Worldwide Pollution Control Association

WPCA/LG&E and KU

Coal-fired APC Environmental Seminar

May 23-24, 2017

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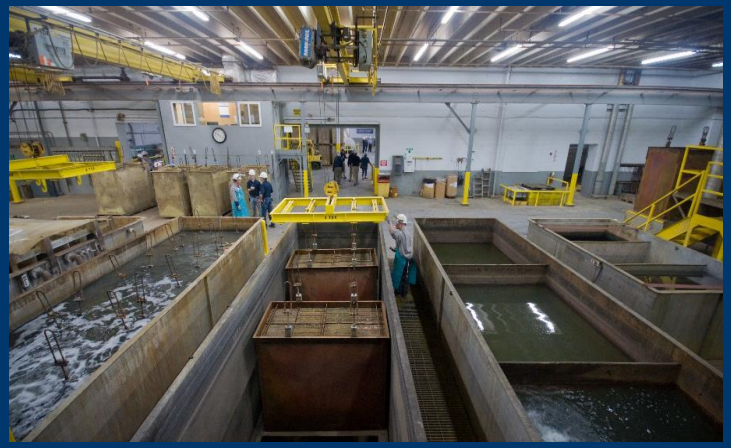

WPCA / LG&E Seminar
SCR Catalyst – New vs Regenerated

Mike Mattes - CEO

Thies Hoffmann – EVP & COO

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Regeneration Experience

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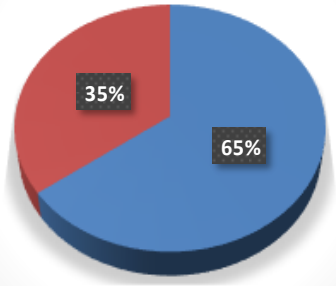
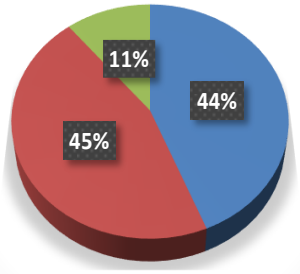
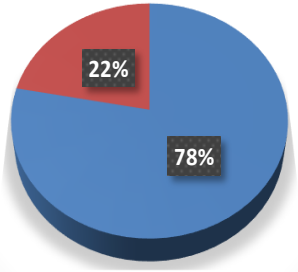
Regeneration Experience by Installed Base
81,000 Regen. Modules Vs 125,000 Installed



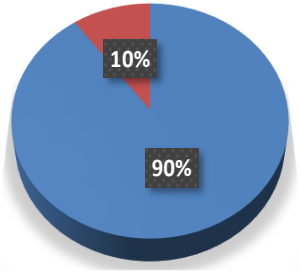
Regeneration Experience by Catalyst Type



Regeneration Experience by Utilities
51 of 65 Utilities



Regeneration Experience by Installed Mw
133,000Mw of 148,000Mw



SCR Catalyst Performance Indicators

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SCR Catalyst Performance Expectations

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Maximize

- NOx removal – 70 to 90%
- Mercury Oxidation – 50 to 90%
- Operating Hours - Life

Minimize

- SO_2 conversion to SO_3 – 5 to 15ppm SO_3 increase
- Pressure drop – 0.5 to 1.0 Inch H_20
- Ammonia slip – 2 to 4 ppm

The SCR has Become a "Multi-Pollutant Reduction Reactor" (MPRR)

Catalyst DeNOx Terms & Equations

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Term	Symbol	Units	Source	Formula
Flue Gas Flow	FGF	m3/hr.	Specified	NA
Visible Catalyst Surface Area	VCSA	m2	Specified	NA
NOx inlet	NOXIN	ppm	Measured	NA
NOx outlet	NOXOUT	ppm	Measured	NA
Fraction NOx Remaining	FNR	Fraction	Calculated	FNR = 1 - (NOXOUT / NOXIN)
Area Velocity (1/Residence Time)	AV	m/hr.	Calculated	AV = FGF / VCSA
Potential (Life)	P	Unitless	Calculated	P = -ln (FNR) or K / AV
DeNOx Activity (Speed)	K	m/hr.	Calculated	K = P*AV

DeNOx Potential (P) is more meaningful than DeNOx (K)

DeNOx Terms – Importance of Potential

Analogy	Units	Ford F 150	Lexus RCF
0 to 60 mph) DeNOx K (Speed)	seconds	7.5	4.4
Fuel Economy	mpg	18	25
Fuel Tank Size	gallons	36.0	17.4
Range DeNOx P (Life)	miles	648	435

You are purchasing SCR Life (DeNOx Potential)

DeNOx Terms – Importance of Potential

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Term	Units	Plate	Honeycomb
Pitch	mm	7.0	7.1
Catalyst length	mm	1,250	1,250
Gas Flow	NM3 / Hr.	Same	Same
Area Velocity	m/hr.	20.0	12.0
DeNOx Activity, K	Fraction	46.0	35.0

Catalyst SO_2 Conv. Terms & Equations

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Term	Symbol	Units	Source	Formula
Flue Gas Flow	FGF	m3/hr.	Specified	NA
Visible Catalyst Surface Area	VCSA	m2	Specified	NA
SO2 inlet	SO2IN	ppm	Measured	NA
SO3 inlet	SO3IN	ppm	Measured	NA
SO3 outlet	SO3OUT	ppm	Measured	NA
SO2 Conversion	% SO2 Conv.	%	Calculated	% SO2 Conv. = (SO3OUT - SO3IN)/ SO2IN
SO3 Increase	SO3 Increase	ppm	Calculated	SO3 Increase = (SO3OUT - SO3IN)

Focus on SO3 increase (ppm) vs. % SO2 conversion

Terms – Importance of ppm SO_3 Increase

Term	Units	PRB Coal	Eastern Bituminous Coal
SO2 Inlet	ppm	300	2,500
SO3 Inlet	ppm	3	25
% SO2 Conversion (α = 0)	%	1.5%	0.5%
SO3 Outlet	ppm	7.5	37.5
SO3 Increase by Catalyst	ppm	4.5	12.5

Increase in ammonia significantly reduces SO3 increase (ppm)

Top layer has far less SO_3 increase vs. bottom layer

Factors That Impact SCR Catalyst Performance

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Factors Affecting Catalyst Performance

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Item	SCR Performance	Regeneration of HC & Corr. Cat.	Regeneration of Plate Cat.	Catalyst Decay Rate	Catalyst Potential
OEM Pore Structure	Yes	Yes	Yes	Yes	Yes
OEM Chemistry (Formulation)	Yes	Yes	Yes	Yes	Yes
Erosion / Delamination	Yes	Yes	Yes		
Pluggage	Yes	Not Often		Yes	Yes
Corrosion	Yes		Yes		
Mesh materials	Yes		Yes		
Minimum operating temperature (MOT)	Yes			Yes	Yes
Maintenance	Yes			Yes	Yes
Gas contaminants – SO3, Arsenic, calcium, potassium, phosphorous, sodium, etc.	Yes			Yes	
Burner staging	Yes			Yes	
Boiler cycling	Yes			Yes	
Fuel	Yes			Yes	
Fuel additives	Yes			Yes	
Gas additives	Yes			Yes	
Gas Temperature	Yes				Yes
Gas flow	Yes				Yes
Ammonia / NOx distribution	Yes				Yes
Temperature and flow distribution	Yes				Yes
By-pass	Yes				
SCR Control system	Yes				

