Catalyst Performance Test

TECHNICIAN: Peter Bartolomeo
TEST DATE: 11/18/2019
TEST REACTOR: Button
Customer: NRG
Project Name: GennConn Middletown
Customer P.O. #: 4501903349
Catalyst Manufacturer: BASF
Module Number: SN-030
Date of Manufacture: Unknown
Project #: SO-027142
Additional Comments: Unit 12, installed 1/15/11, removed 10/3/19

PreShipment Test: ☐
As-Received/PreWash Test: ☑
Post Wash Test: ☐
Recoated: ☐
Exposed to Exhaust Gas: ☑
Foil Sample Taken: ☐

Contaminant Tested	Temp @ Catalyst Inlet	Contaminant In	Contaminant Out	% DRE	Performance Requirements:	
	(°F)	(ppm)	(ppm)	(%)	% DRE	TEMP (°F)
CO	679	73	2.5	96.5%	95.5%	680
VOC (Toluene)	679	75	1.6	97.9%	84.5%	680

DRE = destruction and removal efficiency = Contaminant concentration in, minus out, divided by in
CO = carbon monoxide
VOC = volatile organic compound

Catalyst Performance Test

TECHNICIAN: Peter Bartolomeo
TEST DATE: 11/19/2019
TEST REACTOR: Button
Customer: NRG
Project Name: GennConn Middletown
Customer P.O. #: 4501903349
Catalyst Manufacturer: BASF
Module Number: SN-020
Date of Manufacture: Unknown
Project #: SO-027142
Additional Comments: Unit 13, installed 1/28/11, removed 10/10/19

PreShipment Test: ☐
As-Received/PreWash Test: ☑
Post Wash Test: ☐
Recoated: ☐
Exposed to Exhaust Gas: ☑
Foil Sample Taken: ☐

Contaminant Tested	Temp @ Catalyst Inlet	Contaminant In	Contaminant Out	% DRE	Performance Requirements:	
	(°F)	(ppm)	(ppm)	(%)	% DRE	TEMP (°F)
CO	680	72	2.8	96.1%	95.5%	680
VOC (Toluene)	680	74	2.2	97.1%	84.5%	680

DRE = destruction and removal efficiency = Contaminant concentration in, minus out, divided by in
CO = carbon monoxide
VOC = volatile organic compound

Catalyst Performance Test

TECHNICIAN: Peter Bartolomeo
TEST DATE: 11/19/2019
TEST REACTOR: Button
Customer: NRG
Project Name: GennConn Middletown
Customer P.O. #: 4501903349
Catalyst Manufacturer: BASF
Module Number: SN-009
Date of Manufacture: Unknown
Project #: SO-027142
Additional Comments: Unit 14, installed 2/15/11, removed 10/17/19

PreShipment Test: ☐
As-Received/PreWash Test: ☑
Post Wash Test: ☐
Recoated: ☐
Exposed to Exhaust Gas: ☑
Foil Sample Taken: ☐

Contaminant Tested	Temp @ Catalyst Inlet	Contaminant In	Contaminant Out	% DRE	Performance Requirements:	
	(°F)	(ppm)	(ppm)	(%)	% DRE	TEMP (°F)
CO	681	74	2.7	96.3%	95.5%	680
VOC (Toluene)	681	76	1.8	97.6%	84.5%	680

DRE = destruction and removal efficiency = Contaminant concentration in, minus out, divided by in
CO = carbon monoxide
VOC = volatile organic compound

Catalyst Performance Test

TECHNICIAN: Peter Bartolomeo
TEST DATE: 11/19/2019
TEST REACTOR: Button
Customer: NRG
Project Name: GennConn Middletown
Customer P.O. #: 4501903349
Catalyst Manufacturer: BASF
Module Number: SN-004
Date of Manufacture: Unknown
Project #: SO-027142
Additional Comments: Unit 15, installed 2/28/11, removed 10/27/19

PreShipment Test: ☐
As-Received/PreWash Test: ☑
Post Wash Test: ☐
Recoated: ☐
Exposed to Exhaust Gas: ☑
Foil Sample Taken: ☐

Contaminant Tested	Temp @ Catalyst Inlet	Contaminant In	Contaminant Out	% DRE	Performance Requirements:	
	(°F)	(ppm)	(ppm)	(%)	% DRE	TEMP (°F)
CO	678	72	2.6	96.3%	95.5%	680
VOC (Toluene)	678	71	1.6	97.8%	84.5%	680

DRE = destruction and removal efficiency = Contaminant concentration in, minus out, divided by in
CO = carbon monoxide
VOC = volatile organic compound

Catalyst Performance Test

TECHNICIAN: Peter Bartolomeo
TEST DATE: 5/10/2019
TEST REACTOR: 1
Customer: NRG
Project Name: Genn Conn, Devon
Customer P.O. #: 4501881625
Catalyst Manufacturer: EmeraChem, LLC
Module Number: EC-EIT-011 (23)
Date of Manufacture: Feb-10
Project #: RMA-6699
Additional Comments: Unit 16; removed 4/16/19

PreShipment Test: ☐
As-Received/PreWash Test: ☑
Post Wash Test: ☐
Recoated: ☐
Exposed to Exhaust Gas: ☑
Foil Sample Taken: ☐

Contaminant Tested	Temp @ Catalyst Inlet	Contaminant In	Contaminant Out	% DRE	Performance Requirements:		Pass/Fail
	(°F)	(ppm)	(ppm)	(%)	% DRE	TEMP (°F)	
CO	682	194	5	97.6%	95.5%	680	PASS
VOC (Toluene)	682	228	18	92.2%	84.5%	680	PASS

DRE = destruction and removal efficiency = Contaminant concentration in, minus out, divided by in
CO = carbon monoxide
VOC = volatile organic compound

Catalyst Performance Test

TECHNICIAN: Peter Bartolomeo
TEST DATE: 5/9/2019
TEST REACTOR: 1
Customer: NRG
Project Name: Genn Conn, Devon
Customer P.O. #: 4501881625
Catalyst Manufacturer: EmeraChem, LLC
Module Number: EC-EIT-040 (9)
Date of Manufacture: Feb-10
Project #: RMA-6699
Additional Comments: Unit 18 East; removed 4/29/19

PreShipment Test: ☐
As-Received/PreWash Test: ☑
Post Wash Test: ☐
Recoated: ☐
Exposed to Exhaust Gas: ☑
Foil Sample Taken: ☐

Contaminant Tested	Temp @ Catalyst Inlet	Contaminant In	Contaminant Out	% DRE	Performance Requirements:		Pass/Fail
	(°F)	(ppm)	(ppm)	(%)	% DRE	TEMP (°F)	
CO	687	188	4	97.8%	95.5%	680	PASS
VOC (Toluene)	687	198	12	93.7%	84.5%	680	PASS

DRE = destruction and removal efficiency = Contaminant concentration in, minus out, divided by in
CO = carbon monoxide
VOC = volatile organic compound

CORMETECH

NRG GenConn Devon Power
Unit 15

SCR Catalyst
Performance Test Report
728 Operating Hours
88 Months Since First Gas-In

Submitted by

CORMETECH, INC.
Environmental Technologies
5000 International Drive
Durham, NC 27712
(919) 620-3000

John A. Nivens
Sr. Engineering Technician

Mark Conger
Sr. Project Engineer

Certifying Laboratory Representative
Silas Christian, Laboratory Manager

February 7, 2018

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EXECUTIVE SUMMARY

The following summarizes the key results for this audit of the NRG GenConn Devon Power Unit 15 SCR after 88 months and 728 operating hours since first gas-in.

Observations and Predictions

This audit of the GenConn Devon Power Unit 15 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Devon Power Unit 15 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,200 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

Field Data Commentary

Based on the provided operational data, GenConn Devon Power Unit 15 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

Recommendations

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

PURPOSE

This test is conducted to audit the catalytic potential of an SCR catalyst by measuring the performance of a field catalyst sample that has been in operation for a known duration. The catalytic potential is measured by laboratory scale testing of field samples removed from the SCR. Performance tests are conducted in a controlled, laboratory environment allowing accurate comparisons of field sample catalytic potential to that of fresh catalyst. The deactivation rate is determined by comparing the change in catalytic potential to the operating hours of the sample.

Field performance, as indicated by plant-supplied measurements and observations, is also analyzed and discussed relative to the performance of the catalyst samples tested. Measured field performance in conjunction with laboratory measurements of field sample catalytic potential is used to determine actual unit scale-up factors. Utilizing actual unit scale-up factors significantly improves the accuracy of future performance predictions.

Further catalyst and/or field operation analysis may be recommended if laboratory test results are inconsistent with any of the following:

- Cormetech's experience base of comparable units
- The plant's reported field performance, if available
- The results of previous audits of the unit, if applicable
- The performance expectations for the unit.

BACKGROUND

In order to achieve the design performance requirements of a Selective Catalytic Reduction system for a specified timeframe (life) of the SCR catalyst, the catalyst formulation, structure, and volume are specifically designed to accommodate the system operating conditions, the predicted system scale-up factors, and a predicted rate of decrease in catalyst potential over time.

If any of the design or operating parameters above is not realized, then the actual duration that the design performance requirements can be met may deviate from the design life. The individual contribution of each parameter on actual life is described below. In actual practice, one or more of these parameters may deviate from design and either counteract or complement each other.

Performance Requirements: If the actual plant performance requirements are more severe than the design performance requirements, actual life will be less than design life. An example of this would be a unit that is required to achieve a higher NOx reduction than the unit was designed for.

Operating Conditions: Flue gas flow rate, inlet NO_X levels, temperature, oxygen content, and water content impact catalytic potential. If the catalyst is at an operating condition where the potential is lower than design, actual life will be less than design life.

Scale-Up Factors: The full NO_X reduction potential of the catalyst is not attained in the field due to non-ideal flow distribution, temperature distribution, ammonia to NO_X molar ratio distribution,

catalyst blockage, and/or flue gas bypass. Collectively, these non-ideal conditions are accounted for with 'system scale-up factors'. If the overall actual system scale-up factors are more severe than the design scale-up factors, then the potential of the SCR system to meet a given performance requirement is reduced.

Catalyst Deactivation Rate: Catalytic potential decreases over time. This catalyst deactivation rate has a direct impact on actual life. If the deactivation rate is more than design, then actual life is effectively reduced. If the deactivation rate is less than design, the actual life is effectively increased.

If the performance requirements, operating conditions, and/or scale-up factors are more severe than the initial design, less margin remains for catalyst deactivation. Therefore, actual life will be less than design life.

At any given time and operating condition, the SCR system performance is dictated by the NO_X reduction potential of the catalyst and the system scale-up factors. These factors reduce performance from the catalytic potential to the performance achievable in the operating SCR system.

Performance tests are purposefully conducted in a controlled environment, free from the scale-up factors that adversely affect SCR system performance, and at repeatable operating conditions, so that changes in catalytic potential may be evaluated accurately. Catalyst deactivation is determined by testing the field catalyst sample at the same operating conditions as the fresh sample.

In conjunction with performance test results, analysis of field SCR system performance data can confirm the field performance requirements, the plant operating conditions, and actual system scale-up factors.

Cormetech's SCR catalyst design and testing experience enables analysis of the actual versus design values of performance requirements, operating conditions, system scale-up, and catalyst deactivation to predict future catalyst performance.

FACILITY OPERATIONAL HISTORY

The SCR system at the GenConn Devon Power Unit 15 consists of 1 layer of CM21MHT™ 70 cell catalyst. The unit was originally put into service on June 2010.

On October 23, 2017 on catalyst sample was removed from the field sampler at GenConn Devon Power Unit 15 and returned to Cormetech for laboratory testing. At the time the sample was removed, the audited element had accumulated 728 operating hours. The results of the October 23, 2017 audit are summarized in this report.

PROCEDURE OVERVIEW

1. One catalyst sample was removed from the field sampler module at the GenConn Devon Power Unit 15 SCR and was shipped to Cormetech's laboratory. Operating history was recorded by the plant and forwarded to Cormetech.

2. The physical condition of the catalyst was documented by Cormetech.

3. The catalyst was prepared and loaded into an Activity Test Apparatus and then evaluated at the original design conditions for the SCR. The Performance Test Standard Procedure is included in Appendix 3.

4. The results include catalyst potential expressed as NO_X removal efficiency at a constant 5 ppmvdc ammonia slip.

5. Test results were compared to design expectations and to the results of the fresh reference. Expectations of catalyst deactivation were determined by the time on-line and experience data of similar gas-fired facilities.

6. A catalyst life prediction is based on the above testing and analysis.

7. Additional data submitted by the plant was reviewed for the field performance of the SCR system.

FIELD SAMPLING AND UNIT OPERATING CONDITIONS

Field Sampling

One SCR catalyst sample from GenConn Devon Power Unit 15 was removed and sent to Cormetech's Laboratory for evaluation. The sample retrieval location is shown in Appendix 1.

Operating Status

Field records supplied by GenConn Devon Power are summarized in the table below. The field records are reproduced in Appendix 2.

First Gas-In Date with Catalyst Installed	June 2010
Sample Removal Date	October 23, 2017
Total Operating Hours On Catalyst Sample	728
Primary Fuel Fired	Ultra-Low Sulfur Kerosene
Hours Burning Primary Fuel	639
Secondary Fuel Fired	Natural Gas
Hours Burning Secondary Fuel	89
Number of Starts and Stops since catalyst was installed	170

LABORATORY PERFORMANCE TEST CONDITIONS

A performance test was conducted on the sample received using the conditions below. These conditions reflect the original design conditions for which there is fresh catalyst test data available for direct comparison.

Temperature	442°C (828°F)
Entrance Gas Velocity	3.84 Nm/s
O_2	14.4 vol% dry
Inlet NO_X	46.0 ppmvd @ 14.4% O_2 (42.0 ppmvdc @ 15% O_2)

RESULTS

Sample Visual Inspection

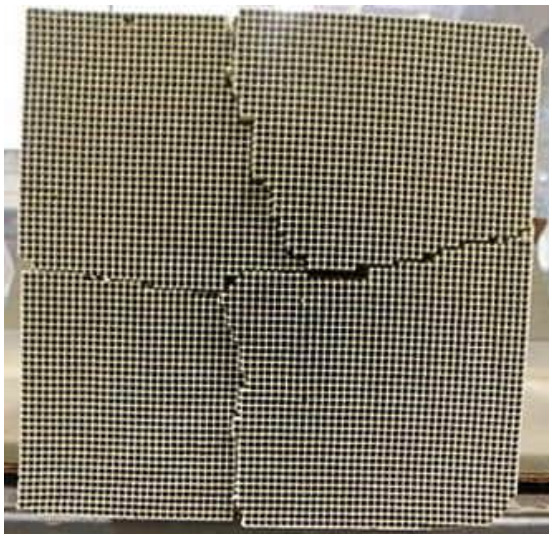
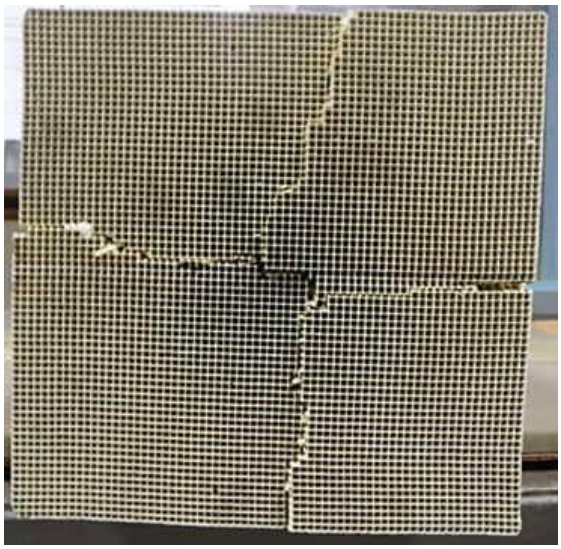
One field sample was received from the GenConn Devon Power Unit 15 SCR.

Below are photographs of the flow entrance face and the flow exit face of the element with an as received inspection report.

Element ID	2388-1026-0439

Box Markings	2 of 2
Sample Markings	Calc 3 flow 15-3 Second from bottom
Flow Direction Marked	Yes
Other Markings	None

Visual Inspection Notes	Element arrived broken into four pieces, but it is in testable condition.
Product Description	CM21MHT™ 70 X 70 cell array
Length, mm	447
Blocked Cell Count, as received	1
Blocked Cell Count, after light cleaning	1

Flow Entrance	*Flow Exit*
	

Results of Laboratory Tests

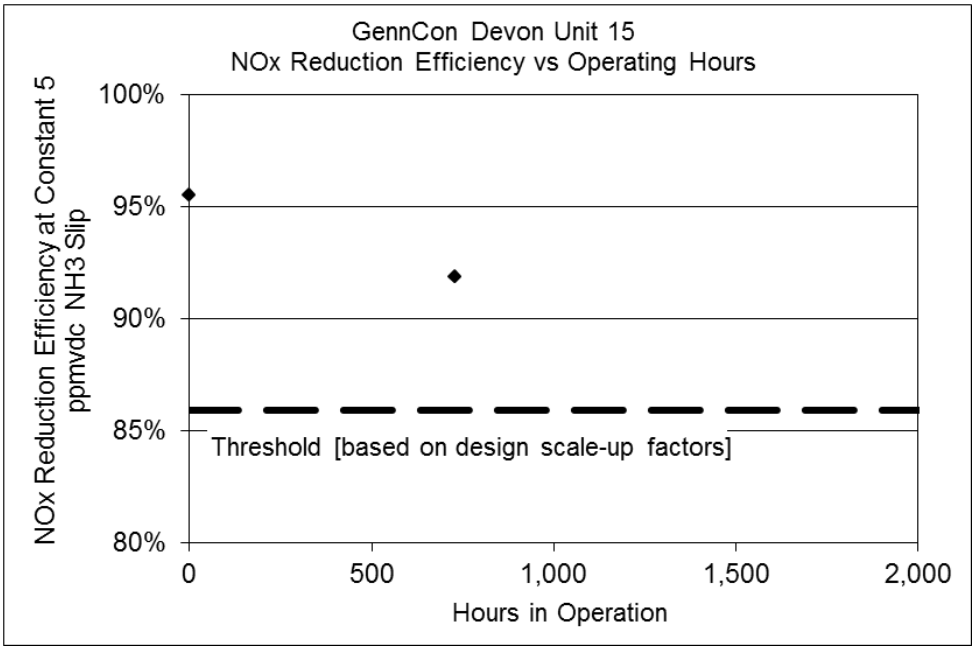
The catalyst performance below is reported under constant 5 ppmvdc ammonia slip and design operating conditions.

The lab performance threshold represents the design NO_X removal efficiency, as measured in lab apparatus, at which the actual *field* performance at *design* operating conditions is expected to reach end-of-life. Field performance is based on a design performance requirement of 85.9% NO_X removal efficiency and 5 ppmvdc ammonia slip.

In field scale (actual) operation, flow, temperature and ammonia/NOx non-uniformities exist. In the highly controlled laboratory environment these non-uniformities do not exist; therefore, the lab results must be scaled-up to reflect expected field performance. The scale-up factors limit achievable NO_X reduction performance in operating SCR systems. The performance threshold value is based on design values for the scale-up factors. The *actual* threshold may be lower if actual scale-up is less severe, or higher if more severe.

	Element ID	**Time On-Line** (Hours)	**NOx Removal Efficiency, %** at 5 ppmvdc NH_3 Slip
Fresh Reference	# 2388-1026-0430	0	95.5
October 2017 Audit	# 2388-1026-0439	728	91.8
Threshold (based on design scale-up factors)			85.9

The figure below shows the trend in catalyst performance.



This audit of the GenConn Devon Power Unit 15 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Devon Power Unit 15 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,200 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

FIELD DATA COMMENTARY

A review of field data has three primary purposes. First, the field data can show if any operating parameters are significantly different than the original design of the unit. Second, the field data can show if actual plant performance requirements are more severe than the design. If significant differences are evident in operating parameters or performance requirements, their effect on the performance threshold can be determined. Third, the field data can be used to examine if any factors that adversely impact scale-up are present. Typically the factors that adversely impact scale-up are as follows:

- Plugged/ poorly performing Ammonia Injection System resulting in poor mixing of the NH_3 prior to the catalyst.
- Flue gas flow velocity maldistribution.
- Flue gas flow bypass around the catalyst.
- Plugged catalyst.

Below is a table that compares the field data provided by GenConn Devon Power Unit 15 SCR against the design criteria for the installed SCR catalyst:

Parameter	Design Value	Field Value (oil)	Field Value (gas)
Flue Gas Temperature (°F)	828	836	836
Flue Gas Flow Rate (lb/hr)	1,088,460	N/A	N/A
Inlet NOx (ppmvd @ 15% O_2)	42	42 (estimated)	25 (estimated)
Outlet NOx (ppmvd @ 15% O_2)	5.9	4.2	2.0
NOx Reduction Efficiency (%)	85.9	90	92
NH_3 Slip (ppmvd @ 15% O_2)	5 (end of life)	1.8	2.3
NH_3 Flow Rate (lb/hr)	180 (end of life)	142	81
NH_3 Supply Concentration (wgt %)	19	19	19
Flue Gas O_2 Conc. (% vol dry)	14.4	14.7	14.4
Catalyst Pressure Drop (in. wg.)	5.1	5	5

Permit Limit

Outlet NOx = 5.9 ppmvd @ 15% O_2 (ULSK), 2.5 ppm vd @15% O_2 (Gas)
Ammonia Slip = 5 ppm

Based on the provided operational data, GenConn Devon Power Unit 15 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

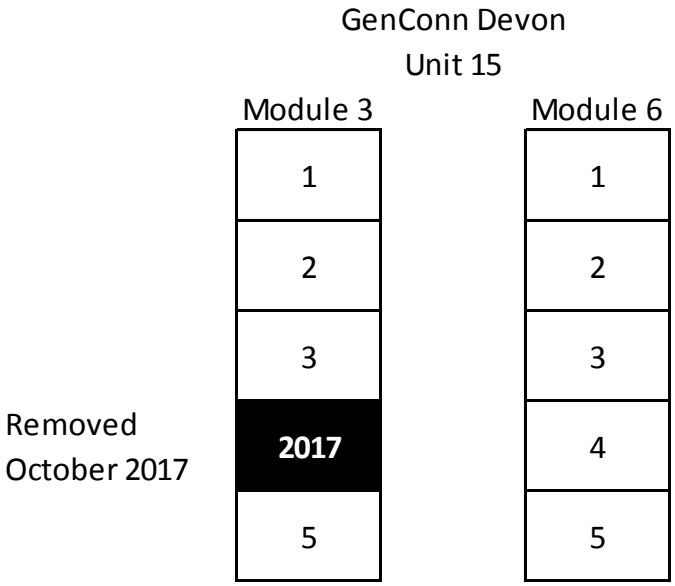
RECOMMENDATIONS

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

APPENDIX 1: Location of Sample Retrieval

The sample retrieval location for GenConn Devon Power Unit 15 is shown in the following schematic.



APPENDIX 2: Field Records

Field records received from GenConn Devon Po

Facility Information	
Facility Owner	NRG
Facility Name	GenConn Devon Power
Facility Street Address	734 Naugatuck Avenue
City, State, Zip Code	Milford, CT 06461
Unit Designation	Unit 15

Contact Information	*Person completing form*	*Person report goes to*
Name	Paul Bukowsky	Same
Title	Environmental Compliance Engineer	
Telephone Number	203-783-6143	
E-mail Address	Paul.Bukowsky@nrg.com	

Sample Operational History		
Catalyst Installation Date	June 2010	
First Gas In Date	June/July 2010	
Sample Removal Date	10/23/2017	
Sample Removal Position *Indicate sampling position: Circle, Mark with 'X" or Note sampling position here ___* *View from Upstream Side*	Module 3: 1, 2, 3, **X**, 5 Module 6: 1, 2, 3, 4, 5	*You may pull the sample from any of the "white boxes."* *Note: Blackened boxes have been sampled previously.*
Removed Sample Element Serial Number, stamped on element	~~None~~ 23881026043 9	
# Starts and Stops on Catalyst	42 (gas) / 128 (oil)	
Operating Hours by Fuel Type	*# Operating Hours burning this fuel*	*Type of Fuel*
Primary Fuel	639	Ultra Low Sulfur Kerosene
Secondary Fuel	89	Natural Gas
Total # Operating Hours	728	

wer are reproduced below.

