# REINHOLD ENVIRONMENTAL ®

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2025 REINHOLD / PCUG CONFERENCE

# Updating the Catalyst Testing Protocol for CT Catalysts

## How to interpret and utilize CT catalyst test data for SCR management

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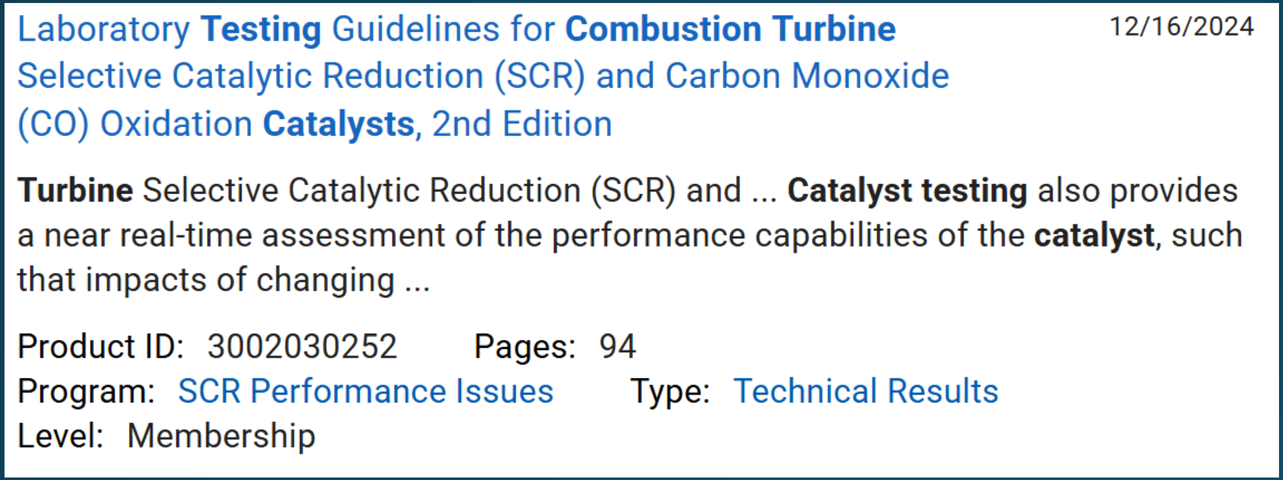
- Jeff Rodefeld (DeNOx Environment & Technology Co.)

### Utility Participants

- Randy Bullock (Southern Company Services, Inc.)
- Ethan Croft (PacifiCorp)

# Overview

- Protocol is publicly available on EPRI's website (EPRI.com).



Laboratory **Testing** Guidelines for **Combustion Turbine** Selective Catalytic Reduction (SCR) and Carbon Monoxide (CO) Oxidation **Catalysts**, 2nd Edition

12/16/2024

**Turbine** Selective Catalytic Reduction (SCR) and ... **Catalyst testing** also provides a near real-time assessment of the performance capabilities of the **catalyst**, such that impacts of changing ...

Product ID: 3002030252 Pages: 94

Program: SCR Performance Issues Type: Technical Results

Level: Membership

- Protocol covers both SCR (deNOx) and CO catalysts – presentation will focus on SCR catalysts

- Won't repeat discussions that are well-covered in the guideline

- Focus will be on usefulness to end-users

# As an end-user, why do I care about a testing protocol?

## Value of Catalyst Testing

**Ultimately, catalyst testing provides an assessment of the capability of the currently installed catalyst.** It also confirms guaranteed performance parameters. The data acquired is not necessarily directly applicable to the field, and may require modeling.

## Standardization of Catalyst Testing

**The protocol ensures that testing is preformed according to a standard,** such that the appropriate methodology is used and data accuracy is ensured.