Effect of Increasing Each Parameter

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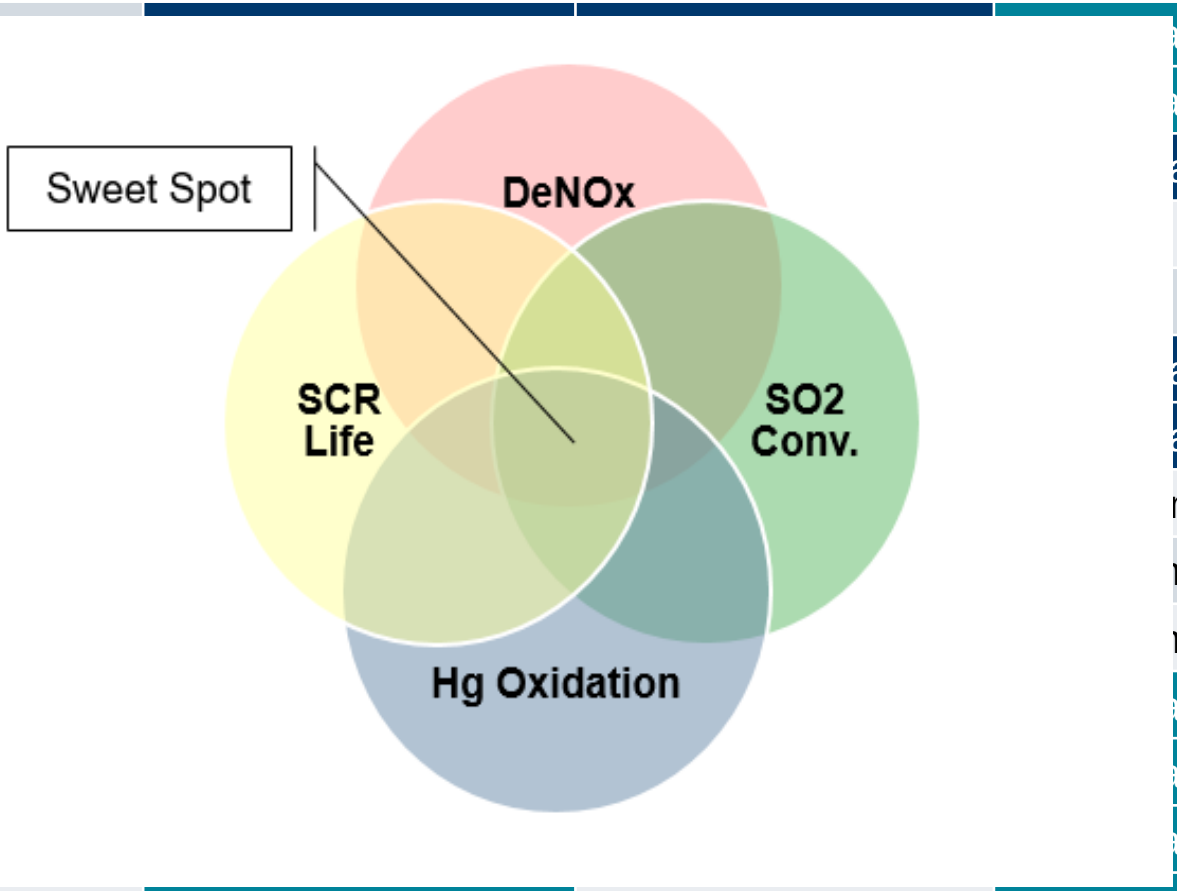
Parameter	NOx Reduction	SO_2 Conversion	Mercury Oxidation
NH_3	Significant Positive	Significant Positive	Significant Negative
Temperature	Significant Positive	Significant Negative	Significant Negative
Catalyst Length	Significant Positive	Significant Negative	Significant Positive
SO_2	Slight Positive	Significant Positive	Slight Negative
SO_3	Slight Positive	Significant Positive	Slight Negative
HCl	Little Effect	Little Effect	Significant Positive
HBr	Little Effect	Little Effect	Significant Positive
O_2	Little Effect	Significant Negative	Medium Positive
H_2O	Little Effect	Little Effect	Medium Negative
CO	Little Effect	Little Effect	Medium Negative
Velocity	Significant Negative	Significant Positive	Significant Negative
Catalyst Pitch	Significant Negative	Significant Positive	Significant Negative
Pluggage	Significant Negative	Slight Positive	Significant Negative
NH_3/NOx Maldistribution	Significant Negative	Slight Negative	Significant Negative

Effect of Increasing Each Parameter

Parameter	NOx Reduction	SO_2 Conversion	Mercury Oxidation
NH_3			ficant Negative
Temperature			ficant Negative
Catalyst Len			ficant Positive
SO_2			ght Negative
SO_3			ght Negative
HCl			ficant Positive
HBr			ficant Positive
O_2			dium Positive
H_2O			lium Negative
CO			lium Negative
Velocity			ficant Negative
Catalyst Pitc			ficant Negative
Pluggage			ficant Negative
NH_3/NOx Maldistribution	Significant Negative	Slight Negative	Significant Negative

Effect of Increasing Each Parameter

Parameter	NOx Reduction	SO_2 Conversion	Mercury Oxidation
NH_3			ant Negative
Temperature			ant Negative
Catalyst Length			ant Positive
SO_2			Negative
SO_3			Negative
HCl			ant Positive
HBr			ant Positive
O_2			m Positive
H_2O			n Negative
CO			n Negative
Velocity			ant Negative
Catalyst Pitch			ant Negative
Pluggage			ant Negative
NH_3/NOx Maldistribution	Significant Negative	Slight Negative	Significant Negative



SCR Catalyst

Regeneration vs New Experience

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Regenerated vs. New Catalyst

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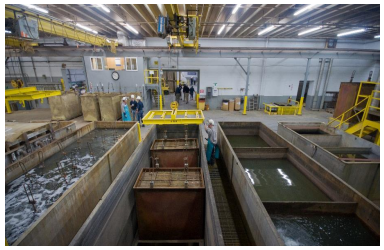
General Comments

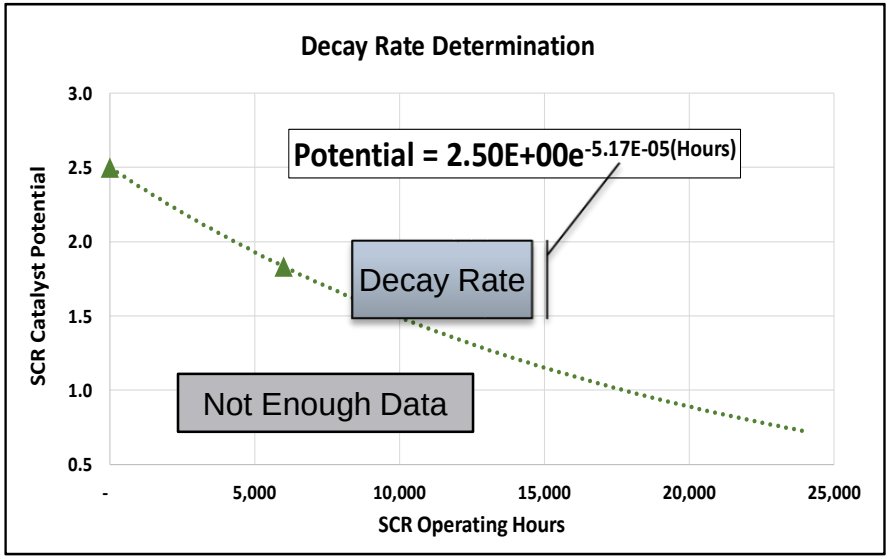


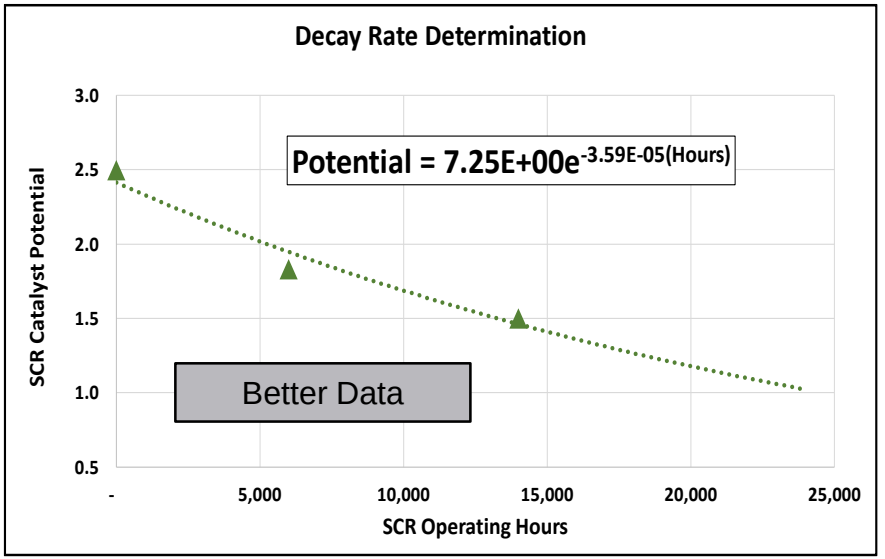
- Can normally match the original catalyst's performance
- Regenerating "original" catalyst to meet "current" catalyst formulation may not be possible