Data Sheet for GenConn Devon Unit 15

Present Operating Conditions				
	Units [Circle correct unit or change as required]	Value	Continuously monitored?	Measurement Method [1]
Flue Gas Temperature (at SCR)	°F	836	Y	Unit DAS
Flue Gas Flow Rate	Lb/hr wet	N/A	N	Not Available
SCR Inlet NOx	ppmvd @15% O_2	25 (gas) 42 (oil)	N	Estimate - 2015
SCR Outlet NOx	ppmvd @15% O_2	2.0 (gas) 4.2 (oil)	N	Stack Test - 2015
NH_3 Slip	ppmvd @15% O_2	2.32	N	Stack Test (FTIR) – 2015 Stack Test (CTM 027) - 2010
NH_3 Flow rate	lb/hr	81 (gas) 142 (oil)	Y	Unit DAS
NH_3 Supply Concentration	wgt %	19	N	Lab Certification
Flue gas O_2 Concentration	Dry Volume %	14.4 (gas) 14.7 (oil)	N	Stack Test - 2015
Flue gas H_2O Concentration	Volume %	12.3 (gas) 9.5 (oil)	N	Stack Test - 2015
Catalyst Pressure Drop	Inches H2O	5	Y	Unit DAS

[1] *Method of measurement and accuracy should be provided for all measured values, i.e., flow (boiler load signal or stack measurement), NOx (dilution method chemiluminescence), NH_3 (chemiluminescence subtraction method, ammonia flow gpm/± 5%, etc.).*

Permit Limits	(List units as appropriate)
NOx Out	5.9 ppmvd @ 15% O2 (ULSK), 2.5 ppmvd @ 15% O2 (Gas)
NH_3 Slip Out	5 ppm
NOx Removal	95 %

Data Sheet for GenConn Devon Unit 15

Testing History (where NH_3 slip is measured)

	Units [Circle correct unit or change as required]	Following Installation of SCR Catalyst	Test 1		
Test Date		7/15/2010 oil 8/28/2010 gas	7/7/2015 oil 7/8/2015 gas		
Load Case	Mw	50	50		
Flue Gas Temperature (at SCR)	°F	790 gas 802 oil	836		
Flue Gas Flow Rate	acfm	807,843 (gas) 763,563 (oil)	N/A		
SCR Inlet NOx	ppmvd @15% O_2	25 (gas) 42 (oil)	25 (gas) 42 (oil)		
SCR Outlet NOx	ppmvd @15% O_2	2.46 (gas) 3.98 (oil)	2.0 (gas) 4.2 (oil)		
NH_3 Slip	ppmvd @15% O_2	0.9 (gas) 0.8 (oil)	2.32 (gas) 1.79 (oil)	Stack Test (FTIR) – 2015 Stack Test (CTM 027) - 2010	
NH_3 Flow Rate	lb/hr	73 (gas) 146 (oil)	81 (gas) 142 (oil)		
NH_3 Supply Concentration	wgt %	19	19		
Flue Gas O_2 Concentration	Dry Volume %	14.6 (gas) 14.8 (oil)	14.4 (gas) 14.7 (oil)		
Flue Gas H_2O Concentration	Volume %	10.9 (gas) 8.8 (oil)	12.3 (gas) 9.5 (oil)		
SCR Catalyst Pressure Drop	in. wg. or mm Hg	5	5		

APPENDIX 3: Performance Test Standard Procedure

Purpose

The *laboratory performance testing* for SCR catalyst is conducted to determine the catalytic potential of a representative sample of SCR catalyst at conditions that closely match the actual operating conditions of the SCR system. The sample should represent a typical cross section of the SCR, and the operating history should be known. The test is conducted in a controlled, laboratory environment on custom-built, rigorously validated SCR catalyst test apparatus allowing accurate determination of performance and comparisons of the sample catalytic potential to the system requirements previously tested catalyst(s).

Test Equipment Description

The Cormetech Laboratory SCR test reactors consist of three basic systems:

- Simulated flue gas generator
- SCR catalyst test chamber
- Measurement system

The purpose of the simulated flue gas generator is to provide a stable controlled supply of heated gas with the required mix of gases at the required flow rate and temperature to the SCR catalyst test chamber. It consists of a bulk flue gas generator, a flue gas modification system, a flue gas heater, a reactive gas injection system, and a flue gas mixer.

Bulk Flue Gas Generator -The bulk flue gas is produced by either the combustion of air in a natural gas fired water-cooled combustion chamber, the extraction of nitrogen from air via a membrane system, or the delivery of nitrogen from liquefied nitrogen. This system is adjusted to achieve the overall flue gas flow rate required for the specified test.

Flue Gas Modification System – The gas stream produced by the bulk flue gas generator is modified by the addition of oxygen/air and water/steam to achieve the targeted concentrations of water vapor and oxygen in the flue gas stream.

Flue Gas Heater – The flue gas stream is heated to the target test temperature by an electric pre-heater.

Reactive Gas Injection System – Calibrated mass flow controllers are used to deliver SO_2, SO_3, NO_2, NO, and NH_3 into the flue gas stream.

The table below summarizes the range of process conditions that can be produced by various apparatus in Cormetech's laboratory. Cormetech's laboratory maintains multiple testing units, each with varying capabilities for temperature, flow, and gas composition. The unit selected for a given test will depend on the specific requirements for the sample tested.

Parameter	Units	Range
Gas Temperature	^{o}C	200 – 600
Flow rate/Entrance velocity	Nm/s	1.25 - 7.05
O_2	volume % dry	1 – 20
H_2O	volume %	1-20[1]
NO	ppmvd	0 - 2,000
NO_2	ppmvd	0 - 2000[2]
NH_3	ppmvd	0 - 4,000
SO_2	ppmvd	0 - 2,000
SO_3	ppmvd	0 – 25

1: Some apparatus have the capability to control water concentration. Other units supply water as a product of combustion. When water concentration is not controlled, Cormetech corrects the results to the target concentration with a standardized correction factor.
2: NO_2 addition capability is not available on all test units.

Flue Gas Mixer – Following the reactive gas injection, the gases are mixed using a high efficiency static mixing element.

The simulated flue gas next enters the SCR test reactor where the SCR test sample or samples are located. Each sample is sealed tightly to the walls of the test chamber to ensure that all of the flue gas passes though the sample[s]. Along the length of the test chamber there are electric heating elements that maintain the specified test temperature. There are test ports located at the entrance to the test reactor and at the exit of each sample layer to extract a sample of flue gas for analysis, measure the static pressure of the flue gas, and monitor the temperature of the catalyst samples and the flue gas.

The process conditions of the SCR catalyst under test are monitored by the measurement system:

Gas Flow Rate – The flue gas flow rate is measured by an averaging pitot tube in the exit of the simulated flue gas generator. The flow rate is also calculated from the mass flow controllers for the various gas constituents as they are added. Finally, an annubar is installed in the exhaust of the reactor which allows another cross-check of the flow rate. For the testing to be determined valid, the flow rate must be within the allowable limits from the target flow rate.

Gas Temperature – The temperature of the gas and the catalyst samples is measured by a series of thermocouples throughout the test reactor. For the testing to be determined valid, both the spatial and temporal variability must be within the allowable limits from the specified set point.

Component Concentration – The components of the flue gas are determined by the methods described below. Different systems may not have every type of sampling measurement system.

- *NOx* – Chemiluminescent NOx Analyzer / Infrared Spectroscopy. Average value at each sampling point recorded for each sampling cycle
- NH_3 – Ion Chromatography/infrared spectroscopy
- SO_2 – Precipitation Method/infrared spectroscopy
- SO_3 – Controlled Condensation; Collective Precipitation Method
- O_2 – Micro-fuel cell and Paramagnetic O_2 Analyzer

Procedure Description Summary

The following stepwise description is a guideline to understand how an audit proceeds from sample receipt to reported results.

1. Upon receipt, each sample is inspected for condition and photographed. The sample dimensions are recorded.
2. The Test Plan is prepared based on the needs of audit. The appropriate test apparatus is selected based on the test requirements and the test is scheduled.
3. Each sample is prepared for testing. [This process includes cleaning the sample, and cutting to the required test sample size.]
4. The reactor is opened, inspected, and prepared for operation.
5. Each catalyst sample is loaded according to the Test Plan and sealed in the reactor.
6. An equipment leak test is performed.

7. The Bulk Flue Gas Generator is started and the test conditions are set for O_2%, temperature, and bulk flow rate.
8. NO and NO_2 injection is started and then adjusted in order to meet the test conditions.
9. Ammonia, SO_2 and SO_3 injection is started and then adjusted in order to meet the test conditions.
10. The catalyst is allowed to equilibrate at the test conditions specified.
11. A calibration check is run for the analyzers.
12. For each sampling cycle, the following measurements are taken, as required:

Item	Location Measured	Frequency
NO_X Concentration	Multiplexed to measure NO_X at each sampling point	Average value at each sampling point recorded per each sampling cycle
NH_3 Concentration	At exit of sample[s]	Depends on test method [Multiple analyses recorded]
SO_2 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
SO_3 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
O_2 Concentration	Exit of combustion chamber and multiplexed with NO_X Analyzer	Continuously controlled and monitored
Gas Flow	Exit of combustion chamber	Continuously controlled and monitored
Gas Temperature	At each sampling port	Inlet continuously controlled
Pressure Drop	Entrance and at exit of testing chamber	Continuously monitored, recorded as required

13. The results are recorded and checked per Quality Assurance requirements and compared to the Test Plan.
14. The results are reported.

NRG GenConn Devon Power
Unit 16

SCR Catalyst
Performance Test Report
772 Operating Hours
April 2019 Audit

Submitted by

CORMETECH, INC.
Environmental Technologies
5000 International Drive
Durham, NC 27712
(919) 620-3000

Max Morris
Project Engineer

John A. Nivens
Sr. Engineering Technician

Certifying Laboratory Representative
Silas Christian, Laboratory Manager

July 17, 2019

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EXECUTIVE SUMMARY

The following summarizes the key results for this audit of the NRG GenConn Devon Power Unit 16 SCR after 772 operating hours since first gas-in.

Observations and Predictions

This audit of the GenConn Devon Power Unit 16 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Devon Power Unit 16 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,300 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

Field Data Commentary

Based on the provided operational data, GenConn Devon Power Unit 16 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

Recommendations

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

PURPOSE

This test is conducted to audit the catalytic potential of an SCR catalyst by measuring the performance of a field catalyst sample that has been in operation for a known duration. The catalytic potential is measured by laboratory scale testing of field samples removed from the SCR. Performance tests are conducted in a controlled, laboratory environment allowing accurate comparisons of field sample catalytic potential to that of fresh catalyst. The deactivation rate is determined by comparing the change in catalytic potential to the operating hours of the sample.

Field performance, as indicated by plant-supplied measurements and observations, is also analyzed and discussed relative to the performance of the catalyst samples tested. Measured field performance in conjunction with laboratory measurements of field sample catalytic potential is used to determine actual unit scale-up factors. Utilizing actual unit scale-up factors significantly improves the accuracy of future performance predictions.

Further catalyst and/or field operation analysis may be recommended if laboratory test results are inconsistent with any of the following:

- Cormetech's experience base of comparable units
- The plant's reported field performance, if available
- The results of previous audits of the unit, if applicable
- The performance expectations for the unit.

BACKGROUND

In order to achieve the design performance requirements of a Selective Catalytic Reduction system for a specified timeframe (life) of the SCR catalyst, the catalyst formulation, structure, and volume are specifically designed to accommodate the system operating conditions, the predicted system scale-up factors, and a predicted rate of decrease in catalyst potential over time.

If any of the design or operating parameters above is not realized, then the actual duration that the design performance requirements can be met may deviate from the design life. The individual contribution of each parameter on actual life is described below. In actual practice, one or more of these parameters may deviate from design and either counteract or complement each other.

Performance Requirements: If the actual plant performance requirements are more severe than the design performance requirements, actual life will be less than design life. An example of this would be a unit that is required to achieve a higher NOx reduction than the unit was designed for.

Operating Conditions: Flue gas flow rate, inlet NO_X levels, temperature, oxygen content, and water content impact catalytic potential. If the catalyst is at an operating condition where the potential is lower than design, actual life will be less than design life.

Scale-Up Factors: The full NO_X reduction potential of the catalyst is not attained in the field due to non-ideal flow distribution, temperature distribution, ammonia to NO_X molar ratio distribution,

catalyst blockage, and/or flue gas bypass. Collectively, these non-ideal conditions are accounted for with 'system scale-up factors'. If the overall actual system scale-up factors are more severe than the design scale-up factors, then the potential of the SCR system to meet a given performance requirement is reduced.

Catalyst Deactivation Rate: Catalytic potential decreases over time. This catalyst deactivation rate has a direct impact on actual life. If the deactivation rate is more than design, then actual life is effectively reduced. If the deactivation rate is less than design, the actual life is effectively increased.

If the performance requirements, operating conditions, and/or scale-up factors are more severe than the initial design, less margin remains for catalyst deactivation. Therefore, actual life will be less than design life.

At any given time and operating condition, the SCR system performance is dictated by the NO_X reduction potential of the catalyst and the system scale-up factors. These factors reduce performance from the catalytic potential to the performance achievable in the operating SCR system.

Performance tests are purposefully conducted in a controlled environment, free from the scale-up factors that adversely affect SCR system performance, and at repeatable operating conditions, so that changes in catalytic potential may be evaluated accurately. Catalyst deactivation is determined by testing the field catalyst sample at the same operating conditions as the fresh sample.

In conjunction with performance test results, analysis of field SCR system performance data can confirm the field performance requirements, the plant operating conditions, and actual system scale-up factors.

Cormetech's SCR catalyst design and testing experience enables analysis of the actual versus design values of performance requirements, operating conditions, system scale-up, and catalyst deactivation to predict future catalyst performance.

FACILITY OPERATIONAL HISTORY

The SCR system at the GenConn Devon Power Unit 16 consists of 1 layer of CM21MHT™ 70 cell catalyst. The unit was originally put into service on July 2010.

On April 26, 2019 one catalyst sample was removed from the field sampler at GenConn Devon Power Unit 16 and returned to Cormetech for laboratory testing. At the time the sample was removed, the audited element had accumulated 772 operating hours. The results of the April 26, 2019 audit are summarized in this report.

PROCEDURE OVERVIEW

1. One catalyst sample was removed from the field sampler module at the GenConn Devon Power Unit 16 SCR and was shipped to Cormetech's laboratory. Operating history was recorded by the plant and forwarded to Cormetech.

2. The physical condition of the catalyst was documented by Cormetech.

3. The catalyst was prepared and loaded into an Activity Test Apparatus and then evaluated at the original design conditions for the SCR. The Performance Test Standard Procedure is included in Appendix 3.

4. The results include catalyst potential expressed as NO_X removal efficiency at a constant 5 ppmvdc ammonia slip.

5. Test results were compared to design expectations and to the results of the fresh reference. Expectations of catalyst deactivation were determined by the time on-line and experience data of similar gas-fired facilities.

6. A catalyst life prediction is based on the above testing and analysis.

7. Additional data submitted by the plant was reviewed for the field performance of the SCR system.

FIELD SAMPLING AND UNIT OPERATING CONDITIONS

Field Sampling

One SCR catalyst sample from GenConn Devon Power Unit 16 was removed and sent to Cormetech's Laboratory for evaluation. The sample retrieval location is shown in Appendix 1.

Operating Status

Field records supplied by GenConn Devon Power are summarized in the table below. The field records are reproduced in Appendix 2.

First Gas-In Date with Catalyst Installed	July 2010
Sample Removal Date	April 16, 2019
Total Operating Hours On Catalyst Sample	772
Primary Fuel Fired	Ultra-Low Sulfur Kerosene
Hours Burning Primary Fuel	669
Secondary Fuel Fired	Natural Gas
Hours Burning Secondary Fuel	76
Number of Starts and Stops since catalyst was installed	324

LABORATORY PERFORMANCE TEST CONDITIONS

A performance test was conducted on the sample received using the conditions below. These conditions reflect the original design conditions for which there is fresh catalyst test data available for direct comparison.

Temperature	442°C (828°F)
Entrance Gas Velocity	3.76 Nm/s
O_2	14.4 vol% dry
Inlet NO_X	46.0 ppmvd @ 14.4% O_2 (42.0 ppmvdc @ 15% O_2)

RESULTS

Sample Visual Inspection

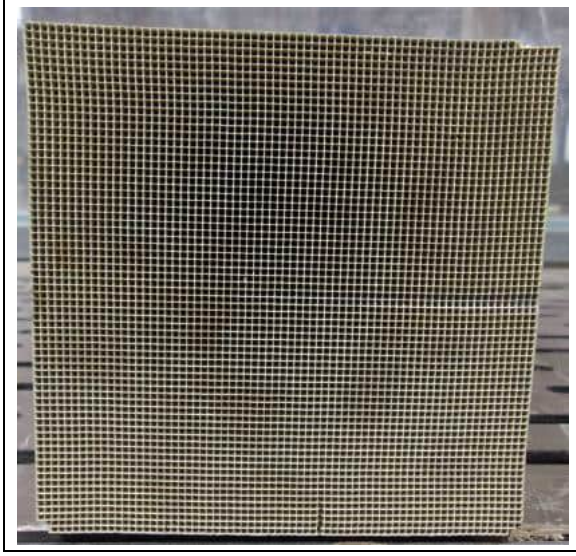
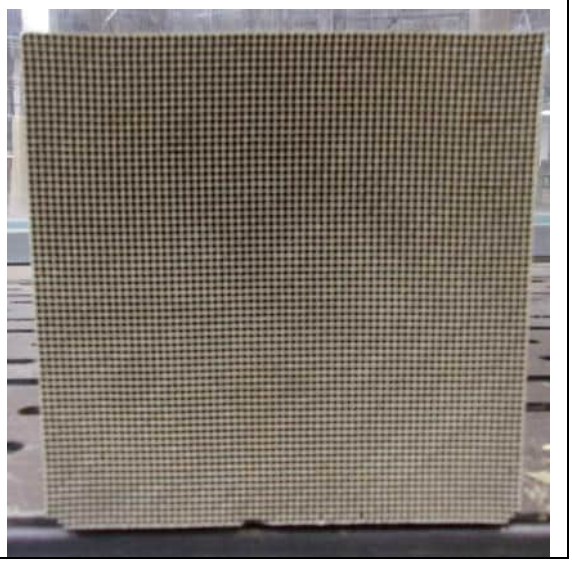
One field sample was received from the GenConn Devon Power Unit 16 SCR.

Below are photographs of the flow entrance face and the flow exit face of the element with an as received inspection report.

Element ID	2388-1026-0478

Box Markings	GenConn Devon Power Attn: Paul Bukowsky #2388 Box 1 of 2
Sample Markings	GenConn Devon Unit #16 removed 4-16-19
Flow Direction Marked	Yes
Other Markings	None

Visual Inspection Notes	Element is in good physical condition
Product Description	CM21MHT^{tM}
Length, mm	447
Blocked Cell Count, as received	0
Blocked Cell Count, after light cleaning	0

Flow Entrance	*Flow Exit*
	

Results of Laboratory Tests

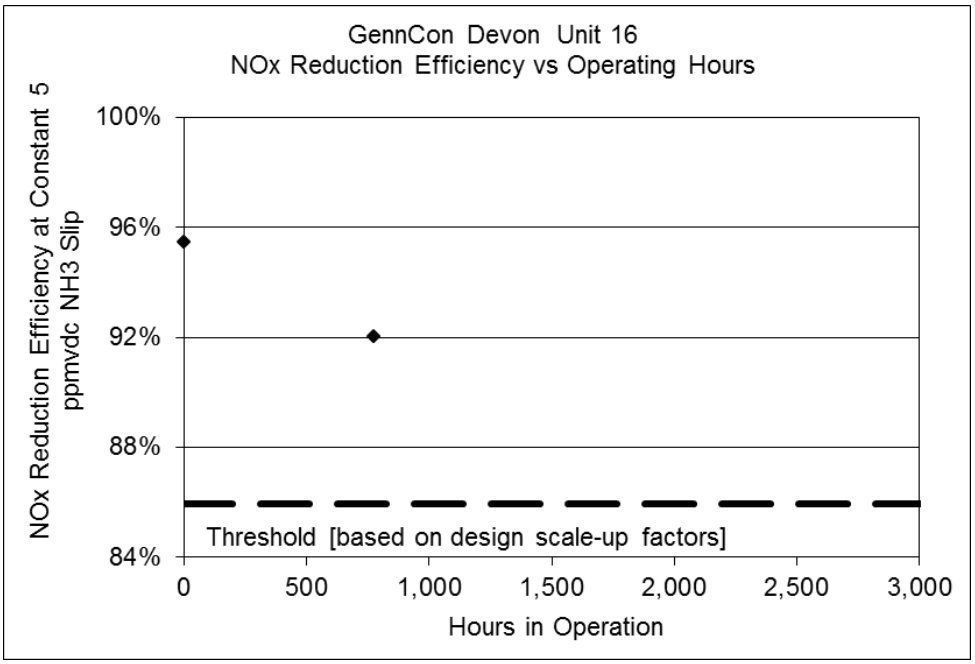
The catalyst performance below is reported under constant 5 ppmvdc ammonia slip and design operating conditions.

The lab performance threshold represents the design NO_X removal efficiency, as measured in lab apparatus, at which the actual *field* performance at *design* operating conditions is expected to reach end-of-life. Field performance is based on a design performance requirement of 85.9% NO_X removal efficiency and 5 ppmvdc ammonia slip.

In field scale (actual) operation, flow, temperature and ammonia/NOx non-uniformities exist. In the highly controlled laboratory environment these non-uniformities do not exist; therefore, the lab results must be scaled-up to reflect expected field performance. The scale-up factors limit achievable NO_X reduction performance in operating SCR systems. The performance threshold value is based on design values for the scale-up factors. The *actual* threshold may be lower if actual scale-up is less severe, or higher if more severe.

	Element ID	**Time On-Line** (Hours)	**NOx Removal Efficiency, %** at 5 ppmvdc NH_3 Slip
Fresh Reference	# 2388-1026-0430	0	95.5
April 2019 Audit	# 2388-1026-0478	772	92.1
Threshold (based on design scale-up factors)			85.9

The figure below shows the trend in catalyst performance.



This audit of the GenConn Devon Power Unit 16 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Devon Power Unit 16 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,300 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

FIELD DATA COMMENTARY

A review of field data has three primary purposes. First, the field data can show if any operating parameters are significantly different than the original design of the unit. Second, the field data can show if actual plant performance requirements are more severe than the design. If significant differences are evident in operating parameters or performance requirements, their effect on the performance threshold can be determined. Third, the field data can be used to examine if any factors that adversely impact scale-up are present. Typically the factors that adversely impact scale-up are as follows:

- Plugged/ poorly performing Ammonia Injection System resulting in poor mixing of the NH_3 prior to the catalyst.
- Flue gas flow velocity maldistribution.
- Flue gas flow bypass around the catalyst.
- Plugged catalyst.