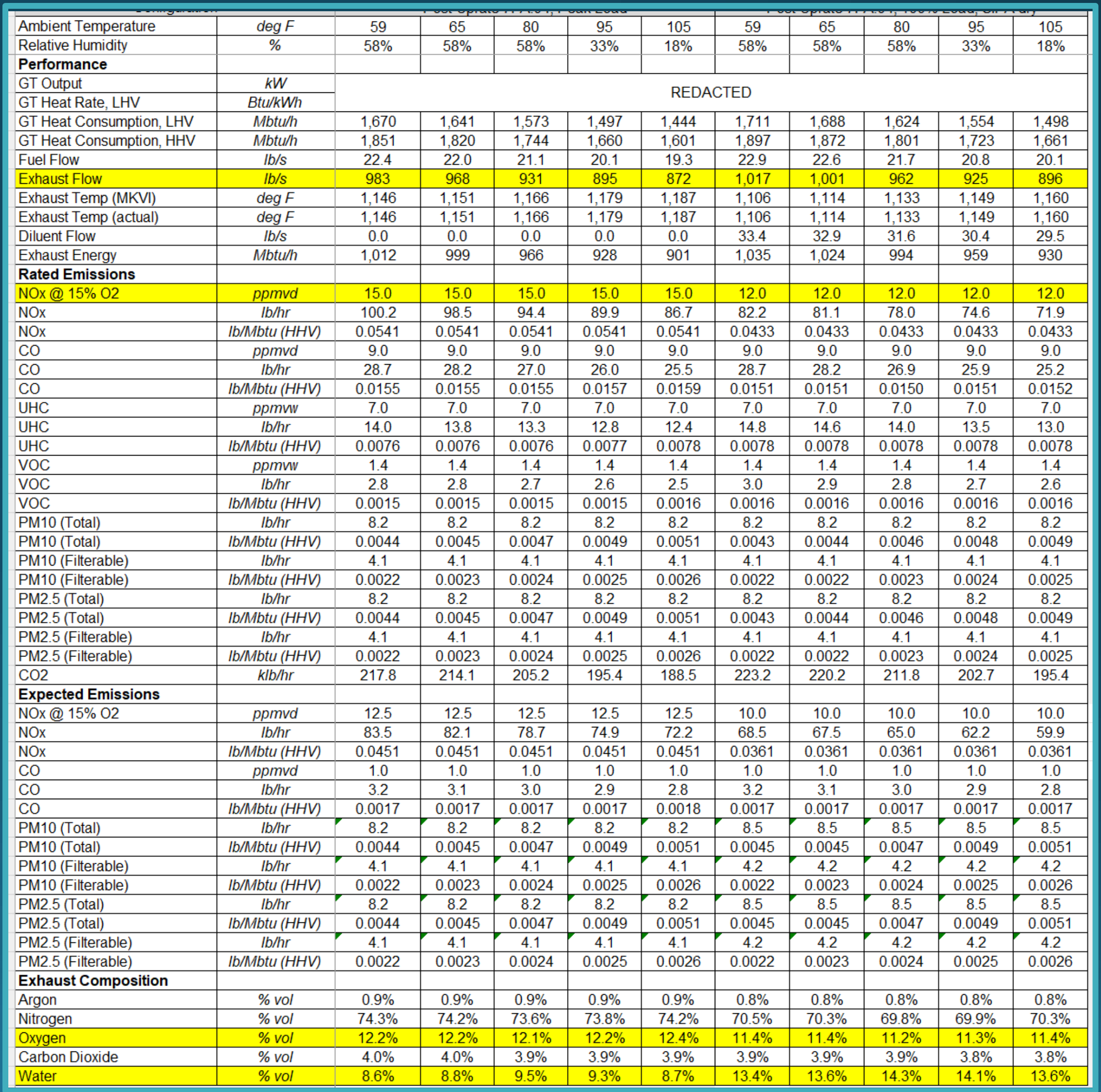
## Test Condition Selection

**The selected laboratory test conditions will affect the outcome of the tests** – this must be taken into consideration when utilizing the data. In other words, **how do I interpret laboratory data to make field performance and life predictions?**

# Example of Various Operating Conditions for CT

Example of just a few operating conditions: CT manufacturer gave 73 operating conditions for this CT. Which one is controlling – what do I design for?

- What is the "design" condition? What condition am I currently concerned about?
- How does that relate to the testing conditions?
- How do I use lab data to estimate field performance and/or catalyst life?