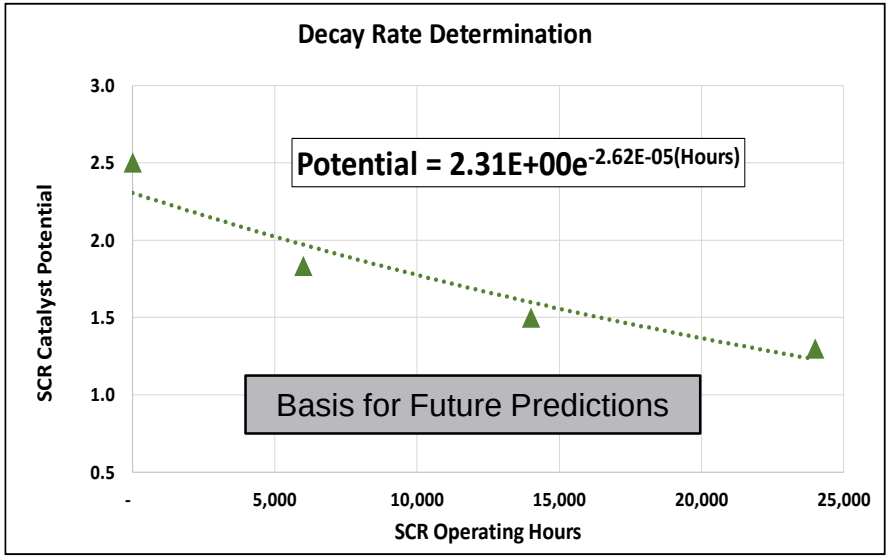
- Some plate catalyst can present significant regeneration issues
- SO_3 ppm increase (% SO_2 Conversion) is most common issue
- Regeneration can change the original catalyst formulation to better meet current plant operating conditions

- Good news – The regeneration evaluation process has greatly improved (minimizes surprises)

Decay Rate (Lambda –λ) Calculation







Think of decay rates as ranges

Accurate decay rates require multiple samples over multiple years

Decay rates under 8,000 hours are normally higher than actual

Decay Rate (Lambda –λ) Impact

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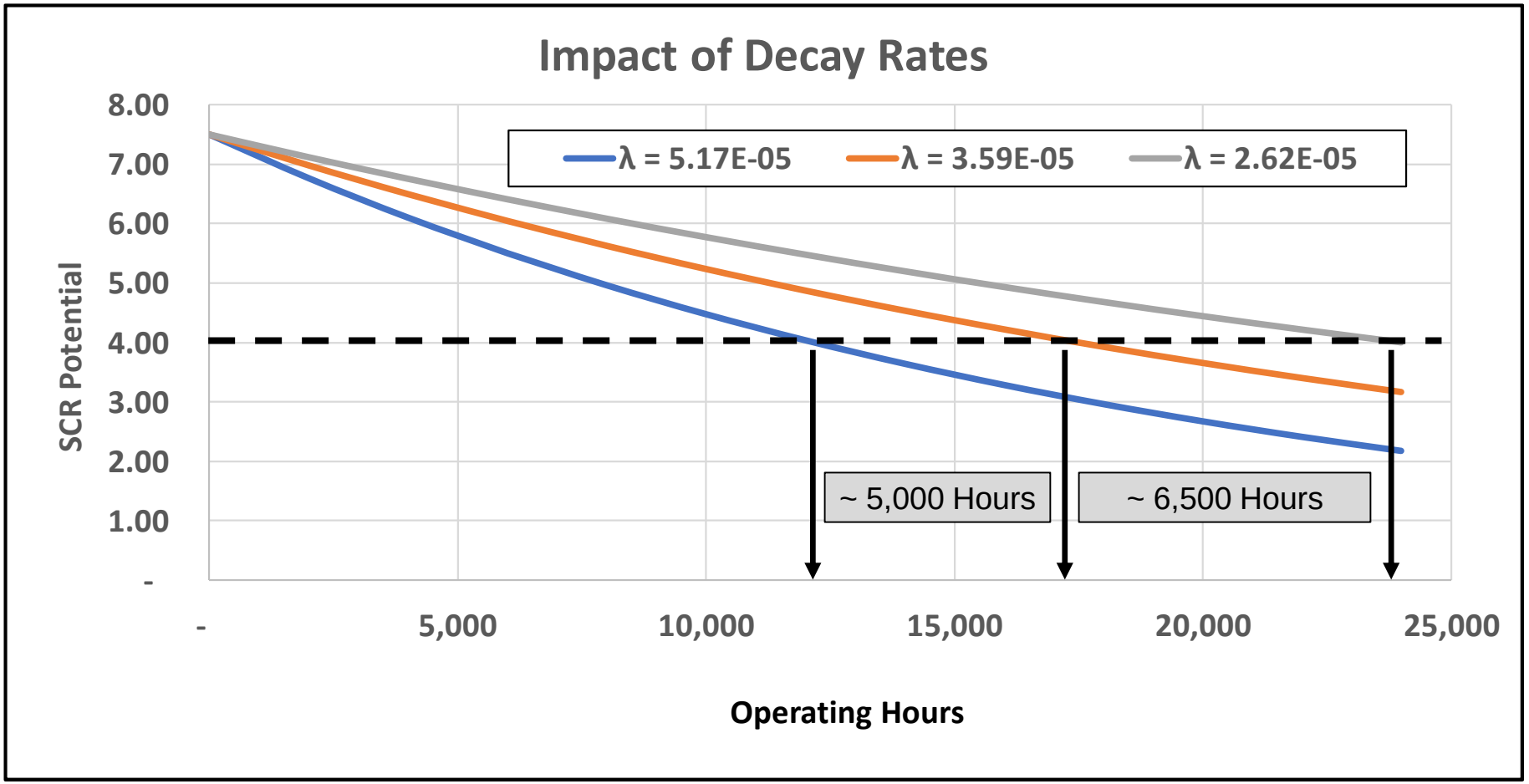
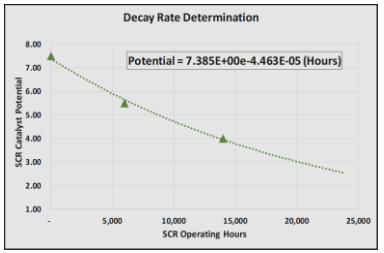


Decay Rate (Lambda –λ) - Challenges

Tolerances (Source of Errors)

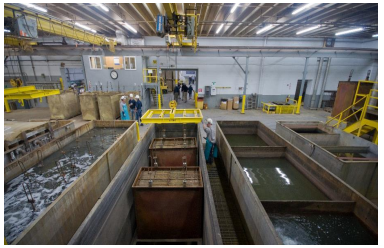
- OEM Manufacturing
- Exposure to Flue Gas Contaminants Not Equal
- Catalyst Testing Process (± 1.5 m/hr. or ~ 6%)
- Bias Between Testing Laboratories



Sample Size is Statistically Insignificant < 0.015%

Six Years of Operations

- How many operational changes? (fuel, cycling, etc.)
- How many events? (tube leaks, pluggage, etc.)