Below is a table that compares the field data provided by GenConn Devon Power Unit 16 SCR against the design criteria for the installed SCR catalyst:

Parameter	Design Value	Field Value (oil)	Field Value (gas)
Flue Gas Temperature (°F)	828	836	817
Flue Gas Flow Rate (lb/hr)	1,088,460	N/A	N/A
Inlet NOx (ppmvd @ 15% O_2)	42	42 (estimated)	25 (estimated)
Outlet NOx (ppmvd @ 15% O_2)	5.9	3.2	2.0
NOx Reduction Efficiency (%)	85.9	92.3	92
NH_3 Slip (ppmvd @ 15% O_2)	5 (end of life)	4.07	4.07
NH_3 Flow Rate (lb/hr)	180 (end of life)	146	109
NH_3 Supply Concentration (wgt %)	19	19	19
Flue Gas O_2 Conc. (% vol dry)	14.4	14.6	14.6
Catalyst Pressure Drop (in. wg.)	5.1	5	5

Permit Limit

Outlet NOx = 5.9 ppmvd @ 15% O_2 (ULSK), 2.5 ppmvd @15% O_2 (Gas)
Ammonia Slip = 5 ppm

Based on the provided operational data, GenConn Devon Power Unit 16 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

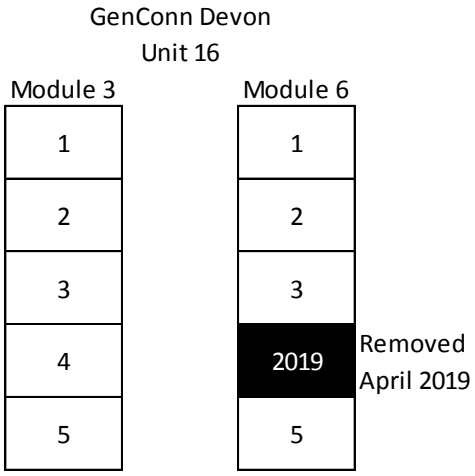
RECOMMENDATIONS

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

APPENDIX 1: Location of Sample Retrieval

The sample retrieval location for GenConn Devon Power Unit 16 is shown in the following schematic.



APPENDIX 2: Field Records

Field records received from GenConn Devon Power are reproduced below

Facility Information	
Facility Owner	NRG
Facility Name	GenConn Devon Power
Facility Street Address	734 Naugatuck Avenue
City, State, Zip Code	Milford, CT 06461
Unit Designation	Unit 16

Contact Information	*Person completing form*	*Person report goes to*
Name	Paul Bukowsky	Same
Title	Environmental Compliance Engineer	
Telephone Number	203-783-6143	203-627-9278 cell
E-mail Address	Paul.Bukowsky@nrg.com	

Sample Operational History		
Catalyst Installation Date	June 2010	
First Gas In Date	June/July 2010	
Sample Removal Date	4/16/2019	
Sample Removal Position *Indicate sampling position: Circle, Mark with "X" or Note sampling position here ___* *View from Upstream Side*	Module 3: 1, 2, 3, 4, 5 Module 6: 1, 2, 3, X, 5	*You may pull the sample from any of the "white boxes."* *Note: Blackened boxes have been sampled previously.*
Removed Sample Element Serial Number, stamped on element	238810260478	
# Starts and Stops on Catalyst	29 (gas) / 295 (oil)	
Operating Hours by Fuel Type	*# Operating Hours burning this fuel*	*Type of Fuel*
Primary Fuel	696	Ultra Low Sulfur Kerosene
Secondary Fuel	76	Natural Gas
Total # Operating Hours	772	

Data Sheet for GenConn Devon Unit 16

Present Operating Conditions				
	Units [Circle correct unit or change as required]	Value	Continuously monitored?	Measurement Method [1]
Flue Gas Temperature (at SCR)	°F	826 / 817	Y	Gas / Oil - Unit DAS
Flue Gas Flow Rate	Lb/hr wet	N/A	N	Not Available
SCR Inlet NOx	ppmvd @15% O_2	25 (gas) 42 (oil)	N	Estimate - 2015
SCR Outlet NOx	ppmvd @15% O_2	2.0 (gas) 3.2 (oil)	N	Stack Test - 2015
NH_3 Slip	ppmvd @15% O_2	4.07	N	Stack Test (FTIR) – 2015 Stack Test (CTM 027) - 2010
NH_3 Flow rate	lb/hr	109 (gas) 146 (oil)	Y	Unit DAS
NH_3 Supply Concentration	wgt %	19	N	Lab Certification
Flue gas O_2 Concentration	Dry Volume %	14.6 (gas) 14.6 (oil)	N	Stack Test - 2015
Flue gas H_2O Concentration	Volume %	11.6 (gas) 9.5 (oil)	N	Stack Test - 2015
Catalyst Pressure Drop	Inches H2O	5	Y	Unit DAS

[1]Method of measurement and accuracy should be provided for all measured values, i.e., flow (boiler load signal or stack measurement), NOx (dilution method chemiluminescence), NH_3 (chemiluminescence subtraction method, ammonia flow gpm/± 5%, etc.).

Permit Limits	(List units as appropriate)
NOx Out	5.9 ppmvd @ 15% O2 (ULSK), 2.5 ppmvd @ 15% O2 (Gas)
NH_3 Slip Out	5 ppm
NOx Removal	95 %

Data Sheet for GenConn Devon Unit 16

Testing History (where NH_3 slip is measured)

	Units [Circle correct unit or change as required]	Following Installation of SCR Catalyst	Test 1		
Test Date		7/17/2010 oil 7/22/2010 gas	7/15/15 oil 7/10/15 gas		
Load Case	Mw	51 gas 49 oil	51 gas 48 oil		
Flue Gas Temperature (at SCR)	°F	808 gas 805 oil	826 gas 815 oil		
Flue Gas Flow Rate	acfm	831,206 (gas) 779,197 (oil)	N/A		
SCR Inlet NOx	ppmvd @15% O_2	25 (gas) 42 (oil)	25 (gas) 42 (oil)		
SCR Outlet NOx	ppmvd @15% O_2	1.49 (gas) 4.26 (oil)	2.0 (gas) 4.2 (oil)		
NH_3 Slip	ppmvd @15% O_2	2.47 (gas) 1.32 (oil)	4.07 (gas) 2.24 (oil)	Stack Test (FTIR) – 2015 Stack Test (CTM 027) - 2010	
NH_3 Flow Rate	lb/hr	92 (gas) 149 (oil)	109 (gas) 146 (oil)		
NH_3 Supply Concentration	wgt %	19	19		
Flue Gas O_2 Concentration	Dry Volume %	15.0 (gas) 14.6 (oil)	14.6 (gas) 14.6 (oil)		
Flue Gas H_2O Concentration	Volume %	11.3 (gas) 9.5 (oil)	11.6 (gas) 9.5 (oil)		
SCR Catalyst Pressure Drop	in. wg. or mm Hg	5	5		

APPENDIX 3: Performance Test Standard Procedure

Purpose

The *laboratory performance testing* for SCR catalyst is conducted to determine the catalytic potential of a representative sample of SCR catalyst at conditions that closely match the actual operating conditions of the SCR system. The sample should represent a typical cross section of the SCR, and the operating history should be known. The test is conducted in a controlled, laboratory environment on custom-built, rigorously validated SCR catalyst test apparatus allowing accurate determination of performance and comparisons of the sample catalytic potential to the system requirements previously tested catalyst(s).

Test Equipment Description

The Cormetech Laboratory SCR test reactors consist of three basic systems:

- Simulated flue gas generator
- SCR catalyst test chamber
- Measurement system

The purpose of the simulated flue gas generator is to provide a stable controlled supply of heated gas with the required mix of gases at the required flow rate and temperature to the SCR catalyst test chamber. It consists of a bulk flue gas generator, a flue gas modification system, a flue gas heater, a reactive gas injection system, and a flue gas mixer.

Bulk Flue Gas Generator -The bulk flue gas is produced by either the combustion of air in a natural gas fired water-cooled combustion chamber, the extraction of nitrogen from air via a membrane system, or the delivery of nitrogen from liquefied nitrogen. This system is adjusted to achieve the overall flue gas flow rate required for the specified test.

Flue Gas Modification System – The gas stream produced by the bulk flue gas generator is modified by the addition of oxygen/air and water/steam to achieve the targeted concentrations of water vapor and oxygen in the flue gas stream.

Flue Gas Heater – The flue gas stream is heated to the target test temperature by an electric pre-heater.

Reactive Gas Injection System – Calibrated mass flow controllers are used to deliver SO_2, SO_3, NO_2, NO, and NH_3 into the flue gas stream.

The table below summarizes the range of process conditions that can be produced by various apparatus in Cormetech's laboratory. Cormetech's laboratory maintains multiple testing units, each with varying capabilities for temperature, flow, and gas composition. The unit selected for a given test will depend on the specific requirements for the sample tested.

Parameter	Units	Range
Gas Temperature	°C	200 – 600
Flow rate/Entrance velocity	Nm/s	1.25 - 7.05
O_2	volume % dry	1 – 20
H_2O	volume %	1-20[1]
NO	ppmvd	0 - 2,000
NO_2	ppmvd	0 - 2000[2]
NH_3	ppmvd	0 - 4,000
SO_2	ppmvd	0 - 2,000
SO_3	ppmvd	0 – 25

1: Some apparatus have the capability to control water concentration. Other units supply water as a product of combustion. When water concentration is not controlled, Cormetech corrects the results to the target concentration with a standardized correction factor.
2: NO_2 addition capability is not available on all test units.

Flue Gas Mixer – Following the reactive gas injection, the gases are mixed using a high efficiency static mixing element.

The simulated flue gas next enters the SCR test reactor where the SCR test sample or samples are located. Each sample is sealed tightly to the walls of the test chamber to ensure that all of the flue gas passes though the sample[s]. Along the length of the test chamber there are electric heating elements that maintain the specified test temperature. There are test ports located at the entrance to the test reactor and at the exit of each sample layer to extract a sample of flue gas for analysis, measure the static pressure of the flue gas, and monitor the temperature of the catalyst samples and the flue gas.

The process conditions of the SCR catalyst under test are monitored by the measurement system:

Gas Flow Rate – The flue gas flow rate is measured by an averaging pitot tube in the exit of the simulated flue gas generator. The flow rate is also calculated from the mass flow controllers for the various gas constituents as they are added. Finally, an annubar is installed in the exhaust of the reactor which allows another cross-check of the flow rate. For the testing to be determined valid, the flow rate must be within the allowable limits from the target flow rate.

Gas Temperature – The temperature of the gas and the catalyst samples is measured by a series of thermocouples throughout the test reactor. For the testing to be determined valid, both the spatial and temporal variability must be within the allowable limits from the specified set point.

Component Concentration – The components of the flue gas are determined by the methods described below. Different systems may not have every type of sampling measurement system.

- *NOx* – Chemiluminescent NOx Analyzer / Infrared Spectroscopy. Average value at each sampling point recorded for each sampling cycle
- NH_3 – Ion Chromatography/infrared spectroscopy
- SO_2 – Precipitation Method/infrared spectroscopy
- SO_3 – Controlled Condensation; Collective Precipitation Method
- O_2 – Micro-fuel cell and Paramagnetic O_2 Analyzer

Procedure Description Summary

The following stepwise description is a guideline to understand how an audit proceeds from sample receipt to reported results.

1. Upon receipt, each sample is inspected for condition and photographed. The sample dimensions are recorded.
2. The Test Plan is prepared based on the needs of audit. The appropriate test apparatus is selected based on the test requirements and the test is scheduled.
3. Each sample is prepared for testing. [This process includes cleaning the sample, and cutting to the required test sample size.]
4. The reactor is opened, inspected, and prepared for operation.
5. Each catalyst sample is loaded according to the Test Plan and sealed in the reactor.
6. An equipment leak test is performed.

7. The Bulk Flue Gas Generator is started and the test conditions are set for O_2%, temperature, and bulk flow rate.
8. NO and NO_2 injection is started and then adjusted in order to meet the test conditions.
9. Ammonia, SO_2 and SO_3 injection is started and then adjusted in order to meet the test conditions.
10. The catalyst is allowed to equilibrate at the test conditions specified.
11. A calibration check is run for the analyzers.
12. For each sampling cycle, the following measurements are taken, as required:

Item	Location Measured	Frequency
NO_X Concentration	Multiplexed to measure NO_X at each sampling point	Average value at each sampling point recorded per each sampling cycle
NH_3 Concentration	At exit of sample[s]	Depends on test method [Multiple analyses recorded]
SO_2 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
SO_3 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
O_2 Concentration	Exit of combustion chamber and multiplexed with NO_X Analyzer	Continuously controlled and monitored
Gas Flow	Exit of combustion chamber	Continuously controlled and monitored
Gas Temperature	At each sampling port	Inlet continuously controlled
Pressure Drop	Entrance and at exit of testing chamber	Continuously monitored, recorded as required

13. The results are recorded and checked per Quality Assurance requirements and compared to the Test Plan.
14. The results are reported.

CORMETECH

NRG GenConn Devon Power
Unit 17

SCR Catalyst
Performance Test Report
772 Operating Hours
88 Months Since First Gas-In

Submitted by

CORMETECH, INC.
Environmental Technologies
5000 International Drive
Durham, NC 27712
(919) 620-3000

John A. Nivens
Sr. Engineering Technician

Mark Conger
Sr. Project Engineer

Certifying Laboratory Representative
Silas Christian, Laboratory Manager

February 7, 2018

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EXECUTIVE SUMMARY

The following summarizes the key results for this audit of the NRG GenConn Devon Power Unit 17 SCR after 88 months and 772 operating hours since first gas-in.

Observations and Predictions

This audit of the GenConn Devon Power Unit 17 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Devon Power Unit 17 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 3,500 operating hours from the date this sample was removed.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the first 772 operating hours. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

Field Data Commentary

Based on the provided operational data, GenConn Devon Power Unit 17 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip within permit requirements.

Recommendations

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 1000 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

PURPOSE

This test is conducted to audit the catalytic potential of an SCR catalyst by measuring the performance of a field catalyst sample that has been in operation for a known duration. The catalytic potential is measured by laboratory scale testing of field samples removed from the SCR. Performance tests are conducted in a controlled, laboratory environment allowing accurate comparisons of field sample catalytic potential to that of fresh catalyst. The deactivation rate is determined by comparing the change in catalytic potential to the operating hours of the sample.

Field performance, as indicated by plant-supplied measurements and observations, is also analyzed and discussed relative to the performance of the catalyst samples tested. Measured field performance in conjunction with laboratory measurements of field sample catalytic potential is used to determine actual unit scale-up factors. Utilizing actual unit scale-up factors significantly improves the accuracy of future performance predictions.

Further catalyst and/or field operation analysis may be recommended if laboratory test results are inconsistent with any of the following:

- Cormetech's experience base of comparable units
- The plant's reported field performance, if available
- The results of previous audits of the unit, if applicable
- The performance expectations for the unit.

BACKGROUND

In order to achieve the design performance requirements of a Selective Catalytic Reduction system for a specified timeframe (life) of the SCR catalyst, the catalyst formulation, structure, and volume are specifically designed to accommodate the system operating conditions, the predicted system scale-up factors, and a predicted rate of decrease in catalyst potential over time.

If any of the design or operating parameters above is not realized, then the actual duration that the design performance requirements can be met may deviate from the design life. The individual contribution of each parameter on actual life is described below. In actual practice, one or more of these parameters may deviate from design and either counteract or complement each other.

Performance Requirements: If the actual plant performance requirements are more severe than the design performance requirements, actual life will be less than design life. An example of this would be a unit that is required to achieve a higher NOx reduction than the unit was designed for.

Operating Conditions: Flue gas flow rate, inlet NO_X levels, temperature, oxygen content, and water content impact catalytic potential. If the catalyst is at an operating condition where the potential is lower than design, actual life will be less than design life.

Scale-Up Factors: The full NO_X reduction potential of the catalyst is not attained in the field due to non-ideal flow distribution, temperature distribution, ammonia to NO_X molar ratio distribution,

catalyst blockage, and/or flue gas bypass. Collectively, these non-ideal conditions are accounted for with 'system scale-up factors'. If the overall actual system scale-up factors are more severe than the design scale-up factors, then the potential of the SCR system to meet a given performance requirement is reduced.

Catalyst Deactivation Rate: Catalytic potential decreases over time. This catalyst deactivation rate has a direct impact on actual life. If the deactivation rate is more than design, then actual life is effectively reduced. If the deactivation rate is less than design, the actual life is effectively increased.

If the performance requirements, operating conditions, and/or scale-up factors are more severe than the initial design, less margin remains for catalyst deactivation. Therefore, actual life will be less than design life.

At any given time and operating condition, the SCR system performance is dictated by the NO_X reduction potential of the catalyst and the system scale-up factors. These factors reduce performance from the catalytic potential to the performance achievable in the operating SCR system.

Performance tests are purposefully conducted in a controlled environment, free from the scale-up factors that adversely affect SCR system performance, and at repeatable operating conditions, so that changes in catalytic potential may be evaluated accurately. Catalyst deactivation is determined by testing the field catalyst sample at the same operating conditions as the fresh sample.

In conjunction with performance test results, analysis of field SCR system performance data can confirm the field performance requirements, the plant operating conditions, and actual system scale-up factors.

Cormetech's SCR catalyst design and testing experience enables analysis of the actual versus design values of performance requirements, operating conditions, system scale-up, and catalyst deactivation to predict future catalyst performance.

FACILITY OPERATIONAL HISTORY

The SCR system at the GenConn Devon Power Unit 17 consists of 1 layer of CM21MHT™ 70 cell catalyst. The unit was originally put into service on June 2010.

In July 2010 Unit 17 experienced an event, during which the catalyst was potentially sintered. Elements were shipped to Cormetech for emergency testing. The results of this audit are presented in this report. Based on the results of the July 2010 audits and surface area testing, it was determined that the catalyst was not sintered.

On October 23, 2017 on catalyst sample was removed from the field sampler at GenConn Devon Power Unit 17 and returned to Cormetech for laboratory testing. At the time the sample was removed, the audited element had accumulated 728 operating hours. The results of the October 23, 2017 audit are summarized in this report.

PROCEDURE OVERVIEW

1. One catalyst sample was removed from the field sampler module at the GenConn Devon Power Unit 17 SCR and was shipped to Cormetech's laboratory. Operating history was recorded by the plant and forwarded to Cormetech.

2. The physical condition of the catalyst was documented by Cormetech.

3. The catalyst was prepared and loaded into an Activity Test Apparatus and then evaluated at the original design conditions for the SCR. The Performance Test Standard Procedure is included in Appendix 3.

4. The results include catalyst potential expressed as NO_X removal efficiency at a constant 5 ppmvdc ammonia slip.

5. Test results were compared to design expectations and to the results of the fresh reference and previous audit. Expectations of catalyst deactivation were determined by the time on-line and experience data of similar gas-fired facilities.

6. A catalyst life prediction is based on the above testing and analysis.

7. Additional data submitted by the plant was reviewed for the field performance of the SCR system.

FIELD SAMPLING AND UNIT OPERATING CONDITIONS

Field Sampling

One SCR catalyst sample from GenConn Devon Power Unit 17 was removed and sent to Cormetech's Laboratory for evaluation. The sample retrieval location is shown in Appendix 1.

Operating Status

Field records supplied by GenConn Devon Power are summarized in the table below. The field records are reproduced in Appendix 2.

First Gas-In Date with Catalyst Installed	June 2010
Sample Removal Date	November 7, 2017
Total Operating Hours On Catalyst Sample	772
Primary Fuel Fired	Ultra-Low Sulfur Kerosene
Hours Burning Primary Fuel	635
Secondary Fuel Fired	Natural Gas
Hours Burning Secondary Fuel	137
Number of Starts and Stops since catalyst was installed	306

LABORATORY PERFORMANCE TEST CONDITIONS

A performance test was conducted on the sample received using the conditions below. These conditions reflect the original design conditions for which there is fresh catalyst test data available for direct comparison.

Temperature	442°C (828°F)
Entrance Gas Velocity	3.84 Nm/s
O_2	14.4 vol% dry
Inlet NO_X	46.0 ppmvd @ 14.4% O_2 (42.0 ppmvdc @ 15% O_2)

RESULTS

Sample Visual Inspection

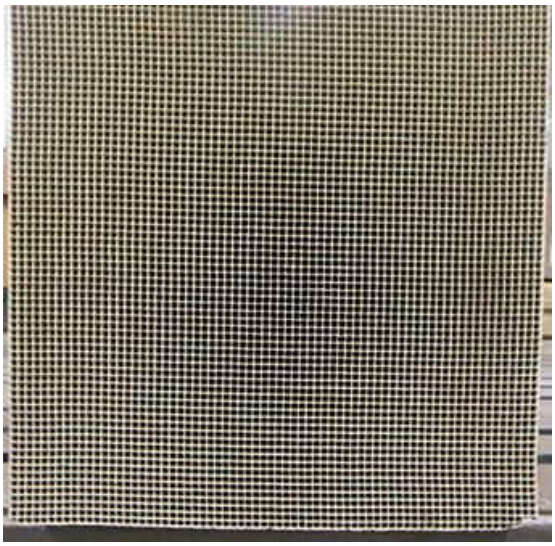
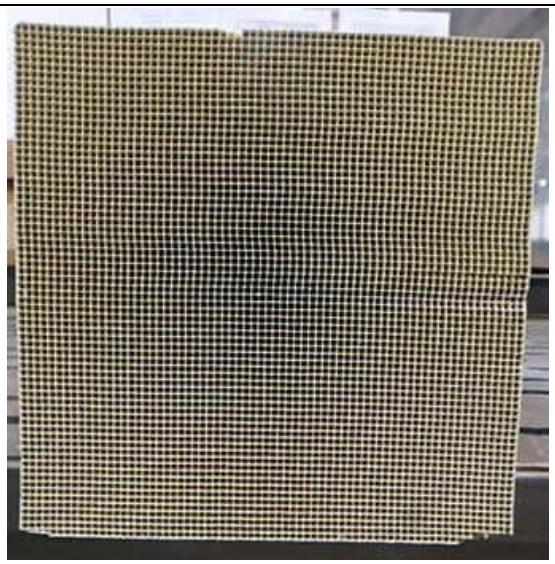
One field sample was received from the GenConn Devon Power Unit 17 SCR.

Below are photographs of the flow entrance face and the flow exit face of the element with an as received inspection report.

Element ID	2388-1026-0463

Box Markings	1 of 2
Sample Markings	2388-1026-0463 Flow X Calc 3
Flow Direction Marked	Yes
Other Markings	None

Visual Inspection Notes	Element is in good physical condition
Product Description	CM21MHT^{tM} 70 X 70 cell array
Length, mm	447
Blocked Cell Count, as received	0
Blocked Cell Count, after light cleaning	0

Flow Entrance	*Flow Exit*
	

Results of Laboratory Tests

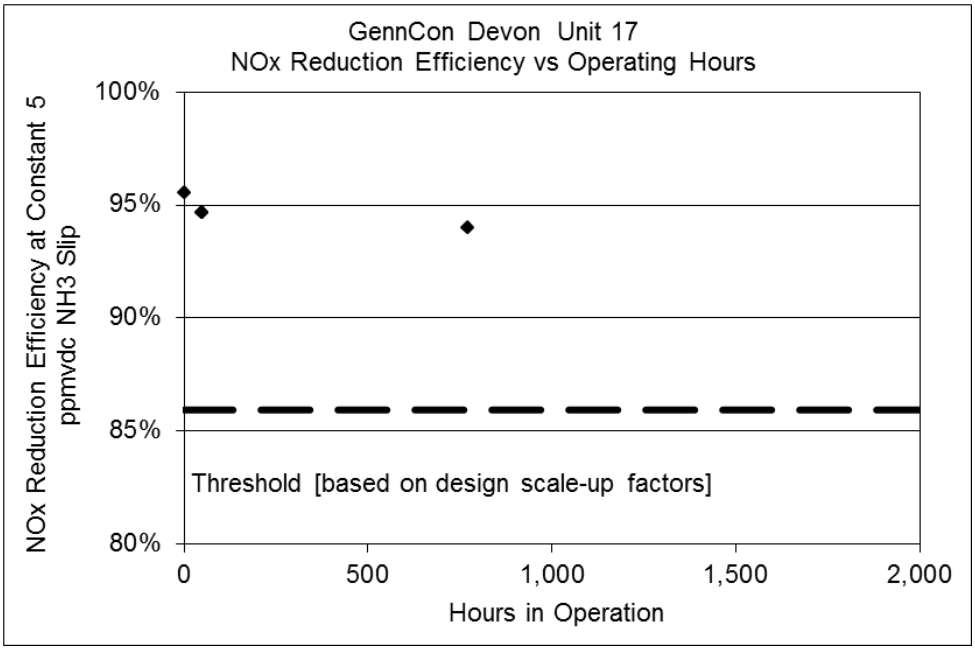
The catalyst performance below is reported under constant 5 ppmvdc ammonia slip and design operating conditions.