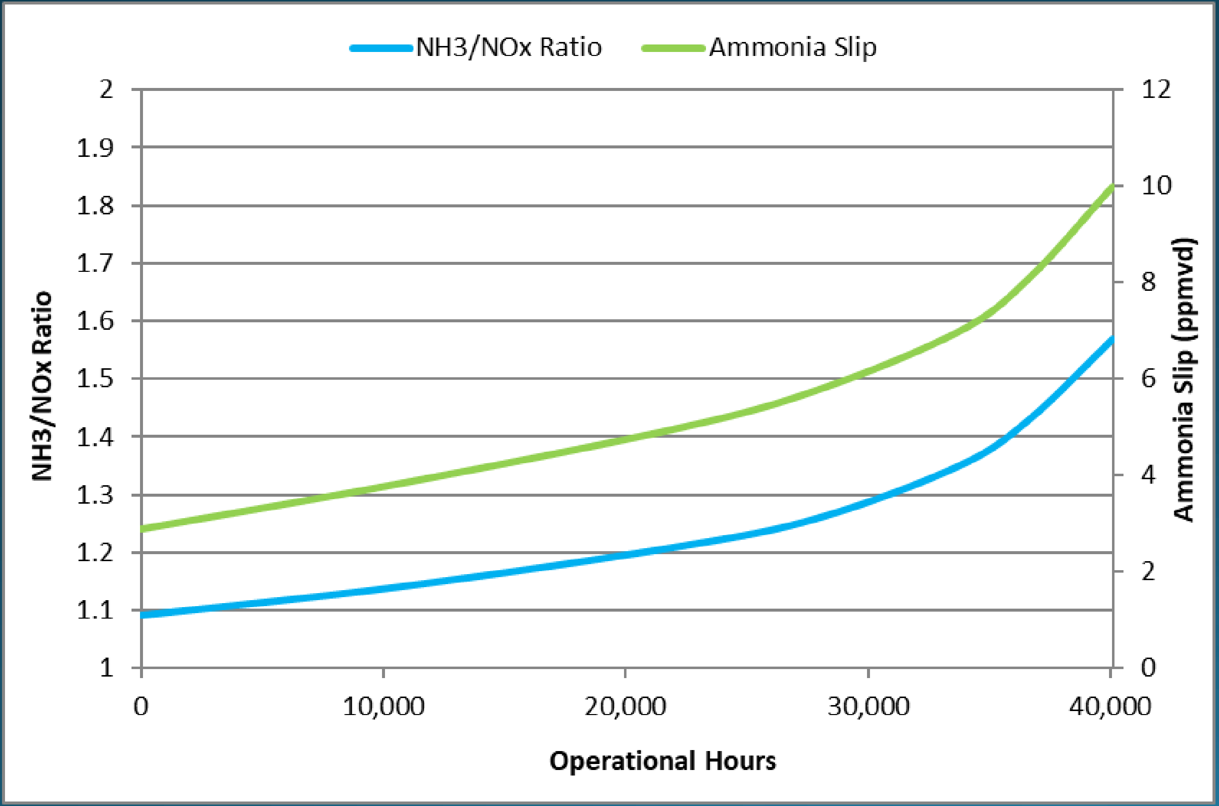


| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ambient Temperature | deg F | 59 | 65 | 80 | 95 | 105 | 59 | 65 | 80 | 95 | 105 |
| Relative Humidity | % | 58% | 58% | 58% | 33% | 18% | 58% | 58% | 58% | 33% | 18% |
| **Performance** | | | | | | | | | | | |
| GT Output | kW | REDACTED | | | | | | | | | |
| GT Heat Rate, LHV | Btu/kWh | | | | | | | | | | |
| GT Heat Consumption, LHV | Mbtu/h | 1,670 | 1,641 | 1,573 | 1,497 | 1,444 | 1,711 | 1,688 | 1,624 | 1,554 | 1,498 |
| GT Heat Consumption, HHV | Mbtu/h | 1,851 | 1,820 | 1,744 | 1,660 | 1,601 | 1,897 | 1,872 | 1,801 | 1,723 | 1,661 |
| Fuel Flow | lb/s | 22.4 | 22.0 | 21.1 | 20.1 | 19.3 | 22.9 | 22.6 | 21.7 | 20.8 | 20.1 |
| Exhaust Flow | lb/s | 983 | 968 | 931 | 895 | 872 | 1,017 | 1,001 | 962 | 925 | 896 |
| Exhaust Temp (MKVI) | deg F | 1,146 | 1,151 | 1,166 | 1,179 | 1,187 | 1,106 | 1,114 | 1,133 | 1,149 | 1,160 |
| Exhaust Temp (actual) | deg F | 1,146 | 1,151 | 1,166 | 1,179 | 1,187 | 1,106 | 1,114 | 1,133 | 1,149 | 1,160 |
| Diluent Flow | lb/s | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 33.4 | 32.9 | 31.6 | 30.4 | 29.5 |
| Exhaust Energy | Mbtu/h | 1,012 | 999 | 966 | 928 | 901 | 1,035 | 1,024 | 994 | 959 | 930 |
| **Rated Emissions** | | | | | | | | | | | |
| NOx @ 15% O2 | ppmvd | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 |
| NOx | lb/hr | 100.2 | 98.5 | 94.4 | 89.9 | 86.7 | 82.2 | 81.1 | 78.0 | 74.6 | 71.9 |
| NOx | lb/Mbtu (HHV) | 0.0541 | 0.0541 | 0.0541 | 0.0541 | 0.0541 | 0.0433 | 0.0433 | 0.0433 | 0.0433 | 0.0433 |
| CO | ppmvd | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 |
| CO | lb/hr | 28.7 | 28.2 | 27.0 | 26.0 | 25.5 | 28.7 | 28.2 | 26.9 | 25.9 | 25.2 |
| CO | lb/Mbtu (HHV) | 0.0155 | 0.0155 | 0.0155 | 0.0157 | 0.0159 | 0.0151 | 0.0151 | 0.0150 | 0.0151 | 0.0152 |
| UHC | ppmvw | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 |
| UHC | lb/hr | 14.0 | 13.8 | 13.3 | 12.8 | 12.4 | 14.8 | 14.6 | 14.0 | 13.5 | 13.0 |
| UHC | lb/Mbtu (HHV) | 0.0076 | 0.0076 | 0.0076 | 0.0077 | 0.0078 | 0.0078 | 0.0078 | 0.0078 | 0.0078 | 0.0078 |
| VOC | ppmvw | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| VOC | lb/hr | 2.8 | 2.8 | 2.7 | 2.6 | 2.5 | 3.0 | 2.9 | 2.8 | 2.7 | 2.6 |
| VOC | lb/Mbtu (HHV) | 0.0015 | 0.0015 | 0.0015 | 0.0015 | 0.0016 | 0.0016 | 0.0016 | 0.0016 | 0.0016 | 0.0016 |
| PM10 (Total) | lb/hr | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 |
| PM10 (Total) | lb/Mbtu (HHV) | 0.0044 | 0.0045 | 0.0047 | 0.0049 | 0.0051 | 0.0043 | 0.0044 | 0.0046 | 0.0048 | 0.0049 |
| PM10 (Filterable) | lb/hr | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| PM10 (Filterable) | lb/Mbtu (HHV) | 0.0022 | 0.0023 | 0.0024 | 0.0025 | 0.0026 | 0.0022 | 0.0022 | 0.0023 | 0.0024 | 0.0025 |
| PM2.5 (Total) | lb/hr | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 |
| PM2.5 (Total) | lb/Mbtu (HHV) | 0.0044 | 0.0045 | 0.0047 | 0.0049 | 0.0051 | 0.0043 | 0.0044 | 0.0046 | 0.0048 | 0.0049 |
| PM2.5 (Filterable) | lb/hr | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| PM2.5 (Filterable) | lb/Mbtu (HHV) | 0.0022 | 0.0023 | 0.0024 | 0.0025 | 0.0026 | 0.0022 | 0.0022 | 0.0023 | 0.0024 | 0.0025 |
| CO2 | klb/hr | 217.8 | 214.1 | 205.2 | 195.4 | 188.5 | 223.2 | 220.2 | 211.8 | 202.7 | 195.4 |
| **Expected Emissions** | | | | | | | | | | | |
| NOx @ 15% O2 | ppmvd | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| NOx | lb/hr | 83.5 | 82.1 | 78.7 | 74.9 | 72.2 | 68.5 | 67.5 | 65.0 | 62.2 | 59.9 |
| NOx | lb/Mbtu (HHV) | 0.0451 | 0.0451 | 0.0451 | 0.0451 | 0.0451 | 0.0361 | 0.0361 | 0.0361 | 0.0361 | 0.0361 |
| CO | ppmvd | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| CO | lb/hr | 3.2 | 3.1 | 3.0 | 2.9 | 2.8 | 3.2 | 3.1 | 3.0 | 2.9 | 2.8 |
| CO | lb/Mbtu (HHV) | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0018 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 |
| PM10 (Total) | lb/hr | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| PM10 (Total) | lb/Mbtu (HHV) | 0.0044 | 0.0045 | 0.0047 | 0.0049 | 0.0051 | 0.0045 | 0.0045 | 0.0047 | 0.0049 | 0.0051 |
| PM10 (Filterable) | lb/hr | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 |
| PM10 (Filterable) | lb/Mbtu (HHV) | 0.0022 | 0.0023 | 0.0024 | 0.0025 | 0.0026 | 0.0022 | 0.0023 | 0.0024 | 0.0025 | 0.0026 |
| PM2.5 (Total) | lb/hr | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| PM2.5 (Total) | lb/Mbtu (HHV) | 0.0044 | 0.0045 | 0.0047 | 0.0049 | 0.0051 | 0.0045 | 0.0045 | 0.0047 | 0.0049 | 0.0051 |
| PM2.5 (Filterable) | lb/hr | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 |
| PM2.5 (Filterable) | lb/Mbtu (HHV) | 0.0022 | 0.0023 | 0.0024 | 0.0025 | 0.0026 | 0.0022 | 0.0023 | 0.0024 | 0.0025 | 0.0026 |
| **Exhaust Composition** | | | | | | | | | | | |
| Argon | % vol | 0.9% | 0.9% | 0.9% | 0.9% | 0.9% | 0.8% | 0.8% | 0.8% | 0.8% | 0.8% |
| Nitrogen | % vol | 74.3% | 74.2% | 73.6% | 73.8% | 74.2% | 70.5% | 70.3% | 69.8% | 69.9% | 70.3% |
| Oxygen | % vol | 12.2% | 12.2% | 12.1% | 12.2% | 12.4% | 11.4% | 11.4% | 11.2% | 11.3% | 11.4% |
| Carbon Dioxide | % vol | 4.0% | 4.0% | 3.9% | 3.9% | 3.9% | 3.9% | 3.9% | 3.9% | 3.8% | 3.8% |
| Water | % vol | 8.6% | 8.8% | 9.5% | 9.3% | 8.7% | 13.4% | 13.6% | 14.3% | 14.1% | 13.6% |