Decay Rate Comparison

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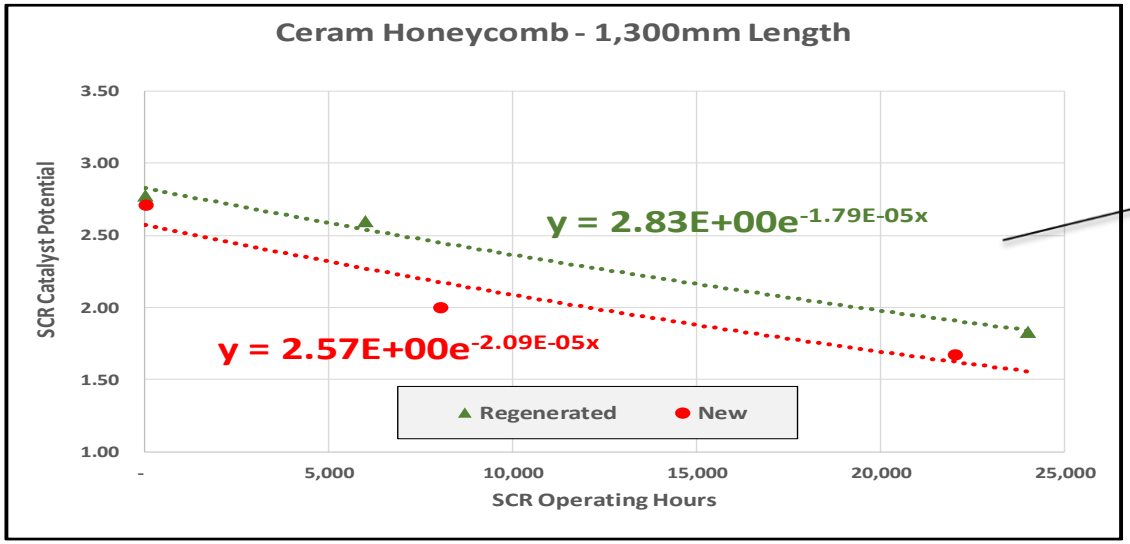
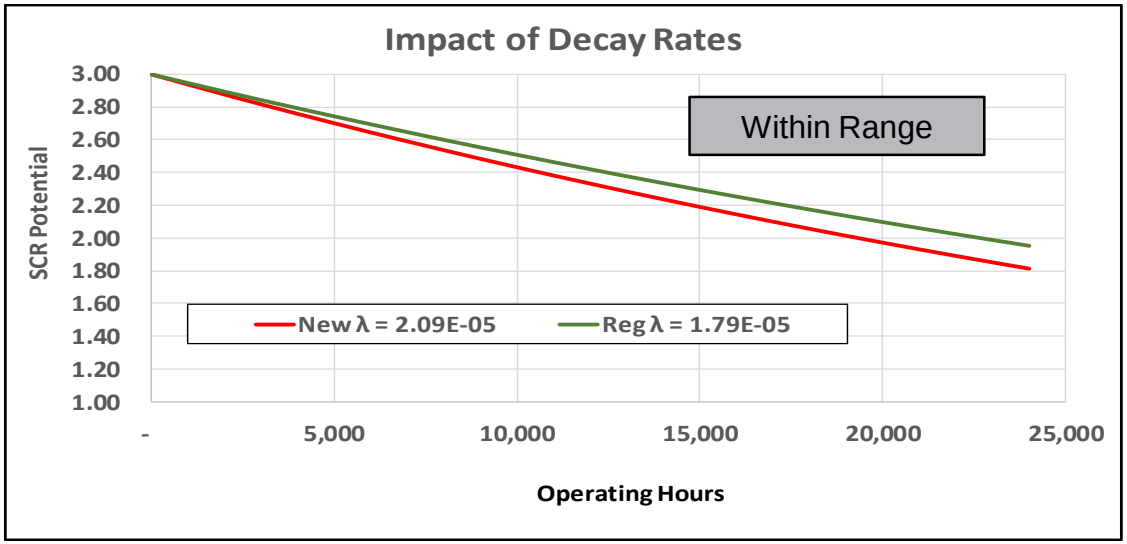
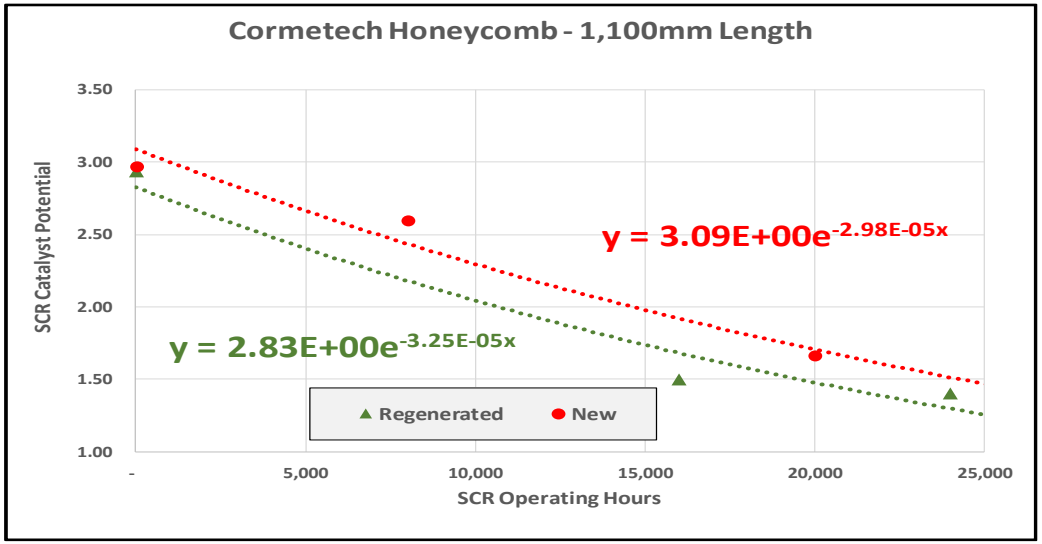