The lab performance threshold represents the design NO_X removal efficiency, as measured in lab apparatus, at which the actual *field* performance at *design* operating conditions is expected to reach end-of-life. Field performance is based on a design performance requirement of 85.9% NO_X removal efficiency and 5 ppmvdc ammonia slip.

In field scale (actual) operation, flow, temperature and ammonia/NOx non-uniformities exist. In the highly controlled laboratory environment these non-uniformities do not exist; therefore, the lab results must be scaled-up to reflect expected field performance. The scale-up factors limit achievable NO_X reduction performance in operating SCR systems. The performance threshold value is based on design values for the scale-up factors. The *actual* threshold may be lower if actual scale-up is less severe, or higher if more severe.

	Element ID	**Time On-Line** (Hours)	**NOx Removal Efficiency, %** at 5 ppmvdc NH_3 Slip
Fresh Reference	# 2388-1026-0430	0	95.5
July 2010 Audit	# 2388-1026-0464	<100	94.6
July 2010 Audit	# 2388-1026-0460	<100	94.6
November 2017 Audit	# 2388-1026-0463	772	93.9
Threshold (based on design scale-up factors)			85.9

The figure below shows the trend in catalyst performance.



This audit of the GenConn Devon Power Unit 17 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Devon Power Unit 17 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 3,500 operating hours from the date this sample was removed.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the first 772 operating hours. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

FIELD DATA COMMENTARY

A review of field data has three primary purposes. First, the field data can show if any operating parameters are significantly different than the original design of the unit. Second, the field data can show if actual plant performance requirements are more severe than the design. If significant differences are evident in operating parameters or performance requirements, their effect on the performance threshold can be determined. Third, the field data can be used to examine if any factors that adversely impact scale-up are present. Typically the factors that adversely impact scale-up are as follows:

- Plugged/ poorly performing Ammonia Injection System resulting in poor mixing of the NH_3 prior to the catalyst.
- Flue gas flow velocity maldistribution.
- Flue gas flow bypass around the catalyst.
- Plugged catalyst.

Below is a table that compares the field data provided by GenConn Devon Power Unit 17 SCR against the design criteria for the installed SCR catalyst:

Parameter	Design Value	Field Value (oil)	Field Value (gas)
Flue Gas Temperature (°F)	828	819	819
Flue Gas Flow Rate (lb/hr)	1,088,460	N/A	N/A
Inlet NOx (ppmvd @ 15% O_2)	42	42 (estimated)	25 (estimated)
Outlet NOx (ppmvd @ 15% O_2)	5.9	4.1	1.9
NOx Reduction Efficiency (%)	85.9	90.2	92.4
NH_3 Slip (ppmvd @ 15% O_2)	5 (end of life)	2.3	3.5
NH_3 Flow Rate (lb/hr)	180 (end of life)	163	100
NH_3 Supply Concentration (wgt %)	19	19	19
Flue Gas O_2 Conc. (% vol dry)	14.4	14.6	14.5
Catalyst Pressure Drop (in. wg.)	5.1	5.2	5.2

Permit Limit

Outlet NOx = 5.9 ppmvd @ 15% O_2 (ULSK), 2.5 ppm vd @15% O_2 (Gas)
Ammonia Slip = 5 ppm

Based on the provided operational data, GenConn Devon Power Unit 17 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip within permit requirements.

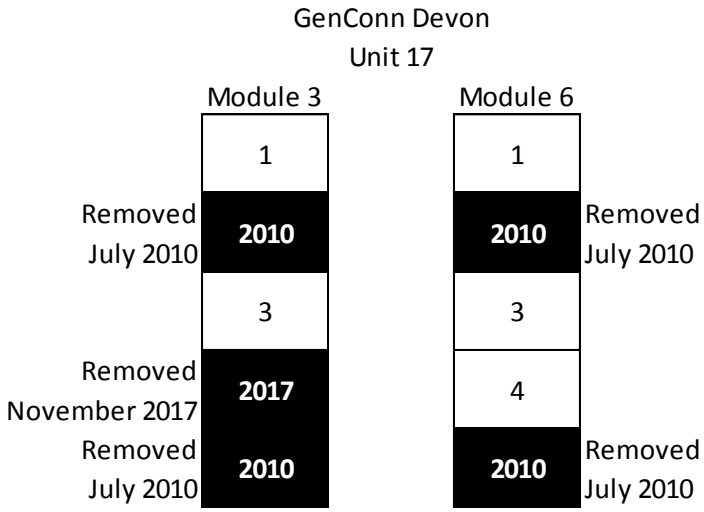
RECOMMENDATIONS

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 1000 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

APPENDIX 1: Location of Sample Retrieval

The sample retrieval location for GenConn Devon Power Unit 17 is shown in the following schematic.



APPENDIX 2: Field Records

Field records received from GenConn Devon Power are reproduced below.

Facility Information	
Facility Owner	NRG
Facility Name	GenConn Devon Power
Facility Street Address	734 Naugatuck Avenue
City, State, Zip Code	Milford, CT 06461
Unit Designation	Unit 17

Contact Information	*Person completing form*	*Person report goes to*
Name	Paul Bukowsky	Same
Title	Environmental Compliance Engineer	
Telephone Number	203-783-6143	
E-mail Address	Paul.Bukowsky@nrg.com	

Sample Operational History		
Catalyst Installation Date	July 2010	
First Gas In Date	July/August 2010	
Sample Removal Date	11/7/2017	
Sample Removal Position *Indicate sampling position: Circle, Mark with 'X" or Note sampling position here ___* *View from Upstream Side*	Module 3: 1, 2, 3, X, 5 Module 6: 1, 2, 3, 4, 5	*You may pull the sample from any of the "white boxes."* *Note: Blackened boxes have been sampled previously.*
Removed Sample Element Serial Number, stamped on element	[redacted] 2388102 60463	
# Starts and Stops on Catalyst	51 (gas) / 255 (oil)	
Operating Hours by Fuel Type	*# Operating Hours burning this fuel*	*Type of Fuel*
Primary Fuel	635	Ultra Low Sulfur Kerosene
Secondary Fuel	137	Natural Gas
Total # Operating Hours	772	

Data Sheet for GenConn Devon Unit 17

Present Operating Conditions				
	Units [Circle correct unit or change as required]	Value	Continuously monitored?	Measurement Method [1]
Flue Gas Temperature (at SCR)	°F	819	Y	Unit DAS
Flue Gas Flow Rate	Lb/hr wet	N/A	N	Not Available
SCR Inlet NOx	ppmvd @15% O_2	25 (gas) 42 (oil)	N	Estimate - 2015
SCR Outlet NOx	ppmvd @15% O_2	1.9 (gas) 4.1 (oil)	N	Stack Test - 2015
NH_3 Slip	ppmvd @15% O_2	3.5 gas 2.3 oil	N	Stack Test (FTIR) – 2015 Stack Test (CTM 027) - 2010
NH_3 Flow rate	lb/hr	100 (gas) 163 (oil)	Y	Unit DAS
NH_3 Supply Concentration	wgt %	19	N	Lab Certification
Flue gas O_2 Concentration	Dry Volume %	14.5 (gas) 14.6 (oil)	N	Stack Test - 2015
Flue gas H_2O Concentration	Volume %	11.8 (gas) 9.2 (oil)	N	Stack Test - 2015
Catalyst Pressure Drop	Inches H2O	5.2	Y	Unit DAS

[1] *Method of measurement and accuracy should be provided for all measured values, i.e., flow (boiler load signal or stack measurement), NOx (dilution method chemiluminescence), NH_3 (chemiluminescence subtraction method, ammonia flow gpm/± 5%, etc.).*

Permit Limits	(List units as appropriate)
NOx Out	5.9 ppmvd @ 15% O2 (ULSK), 2.5 ppmvd @ 15% O2 (Gas)
NH_3 Slip Out	5 ppm
NOx Removal	95 %

Data Sheet for GenConn Devon Unit 17

Testing History (where NH_3 slip is measured)

	Units [Circle correct unit or change as required]	Following Installation of SCR Catalyst	Test 1		
Test Date		8/31/2010 oil 8/18/2010 gas	7/9/2015 oil 7/10/2015gas		
Load Case	Mw	50	50		
Flue Gas Temperature (at SCR)	°F	801 gas 734 oil	819		
Flue Gas Flow Rate	acfm	788,101 (gas) 752,104 (oil)	N/A		
SCR Inlet NOx	ppmvd @15% O_2	25 (gas) 42 (oil)	25 (gas) 42 (oil)		
SCR Outlet NOx	ppmvd @15% O_2	2.25 (gas) 3.73 (oil)	1.9 (gas) 4.1 (oil)		
NH_3 Slip	ppmvd @15% O_2	2.85 (gas) 2.73 (oil)	3.5 gas 2.3 oil	Stack Test (FTIR) – 2015 Stack Test (CTM 027) - 2010	
NH_3 Flow Rate	lb/hr	89 (gas) 156 (oil)	100 (gas) 163 (oil)		
NH_3 Supply Concentration	wgt %	19	19		
Flue Gas O_2 Concentration	Dry Volume %	14.6 (gas) 14.8 (oil)	14.5 (gas) 14.6 (oil)		
Flue Gas H_2O Concentration	Volume %	10.9 (gas) 8.9 (oil)	11.8 (gas) 9.2 (oil)		
SCR Catalyst Pressure Drop	Inches H2O	5.2	5.2		

APPENDIX 3: Performance Test Standard Procedure

Purpose

The *laboratory performance testing* for SCR catalyst is conducted to determine the catalytic potential of a representative sample of SCR catalyst at conditions that closely match the actual operating conditions of the SCR system. The sample should represent a typical cross section of the SCR, and the operating history should be known. The test is conducted in a controlled, laboratory environment on custom-built, rigorously validated SCR catalyst test apparatus allowing accurate determination of performance and comparisons of the sample catalytic potential to the system requirements previously tested catalyst(s).

Test Equipment Description

The Cormetech Laboratory SCR test reactors consist of three basic systems:

- Simulated flue gas generator
- SCR catalyst test chamber
- Measurement system

The purpose of the simulated flue gas generator is to provide a stable controlled supply of heated gas with the required mix of gases at the required flow rate and temperature to the SCR catalyst test chamber. It consists of a bulk flue gas generator, a flue gas modification system, a flue gas heater, a reactive gas injection system, and a flue gas mixer.

Bulk Flue Gas Generator -The bulk flue gas is produced by either the combustion of air in a natural gas fired water-cooled combustion chamber, the extraction of nitrogen from air via a membrane system, or the delivery of nitrogen from liquefied nitrogen. This system is adjusted to achieve the overall flue gas flow rate required for the specified test.

Flue Gas Modification System – The gas stream produced by the bulk flue gas generator is modified by the addition of oxygen/air and water/steam to achieve the targeted concentrations of water vapor and oxygen in the flue gas stream.

Flue Gas Heater – The flue gas stream is heated to the target test temperature by an electric pre-heater.

Reactive Gas Injection System – Calibrated mass flow controllers are used to deliver SO_2, SO_3, NO_2, NO, and NH_3 into the flue gas stream.

The table below summarizes the range of process conditions that can be produced by various apparatus in Cormetech's laboratory. Cormetech's laboratory maintains multiple testing units, each with varying capabilities for temperature, flow, and gas composition. The unit selected for a given test will depend on the specific requirements for the sample tested.

Parameter	Units	Range
Gas Temperature	^{o}C	200 – 600
Flow rate/Entrance velocity	Nm/s	1.25 - 7.05
O_2	volume % dry	1 – 20
H_2O	volume %	1-20[1]
NO	ppmvd	0 - 2,000
NO_2	ppmvd	0 - 2000[2]
NH_3	ppmvd	0 - 4,000
SO_2	ppmvd	0 - 2,000
SO_3	ppmvd	0 – 25

1: Some apparatus have the capability to control water concentration. Other units supply water as a product of combustion. When water concentration is not controlled, Cormetech corrects the results to the target concentration with a standardized correction factor.
2: NO_2 addition capability is not available on all test units.

Flue Gas Mixer – Following the reactive gas injection, the gases are mixed using a high efficiency static mixing element.

The simulated flue gas next enters the SCR test reactor where the SCR test sample or samples are located. Each sample is sealed tightly to the walls of the test chamber to ensure that all of the flue gas passes though the sample[s]. Along the length of the test chamber there are electric heating elements that maintain the specified test temperature. There are test ports located at the entrance to the test reactor and at the exit of each sample layer to extract a sample of flue gas for analysis, measure the static pressure of the flue gas, and monitor the temperature of the catalyst samples and the flue gas.

The process conditions of the SCR catalyst under test are monitored by the measurement system:

Gas Flow Rate – The flue gas flow rate is measured by an averaging pitot tube in the exit of the simulated flue gas generator. The flow rate is also calculated from the mass flow controllers for the various gas constituents as they are added. Finally, an annubar is installed in the exhaust of the reactor which allows another cross-check of the flow rate. For the testing to be determined valid, the flow rate must be within the allowable limits from the target flow rate.

Gas Temperature – The temperature of the gas and the catalyst samples is measured by a series of thermocouples throughout the test reactor. For the testing to be determined valid, both the spatial and temporal variability must be within the allowable limits from the specified set point.

Component Concentration – The components of the flue gas are determined by the methods described below. Different systems may not have every type of sampling measurement system.

- *NOx* – Chemiluminescent NOx Analyzer / Infrared Spectroscopy. Average value at each sampling point recorded for each sampling cycle
- NH_3 – Ion Chromatography/infrared spectroscopy
- SO_2 – Precipitation Method/infrared spectroscopy
- SO_3 – Controlled Condensation; Collective Precipitation Method
- O_2 – Micro-fuel cell and Paramagnetic O_2 Analyzer

Procedure Description Summary

The following stepwise description is a guideline to understand how an audit proceeds from sample receipt to reported results.

1. Upon receipt, each sample is inspected for condition and photographed. The sample dimensions are recorded.
2. The Test Plan is prepared based on the needs of audit. The appropriate test apparatus is selected based on the test requirements and the test is scheduled.
3. Each sample is prepared for testing. [This process includes cleaning the sample, and cutting to the required test sample size.]
4. The reactor is opened, inspected, and prepared for operation.
5. Each catalyst sample is loaded according to the Test Plan and sealed in the reactor.
6. An equipment leak test is performed.

7. The Bulk Flue Gas Generator is started and the test conditions are set for O_2%, temperature, and bulk flow rate.
8. NO and NO_2 injection is started and then adjusted in order to meet the test conditions.
9. Ammonia, SO_2 and SO_3 injection is started and then adjusted in order to meet the test conditions.
10. The catalyst is allowed to equilibrate at the test conditions specified.
11. A calibration check is run for the analyzers.
12. For each sampling cycle, the following measurements are taken, as required:

Item	Location Measured	Frequency
NO_X Concentration	Multiplexed to measure NO_X at each sampling point	Average value at each sampling point recorded per each sampling cycle
NH_3 Concentration	At exit of sample[s]	Depends on test method [Multiple analyses recorded]
SO_2 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
SO_3 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
O_2 Concentration	Exit of combustion chamber and multiplexed with NO_X Analyzer	Continuously controlled and monitored
Gas Flow	Exit of combustion chamber	Continuously controlled and monitored
Gas Temperature	At each sampling port	Inlet continuously controlled
Pressure Drop	Entrance and at exit of testing chamber	Continuously monitored, recorded as required

13. The results are recorded and checked per Quality Assurance requirements and compared to the Test Plan.
14. The results are reported.

CORMETECH

NRG GenConn Devon Power
Unit 18

SCR Catalyst
Performance Test Report
845 Operating Hours
April 2019 Audit

Submitted by

CORMETECH, INC.
Environmental Technologies
5000 International Drive
Durham, NC 27712
(919) 620-3000



Max Morris
Project Engineer



John A. Nivens
Sr. Engineering Technician

Certifying Laboratory Representative
Silas Christian, Laboratory Manager

July 17, 2019

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EXECUTIVE SUMMARY

The following summarizes the key results for this audit of the NRG GenConn Devon Power Unit 18 SCR after 845 operating hours since first gas-in.

Observations and Predictions

This audit of the GenConn Devon Power Unit 18 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Devon Power Unit 18 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 4,000 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

Field Data Commentary

Based on the provided operational data, GenConn Devon Power Unit 18 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip within permit requirements.

Recommendations

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 1000 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

PURPOSE

This test is conducted to audit the catalytic potential of an SCR catalyst by measuring the performance of a field catalyst sample that has been in operation for a known duration. The catalytic potential is measured by laboratory scale testing of field samples removed from the SCR. Performance tests are conducted in a controlled, laboratory environment allowing accurate comparisons of field sample catalytic potential to that of fresh catalyst. The deactivation rate is determined by comparing the change in catalytic potential to the operating hours of the sample.

Field performance, as indicated by plant-supplied measurements and observations, is also analyzed and discussed relative to the performance of the catalyst samples tested. Measured field performance in conjunction with laboratory measurements of field sample catalytic potential is used to determine actual unit scale-up factors. Utilizing actual unit scale-up factors significantly improves the accuracy of future performance predictions.

Further catalyst and/or field operation analysis may be recommended if laboratory test results are inconsistent with any of the following:

- Cormetech's experience base of comparable units
- The plant's reported field performance, if available
- The results of previous audits of the unit, if applicable
- The performance expectations for the unit.

BACKGROUND

In order to achieve the design performance requirements of a Selective Catalytic Reduction system for a specified timeframe (life) of the SCR catalyst, the catalyst formulation, structure, and volume are specifically designed to accommodate the system operating conditions, the predicted system scale-up factors, and a predicted rate of decrease in catalyst potential over time.

If any of the design or operating parameters above is not realized, then the actual duration that the design performance requirements can be met may deviate from the design life. The individual contribution of each parameter on actual life is described below. In actual practice, one or more of these parameters may deviate from design and either counteract or complement each other.

Performance Requirements: If the actual plant performance requirements are more severe than the design performance requirements, actual life will be less than design life. An example of this would be a unit that is required to achieve a higher NOx reduction than the unit was designed for.

Operating Conditions: Flue gas flow rate, inlet NO_X levels, temperature, oxygen content, and water content impact catalytic potential. If the catalyst is at an operating condition where the potential is lower than design, actual life will be less than design life.

Scale-Up Factors: The full NO_X reduction potential of the catalyst is not attained in the field due to non-ideal flow distribution, temperature distribution, ammonia to NO_X molar ratio distribution,

catalyst blockage, and/or flue gas bypass. Collectively, these non-ideal conditions are accounted for with 'system scale-up factors'. If the overall actual system scale-up factors are more severe than the design scale-up factors, then the potential of the SCR system to meet a given performance requirement is reduced.

Catalyst Deactivation Rate: Catalytic potential decreases over time. This catalyst deactivation rate has a direct impact on actual life. If the deactivation rate is more than design, then actual life is effectively reduced. If the deactivation rate is less than design, the actual life is effectively increased.

If the performance requirements, operating conditions, and/or scale-up factors are more severe than the initial design, less margin remains for catalyst deactivation. Therefore, actual life will be less than design life.

At any given time and operating condition, the SCR system performance is dictated by the NO_X reduction potential of the catalyst and the system scale-up factors. These factors reduce performance from the catalytic potential to the performance achievable in the operating SCR system.

Performance tests are purposefully conducted in a controlled environment, free from the scale-up factors that adversely affect SCR system performance, and at repeatable operating conditions, so that changes in catalytic potential may be evaluated accurately. Catalyst deactivation is determined by testing the field catalyst sample at the same operating conditions as the fresh sample.

In conjunction with performance test results, analysis of field SCR system performance data can confirm the field performance requirements, the plant operating conditions, and actual system scale-up factors.

Cormetech's SCR catalyst design and testing experience enables analysis of the actual versus design values of performance requirements, operating conditions, system scale-up, and catalyst deactivation to predict future catalyst performance.

FACILITY OPERATIONAL HISTORY

The SCR system at the GenConn Devon Power Unit 18 consists of 1 layer of CM21MHT™ 70 cell catalyst. The unit was originally put into service on July 2010.

On April 29, 2019 on catalyst sample was removed from the field sampler at GenConn Devon Power Unit 18 and returned to Cormetech for laboratory testing. At the time the sample was removed, the audited element had accumulated 845 operating hours. The results of the April 29, 2019 audit are summarized in this report.

PROCEDURE OVERVIEW

1. One catalyst sample was removed from the field sampler module at the GenConn Devon Power Unit 18 SCR and was shipped to Cormetech's laboratory. Operating history was recorded by the plant and forwarded to Cormetech.

2. The physical condition of the catalyst was documented by Cormetech.

3. The catalyst was prepared and loaded into an Activity Test Apparatus and then evaluated at the original design conditions for the SCR. The Performance Test Standard Procedure is included in Appendix 3.

4. The results include catalyst potential expressed as NO_X removal efficiency at a constant 5 ppmvdc ammonia slip.

5. Test results were compared to design expectations and to the results of the fresh reference and previous audit. Expectations of catalyst deactivation were determined by the time on-line and experience data of similar gas-fired facilities.

6. A catalyst life prediction is based on the above testing and analysis.

7. Additional data submitted by the plant was reviewed for the field performance of the SCR system.

FIELD SAMPLING AND UNIT OPERATING CONDITIONS

Field Sampling

One SCR catalyst sample from GenConn Devon Power Unit 18 was removed and sent to Cormetech's Laboratory for evaluation. The sample retrieval location is shown in Appendix 1.

Operating Status

Field records supplied by GenConn Devon Power are summarized in the table below. The field records are reproduced in Appendix 2.

First Gas-In Date with Catalyst Installed	July 2010
Sample Removal Date	April 29, 2019
Total Operating Hours On Catalyst Sample	845
Primary Fuel Fired	Ultra-Low Sulfur Kerosene
Hours Burning Primary Fuel	707
Secondary Fuel Fired	Natural Gas
Hours Burning Secondary Fuel	138
Number of Starts and Stops since catalyst was installed	197

LABORATORY PERFORMANCE TEST CONDITIONS

A performance test was conducted on the sample received using the conditions below. These conditions reflect the original design conditions for which there is fresh catalyst test data available for direct comparison.