# Ammonia-NOx Ratio versus Time

There is no single $NH_3$/NOx ratio that represents the field conditions over time – it is a moving target as the catalyst deactivates. How do we select a test condition that is representative of the field?

Example of ammonia slip and $NH_3$/NOx ratio over time



**EXAMPLE SPECIFICS**
NOx in = 15 ppmvd
NOx out = 1.5 ppmvd
deNOx = 90%
Slip Limit = 10 ppmvd
Assumed K/Ko EOL = 0.75

# Testing Approaches

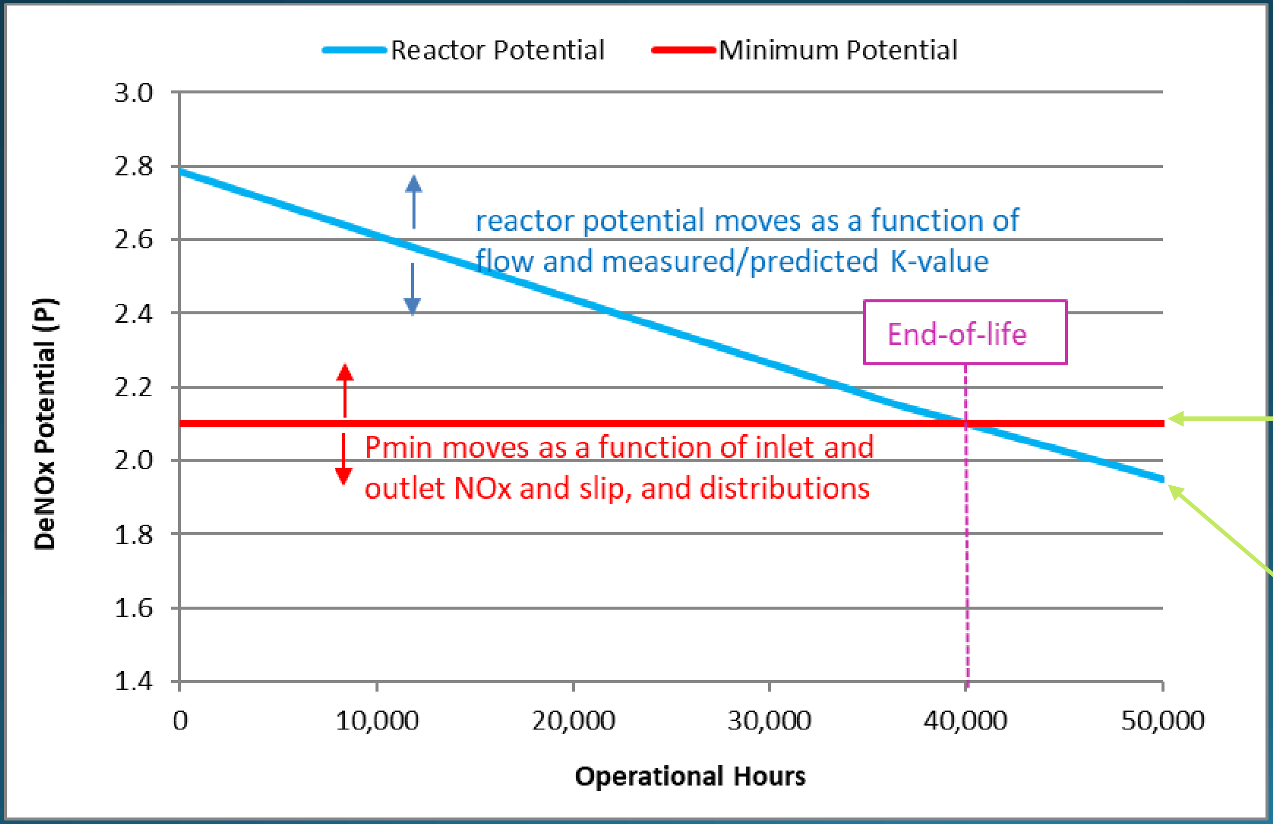
METHOD #1 (standard approach): Test at a set $NH_3/NO_x$ ratio to determine activity (k) and make adjustments to actual operating conditions if needed.