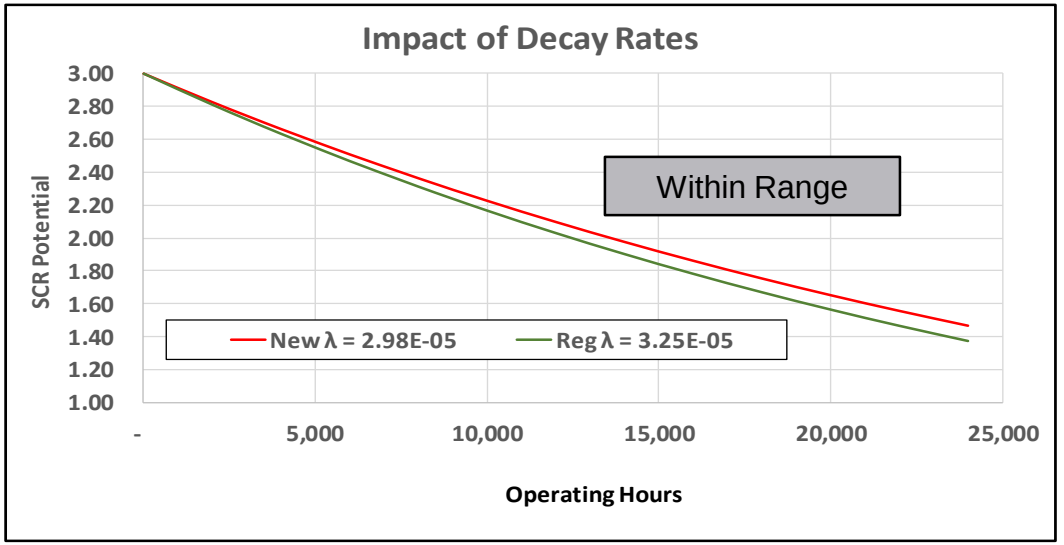
Data Used to Calculate the Decay Rate

Impact of Calculated Decay Rate

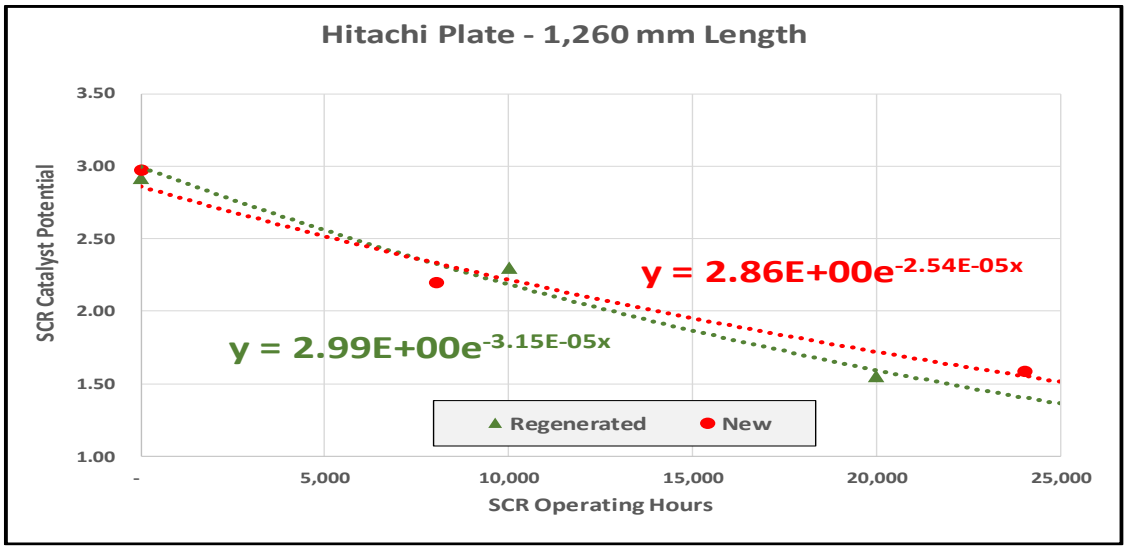


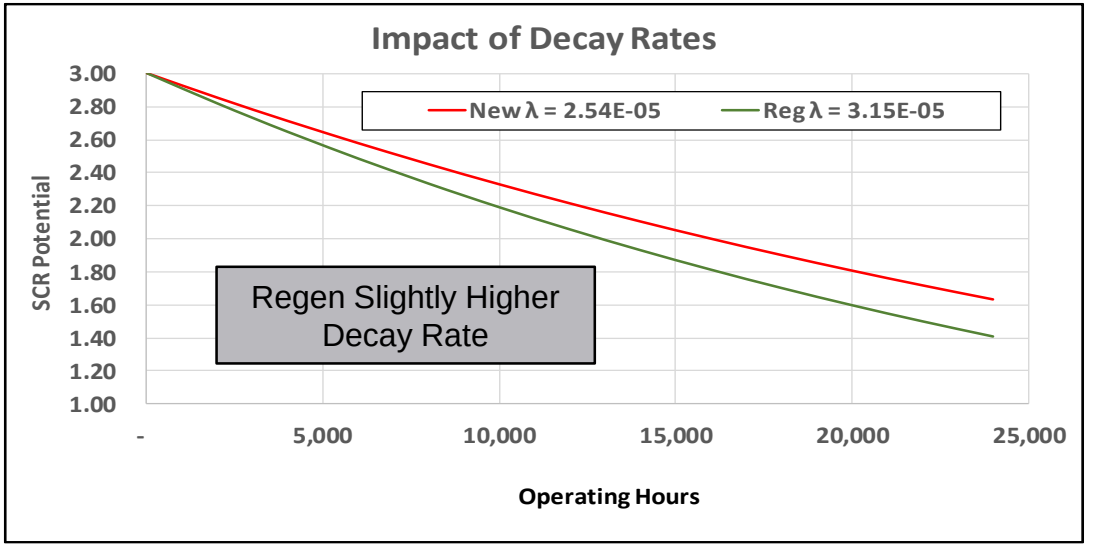
Decay Rate Comparison



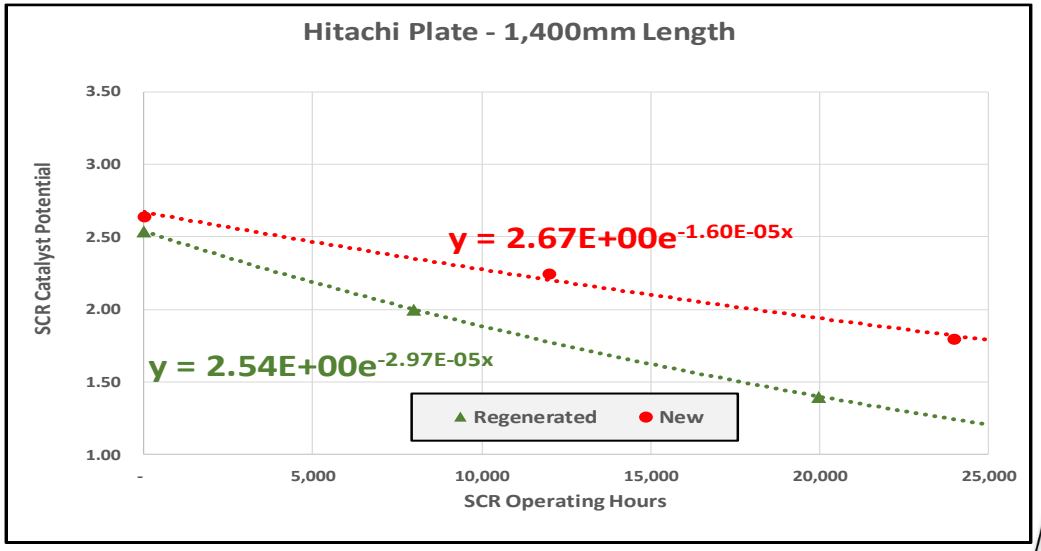


Decay Rate Comparison





Decay Rate Comparison



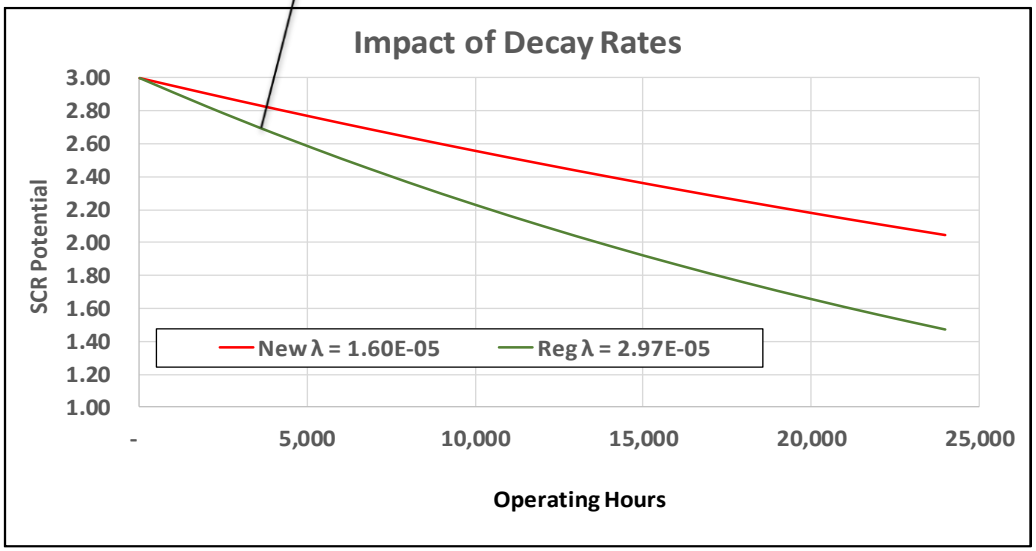
Regen. Has Significantly Higher Decay Rate. Problem Identified and Corrected for Future Regen.