Temperature	442°C (828°F)
Entrance Gas Velocity	3.84 Nm/s
O_2	14.4 vol% dry
Inlet NO_X	46.0 ppmvd @ 14.4% O_2 (42.0 ppmvdc @ 15% O_2)

RESULTS

Sample Visual Inspection

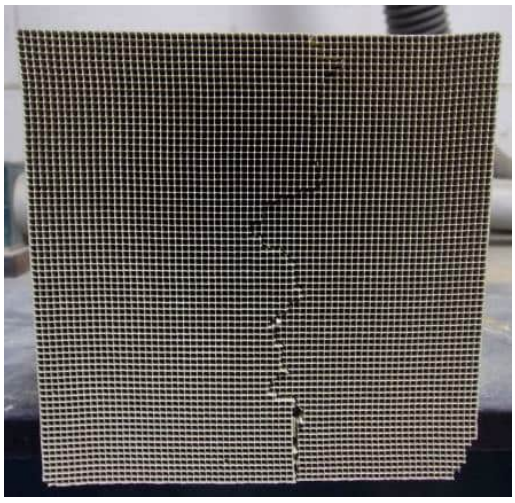
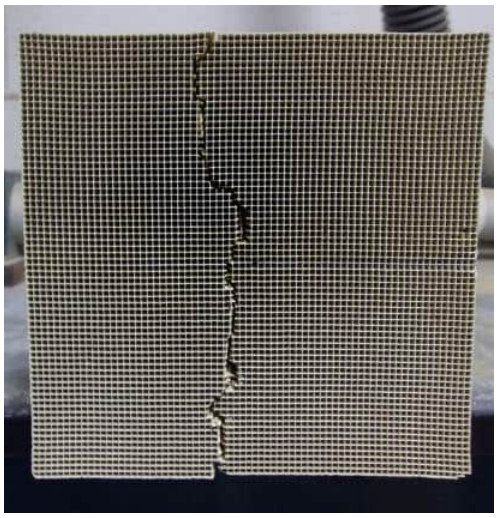
One field sample was received from the GenConn Devon Power Unit 18 SCR.

Below are photographs of the flow entrance face and the flow exit face of the element with an as received inspection report.

Element ID	2388-1026-0462

Box Markings	GenConn Devon Power Attn: Paul Bukowsky #2388 Box 2 of 2 SCR Replacment Nox catalyst coupon #18
Sample Markings	GenConn Devon Unit #18 Removed 4/29/19
Flow Direction Marked	Yes
Other Markings	None

Visual Inspection Notes	Sample is split in the middle but in testable condition
Product Description	CM21MHT^{tM} 70 X 70 cell array
Length, mm	447
Blocked Cell Count, as received	0
Blocked Cell Count, after light cleaning	0

Flow Entrance	*Flow Exit*
	

Results of Laboratory Tests

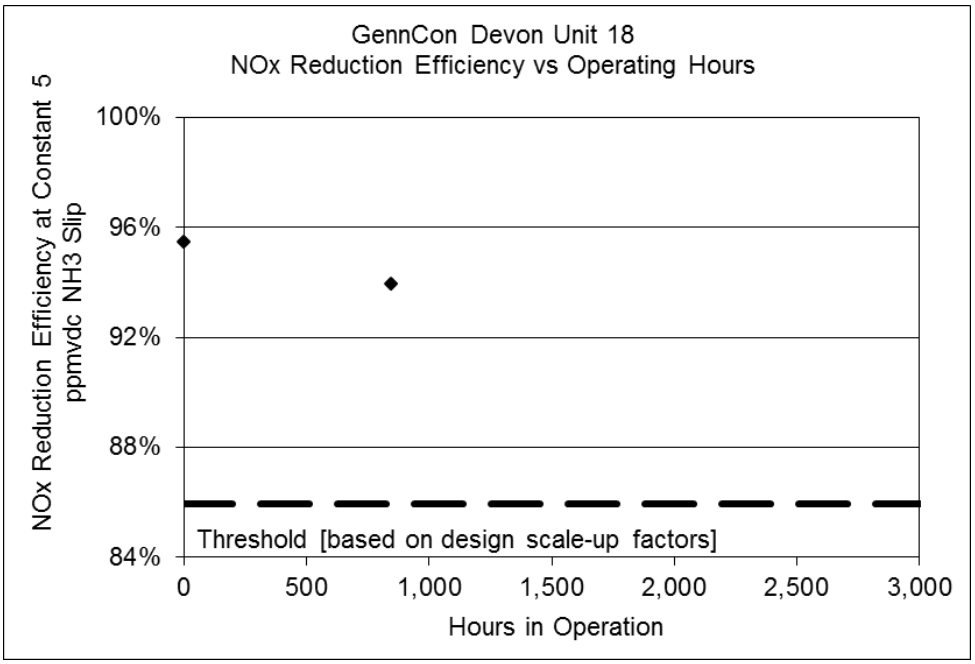
The catalyst performance below is reported under constant 5 ppmvdc ammonia slip and design operating conditions.

The lab performance threshold represents the design NO_X removal efficiency, as measured in lab apparatus, at which the actual *field* performance at *design* operating conditions is expected to reach end-of-life. Field performance is based on a design performance requirement of 85.9% NO_X removal efficiency and 5 ppmvdc ammonia slip.

In field scale (actual) operation, flow, temperature and ammonia/NOx non-uniformities exist. In the highly controlled laboratory environment these non-uniformities do not exist; therefore, the lab results must be scaled-up to reflect expected field performance. The scale-up factors limit achievable NO_X reduction performance in operating SCR systems. The performance threshold value is based on design values for the scale-up factors. The *actual* threshold may be lower if actual scale-up is less severe, or higher if more severe.

	Element ID	**Time On-Line** (Hours)	**NOx Removal Efficiency, %** at 5 ppmvdc NH_3 Slip
Fresh Reference	# 2388-1026-0430	0	95.5
April 2019 Audit	# 2388-1026-0462	845	94.0
Threshold (based on design scale-up factors)			85.9

The figure below shows the trend in catalyst performance.



This audit of the GenConn Devon Power Unit 18 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Devon Power Unit 18 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 4,000 operating hours from the date this sample was removed.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

FIELD DATA COMMENTARY

A review of field data has three primary purposes. First, the field data can show if any operating parameters are significantly different than the original design of the unit. Second, the field data can show if actual plant performance requirements are more severe than the design. If significant differences are evident in operating parameters or performance requirements, their effect on the performance threshold can be determined. Third, the field data can be used to examine if any factors that adversely impact scale-up are present. Typically the factors that adversely impact scale-up are as follows:

- Plugged/ poorly performing Ammonia Injection System resulting in poor mixing of the NH_3 prior to the catalyst.
- Flue gas flow velocity maldistribution.
- Flue gas flow bypass around the catalyst.
- Plugged catalyst.

Below is a table that compares the field data provided by GenConn Devon Power Unit 18 SCR against the design criteria for the installed SCR catalyst:

Parameter	Design Value	Field Value (oil)	Field Value (gas)
Flue Gas Temperature (°F)	828	831	831
Flue Gas Flow Rate (lb/hr)	1,088,460	N/A	N/A
Inlet NOx (ppmvd @ 15% O_2)	42	42 (estimated)	25 (estimated)
Outlet NOx (ppmvd @ 15% O_2)	5.9	4.6	1.9
NOx Reduction Efficiency (%)	85.9	89	92.4
NH_3 Slip (ppmvd @ 15% O_2)	5 (end of life)	2.59	2.59
NH_3 Flow Rate (lb/hr)	180 (end of life)	147	106
NH_3 Supply Concentration (wgt %)	19	19	19
Flue Gas O_2 Conc. (% vol dry)	14.4	8.9	11.3
Catalyst Pressure Drop (in. wg.)	5.1	5	5

Permit Limit

Outlet NOx = 5.9 ppmvd @ 15% O_2 (ULSK), 2.5 ppm vd @15% O_2 (Gas)
Ammonia Slip = 5 ppm

Based on the provided operational data, GenConn Devon Power Unit 18 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip within permit requirements.

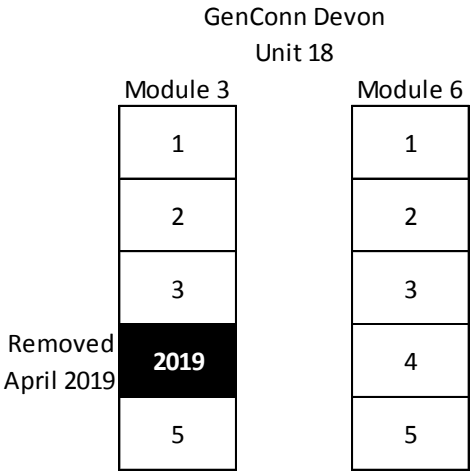
RECOMMENDATIONS

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 1000 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

APPENDIX 1: Location of Sample Retrieval

The sample retrieval location for GenConn Devon Power Unit 18 is shown in the following schematic.



APPENDIX 2: Field Records

Field records received from GenConn Devon Power are reproduced below.

Facility Information	
Facility Owner	NRG
Facility Name	GenConn Devon Power
Facility Street Address	734 Naugatuck Avenue
City, State, Zip Code	Milford, CT 06461
Unit Designation	Unit 18

Contact Information	*Person completing form*	*Person report goes to*
Name	Paul Bukowsky	Same
Title	Environmental Compliance Engineer	
Telephone Number	203-783-6143	203-627-9278 cell
E-mail Address	Paul.Bukowsky@nrg.com	

Sample Operational History		
Catalyst Installation Date	June 2010	
First Gas In Date	June/July 2010	
Sample Removal Date	4/29/2019	
Sample Removal Position *Indicate sampling position: Circle, Mark with "X" or Note sampling position here ___* *View from Upstream Side*	Module 3: 1, 2, 3, X, 5 Module 6: 1, 2, 3, 4, 5	*You may pull the sample from any of the "white boxes."* *Note: Blackened boxes have been sampled previously.*
Removed Sample Element Serial Number, stamped on element	238810260462	
# Starts and Stops on Catalyst	39 (gas) / 158 (oil)	
Operating Hours by Fuel Type	*# Operating Hours burning this fuel*	*Type of Fuel*
Primary Fuel	707	Ultra Low Sulfur Kerosene
Secondary Fuel	138	Natural Gas
Total # Operating Hours	845	

Data Sheet for GenConn Devon Unit 18

Present Operating Conditions				
	Units [Circle correct unit or change as required]	Value	Continuously monitored?	Measurement Method [1]
Flue Gas Temperature (at SCR)	°F	831 / 821	Y	Gas / Oil - Unit DAS
Flue Gas Flow Rate	Lb/hr wet	N/A	N	Not Available
SCR Inlet NOx	ppmvd @15% O_2	25 (gas) 42 (oil)	N	Estimate - 2015
SCR Outlet NOx	ppmvd @15% O_2	1.9 (gas) 4.6 (oil)	N	Stack Test - 2015
NH_3 Slip	ppmvd @15% O_2	2.59	N	Stack Test (FTIR) – 2015 Stack Test (CTM 027) - 2010
NH_3 Flow rate	lb/hr	106 (gas) 147 (oil)	Y	Unit DAS
NH_3 Supply Concentration	wgt %	19	N	Lab Certification
Flue gas O_2 Concentration	Dry Volume %	14.5 (gas) 14.6 (oil)	N	Stack Test - 2015
Flue gas H_2O Concentration	Volume %	11.3 (gas) 8.9 (oil)	N	Stack Test - 2015
Catalyst Pressure Drop	Inches H2O	5	Y	Unit DAS

[1]Method of measurement and accuracy should be provided for all measured values, i.e., flow (boiler load signal or stack measurement), NOx (dilution method chemiluminescence), NH_3 (chemiluminescence subtraction method, ammonia flow gpm/± 5%, etc.).

Permit Limits	(List units as appropriate)
NOx Out	5.9 ppmvd @ 15% O2 (ULSK), 2.5 ppmvd @ 15% O2 (Gas)
NH_3 Slip Out	5 ppm
NOx Removal	95 %

Data Sheet for GenConn Devon Unit 18

Testing History (where NH_3 slip is measured)

	Units [Circle correct unit or change as required]	Following Installation of SCR Catalyst	Test 1		
Test Date		7/12/2010 oil 7/13/2010 gas	7/13/15 oil 7/14/15 gas		
Load Case	Mw	50 gas 50 oil	51 gas 49 oil		
Flue Gas Temperature (at SCR)	°F	813 gas 815 oil	831 gas 821 oil		
Flue Gas Flow Rate	acfm	806,918 (gas) 778,951 (oil)	N/A		
SCR Inlet NOx	ppmvd @15% O_2	25 (gas) 42 (oil)	25 (gas) 42 (oil)		
SCR Outlet NOx	ppmvd @15% O_2	2.03 (gas) 5.03 (oil)	2.0 (gas) 4.2 (oil)		
NH_3 Slip	ppmvd @15% O_2	2.0 (gas) 1.0 (oil)	4.07 (gas) 2.24 (oil)	Stack Test (FTIR) – 2015 Stack Test (CTM 027) - 2010	
NH_3 Flow Rate	lb/hr	95 (gas) 131 (oil)	109 (gas) 146 (oil)		
NH_3 Supply Concentration	wgt %	19	19		
Flue Gas O_2 Concentration	Dry Volume %	14.6 (gas) 14.8 (oil)	14.6 (gas) 14.6 (oil)		
Flue Gas H_2O Concentration	Volume %	11.2 (gas) 9.7 (oil)	11.6 (gas) 9.5 (oil)		
SCR Catalyst Pressure Drop	in. wg. or mm Hg	5	5		

APPENDIX 3: Performance Test Standard Procedure

Purpose

The *laboratory performance testing* for SCR catalyst is conducted to determine the catalytic potential of a representative sample of SCR catalyst at conditions that closely match the actual operating conditions of the SCR system. The sample should represent a typical cross section of the SCR, and the operating history should be known. The test is conducted in a controlled, laboratory environment on custom-built, rigorously validated SCR catalyst test apparatus allowing accurate determination of performance and comparisons of the sample catalytic potential to the system requirements previously tested catalyst(s).

Test Equipment Description

The Cormetech Laboratory SCR test reactors consist of three basic systems:

- Simulated flue gas generator
- SCR catalyst test chamber
- Measurement system

The purpose of the simulated flue gas generator is to provide a stable controlled supply of heated gas with the required mix of gases at the required flow rate and temperature to the SCR catalyst test chamber. It consists of a bulk flue gas generator, a flue gas modification system, a flue gas heater, a reactive gas injection system, and a flue gas mixer.

Bulk Flue Gas Generator -The bulk flue gas is produced by either the combustion of air in a natural gas fired water-cooled combustion chamber, the extraction of nitrogen from air via a membrane system, or the delivery of nitrogen from liquefied nitrogen. This system is adjusted to achieve the overall flue gas flow rate required for the specified test.

Flue Gas Modification System – The gas stream produced by the bulk flue gas generator is modified by the addition of oxygen/air and water/steam to achieve the targeted concentrations of water vapor and oxygen in the flue gas stream.

Flue Gas Heater – The flue gas stream is heated to the target test temperature by an electric pre-heater.

Reactive Gas Injection System – Calibrated mass flow controllers are used to deliver SO_2, SO_3, NO_2, NO, and NH_3 into the flue gas stream.

The table below summarizes the range of process conditions that can be produced by various apparatus in Cormetech's laboratory. Cormetech's laboratory maintains multiple testing units, each with varying capabilities for temperature, flow, and gas composition. The unit selected for a given test will depend on the specific requirements for the sample tested.

Parameter	Units	Range
Gas Temperature	°C	200 – 600
Flow rate/Entrance velocity	Nm/s	1.25 - 7.05
O_2	volume % dry	1 – 20
H_2O	volume %	1-20[1]
NO	ppmvd	0 - 2,000
NO_2	ppmvd	0 - 2000[2]
NH_3	ppmvd	0 - 4,000
SO_2	ppmvd	0 - 2,000
SO_3	ppmvd	0 – 25

1: Some apparatus have the capability to control water concentration. Other units supply water as a product of combustion. When water concentration is not controlled, Cormetech corrects the results to the target concentration with a standardized correction factor.
2: NO_2 addition capability is not available on all test units.

Flue Gas Mixer – Following the reactive gas injection, the gases are mixed using a high efficiency static mixing element.

The simulated flue gas next enters the SCR test reactor where the SCR test sample or samples are located. Each sample is sealed tightly to the walls of the test chamber to ensure that all of the flue gas passes though the sample[s]. Along the length of the test chamber there are electric heating elements that maintain the specified test temperature. There are test ports located at the entrance to the test reactor and at the exit of each sample layer to extract a sample of flue gas for analysis, measure the static pressure of the flue gas, and monitor the temperature of the catalyst samples and the flue gas.

The process conditions of the SCR catalyst under test are monitored by the measurement system:

Gas Flow Rate – The flue gas flow rate is measured by an averaging pitot tube in the exit of the simulated flue gas generator. The flow rate is also calculated from the mass flow controllers for the various gas constituents as they are added. Finally, an annubar is installed in the exhaust of the reactor which allows another cross-check of the flow rate. For the testing to be determined valid, the flow rate must be within the allowable limits from the target flow rate.

Gas Temperature – The temperature of the gas and the catalyst samples is measured by a series of thermocouples throughout the test reactor. For the testing to be determined valid, both the spatial and temporal variability must be within the allowable limits from the specified set point.

Component Concentration – The components of the flue gas are determined by the methods described below. Different systems may not have every type of sampling measurement system.

- *NOx* – Chemiluminescent NOx Analyzer / Infrared Spectroscopy. Average value at each sampling point recorded for each sampling cycle
- NH_3 – Ion Chromatography/infrared spectroscopy
- SO_2 – Precipitation Method/infrared spectroscopy
- SO_3 – Controlled Condensation; Collective Precipitation Method
- O_2 – Micro-fuel cell and Paramagnetic O_2 Analyzer

Procedure Description Summary

The following stepwise description is a guideline to understand how an audit proceeds from sample receipt to reported results.

1. Upon receipt, each sample is inspected for condition and photographed. The sample dimensions are recorded.
2. The Test Plan is prepared based on the needs of audit. The appropriate test apparatus is selected based on the test requirements and the test is scheduled.
3. Each sample is prepared for testing. [This process includes cleaning the sample, and cutting to the required test sample size.]
4. The reactor is opened, inspected, and prepared for operation.
5. Each catalyst sample is loaded according to the Test Plan and sealed in the reactor.
6. An equipment leak test is performed.

7. The Bulk Flue Gas Generator is started and the test conditions are set for O_2%, temperature, and bulk flow rate.
8. NO and NO_2 injection is started and then adjusted in order to meet the test conditions.
9. Ammonia, SO_2 and SO_3 injection is started and then adjusted in order to meet the test conditions.
10. The catalyst is allowed to equilibrate at the test conditions specified.
11. A calibration check is run for the analyzers.
12. For each sampling cycle, the following measurements are taken, as required:

Item	Location Measured	Frequency
NO_X Concentration	Multiplexed to measure NO_X at each sampling point	Average value at each sampling point recorded per each sampling cycle
NH_3 Concentration	At exit of sample[s]	Depends on test method [Multiple analyses recorded]
SO_2 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
SO_3 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
O_2 Concentration	Exit of combustion chamber and multiplexed with NO_X Analyzer	Continuously controlled and monitored
Gas Flow	Exit of combustion chamber	Continuously controlled and monitored
Gas Temperature	At each sampling port	Inlet continuously controlled
Pressure Drop	Entrance and at exit of testing chamber	Continuously monitored, recorded as required

13. The results are recorded and checked per Quality Assurance requirements and compared to the Test Plan.
14. The results are reported.

NRG GenConn Middletown
Unit 12

SCR Catalyst
Performance Test Report
671 Operating Hours
October 2019 Audit

Submitted by

CORMETECH, INC.
Environmental Technologies
5000 International Drive
Durham, NC 27712
(919) 620-3000

Max Morris
Project Engineer

John A. Nivens
Sr. Engineering Technician

Certifying Laboratory Representative
Silas Christian, Laboratory Manager

December 6, 2019

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EXECUTIVE SUMMARY

The following summarizes the key results for this audit of the NRG GenConn Middletown Unit 12 SCR after 671 operating hours since first gas-in.

Observations and Predictions

This audit of the GenConn Middletown Unit 12 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Middletown Unit 12 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,300 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

Field Data Commentary

Based on the provided operational data, GenConn Middletown Unit 12 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

Recommendations

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

PURPOSE

This test is conducted to audit the catalytic potential of an SCR catalyst by measuring the performance of a field catalyst sample that has been in operation for a known duration. The catalytic potential is measured by laboratory scale testing of field samples removed from the SCR. Performance tests are conducted in a controlled, laboratory environment allowing accurate comparisons of field sample catalytic potential to that of fresh catalyst. The deactivation rate is determined by comparing the change in catalytic potential to the operating hours of the sample.

Field performance, as indicated by plant-supplied measurements and observations, is also analyzed and discussed relative to the performance of the catalyst samples tested. Measured field performance in conjunction with laboratory measurements of field sample catalytic potential is used to determine actual unit scale-up factors. Utilizing actual unit scale-up factors significantly improves the accuracy of future performance predictions.

Further catalyst and/or field operation analysis may be recommended if laboratory test results are inconsistent with any of the following:

- Cormetech's experience base of comparable units
- The plant's reported field performance, if available
- The results of previous audits of the unit, if applicable
- The performance expectations for the unit.

BACKGROUND

In order to achieve the design performance requirements of a Selective Catalytic Reduction system for a specified timeframe (life) of the SCR catalyst, the catalyst formulation, structure, and volume are specifically designed to accommodate the system operating conditions, the predicted system scale-up factors, and a predicted rate of decrease in catalyst potential over time.

If any of the design or operating parameters above is not realized, then the actual duration that the design performance requirements can be met may deviate from the design life. The individual contribution of each parameter on actual life is described below. In actual practice, one or more of these parameters may deviate from design and either counteract or complement each other.

Performance Requirements: If the actual plant performance requirements are more severe than the design performance requirements, actual life will be less than design life. An example of this would be a unit that is required to achieve a higher NOx reduction than the unit was designed for.

Operating Conditions: Flue gas flow rate, inlet NO_X levels, temperature, oxygen content, and water content impact catalytic potential. If the catalyst is at an operating condition where the potential is lower than design, actual life will be less than design life.

Scale-Up Factors: The full NO_X reduction potential of the catalyst is not attained in the field due to non-ideal flow distribution, temperature distribution, ammonia to NO_X molar ratio distribution,

catalyst blockage, and/or flue gas bypass. Collectively, these non-ideal conditions are accounted for with 'system scale-up factors'. If the overall actual system scale-up factors are more severe than the design scale-up factors, then the potential of the SCR system to meet a given performance requirement is reduced.

Catalyst Deactivation Rate: Catalytic potential decreases over time. This catalyst deactivation rate has a direct impact on actual life. If the deactivation rate is more than design, then actual life is effectively reduced. If the deactivation rate is less than design, the actual life is effectively increased.

If the performance requirements, operating conditions, and/or scale-up factors are more severe than the initial design, less margin remains for catalyst deactivation. Therefore, actual life will be less than design life.

At any given time and operating condition, the SCR system performance is dictated by the NO_X reduction potential of the catalyst and the system scale-up factors. These factors reduce performance from the catalytic potential to the performance achievable in the operating SCR system.

Performance tests are purposefully conducted in a controlled environment, free from the scale-up factors that adversely affect SCR system performance, and at repeatable operating conditions, so that changes in catalytic potential may be evaluated accurately. Catalyst deactivation is determined by testing the field catalyst sample at the same operating conditions as the fresh sample.

In conjunction with performance test results, analysis of field SCR system performance data can confirm the field performance requirements, the plant operating conditions, and actual system scale-up factors.

Cormetech's SCR catalyst design and testing experience enables analysis of the actual versus design values of performance requirements, operating conditions, system scale-up, and catalyst deactivation to predict future catalyst performance.