METHOD #2 (alternate approach): Test at the end-of-life slip and measure deNOx.

# METHOD #1: Traditional approach, K-value is measured which is used to determine reactor potential and compared to required minimum potential.

Remember that this changes as a function of time and test conditions as compared to field

This plot will look different for every operating condition that you model !



$$P=k/AV$$

$$AV=\frac{\text{Flow}}{\text{(cat. Vol. *SSA vol)}}$$

Accounts for
- $NH_3$ slip
- $NH_3/NO_x$ distribution
- SCR inlet NOx
- deNOx

Accounts for
- Deactivation
- Fouling

# METHOD #1: Pros and Cons

**PROS:**

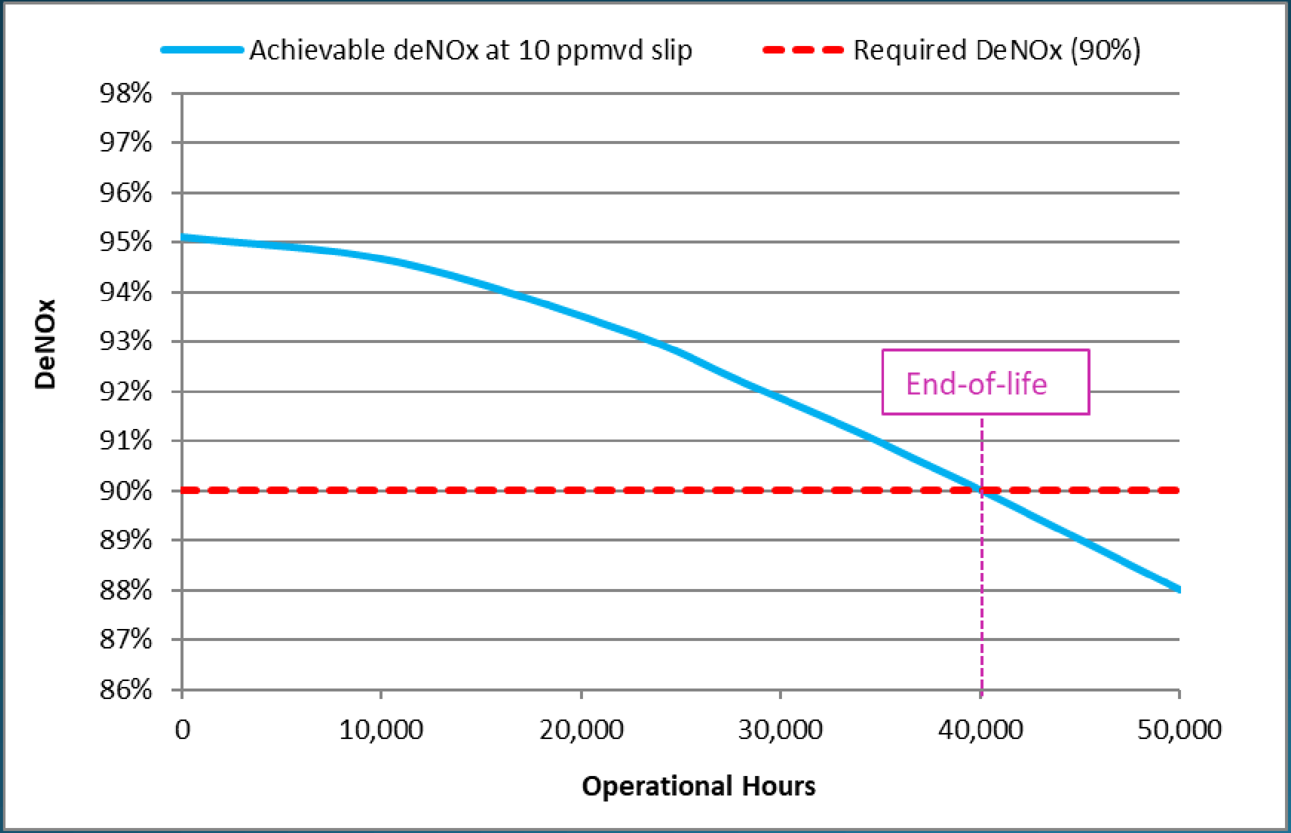
-More “traditional” approach where K-values are generated. This is a more fundamental parameter, but still subject to test conditions.