Problems

Mesh Quality

Iron Deposition

Good Initial Performance with Low % Vanadium



Catalyst Performance Comparison

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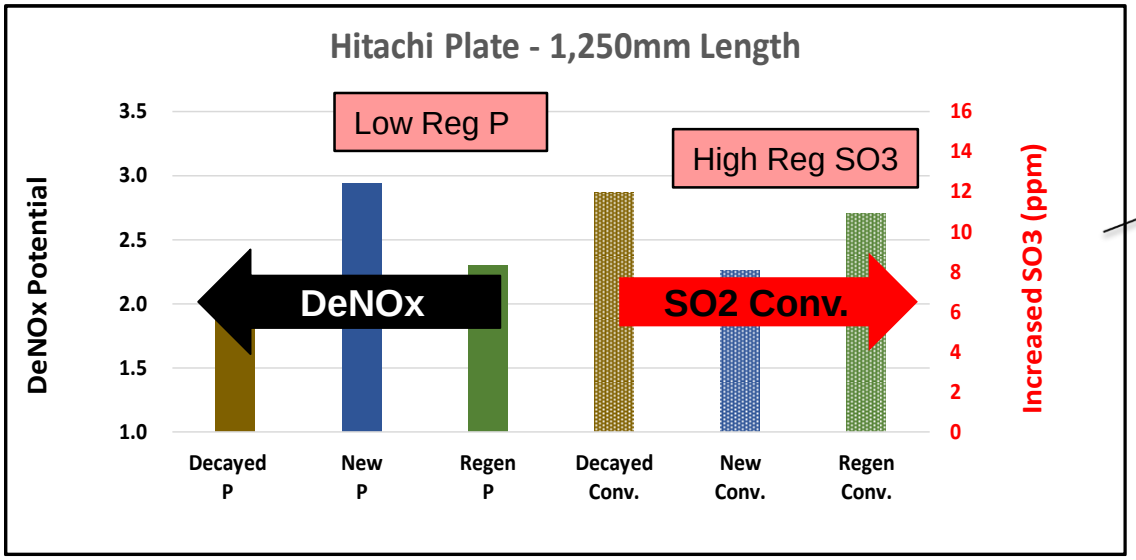
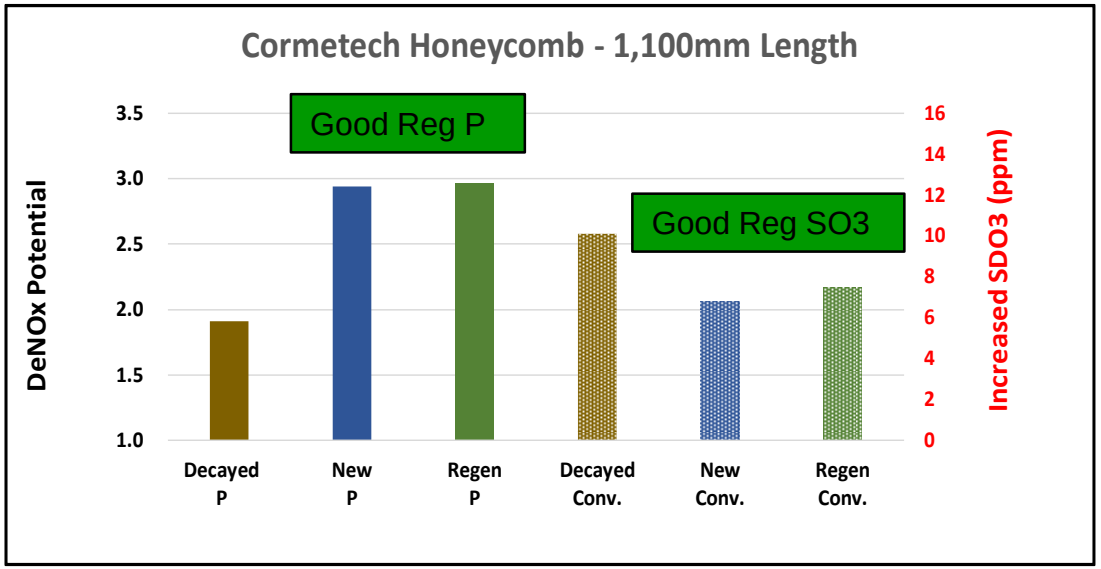
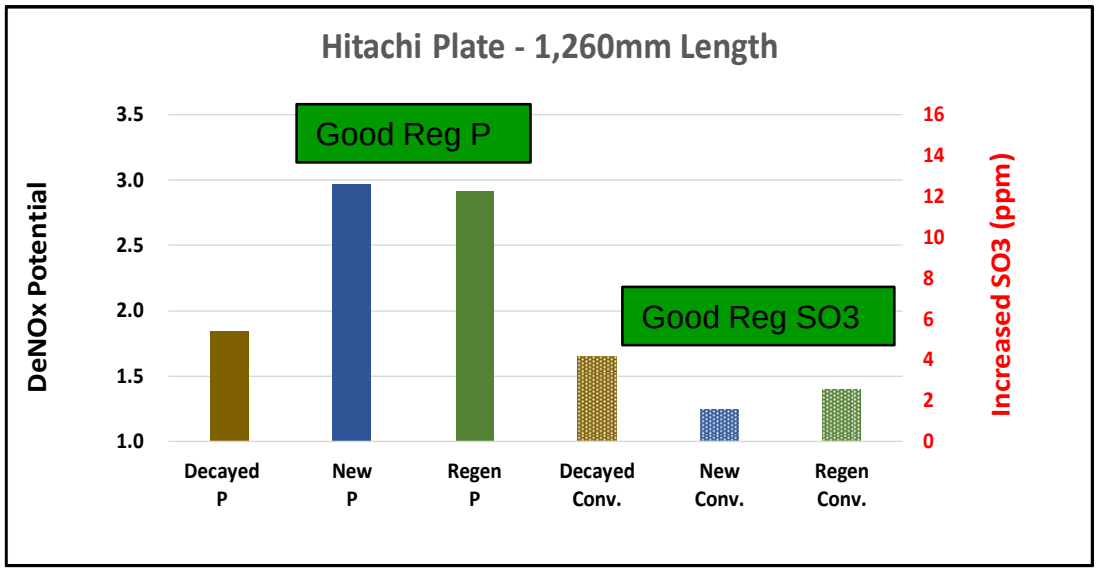
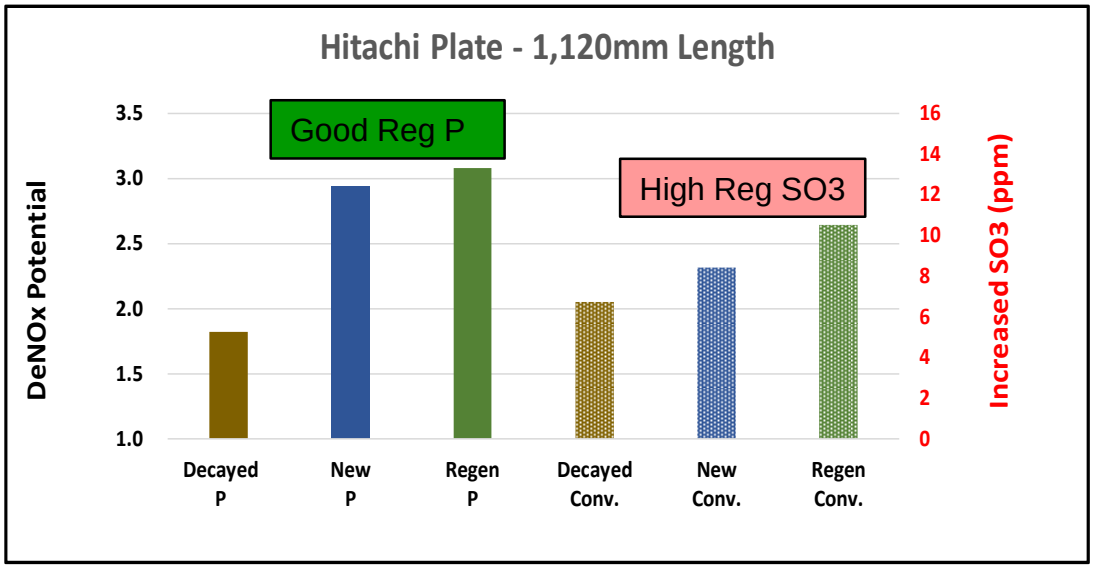


Poor mesh quality and significant iron deposits.
Did not proceed with regeneration.