FACILITY OPERATIONAL HISTORY

The SCR system at the GenConn Middletown Unit 12 consists of 1 layer of CM21MHT™ 70 cell catalyst. The unit was originally put into service on April 2011.

On October 1, 2019 one catalyst sample was removed from the field sampler at GenConn Middletown Unit 12 and returned to Cormetech for laboratory testing. At the time the sample was removed, the audited element had accumulated 671 operating hours. The results of the December 6, 2019 audit are summarized in this report.

PROCEDURE OVERVIEW

1. One catalyst sample was removed from the field sampler module at the GenConn Middletown Unit 12 SCR and was shipped to Cormetech's laboratory. Operating history was recorded by the plant and forwarded to Cormetech.

2. The physical condition of the catalyst was documented by Cormetech.

3. The catalyst was prepared and loaded into an Activity Test Apparatus and then evaluated at the original design conditions for the SCR. The Performance Test Standard Procedure is included in Appendix 3.

4. The results include catalyst potential expressed as NO_X removal efficiency at a constant 5 ppmvdc ammonia slip.

5. Test results were compared to design expectations and to the results of the fresh reference. Expectations of catalyst deactivation were determined by the time on-line and experience data of similar gas-fired facilities.

6. A catalyst life prediction is based on the above testing and analysis.

7. Additional data submitted by the plant was reviewed for the field performance of the SCR system.

FIELD SAMPLING AND UNIT OPERATING CONDITIONS

Field Sampling

One SCR catalyst sample from GenConn Middletown Unit 12 was removed and sent to Cormetech's Laboratory for evaluation. The sample retrieval location is shown in Appendix 1.

Operating Status

Field records supplied by GenConn Middletown are summarized in the table below. The field records are reproduced in Appendix 2.

First Gas-In Date with Catalyst Installed	4/14/2011
Sample Removal Date	October,1,2019
Total Operating Hours On Catalyst Sample	671
Primary Fuel Fired	Ultra-Low Sulfur Kerosene
Hours Burning Primary Fuel	593
Secondary Fuel Fired	Natural Gas
Hours Burning Secondary Fuel	78
Number of Starts and Stops since catalyst was installed	296

LABORATORY PERFORMANCE TEST CONDITIONS

A performance test was conducted on the sample received using the conditions below. These conditions reflect the original design conditions for which there is fresh catalyst test data available for direct comparison.

Temperature	442°C (828°F)
Entrance Gas Velocity	3.76 Nm/s
O_2	14.4 vol% dry
Inlet NO_X	46.0 ppmvd @ 14.4% O_2 (42.0 ppmvdc @ 15% O_2)

RESULTS

Sample Visual Inspection

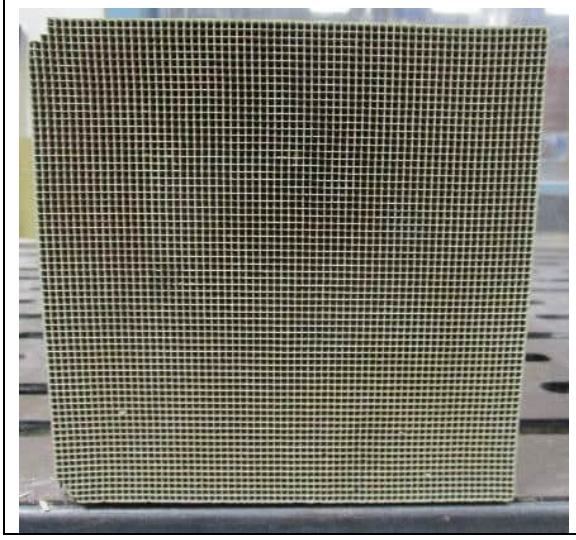
One field sample was received from the GenConn Middletown Unit 12 SCR.

Below are photographs of the flow entrance face and the flow exit face of the element with an as received inspection report.

Element ID	2389-1021-0339

Box Markings	NA
Sample Markings	GenConn Middletown unit 12
Flow Direction Marked	Yes
Other Markings	None

Visual Inspection Notes	Element is in good physical condition
Product Description	CM21MHT^{tM}
Length, mm	447
Blocked Cell Count, as received	0
Blocked Cell Count, after light cleaning	0

Flow Entrance	*Flow Exit*
	

Results of Laboratory Tests

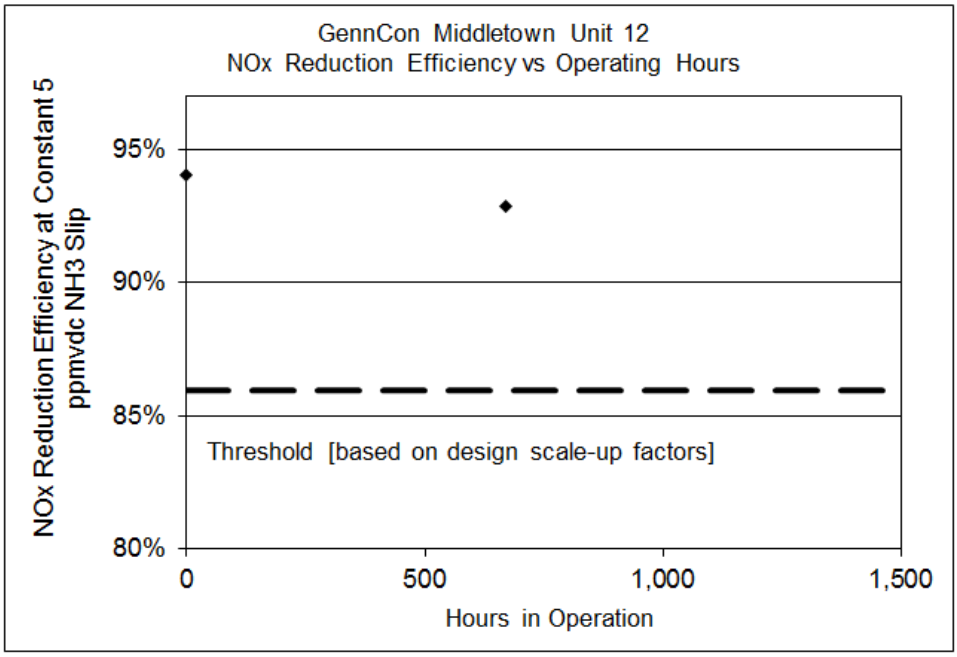
The catalyst performance below is reported under constant 5 ppmvdc ammonia slip and design operating conditions.

The lab performance threshold represents the design NO_X removal efficiency, as measured in lab apparatus, at which the actual *field* performance at *design* operating conditions is expected to reach end-of-life. Field performance is based on a design performance requirement of 85.9% NO_X removal efficiency and 5 ppmvdc ammonia slip.

In field scale (actual) operation, flow, temperature and ammonia/NOx non-uniformities exist. In the highly controlled laboratory environment these non-uniformities do not exist; therefore, the lab results must be scaled-up to reflect expected field performance. The scale-up factors limit achievable NO_X reduction performance in operating SCR systems. The performance threshold value is based on design values for the scale-up factors. The *actual* threshold may be lower if actual scale-up is less severe, or higher if more severe.

	Element ID	**Time On-Line** (Hours)	**NOx Removal Efficiency, %** at 5 ppmvdc NH_3 Slip
Fresh Reference	# 2389-2026-0403	0	94.06
October 2019 Audit	# 2389-1026-0478	671	92.88
Threshold (based on design scale-up factors)			85.9

The figure below shows the trend in catalyst performance.



This audit of the GenConn Middletown Unit 12 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Middletown Unit 12 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,300 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

FIELD DATA COMMENTARY

A review of field data has three primary purposes. First, the field data can show if any operating parameters are significantly different than the original design of the unit. Second, the field data can show if actual plant performance requirements are more severe than the design. If significant differences are evident in operating parameters or performance requirements, their effect on the performance threshold can be determined. Third, the field data can be used to examine if any factors that adversely impact scale-up are present. Typically the factors that adversely impact scale-up are as follows:

- Plugged/ poorly performing Ammonia Injection System resulting in poor mixing of the NH_3 prior to the catalyst.
- Flue gas flow velocity maldistribution.
- Flue gas flow bypass around the catalyst.
- Plugged catalyst.

Below is a table that compares the field data provided by GenConn Middletown Unit 12 SCR against the design criteria for the installed SCR catalyst:

Parameter	Design Value	Field Value (oil)	Field Value (gas)
Flue Gas Temperature (°F)	828	802	792
Flue Gas Flow Rate (lb/hr)	1,088,460	N/A	N/A
Inlet NOx (ppmvd @ 15% O_2)	42	42 (estimated)	25 (estimated)
Outlet NOx (ppmvd @ 15% O_2)	5.9	1.9	1.3
NOx Reduction Efficiency (%)	85.9	95.4	94.8
NH_3 Slip (ppmvd @ 15% O_2)	5 (end of life)	3.3	4.6
NH_3 Flow Rate (lb/hr)	180 (end of life)	139	72
NH_3 Supply Concentration (wgt %)	19	19	19
Flue Gas O_2 Conc. (% vol dry)	14.4	9.98	11.84
Catalyst Pressure Drop (in. wg.)	5.1	4.7	4.2

Permit Limit

Outlet NOx = 5.9 ppmvd @ 15% O_2 (ULSK), 2.5 ppmvd @15% O_2 (Gas)
Ammonia Slip = 5 ppm

Based on the provided operational data, GenConn Middletown Unit 12 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

RECOMMENDATIONS

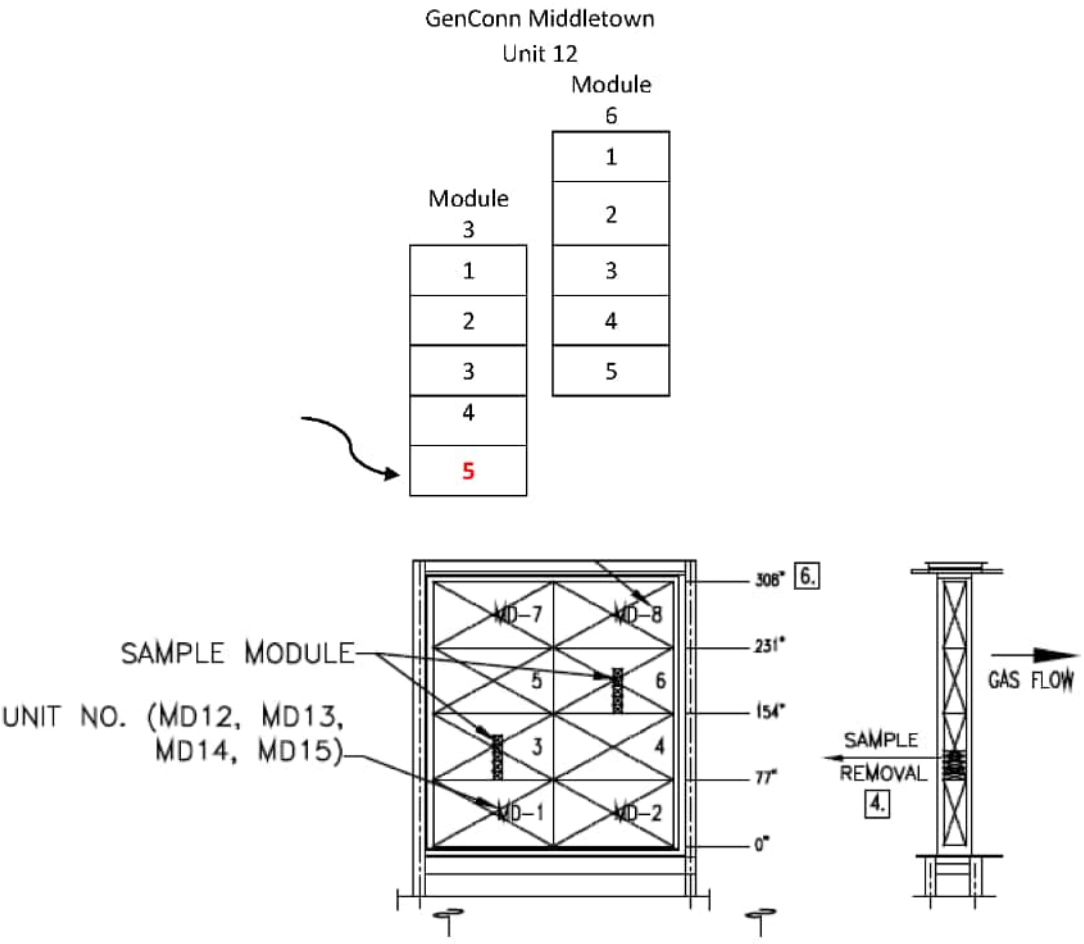
Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

APPENDIX 1: Location of Sample Retrieval

The sample retrieval location for GenConn Middletown Unit 12 is shown in the following schematic.

Data Sheet for Unit 12



APPENDIX 2: Field Records

Field records received from GenConn Middletown are reproduced below

Facility Information	
Facility Owner	NRG
Facility Name	GenConn Middletown
Facility Street Address	1866 River Rd
City, State, Zip Code	Middletown, CT 06457
Unit Designation	Unit 12

Contact Information	*Person completing form*	*Person report goes to*
Name	Keith Shortsleeve	Keith Shortsleeve
Title	Environmental Engineer	Environmental Engineer
Telephone Number	860-638-3102	860-638-3102
E-mail Address	Keith.shortsleeve@nrg.com	Keith.shortsleeve@nrg.com

Sample Operational History		
Catalyst Installation Date	3/1/2011	
First Gas In Date	4/14/2011	
Sample Removal Date	10/1/2019	
Sample Removal Position *Indicate sampling position: Circle, Mark with 'X" or Note sampling position here* ***Unit 12 Module 3 Slot 5*** *View from Upstream Side*	See Page 4	
Removed Sample Element Serial Number, stamped on element	238910210339	
# Starts and Stops on Catalyst	269 Oil / 27 Gas Starts	
Operating Hours by Fuel Type	*# Operating Hours burning this fuel*	*Type of Fuel*
Primary Fuel	593	ULSK
Secondary Fuel	78	Natural Gas
Total # Operating Hours	671	

Data Sheet for Unit 12

Present Operating Conditions				
	Units [Circle correct unit or change as required]	Value	Continuously monitored?	Measurement Method [1]
Flue Gas Temperature (at SCR)	ºF or ºC	802 (oil) 792 (gas)	N	Stack Measurement
Flue Gas Flow Rate	Lb/hr dry (DSCFM)	275783 (oil) 267767 (gas)	N	6/6/2016 TRC Stack Test
SCR Inlet NOx	ppmvd @__15__% O_2	42 (oil) 25(gas)	N	Estimated
SCR Outlet NOx	ppmvd @__15__% O_2	1.9 (oil) 1.3 (gas)	N	6/6/2016 Stack Test
NH_3 Slip	ppmvd @_15___% O_2	3.3 (oil) 4.6 (gas)	N	6/6/2016 Stack Test
NH_3 Flow rate	lb/hr	139 (oil) 72 (gas)	Y	GenConn NH3 Tuning NH3 Flow 2016
NH_3 Supply Concentration	wgt %	19 – 19.5	Y	Supplier Analysis
Flue gas O_2 Concentration	Dry Volume %	14.7 (oil) 14.8 (gas)	N	6/8/2016 Stack Test
Flue gas H_2O Concentration	Volume %	9.98 (oil) 11.84 (gas)	N	6/8/16 Stack Test
Catalyst Pressure Drop	iwg or mm Hg	4.7 (oil) 4.2 (gas)	Y	CEM Data – 2016 Stack Test

[1]Method of measurement and accuracy should be provided for all measured values, i.e., flow (boiler load signal or stack measurement), NOx (dilution method chemiluminescence), NH_3 (chemiluminescence subtraction method, ammonia flow gpm/± 5%, etc.).

Permit Limits	(Unit 12)
NOx Out	[GAS 4.4 lb/hr; 2.5 ppmvd @ 15% O_2] [OIL 10.5 lb/hr; 5.9 ppmvd @ 15% O2]
NH_3 Slip Out	3.27 ppmvd @ 15% O_2 (oil) 4.6 (gas)
NOx Removal	95 %

APPENDIX 3: Performance Test Standard Procedure

Purpose

The *laboratory performance testing* for SCR catalyst is conducted to determine the catalytic potential of a representative sample of SCR catalyst at conditions that closely match the actual operating conditions of the SCR system. The sample should represent a typical cross section of the SCR, and the operating history should be known. The test is conducted in a controlled, laboratory environment on custom-built, rigorously validated SCR catalyst test apparatus allowing accurate determination of performance and comparisons of the sample catalytic potential to the system requirements previously tested catalyst(s).

Test Equipment Description

The Cormetech Laboratory SCR test reactors consist of three basic systems:

- Simulated flue gas generator
- SCR catalyst test chamber
- Measurement system

The purpose of the simulated flue gas generator is to provide a stable controlled supply of heated gas with the required mix of gases at the required flow rate and temperature to the SCR catalyst test chamber. It consists of a bulk flue gas generator, a flue gas modification system, a flue gas heater, a reactive gas injection system, and a flue gas mixer.

Bulk Flue Gas Generator -The bulk flue gas is produced by either the combustion of air in a natural gas fired water-cooled combustion chamber, the extraction of nitrogen from air via a membrane system, or the delivery of nitrogen from liquefied nitrogen. This system is adjusted to achieve the overall flue gas flow rate required for the specified test.

Flue Gas Modification System – The gas stream produced by the bulk flue gas generator is modified by the addition of oxygen/air and water/steam to achieve the targeted concentrations of water vapor and oxygen in the flue gas stream.

Flue Gas Heater – The flue gas stream is heated to the target test temperature by an electric pre-heater.

Reactive Gas Injection System – Calibrated mass flow controllers are used to deliver SO_2, SO_3, NO_2, NO, and NH_3 into the flue gas stream.

The table below summarizes the range of process conditions that can be produced by various apparatus in Cormetech's laboratory. Cormetech's laboratory maintains multiple testing units, each with varying capabilities for temperature, flow, and gas composition. The unit selected for a given test will depend on the specific requirements for the sample tested.

Parameter	Units	Range
Gas Temperature	^{o}C	200 – 600
Flow rate/Entrance velocity	Nm/s	1.25 - 7.05
O_2	volume % dry	1 – 20
H_2O	volume %	1-20[1]
NO	ppmvd	0 - 2,000
NO_2	ppmvd	0 - 2000[2]
NH_3	ppmvd	0 - 4,000
SO_2	ppmvd	0 - 2,000
SO_3	ppmvd	0 – 25

1: Some apparatus have the capability to control water concentration. Other units supply water as a product of combustion. When water concentration is not controlled, Cormetech corrects the results to the target concentration with a standardized correction factor.
2: NO_2 addition capability is not available on all test units.

Flue Gas Mixer – Following the reactive gas injection, the gases are mixed using a high efficiency static mixing element.

The simulated flue gas next enters the SCR test reactor where the SCR test sample or samples are located. Each sample is sealed tightly to the walls of the test chamber to ensure that all of the flue gas passes though the sample[s]. Along the length of the test chamber there are electric heating elements that maintain the specified test temperature. There are test ports located at the entrance to the test reactor and at the exit of each sample layer to extract a sample of flue gas for analysis, measure the static pressure of the flue gas, and monitor the temperature of the catalyst samples and the flue gas.

The process conditions of the SCR catalyst under test are monitored by the measurement system:

Gas Flow Rate – The flue gas flow rate is measured by an averaging pitot tube in the exit of the simulated flue gas generator. The flow rate is also calculated from the mass flow controllers for the various gas constituents as they are added. Finally, an annubar is installed in the exhaust of the reactor which allows another cross-check of the flow rate. For the testing to be determined valid, the flow rate must be within the allowable limits from the target flow rate.

Gas Temperature – The temperature of the gas and the catalyst samples is measured by a series of thermocouples throughout the test reactor. For the testing to be determined valid, both the spatial and temporal variability must be within the allowable limits from the specified set point.

Component Concentration – The components of the flue gas are determined by the methods described below. Different systems may not have every type of sampling measurement system.

- *NOx* – Chemiluminescent NOx Analyzer / Infrared Spectroscopy. Average value at each sampling point recorded for each sampling cycle
- NH_3 – Ion Chromatography/infrared spectroscopy
- SO_2 – Precipitation Method/infrared spectroscopy
- SO_3 – Controlled Condensation; Collective Precipitation Method
- O_2 – Micro-fuel cell and Paramagnetic O_2 Analyzer

Procedure Description Summary

The following stepwise description is a guideline to understand how an audit proceeds from sample receipt to reported results.

1. Upon receipt, each sample is inspected for condition and photographed. The sample dimensions are recorded.
2. The Test Plan is prepared based on the needs of audit. The appropriate test apparatus is selected based on the test requirements and the test is scheduled.
3. Each sample is prepared for testing. [This process includes cleaning the sample, and cutting to the required test sample size.]
4. The reactor is opened, inspected, and prepared for operation.
5. Each catalyst sample is loaded according to the Test Plan and sealed in the reactor.
6. An equipment leak test is performed.

7. The Bulk Flue Gas Generator is started and the test conditions are set for O_2%, temperature, and bulk flow rate.
8. NO and NO_2 injection is started and then adjusted in order to meet the test conditions.
9. Ammonia, SO_2 and SO_3 injection is started and then adjusted in order to meet the test conditions.
10. The catalyst is allowed to equilibrate at the test conditions specified.
11. A calibration check is run for the analyzers.
12. For each sampling cycle, the following measurements are taken, as required:

Item	Location Measured	Frequency
NO_X Concentration	Multiplexed to measure NO_X at each sampling point	Average value at each sampling point recorded per each sampling cycle
NH_3 Concentration	At exit of sample[s]	Depends on test method [Multiple analyses recorded]
SO_2 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
SO_3 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
O_2 Concentration	Exit of combustion chamber and multiplexed with NO_X Analyzer	Continuously controlled and monitored
Gas Flow	Exit of combustion chamber	Continuously controlled and monitored
Gas Temperature	At each sampling port	Inlet continuously controlled
Pressure Drop	Entrance and at exit of testing chamber	Continuously monitored, recorded as required

13. The results are recorded and checked per Quality Assurance requirements and compared to the Test Plan.
14. The results are reported.

NRG GenConn Middletown
Unit 13

SCR Catalyst
Performance Test Report
671 Operating Hours
October 2019 Audit

Submitted by

CORMETECH, INC.
Environmental Technologies
5000 International Drive
Durham, NC 27712
(919) 620-3000



Max Morris
Project Engineer



John A. Nivens
Sr. Engineering Technician

Certifying Laboratory Representative
Silas Christian, Laboratory Manager

December 6, 2019

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EXECUTIVE SUMMARY

The following summarizes the key results for this audit of the NRG GenConn Middletown Unit 13 SCR after 577 operating hours since first gas-in.

Observations and Predictions

This audit of the GenConn Middletown Unit 13 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Middletown Unit 13 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,300 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

Field Data Commentary

Based on the provided operational data, GenConn Middletown Unit 13 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

Recommendations

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

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Cormetech's SCR catalyst design and testing experience enables analysis of the actual versus design values of performance requirements, operating conditions, system scale-up, and catalyst deactivation to predict future catalyst performance.

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FIELD SAMPLING AND UNIT OPERATING CONDITIONS

Field Sampling

One SCR catalyst sample from GenConn Middletown Unit 13 was removed and sent to Cormetech's Laboratory for evaluation. The sample retrieval location is shown in Appendix 1.

Operating Status

Field records supplied by GenConn Middletown are summarized in the table below. The field records are reproduced in Appendix 2.