-Provides the necessary info for modeling purposes, if test conditions are properly considered with respect to the modeled field application.

**CONS:**

-Models must be used to make practical use of the results.

# METHOD #2: Inlet ammonia is set in lab to produce end-of-life slip limit (doesn't actually have to be known), response is the achieved deNOx at that slip limit. Produces a plot of achievable deNOx vs. time, allowing for prediction of end-of-life for the simulated field condition.



**EXAMPLE SPECIFICS**
NOx in = 15 ppmvd
NOx out = varies
deNOx = varies
Slip = 10 ppmvd

# METHOD #2: Pros and Cons

**PROS:**

-Gives direct information as to the capabilities of the current installation, since the results are based on achievable deNOx.

-Captures the end-of-life operating conditions based on the test/design scenario.

-Allows you to maximize deNOx (if desired) at any time during the catalyst life at the max design slip, based on test/design conditions.

**CONS:**

-Data is valid only for the specific test conditions, typically the design conditions. This includes flow rate, inlet NOx, and slip limit.

-Approach does not produce a traditional K-value for use in modeling, and therefore does not work as well for "what-if" scenarios (e.g., other operating conditions (inlet NOx, flow, deNOx, etc.), $NH_3/NO_x$ uniformity, catalyst fouling, etc.)

# Effect of test conditions on laboratory data – how to interpret laboratory data for field performance estimates and catalyst management.

## CRITICAL TEST PARAMETERS

- Effect of $NH_3$/NOx ratio
- Effect of inlet NOx
- Effect of velocity/flow rate

# Effect of NH3/NOx Ratio on deNOx and activity

Example plot – do not use for corrections, etc.

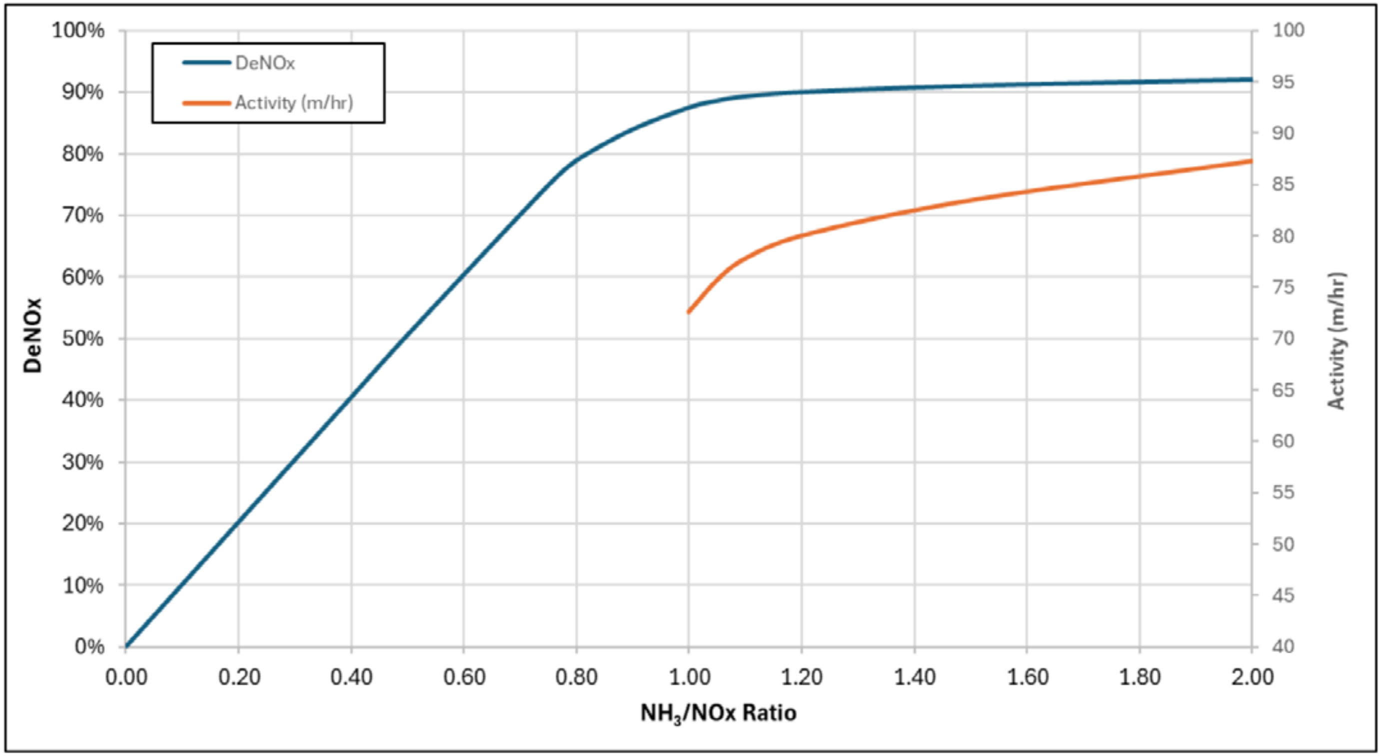


**Figure 6-1**
**Conceptual Laboratory $NO_x$ Reduction vs. $NH_3/NO_x$ and Calculated Catalyst Activity**

# Possible rigorous test method to establish relationship of NH3/NOx ratio and K for a particular catalyst.

Measure K at several points to establish curve – once this correlation has been established it can be used in modeling.