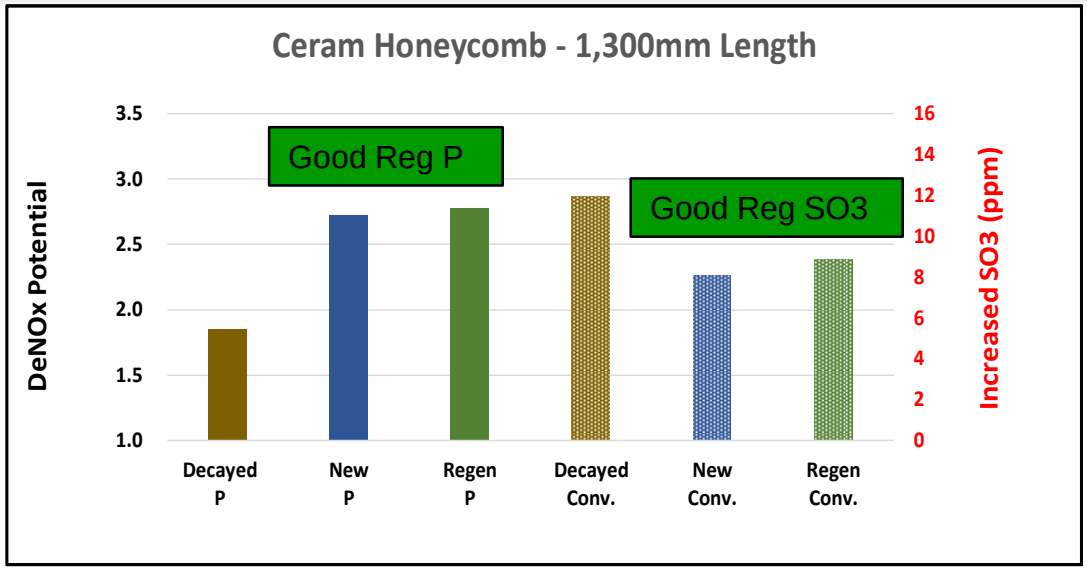


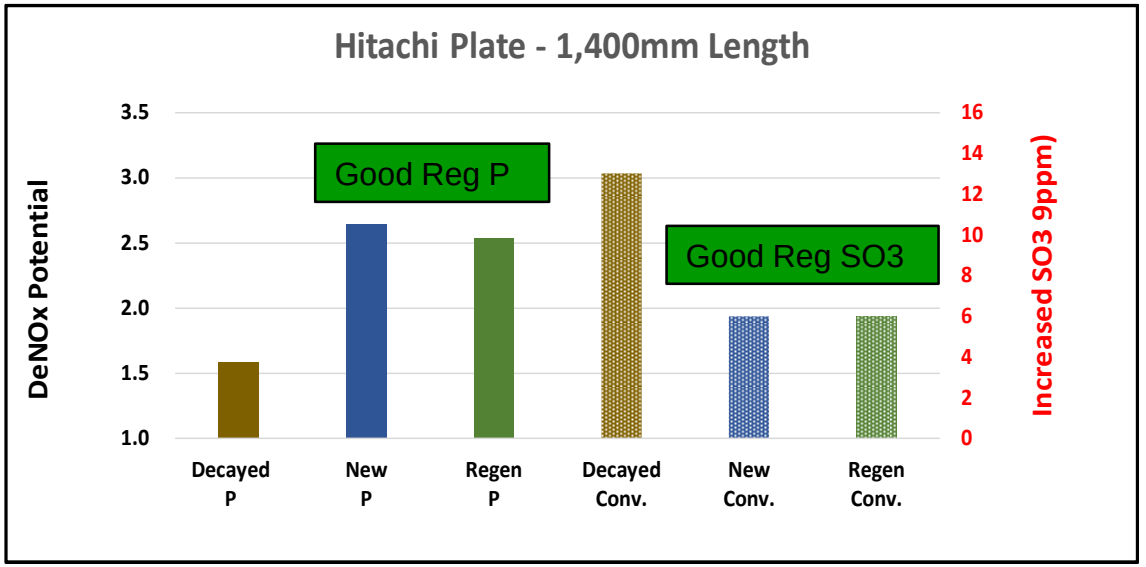
Catalyst Performance Comparison





Catalyst Performance Comparison





Catalyst Hg Performance Comparison

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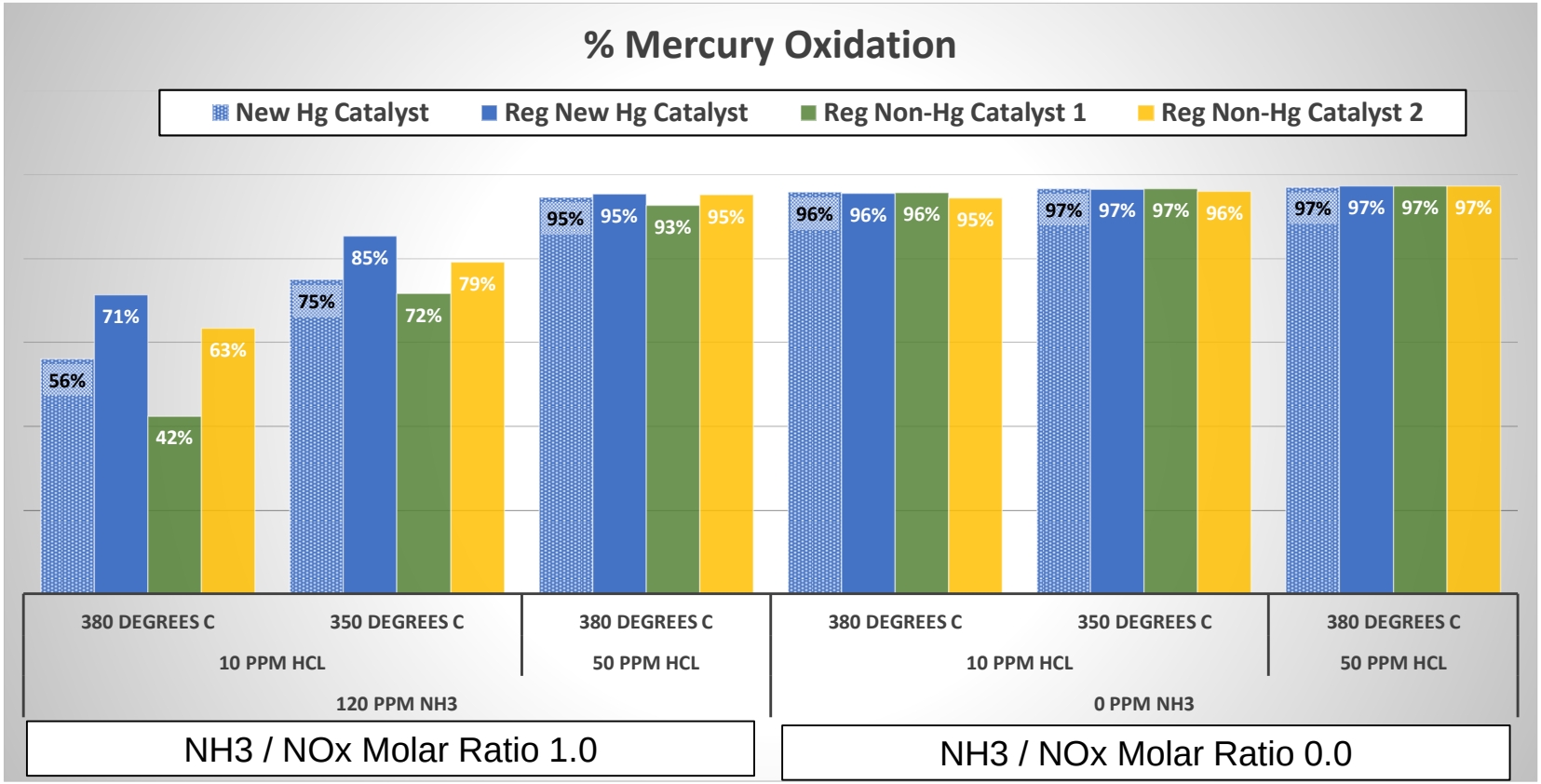

All SCR Catalyst Oxidizes Mercury

Challenge is at High Ammonia and Low Halide Concentrations

More Data Required

Evaluation Process

Should My Catalyst Be Regenerated?

