0	
Outlet NOx (ppmvd at actual O_2)	27.1	82.3
Inlet SO_3 (ppmvd at actual O_2)	3.0	
Outlet SO_3 (ppmvd at actual O_2)	6.50	4.75
O_2 (%,dry)	3.4	
H_2O (%, actual O_2)	10.0	
SO_2 (ppmvd at actual O_2)	1,000	
CO_2/N_2	balance	

Activity Cumulative Errors

Table B-12
Expected Maximum Deviations in Activity Determinations Based on Deviation Limits of Test Parameters

Parameter	Allowed Deviation from Target	Expected Maximum Relative Deviation in Measured K	
		HC	Plate
Temperature	± 5°F (±1.7°C)	±1.50%	±1.50%
Linear Velocity	± 10%	±0.80%	±1.20%
O_2	± 0.2% absolute	±1.00%	±1.00%
H_2O	NA	NA	NA
NH_3/NOx ratio	±0.01 absolute	±0.60%	±0.60%
	Global Deviation	***±2.1%***	***±2.2%***

Table B-13
Expected Maximum Errors in Activity Determinations Based on Required Measurement Accuracy of Test Parameters

Parameter	Required Measurement Accuracy	Expected Maximum Relative Error in Measured K	
		HC	Plate
Temperature	± 3°F (±1.7°C)	±0.90%	±0.90%
Linear Velocity	± 2% of value	±2.00%	±2.00%
O_2	± 0.1% absolute	±0.50%	±0.50%
H_2O	± 1% absolute	±0.70%	±0.70%
Inlet NO_x	± 1% of value	±0.45%	±0.90%
Outlet NO_x	± 1% of value	±0.45%	±0.90%
NH_3/NOx ratio	±0.01 absolute	±0.60%	±0.60%
Geometry[64]	Length: ±1 mm Plate Width (plate cat.): ±1 mm Channel Width (HC cat.): ±0.01 mm	±0.26%	±0.87%
	Global Error	***±2.5%***	***±2.9%***

-Total cumulative potential deviation/error in measured K-values from the true value at the target conditions will be about 4-5%. This corresponds to a total absolute deviation/error of about ±1 m/hr for low activity catalysts (20 m/hr), and about ±2 m/hr for high activity catalysts (40 m/hr).

-If corrections are applied to all pertinent parameters, the deviation/error in the activity measurement can be effectively halved.

-Note that these total deviation/error values do not include the potential effect of SO3.

SO_2 Conversion Cumulative Errors

Table G-6
Expected Maximum Deviations in SO_2 Oxidation Determinations Based on Deviation Limits of Test Parameters

Parameter	Allowed Deviation from Target	Expected Maximum Relative Deviation in Measured SO_2 Oxidation	
		HC	Plate
Temperature	± 5°F (±1.7°C)	±5.6%	±5.6%
Linear Velocity[94]	± 10% of value	±10%	±10%
O_2	± 0.2% absolute	±1.5%	±1.5%
SO_2	± 1% of value	±1.0%	±1.0%
	Total Deviation	***±11.6%***	***±11.6%***

Table G-7
Expected Maximum Errors in SO_2 Oxidation Determinations Based on Required Measurement Accuracy of Test Parameters

Parameter	Required Measurement Accuracy	Expected Maximum Relative Error in Measured SO_2 Oxidation	
		HC	Plate
Temperature	± 3°F (±1.7°C)	±3.4%	±3.4%
Linear Velocity	± 2% of value	±2.0%	±2.0%
O_2	± 0.1% absolute	±0.8%	±0.8%
SO_2	± 1% of value	±1.0%	±1.0%
Inlet SO_3	± 0.2 ppmv	±5.7%	±11.4%
Outlet SO_3	± 0.2 ppmv	±5.7%	±11.4%
Total Error		***±9.0%***	***±16.6%***

-Total cumulative potential deviation/error in measured SO2 oxidation = 20% for honeycomb samples and about 27% for plate samples (relative).

-This corresponds to a total absolute deviation/error of about 0.07% for the honeycomb test sample and about 0.10% for the example plate test sample (absolute).

-Errors associated with deviations in test conditions can be reduced somewhat by applying correction curves, but this is limited to applicability of curves.

-Note that the error analyses do not include the effect of SO3.

Appendix C: Plate Stacking Guidelines

Example element box with 26 coupons – alternating between coupons with 2 notches and coupons with 1 notch. Coupons were cut from full-size plates containing 4 notches.

-Primary Goal: Match field configuration as closely as possible

-Number of beads and bead direction can hinder replicating field configuration

-Surface area calculation approach should be consistent between field total surface area (AV) calculations and the lab basis when applying lab K-values directly for field potential calculations (i.e. how are notches accounted for in the lab and the field calculations?).

-More work needs to be done!

	
Down to the right notch	Down to the left notch

Using Lab Data for Catalyst Management

- Catalyst management plans typically work off of field potential (P) for the entire reactor.
- An accurate estimate of field potential requires a number of inputs, including;

  - Catalyst K-values (absolute) over time; initial activity and a deactivation rate prediction (curve) are required.

  - Accurate catalyst total surface area (K-values from the lab must correspond to the same surface area basis as that used in the field).

  - Estimate of fouling/plugging

- Re-Baselining the unit to get appropriate flow rates, temperatures, and NOx reductions is important – using design conditions will create errors in almost all cases, very large errors in some cases.
- Laboratory K-values should be generated at the correct corresponding field representative full load conditions. If not, correction curves should be applied.
- Don’t change catalyst test conditions mid-stream. Do update test conditions to actual when new catalyst is installed.

Primary EPRI Studies - Mercury

Mercury Oxidation at Semi-Bench and Micro Scale

Laboratory Comparative SCR Catalyst Testing for Mercury Oxidation: 2017 Testing Results

- Product Id: 3002011761
- Date Published: Dec 04, 2018

SCR Catalyst Mercury Oxidation Laboratory Testing Guideline – Industry Version

- Product Id: 3002005087
- Date Published: Mar 03, 2015

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