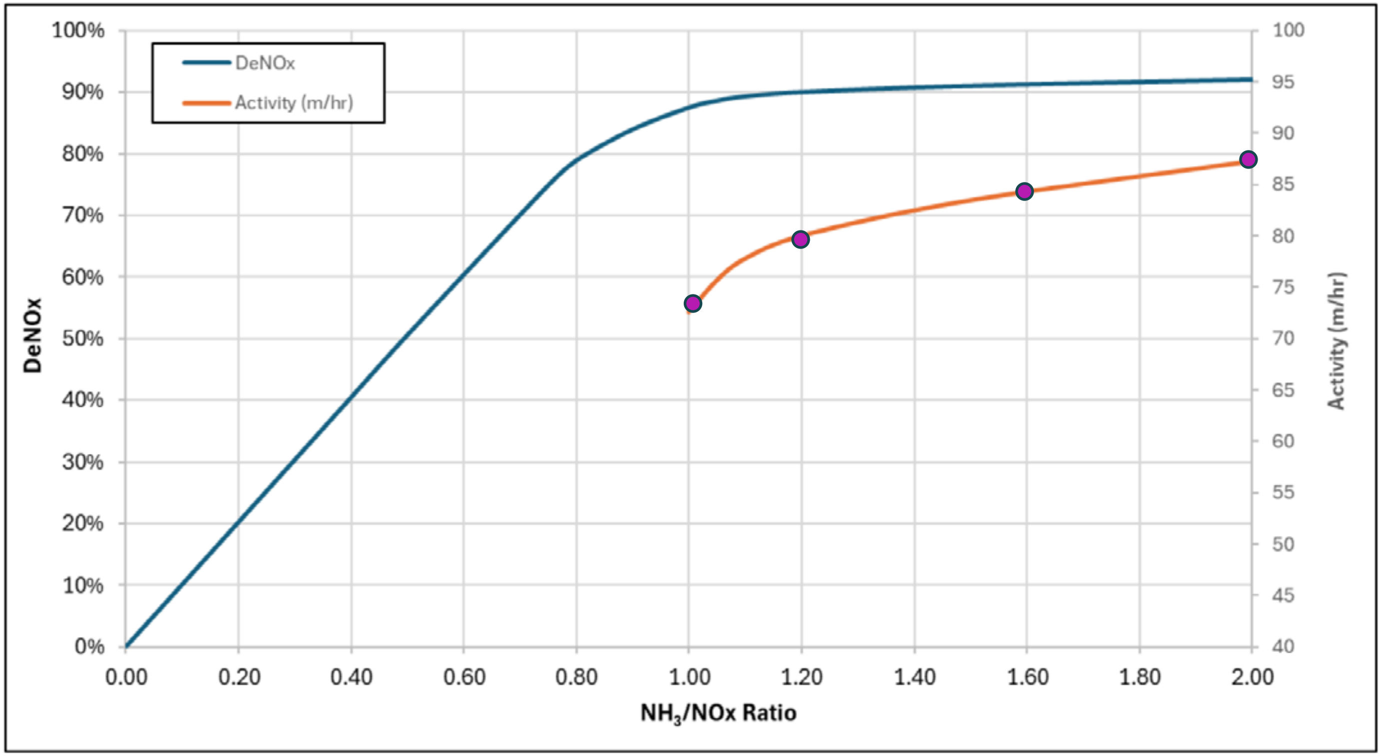


**Figure 6-1**
**Conceptual Laboratory $NO_x$ Reduction vs. $NH_3/NO_x$ and Calculated Catalyst Activity**

# Effect of Inlet NOx and Flow Rate/AV

## Inlet NOx

Differences in inlet NOx for the lab testing as compared to the field will affect the measured K-value. The exact effect is likely catalyst-dependent, and will be influenced by other parameters. Current protocol allows adjustment of inlet NOx to improve test accuracy, but effects of this adjustment should be known. **This has been identified as a future work priority.**

## Flow/AV

Differences in flow rate or AV for the lab testing as compared to the field will affect the measured K-value. The exact effect is likely catalyst-dependent, and will be influenced by other parameters. Current protocol allows adjustment flow rate to improve test accuracy, but effects of this adjustment should be known. Shortening the catalyst sample to increase AV is not recommended. **This has been identified as a future work priority.**

# Other effects to keep in mind

## Moisture

Moisture affects measured K-value and should be matched to the field value when possible. Note that moisture in the field can change substantially due to ambient conditions as well as the use of power augmentation.

## Oxygen

Oxygen levels will impact K-value, different opeating scenarios have different O2.

# Special Consideration: Ammonia Oxidation

## SCR catalysts can oxidize ammonia which affects ammonia consumption and has implications for test data interpretation.

Both test methods can be used to determine if ammonia oxidation is occurring, but additional data may be required as below.

Method #1: slip measurement is required to close NH3 balance and quantify oxidation

Method #2: inlet NH3 measurement is required to close material balance and quantify oxidation.