Critical Step

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Evaluation for Regeneration - Mechanical

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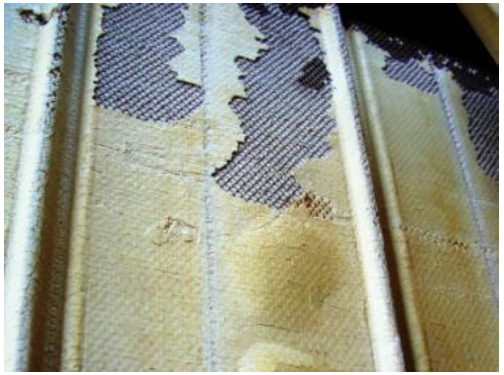
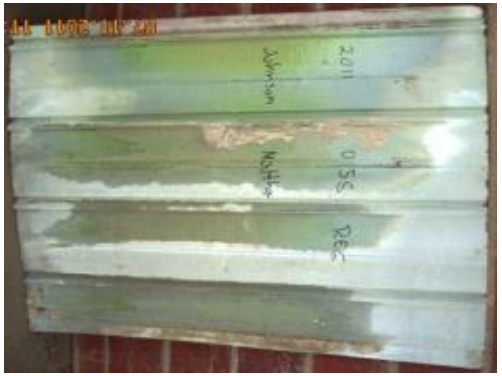
Erosion

Inspect
100% of All Plates

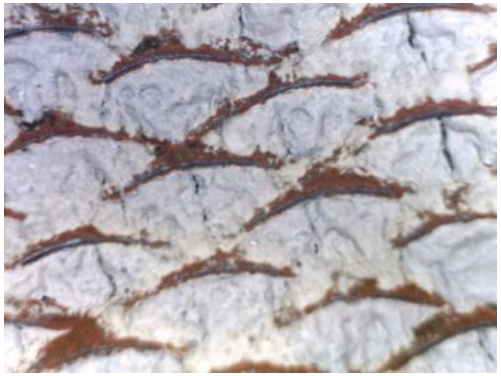
Delamination



Discoloration



Corrosion



Evaluation for Regeneration - Mechanical

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Pluggage

Strength

Cosmetic Damage

Erosion

Evaluation for Regeneration - Chemical

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OEM Formulation

23
V
Vanadium
50.9415

74
W
Tungsten
183.85

42
Mo
Molybdenum
95.94

Decay Agents

11
Na
Sodium
22.990

33
As
Arsenic
74.922

19
K
Potassium
39.098

Evaluation for Regeneration – Catalyst Molecular Structure

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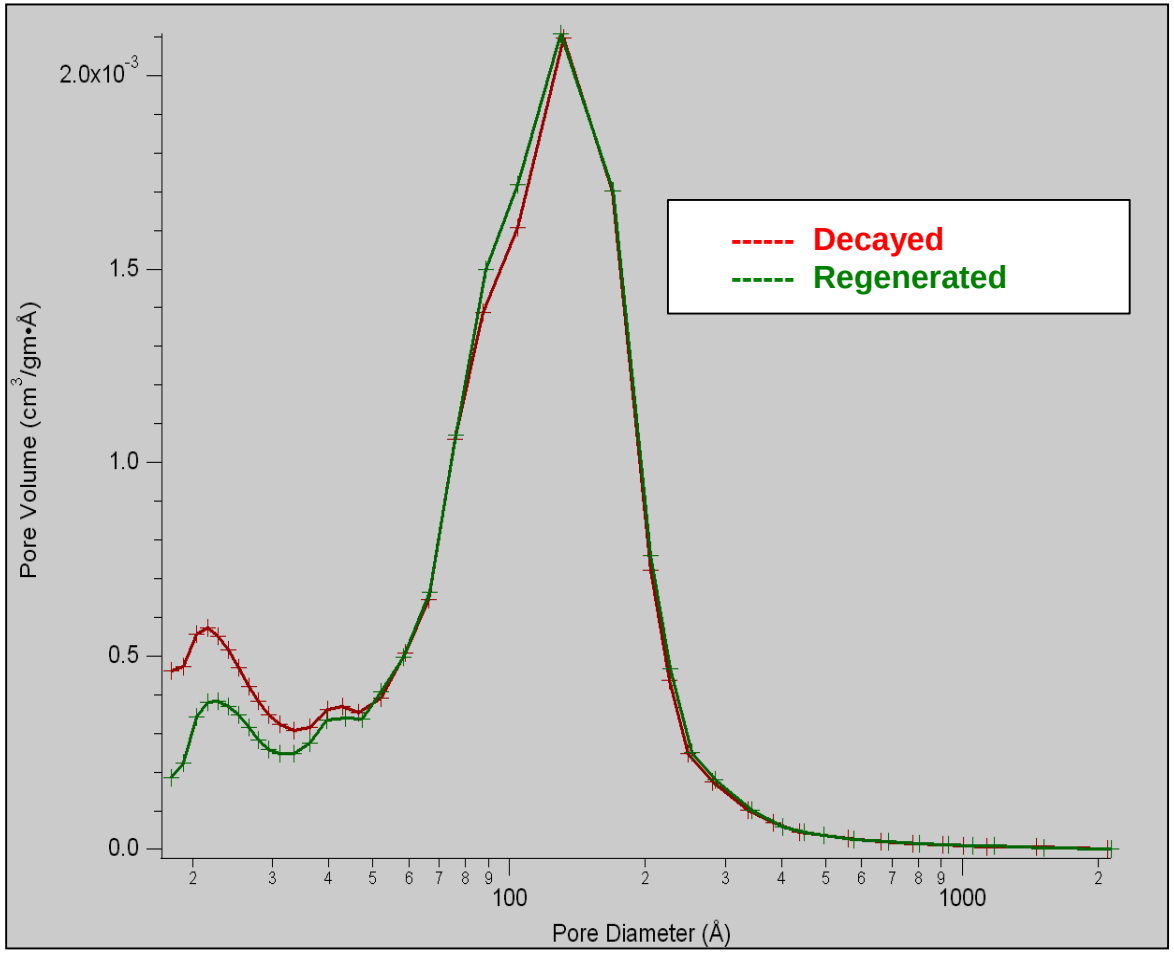
Catalyst Pore Size Distribution



Item	Size (Angstroms)
NO_x Molecule	8
Catallyst Micro Pore	30
Catalyst Meso Pore	500
Catalyst Macro Pore	1,000
Human Hair Diameter	900,000
One Inch	254,000,000

Evaluation for Regeneration – Test Regeneration

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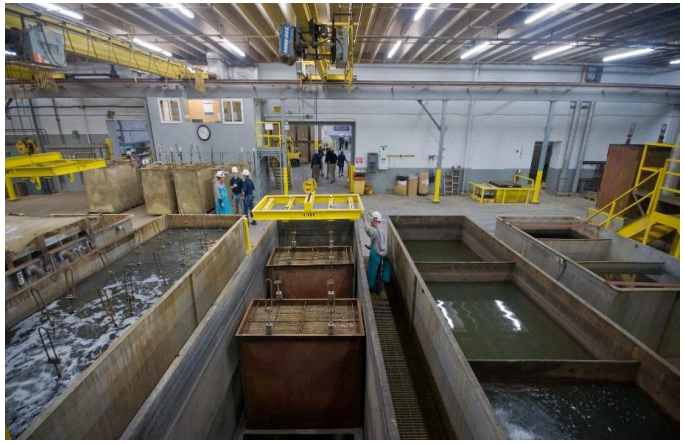
Full Size Module(s) or Element(s)



Critical to Determine Guarantees

Cost Covered by SST

The Regeneration Process

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The Regeneration Process

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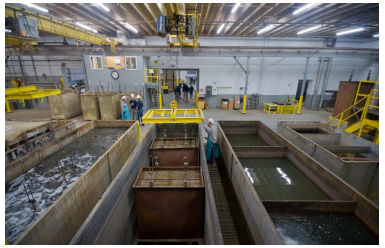
Pre-clean and Inspect



Chemically Remove Decay Agents

Impregnate with Active Ingredient(s)

Repair and Replace Catalyst as Required

Test and Verify Performance

Conclusion

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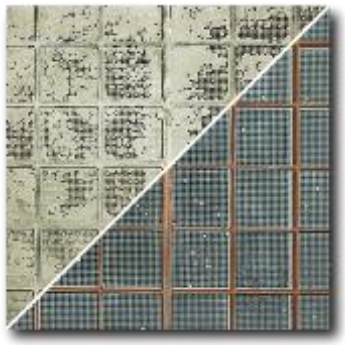
Regenerated SCR Catalyst Generally Performs Well



Past Problems are Understood Much Better

The Evaluation Process is Critical

Test Regeneration Confirms Performance

The Customer Decides if Regeneration Has Value

Thank You

Questions?

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