First Gas-In Date with Catalyst Installed	4/14/2011
Sample Removal Date	October,1,2019
Total Operating Hours On Catalyst Sample	577
Primary Fuel Fired	Ultra-Low Sulfur Kerosene
Hours Burning Primary Fuel	515
Secondary Fuel Fired	Natural Gas
Hours Burning Secondary Fuel	62.1
Number of Starts and Stops since catalyst was installed	252

LABORATORY PERFORMANCE TEST CONDITIONS

A performance test was conducted on the sample received using the conditions below. These conditions reflect the original design conditions for which there is fresh catalyst test data available for direct comparison.

Temperature	442°C (828°F)
Entrance Gas Velocity	3.76 Nm/s
O_2	14.4 vol% dry
Inlet NO_X	46.0 ppmvd @ 14.4% O_2 (42.0 ppmvdc @ 15% O_2)

RESULTS

Sample Visual Inspection

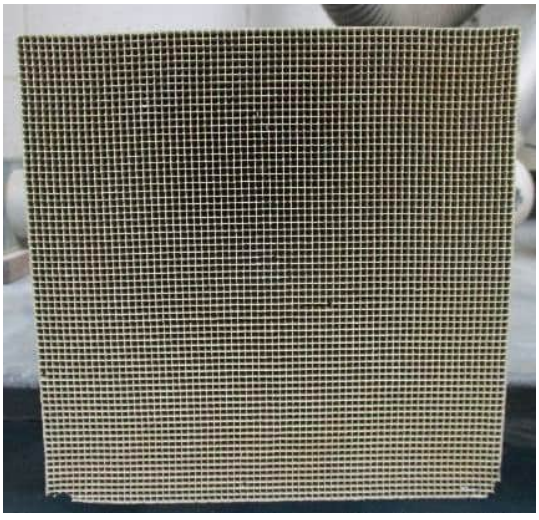
One field sample was received from the GenConn Middletown Unit 13 SCR.

Below are photographs of the flow entrance face and the flow exit face of the element with an as received inspection report.

Element ID	2389-1021-0396

Box Markings	NA
Sample Markings	GenConn Middletown unit 13
Flow Direction Marked	Yes
Other Markings	None

Visual Inspection Notes	Element is in good physical condition
Product Description	CM21MHT^{tM}
Length, mm	446
Blocked Cell Count, as received	0
Blocked Cell Count, after light cleaning	0

Flow Entrance	*Flow Exit*
	

Results of Laboratory Tests

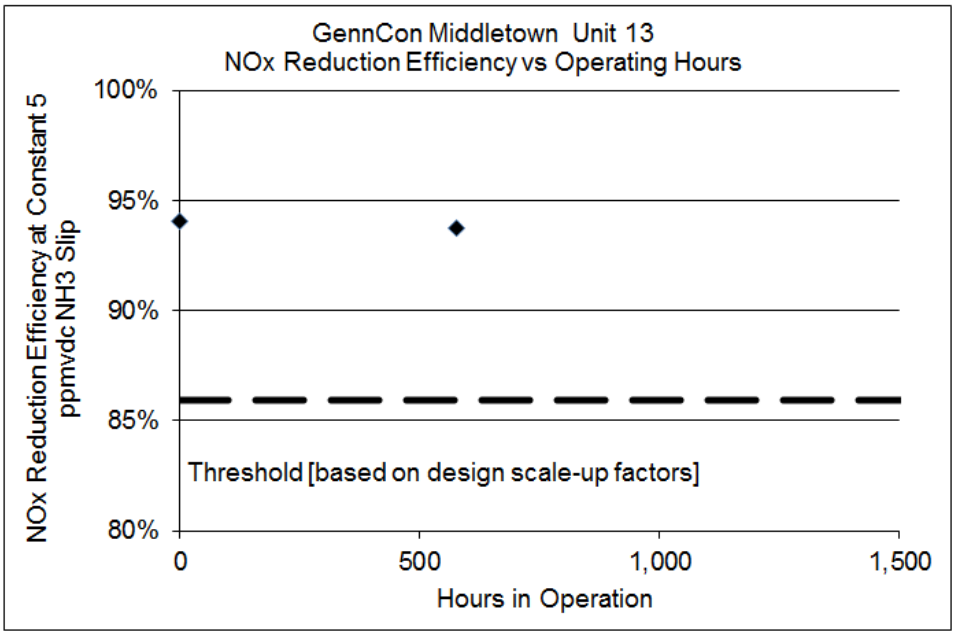
The catalyst performance below is reported under constant 5 ppmvdc ammonia slip and design operating conditions.

The lab performance threshold represents the design NO_X removal efficiency, as measured in lab apparatus, at which the actual *field* performance at *design* operating conditions is expected to reach end-of-life. Field performance is based on a design performance requirement of 85.9% NO_X removal efficiency and 5 ppmvdc ammonia slip.

In field scale (actual) operation, flow, temperature and ammonia/NOx non-uniformities exist. In the highly controlled laboratory environment these non-uniformities do not exist; therefore, the lab results must be scaled-up to reflect expected field performance. The scale-up factors limit achievable NO_X reduction performance in operating SCR systems. The performance threshold value is based on design values for the scale-up factors. The *actual* threshold may be lower if actual scale-up is less severe, or higher if more severe.

	Element ID	**Time On-Line** (Hours)	**NOx Removal Efficiency, %** at 5 ppmvdc NH_3 Slip
Fresh Reference	# 2389-2026-0403	0	94.06
October 2019 Audit	# 2389-1021-0396	577	93.76
Threshold (based on design scale-up factors)			85.9

The figure below shows the trend in catalyst performance.



This audit of the GenConn Middletown Unit 13 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Middletown Unit 13 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,300 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

FIELD DATA COMMENTARY

A review of field data has three primary purposes. First, the field data can show if any operating parameters are significantly different than the original design of the unit. Second, the field data can show if actual plant performance requirements are more severe than the design. If significant differences are evident in operating parameters or performance requirements, their effect on the performance threshold can be determined. Third, the field data can be used to examine if any factors that adversely impact scale-up are present. Typically the factors that adversely impact scale-up are as follows:

- Plugged/ poorly performing Ammonia Injection System resulting in poor mixing of the NH_3 prior to the catalyst.
- Flue gas flow velocity maldistribution.
- Flue gas flow bypass around the catalyst.
- Plugged catalyst.

Below is a table that compares the field data provided by GenConn Middletown Unit 13 SCR against the design criteria for the installed SCR catalyst:

Parameter	Design Value	Field Value (oil)	Field Value (gas)
Flue Gas Temperature (°F)	828	812	789
Flue Gas Flow Rate (lb/hr)	1,088,460	284,859 DSCFM	286904 DSCFM
Inlet NOx (ppmvd @ 15% O_2)	42	42 (estimated)	25 (estimated)
Outlet NOx (ppmvd @ 15% O_2)	5.9	2.8	1.99
NOx Reduction Efficiency (%)	85.9	93.3	92
NH_3 Slip (ppmvd @ 15% O_2)	5 (end of life)	2.43	3.9
NH_3 Flow Rate (lb/hr)	180 (end of life)	127	94
NH_3 Supply Concentration (wgt %)	19	19	19
Flue Gas O_2 Conc. (% vol dry)	14.4	9.44	10.1
Catalyst Pressure Drop (in. wg.)	5.1	5.0	4.8

Permit Limit

Outlet NOx = 5.9 ppmvd @ 15% O_2 (ULSK), 2.5 ppmvd @15% O_2 (Gas)
Ammonia Slip = 5 ppm

Based on the provided operational data, GenConn Middletown Unit 13 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

RECOMMENDATIONS

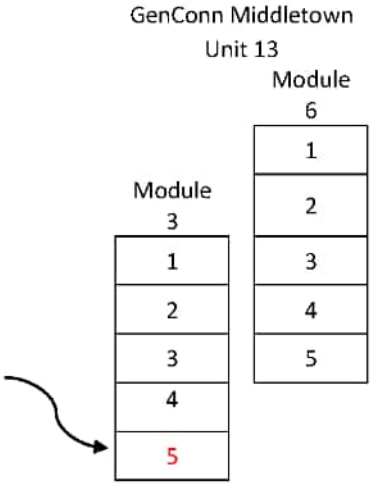
Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

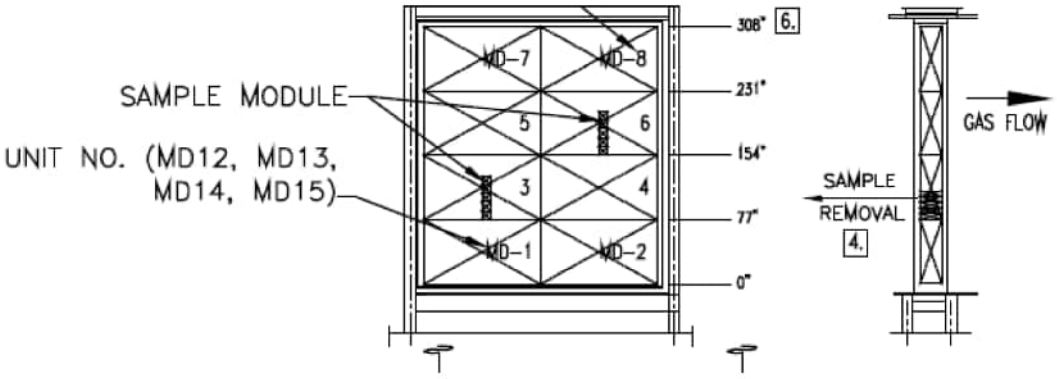
Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

APPENDIX 1: Location of Sample Retrieval

The sample retrieval location for GenConn Middletown Unit 13 is shown in the following schematic.

Data Sheet for Unit 13





APPENDIX 2: Field Records

Field records received from GenConn Middletown are reproduced below

Facility Information	
Facility Owner	NRG
Facility Name	GenConn Middletown
Facility Street Address	1866 River Rd
City, State, Zip Code	Middletown, CT 06457
Unit Designation	Unit 13

Contact Information	*Person completing form*	*Person report goes to*
Name	Keith Shortsleeve	Keith Shortsleeve
Title	Environmental Engineer	Environmental Engineer
Telephone Number	203-376-2229	203-376-2229
E-mail Address	Keith.Shortsleeve@nrg.com	Keith.Shortsleeve@nrg.com

Sample Operational History		
Catalyst Installation Date	~3/1/2011	
First Gas In Date	April 4, 2011	
Sample Removal Date	October 7, 2019	
Sample Removal Position *Indicate sampling position: Circle, Mark with 'X" or Note sampling position here* ***Module 3, Drawer 5*** *View from Upstream Side*	See Page 4	
Removed Sample Element Serial Number, stamped on element	238910210396	
# Starts and Stops on Catalyst	Oil = 227, Gas = 25 (Starts = Stops)	
Operating Hours by Fuel Type	*# Operating Hours burning this fuel*	*Type of Fuel*
Primary Fuel	515	Oil
Secondary Fuel	62.1	Gas
Total # Operating Hours	577.1	

Data Sheet for Unit 13

Present Operating Conditions				
	Units [Circle correct unit or change as required]	Value	Continuously monitored?	Measurement Method [1]
Flue Gas Temperature (at SCR)	°F or °C	812 (oil) 789 (gas)	Y	Stack
Flue Gas Flow Rate	Lb/hr wet DSCFM	284859(oil) 286904 (gas)	N	TRC Stack Test
SCR Inlet NOx	ppmvd @_15___% O_2	42 (oil) 25 (gas)	N	Estimated
SCR Outlet NOx	ppmvd @_15___% O_2	2.8 (oil) 1.99 (gas	N	Stack Test
NH_3 Slip	ppmvd @__15__% O_2	2.43 (oil) 3.9 (gas)	N	Stack Test
NH_3 Flow rate	lb/hr	127 (oil) 94 (gas)	Y	Stack Test 2016
NH_3 Supply Concentration	wgt %	19	Y	Supplier Analysis
Flue gas O_2 Concentration	Dry Volume %	14.3	N	Stack Test
Flue gas H_2O Concentration	Volume %	9.44 (oil) 10.1 (gas)	N	Stack Test
Catalyst Pressure Drop	iwg or mm Hg	5.0 (oil) 4.8(gas)	Y	CEM Data 2016 Stack Test

[1]Method of measurement and accuracy should be provided for all measured values, i.e., flow (boiler load signal or stack measurement), NOx (dilution method chemiluminescence), NH_3 (chemiluminescence subtraction method, ammonia flow gpm/± 5%, etc.).

Permit Limits	(List units as appropriate)
NOx Out	[GAS 4.4 lb/hr; 2.5 ppmvd @ 15% O_2] [OIL 10.5 lb/hr; 5.9 ppmvd @ 15% O2]
NH_3 Slip Out	3.27 ppmvd @ 15% O_2 (oil) 4.6 (gas)
NOx Removal	95 %

APPENDIX 3: Performance Test Standard Procedure

Purpose

The *laboratory performance testing* for SCR catalyst is conducted to determine the catalytic potential of a representative sample of SCR catalyst at conditions that closely match the actual operating conditions of the SCR system. The sample should represent a typical cross section of the SCR, and the operating history should be known. The test is conducted in a controlled, laboratory environment on custom-built, rigorously validated SCR catalyst test apparatus allowing accurate determination of performance and comparisons of the sample catalytic potential to the system requirements previously tested catalyst(s).

Test Equipment Description

The Cormetech Laboratory SCR test reactors consist of three basic systems:

- Simulated flue gas generator
- SCR catalyst test chamber
- Measurement system

The purpose of the simulated flue gas generator is to provide a stable controlled supply of heated gas with the required mix of gases at the required flow rate and temperature to the SCR catalyst test chamber. It consists of a bulk flue gas generator, a flue gas modification system, a flue gas heater, a reactive gas injection system, and a flue gas mixer.

Bulk Flue Gas Generator -The bulk flue gas is produced by either the combustion of air in a natural gas fired water-cooled combustion chamber, the extraction of nitrogen from air via a membrane system, or the delivery of nitrogen from liquefied nitrogen. This system is adjusted to achieve the overall flue gas flow rate required for the specified test.

Flue Gas Modification System – The gas stream produced by the bulk flue gas generator is modified by the addition of oxygen/air and water/steam to achieve the targeted concentrations of water vapor and oxygen in the flue gas stream.

Flue Gas Heater – The flue gas stream is heated to the target test temperature by an electric pre-heater.

Reactive Gas Injection System – Calibrated mass flow controllers are used to deliver SO_2, SO_3, NO_2, NO, and NH_3 into the flue gas stream.

The table below summarizes the range of process conditions that can be produced by various apparatus in Cormetech's laboratory. Cormetech's laboratory maintains multiple testing units, each with varying capabilities for temperature, flow, and gas composition. The unit selected for a given test will depend on the specific requirements for the sample tested.

Parameter	Units	Range
Gas Temperature	^{o}C	200 – 600
Flow rate/Entrance velocity	Nm/s	1.25 - 7.05
O_2	volume % dry	1 – 20
H_2O	volume %	1-20[1]
NO	ppmvd	0 - 2,000
NO_2	ppmvd	0 - 2000[2]
NH_3	ppmvd	0 - 4,000
SO_2	ppmvd	0 - 2,000
SO_3	ppmvd	0 – 25

1: Some apparatus have the capability to control water concentration. Other units supply water as a product of combustion. When water concentration is not controlled, Cormetech corrects the results to the target concentration with a standardized correction factor.
2: NO_2 addition capability is not available on all test units.

Flue Gas Mixer – Following the reactive gas injection, the gases are mixed using a high efficiency static mixing element.

The simulated flue gas next enters the SCR test reactor where the SCR test sample or samples are located. Each sample is sealed tightly to the walls of the test chamber to ensure that all of the flue gas passes though the sample[s]. Along the length of the test chamber there are electric heating elements that maintain the specified test temperature. There are test ports located at the entrance to the test reactor and at the exit of each sample layer to extract a sample of flue gas for analysis, measure the static pressure of the flue gas, and monitor the temperature of the catalyst samples and the flue gas.

The process conditions of the SCR catalyst under test are monitored by the measurement system:

Gas Flow Rate – The flue gas flow rate is measured by an averaging pitot tube in the exit of the simulated flue gas generator. The flow rate is also calculated from the mass flow controllers for the various gas constituents as they are added. Finally, an annubar is installed in the exhaust of the reactor which allows another cross-check of the flow rate. For the testing to be determined valid, the flow rate must be within the allowable limits from the target flow rate.

Gas Temperature – The temperature of the gas and the catalyst samples is measured by a series of thermocouples throughout the test reactor. For the testing to be determined valid, both the spatial and temporal variability must be within the allowable limits from the specified set point.

Component Concentration – The components of the flue gas are determined by the methods described below. Different systems may not have every type of sampling measurement system.

- *NOx* – Chemiluminescent NOx Analyzer / Infrared Spectroscopy. Average value at each sampling point recorded for each sampling cycle
- NH_3 – Ion Chromatography/infrared spectroscopy
- SO_2 – Precipitation Method/infrared spectroscopy
- SO_3 – Controlled Condensation; Collective Precipitation Method
- O_2 – Micro-fuel cell and Paramagnetic O_2 Analyzer

Procedure Description Summary

The following stepwise description is a guideline to understand how an audit proceeds from sample receipt to reported results.

1. Upon receipt, each sample is inspected for condition and photographed. The sample dimensions are recorded.
2. The Test Plan is prepared based on the needs of audit. The appropriate test apparatus is selected based on the test requirements and the test is scheduled.
3. Each sample is prepared for testing. [This process includes cleaning the sample, and cutting to the required test sample size.]
4. The reactor is opened, inspected, and prepared for operation.
5. Each catalyst sample is loaded according to the Test Plan and sealed in the reactor.
6. An equipment leak test is performed.

7. The Bulk Flue Gas Generator is started and the test conditions are set for O_2%, temperature, and bulk flow rate.
8. NO and NO_2 injection is started and then adjusted in order to meet the test conditions.
9. Ammonia, SO_2 and SO_3 injection is started and then adjusted in order to meet the test conditions.
10. The catalyst is allowed to equilibrate at the test conditions specified.
11. A calibration check is run for the analyzers.
12. For each sampling cycle, the following measurements are taken, as required:

Item	Location Measured	Frequency
NO_X Concentration	Multiplexed to measure NO_X at each sampling point	Average value at each sampling point recorded per each sampling cycle
NH_3 Concentration	At exit of sample[s]	Depends on test method [Multiple analyses recorded]
SO_2 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
SO_3 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
O_2 Concentration	Exit of combustion chamber and multiplexed with NO_X Analyzer	Continuously controlled and monitored
Gas Flow	Exit of combustion chamber	Continuously controlled and monitored
Gas Temperature	At each sampling port	Inlet continuously controlled
Pressure Drop	Entrance and at exit of testing chamber	Continuously monitored, recorded as required

13. The results are recorded and checked per Quality Assurance requirements and compared to the Test Plan.
14. The results are reported.

NRG GenConn Middletown
Unit 14

SCR Catalyst
Performance Test Report
632 Operating Hours
October 2019 Audit

Submitted by

CORMETECH, INC.
Environmental Technologies
5000 International Drive
Durham, NC 27712
(919) 620-3000

Max Morris
Project Engineer

Mark Conger
Sr. Project Engineer

Certifying Laboratory Representative
Silas Christian, Laboratory Manager

January 28, 2019

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EXECUTIVE SUMMARY

The following summarizes the key results for this audit of the NRG GenConn Middletown Unit 14 SCR after 632 operating hours since first gas-in.

Observations and Predictions

This audit of the GenConn Middletown Unit 14 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Middletown Unit 14 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,300 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

Field Data Commentary

Based on the provided operational data, GenConn Middletown Unit 14 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

Recommendations

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

PURPOSE

This test is conducted to audit the catalytic potential of an SCR catalyst by measuring the performance of a field catalyst sample that has been in operation for a known duration. The catalytic potential is measured by laboratory scale testing of field samples removed from the SCR. Performance tests are conducted in a controlled, laboratory environment allowing accurate comparisons of field sample catalytic potential to that of fresh catalyst. The deactivation rate is determined by comparing the change in catalytic potential to the operating hours of the sample.

Field performance, as indicated by plant-supplied measurements and observations, is also analyzed and discussed relative to the performance of the catalyst samples tested. Measured field performance in conjunction with laboratory measurements of field sample catalytic potential is used to determine actual unit scale-up factors. Utilizing actual unit scale-up factors significantly improves the accuracy of future performance predictions.

Further catalyst and/or field operation analysis may be recommended if laboratory test results are inconsistent with any of the following:

- Cormetech's experience base of comparable units
- The plant's reported field performance, if available
- The results of previous audits of the unit, if applicable
- The performance expectations for the unit.

BACKGROUND

In order to achieve the design performance requirements of a Selective Catalytic Reduction system for a specified timeframe (life) of the SCR catalyst, the catalyst formulation, structure, and volume are specifically designed to accommodate the system operating conditions, the predicted system scale-up factors, and a predicted rate of decrease in catalyst potential over time.

If any of the design or operating parameters above is not realized, then the actual duration that the design performance requirements can be met may deviate from the design life. The individual contribution of each parameter on actual life is described below. In actual practice, one or more of these parameters may deviate from design and either counteract or complement each other.

Performance Requirements: If the actual plant performance requirements are more severe than the design performance requirements, actual life will be less than design life. An example of this would be a unit that is required to achieve a higher NOx reduction than the unit was designed for.

Operating Conditions: Flue gas flow rate, inlet NO_X levels, temperature, oxygen content, and water content impact catalytic potential. If the catalyst is at an operating condition where the potential is lower than design, actual life will be less than design life.

Scale-Up Factors: The full NO_X reduction potential of the catalyst is not attained in the field due to non-ideal flow distribution, temperature distribution, ammonia to NO_X molar ratio distribution,

catalyst blockage, and/or flue gas bypass. Collectively, these non-ideal conditions are accounted for with 'system scale-up factors'. If the overall actual system scale-up factors are more severe than the design scale-up factors, then the potential of the SCR system to meet a given performance requirement is reduced.

Catalyst Deactivation Rate: Catalytic potential decreases over time. This catalyst deactivation rate has a direct impact on actual life. If the deactivation rate is more than design, then actual life is effectively reduced. If the deactivation rate is less than design, the actual life is effectively increased.

If the performance requirements, operating conditions, and/or scale-up factors are more severe than the initial design, less margin remains for catalyst deactivation. Therefore, actual life will be less than design life.

At any given time and operating condition, the SCR system performance is dictated by the NO_X reduction potential of the catalyst and the system scale-up factors. These factors reduce performance from the catalytic potential to the performance achievable in the operating SCR system.

Performance tests are purposefully conducted in a controlled environment, free from the scale-up factors that adversely affect SCR system performance, and at repeatable operating conditions, so that changes in catalytic potential may be evaluated accurately. Catalyst deactivation is determined by testing the field catalyst sample at the same operating conditions as the fresh sample.

In conjunction with performance test results, analysis of field SCR system performance data can confirm the field performance requirements, the plant operating conditions, and actual system scale-up factors.

Cormetech's SCR catalyst design and testing experience enables analysis of the actual versus design values of performance requirements, operating conditions, system scale-up, and catalyst deactivation to predict future catalyst performance.

FACILITY OPERATIONAL HISTORY

The SCR system at the GenConn Middletown Unit 14 consists of 1 layer of CM21MHT™ 70 cell catalyst. The unit was originally put into service on April 2011.

On October 18, 2019 one catalyst sample was removed from the field sampler at GenConn Middletown Unit 14 and returned to Cormetech for laboratory testing. At the time the sample was removed, the audited element had accumulated 632 operating hours. The results of the December 18, 2019 audit are summarized in this report.

PROCEDURE OVERVIEW

1. One catalyst sample was removed from the field sampler module at the GenConn Middletown Unit 14 SCR and was shipped to Cormetech's laboratory. Operating history was recorded by the plant and forwarded to Cormetech.