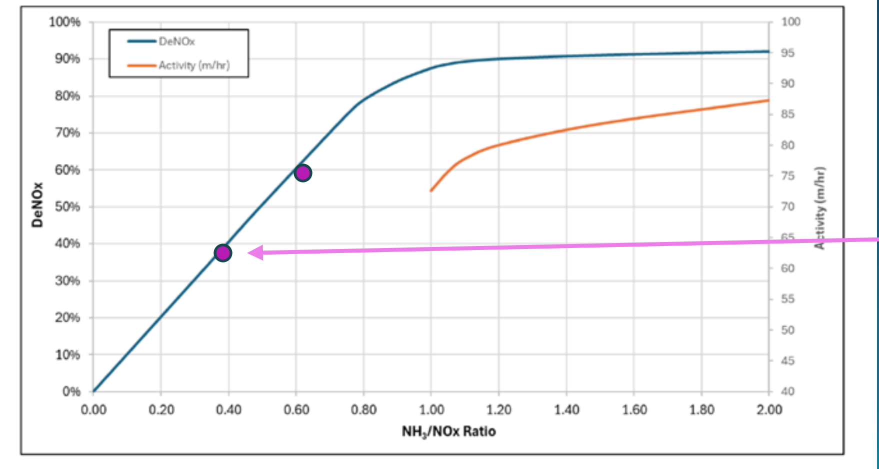
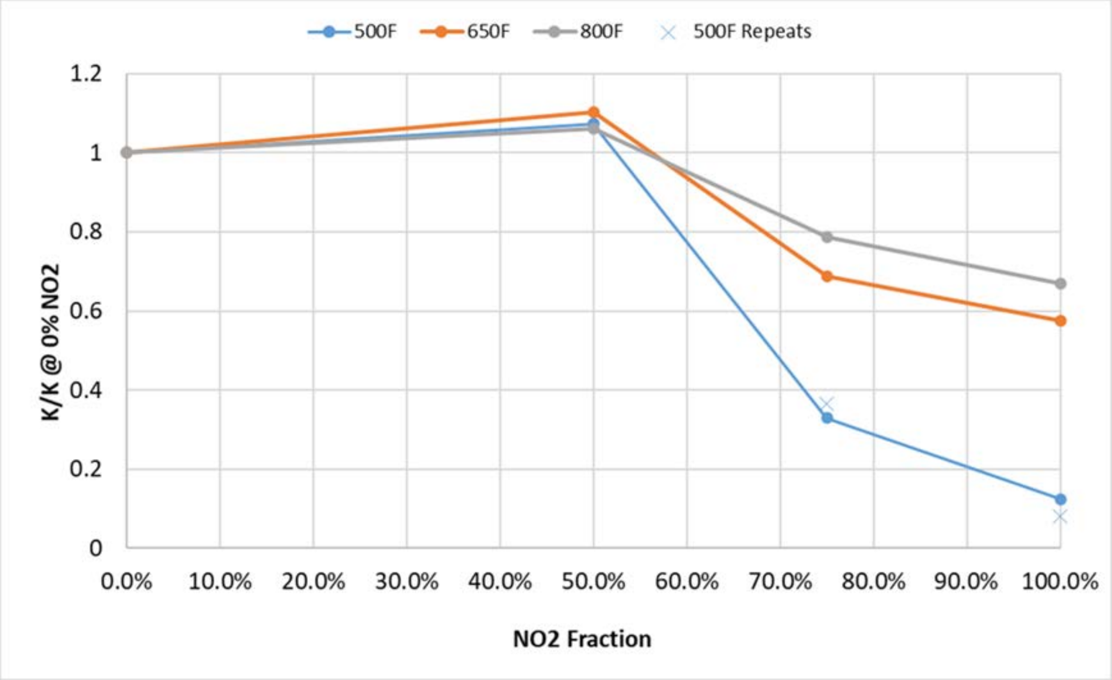


Figure 6-1
Conceptual Laboratory $NO_x$ Reduction vs. $NH_3/NO_x$ and Calculated Catalyst Activity

Also, you can measure inlet NH3 and deNOx at low deNOx. Slip is assumed to be zero, and thus you can close the material balance and calculate ammonia oxidation.

# Special Consideration: NO2 fraction

The level of NO2 can affect the measurement of K. Up to a ratio of about 50% NO2/NOx, there is a slight positive effect – thus assuming zero NO2 will produce a slightly conservative K up to 50% NO2. Above that, K falls rapidly with increasing NO2, so this must be taken into account for high NO2 flue gases.



# FUTURE WORK

## 1. Lab-to-lab comparative testing (round robin)

This EPRI program will determine test results variability between labs for a set of test conditions using test Method #1. **Program is underway, with results expected late 2025.**

## 2. Effect of flow and inlet NOx

Need to get a better understanding of the effect on measured K-value with respect to variations in flow and inlet NOx. Current data in guideline is fairly old and limited. **These are especially important parameters because they are sometime adjusted in the lab to improve accuracy.**

## 3. How to test multi-function catalysts

Determine the best approach for testing multi-function catalysts. Should test conditions replicate the field such that a combined test is performed, or can the different functions be tested separately?

# Conclusions

CT catalyst testing can be complicated compared to coal catalyst testing.

Test results are highly dependent on test conditions – selecting the appropriate test conditions is not straight-forward.

End-users must be knowledgeable about parameters impacting test data to accurately interpret data and utilize it for field performance estimates

Most end-users will not be equipped to understand the effect of operating at conditions other than the original design condition.

# Questions?