2. The physical condition of the catalyst was documented by Cormetech.

3. The catalyst was prepared and loaded into an Activity Test Apparatus and then evaluated at the original design conditions for the SCR. The Performance Test Standard Procedure is included in Appendix 3.

4. The results include catalyst potential expressed as NO_X removal efficiency at a constant 5 ppmvdc ammonia slip.

5. Test results were compared to design expectations and to the results of the fresh reference. Expectations of catalyst deactivation were determined by the time on-line and experience data of similar gas-fired facilities.

6. A catalyst life prediction is based on the above testing and analysis.

7. Additional data submitted by the plant was reviewed for the field performance of the SCR system.

FIELD SAMPLING AND UNIT OPERATING CONDITIONS

Field Sampling

One SCR catalyst sample from GenConn Middletown Unit 14 was removed and sent to Cormetech's Laboratory for evaluation. The sample retrieval location is shown in Appendix 1.

Operating Status

Field records supplied by GenConn Middletown are summarized in the table below. The field records are reproduced in Appendix 2.

First Gas-In Date with Catalyst Installed	4/29/2011
Sample Removal Date	October,18 2019
Total Operating Hours On Catalyst Sample	632
Primary Fuel Fired	Ultra-Low Sulfur Kerosene
Hours Burning Primary Fuel	569
Secondary Fuel Fired	Natural Gas
Hours Burning Secondary Fuel	64
Number of Starts and Stops since catalyst was installed	285

LABORATORY PERFORMANCE TEST CONDITIONS

A performance test was conducted on the sample received using the conditions below. These conditions reflect the original design conditions for which there is fresh catalyst test data available for direct comparison.

Temperature	442°C (828°F)
Entrance Gas Velocity	3.76 Nm/s
O_2	14.4 vol% dry
Inlet NO_X	46.0 ppmvd @ 14.4% O_2 (42.0 ppmvdc @ 15% O_2)

RESULTS

Sample Visual Inspection

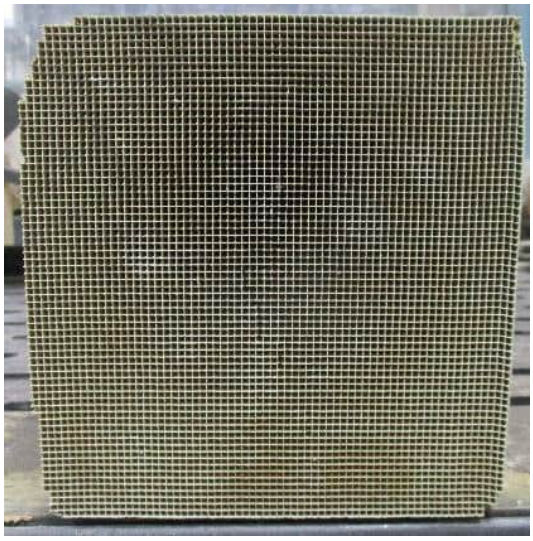
One field sample was received from the GenConn Middletown Unit 14 SCR.

Below are photographs of the flow entrance face and the flow exit face of the element with an as received inspection report.

Element ID	2389-1021-0331

Box Markings	NA
Sample Markings	GenConn Middletown Unit 14
Flow Direction Marked	Yes
Other Markings	None

Visual Inspection Notes	Element has damage on exit side
Product Description	CM21MHT^{tM}
Length, mm	446
Blocked Cell Count, as received	0
Blocked Cell Count, after light cleaning	0

Flow Entrance	*Flow Exit*
	

Results of Laboratory Tests

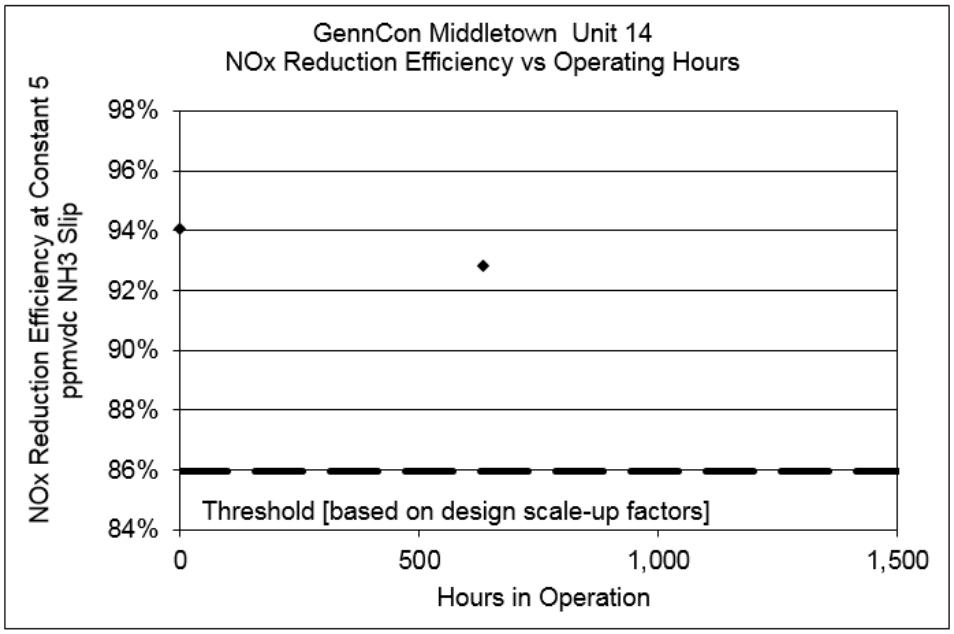
The catalyst performance below is reported under constant 5 ppmvdc ammonia slip and design operating conditions.

The lab performance threshold represents the design NO_X removal efficiency, as measured in lab apparatus, at which the actual *field* performance at *design* operating conditions is expected to reach end-of-life. Field performance is based on a design performance requirement of 85.9% NO_X removal efficiency and 5 ppmvdc ammonia slip.

In field scale (actual) operation, flow, temperature and ammonia/NOx non-uniformities exist. In the highly controlled laboratory environment these non-uniformities do not exist; therefore, the lab results must be scaled-up to reflect expected field performance. The scale-up factors limit achievable NO_X reduction performance in operating SCR systems. The performance threshold value is based on design values for the scale-up factors. The *actual* threshold may be lower if actual scale-up is less severe, or higher if more severe.

	Element ID	**Time On-Line** (Hours)	**NOx Removal Efficiency, %** at 5 ppmvdc NH_3 Slip
Fresh Reference	# 2389-2026-0403	0	94.06
October 2019 Audit	# 2389-1021-0331	632	92.84
Threshold (based on design scale-up factors)			85.9

The figure below shows the trend in catalyst performance.



This audit of the GenConn Middletown Unit 14 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Middletown Unit 14 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,300 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

FIELD DATA COMMENTARY

A review of field data has three primary purposes. First, the field data can show if any operating parameters are significantly different than the original design of the unit. Second, the field data can show if actual plant performance requirements are more severe than the design. If significant differences are evident in operating parameters or performance requirements, their effect on the performance threshold can be determined. Third, the field data can be used to examine if any factors that adversely impact scale-up are present. Typically the factors that adversely impact scale-up are as follows:

- Plugged/ poorly performing Ammonia Injection System resulting in poor mixing of the NH_3 prior to the catalyst.
- Flue gas flow velocity maldistribution.
- Flue gas flow bypass around the catalyst.
- Plugged catalyst.

Below is a table that compares the field data provided by GenConn Middletown Unit 14 SCR against the design criteria for the installed SCR catalyst:

Parameter	Design Value	Field Value (oil)	Field Value (gas)
Flue Gas Temperature (°F)	828	821	779
Flue Gas Flow Rate (lb/hr)	1,088,460	286,834 DSCFM	294299 DSCFM
Inlet NOx (ppmvd @ 15% O_2)	42	42 (estimated)	25 (estimated)
Outlet NOx (ppmvd @ 15% O_2)	5.9	2.27	1.43
NOx Reduction Efficiency (%)	85.9	94.5	94.3
NH_3 Slip (ppmvd @ 15% O_2)	5 (end of life)	3.6	4.1
NH_3 Flow Rate (lb/hr)	180 (end of life)	135.2	84.5
NH_3 Supply Concentration (wgt %)	19	19	19
Flue Gas O_2 Conc. (% vol dry)	14.4	14.8	15.1
Catalyst Pressure Drop (in. wg.)	5.1	4.8	4.7

Permit Limit

Outlet NOx = 5.9 ppmvd @ 15% O_2 (ULSK), 2.5 ppmvd @15% O_2 (Gas)
Ammonia Slip = 5 ppm

Based on the provided operational data, GenConn Middletown Unit 14 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

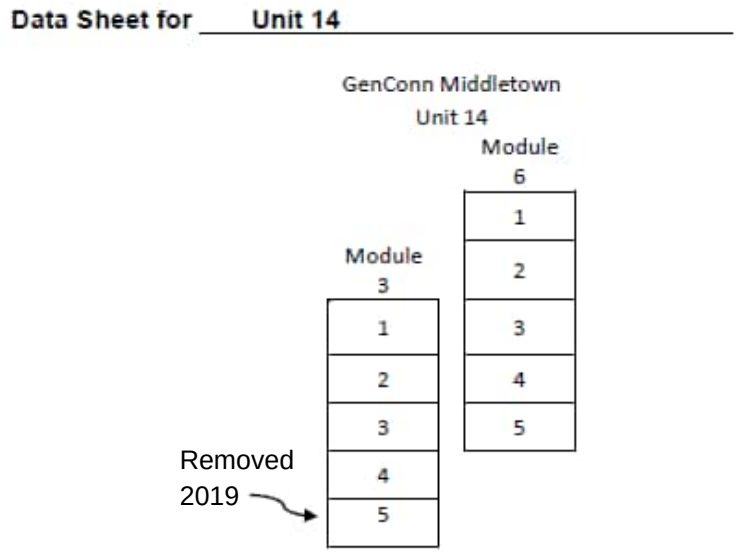
RECOMMENDATIONS

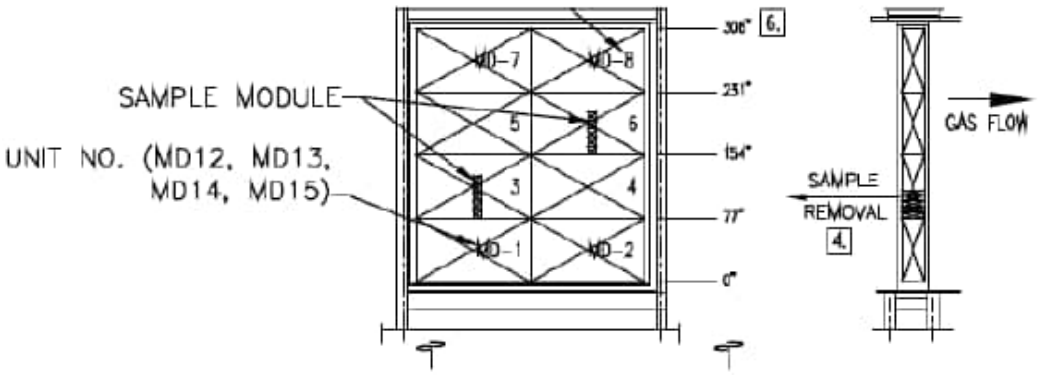
Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

APPENDIX 1: Location of Sample Retrieval

The sample retrieval location for GenConn Middletown Unit 14 is shown in the following schematic.





APPENDIX 2: Field Records

Field records received from GenConn Middletown are reproduced below

Facility Information	
Facility Owner	NRG
Facility Name	GenConn Middletown
Facility Street Address	1866 River Rd
City, State, Zip Code	Middletown, CT 06457
Unit Designation	Unit 14

Contact Information	*Person completing form*	*Person report goes to*
Name	Keith Shortsleeve	Keith Shortsleeve
Title	Environmental Engineer	Environmental Engineer
Telephone Number	860-638-3102	860-638-3102
E-mail Address	Keith.Shortsleeve@nrg.com	Keith.Shortsleeve@nrg.com

Sample Operational History		
Catalyst Installation Date	1/15/2011	
First Gas In Date	4/29/2011	
Sample Removal Date	10/18/2019	
Sample Removal Position *Indicate sampling position: Circle, Mark with 'X" or Note sampling position here* ***Unit 14 Module 3 Slot 5*** *View from Upstream Side*	See Page 4	
Removed Sample Element Serial Number, stamped on element	238910210351	
# Starts and Stops on Catalyst	Oil = 265, Gas = 20 (Total = 285)	
Operating Hours by Fuel Type	*# Operating Hours burning this fuel*	*Type of Fuel*
Primary Fuel	569	ULSK
Secondary Fuel	64	Natural Gas
Total # Operating Hours	632	

Important: Write directly on the removed sample element: the plant name and unit designation along with a gas flow directional arrow; permanent marker (preferred) or pencil okay.

Data Sheet for Unit 14

Present Operating Conditions				
	Units [Circle correct unit or change as required]	Value	Continuously monitored?	Measurement Method [1]
Flue Gas Temperature (at SCR)	°F or °C	Oil=821 Gas=779	Y	
Flue Gas Flow Rate	Lb/hr wet dscfm	Oil=286834 Gas=294299	N	4/28/16 CK Stack Test
SCR Inlet NOx	ppmvd @_15__% O_2	Oil=42 Gas=25	N	Estimated
SCR Outlet NOx	ppmvd @_15___% O_2	Oil=2.27 Gas=1.43	N	6/17/16 CK Stack Test
NH_3 Slip	ppmvd @__15__% O_2	Oil=3.6 Gas=4.1	N	Stack Test
NH_3 Flow rate	lb/hr	Oil=135.2 Gas=84.5	N	6/16-6/17/16 CK Stack Test
NH_3 Supply Concentration	wgt %	19-19.5%	N	Supplier Analysis
Flue gas O_2 Concentration	Dry Volume %	Oil=14.8 Gas=15.1	N	Stack Test
Flue gas H_2O Concentration	Volume %	Oil=8.5 Gas=9.9	N	Stack Test
Catalyst Pressure Drop	iwg or mm Hg	Oil=4.8 Gas=4.7	Y	DEM Data

[1]Method of measurement and accuracy should be provided for all measured values, i.e., flow (boiler load signal or stack measurement), NOx (dilution method chemiluminescence), NH_3 (chemiluminescence subtraction method, ammonia flow gpm/± 5%, etc.).

Permit Limits	(List units as appropriate)
NOx Out	[Gas 4.4 lb/hr; 2.5 ppmvd@15% O_2][OIL 10.5 lb/hr; 5.9 ppmvd@ 15% O_2]
NH_3 Slip Out	3.27 ppmvd@ 15% O2 (OIL) 4.6 ppmvd @ 15% O2 (GAS)
NOx Removal	95%

APPENDIX 3: Performance Test Standard Procedure

Purpose

The *laboratory performance testing* for SCR catalyst is conducted to determine the catalytic potential of a representative sample of SCR catalyst at conditions that closely match the actual operating conditions of the SCR system. The sample should represent a typical cross section of the SCR, and the operating history should be known. The test is conducted in a controlled, laboratory environment on custom-built, rigorously validated SCR catalyst test apparatus allowing accurate determination of performance and comparisons of the sample catalytic potential to the system requirements previously tested catalyst(s).

Test Equipment Description

The Cormetech Laboratory SCR test reactors consist of three basic systems:

- Simulated flue gas generator
- SCR catalyst test chamber
- Measurement system

The purpose of the simulated flue gas generator is to provide a stable controlled supply of heated gas with the required mix of gases at the required flow rate and temperature to the SCR catalyst test chamber. It consists of a bulk flue gas generator, a flue gas modification system, a flue gas heater, a reactive gas injection system, and a flue gas mixer.

Bulk Flue Gas Generator -The bulk flue gas is produced by either the combustion of air in a natural gas fired water-cooled combustion chamber, the extraction of nitrogen from air via a membrane system, or the delivery of nitrogen from liquefied nitrogen. This system is adjusted to achieve the overall flue gas flow rate required for the specified test.

Flue Gas Modification System – The gas stream produced by the bulk flue gas generator is modified by the addition of oxygen/air and water/steam to achieve the targeted concentrations of water vapor and oxygen in the flue gas stream.

Flue Gas Heater – The flue gas stream is heated to the target test temperature by an electric pre-heater.

Reactive Gas Injection System – Calibrated mass flow controllers are used to deliver SO_2, SO_3, NO_2, NO, and NH_3 into the flue gas stream.

The table below summarizes the range of process conditions that can be produced by various apparatus in Cormetech's laboratory. Cormetech's laboratory maintains multiple testing units, each with varying capabilities for temperature, flow, and gas composition. The unit selected for a given test will depend on the specific requirements for the sample tested.

Parameter	Units	Range
Gas Temperature	^{o}C	200 – 600
Flow rate/Entrance velocity	Nm/s	1.25 - 7.05
O_2	volume % dry	1 – 20
H_2O	volume %	1-20[1]
NO	ppmvd	0 - 2,000
NO_2	ppmvd	0 - 2000[2]
NH_3	ppmvd	0 - 4,000
SO_2	ppmvd	0 - 2,000
SO_3	ppmvd	0 – 25

1: Some apparatus have the capability to control water concentration. Other units supply water as a product of combustion. When water concentration is not controlled, Cormetech corrects the results to the target concentration with a standardized correction factor.
2: NO_2 addition capability is not available on all test units.

Flue Gas Mixer – Following the reactive gas injection, the gases are mixed using a high efficiency static mixing element.

The simulated flue gas next enters the SCR test reactor where the SCR test sample or samples are located. Each sample is sealed tightly to the walls of the test chamber to ensure that all of the flue gas passes though the sample[s]. Along the length of the test chamber there are electric heating elements that maintain the specified test temperature. There are test ports located at the entrance to the test reactor and at the exit of each sample layer to extract a sample of flue gas for analysis, measure the static pressure of the flue gas, and monitor the temperature of the catalyst samples and the flue gas.

The process conditions of the SCR catalyst under test are monitored by the measurement system:

Gas Flow Rate – The flue gas flow rate is measured by an averaging pitot tube in the exit of the simulated flue gas generator. The flow rate is also calculated from the mass flow controllers for the various gas constituents as they are added. Finally, an annubar is installed in the exhaust of the reactor which allows another cross-check of the flow rate. For the testing to be determined valid, the flow rate must be within the allowable limits from the target flow rate.

Gas Temperature – The temperature of the gas and the catalyst samples is measured by a series of thermocouples throughout the test reactor. For the testing to be determined valid, both the spatial and temporal variability must be within the allowable limits from the specified set point.

Component Concentration – The components of the flue gas are determined by the methods described below. Different systems may not have every type of sampling measurement system.

- *NOx* – Chemiluminescent NOx Analyzer / Infrared Spectroscopy. Average value at each sampling point recorded for each sampling cycle
- NH_3 – Ion Chromatography/infrared spectroscopy
- SO_2 – Precipitation Method/infrared spectroscopy
- SO_3 – Controlled Condensation; Collective Precipitation Method
- O_2 – Micro-fuel cell and Paramagnetic O_2 Analyzer

Procedure Description Summary

The following stepwise description is a guideline to understand how an audit proceeds from sample receipt to reported results.

1. Upon receipt, each sample is inspected for condition and photographed. The sample dimensions are recorded.
2. The Test Plan is prepared based on the needs of audit. The appropriate test apparatus is selected based on the test requirements and the test is scheduled.
3. Each sample is prepared for testing. [This process includes cleaning the sample, and cutting to the required test sample size.]
4. The reactor is opened, inspected, and prepared for operation.
5. Each catalyst sample is loaded according to the Test Plan and sealed in the reactor.
6. An equipment leak test is performed.

7. The Bulk Flue Gas Generator is started and the test conditions are set for O_2%, temperature, and bulk flow rate.
8. NO and NO_2 injection is started and then adjusted in order to meet the test conditions.
9. Ammonia, SO_2 and SO_3 injection is started and then adjusted in order to meet the test conditions.
10. The catalyst is allowed to equilibrate at the test conditions specified.
11. A calibration check is run for the analyzers.
12. For each sampling cycle, the following measurements are taken, as required:

Item	Location Measured	Frequency
NO_X Concentration	Multiplexed to measure NO_X at each sampling point	Average value at each sampling point recorded per each sampling cycle
NH_3 Concentration	At exit of sample[s]	Depends on test method [Multiple analyses recorded]
SO_2 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
SO_3 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
O_2 Concentration	Exit of combustion chamber and multiplexed with NO_X Analyzer	Continuously controlled and monitored
Gas Flow	Exit of combustion chamber	Continuously controlled and monitored
Gas Temperature	At each sampling port	Inlet continuously controlled
Pressure Drop	Entrance and at exit of testing chamber	Continuously monitored, recorded as required

13. The results are recorded and checked per Quality Assurance requirements and compared to the Test Plan.
14. The results are reported.

CORMETECH

NRG GenConn Middletown
Unit 15

SCR Catalyst Performance Test Report 640 Operating Hours October 2019 Audit

Submitted by

CORMETECH, INC.
Environmental Technologies
5000 International Drive
Durham, NC 27712
(919) 620-3000

Max Morris
Project Engineer

Mark Conger
Sr. Project Engineer

Certifying Laboratory Representative
Silas Christian, Laboratory Manager

January 28, 2020

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EXECUTIVE SUMMARY

The following summarizes the key results for this audit of the NRG GenConn Middletown Unit 15 SCR after 640 operating hours since first gas-in.

Observations and Predictions

This audit of the GenConn Middletown Unit 15 SCR catalyst shows a measurable decrease in catalytic potential of the SCR catalyst, as measured by lab-scale testing. Based on the results of this audit, the SCR catalyst installed for GenConn Middletown Unit 15 is above the performance threshold and is projected to continue to meet the field performance requirements of 85.9% NO_X reduction at 5 ppmvdc ammonia slip for at least an additional 1,300 operating hours from the date this sample was removed. Due to the low operating hours and that this is the first audit, the life prediction is likely conservative.

This prediction assumes that catalyst deactivation will continue at the same rate as measured over the operating hours to date. If this rate of deactivation changes, the prediction of remaining catalyst life will change accordingly; therefore, Cormetech recommends performing regular field performance and laboratory catalyst audits.

Field Data Commentary

Based on the provided operational data, GenConn Middletown Unit 15 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

Recommendations

Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

PURPOSE

This test is conducted to audit the catalytic potential of an SCR catalyst by measuring the performance of a field catalyst sample that has been in operation for a known duration. The catalytic potential is measured by laboratory scale testing of field samples removed from the SCR. Performance tests are conducted in a controlled, laboratory environment allowing accurate comparisons of field sample catalytic potential to that of fresh catalyst. The deactivation rate is determined by comparing the change in catalytic potential to the operating hours of the sample.

Field performance, as indicated by plant-supplied measurements and observations, is also analyzed and discussed relative to the performance of the catalyst samples tested. Measured field performance in conjunction with laboratory measurements of field sample catalytic potential is used to determine actual unit scale-up factors. Utilizing actual unit scale-up factors significantly improves the accuracy of future performance predictions.

Further catalyst and/or field operation analysis may be recommended if laboratory test results are inconsistent with any of the following:

- Cormetech's experience base of comparable units
- The plant's reported field performance, if available
- The results of previous audits of the unit, if applicable
- The performance expectations for the unit.

BACKGROUND

In order to achieve the design performance requirements of a Selective Catalytic Reduction system for a specified timeframe (life) of the SCR catalyst, the catalyst formulation, structure, and volume are specifically designed to accommodate the system operating conditions, the predicted system scale-up factors, and a predicted rate of decrease in catalyst potential over time.

If any of the design or operating parameters above is not realized, then the actual duration that the design performance requirements can be met may deviate from the design life. The individual contribution of each parameter on actual life is described below. In actual practice, one or more of these parameters may deviate from design and either counteract or complement each other.

Performance Requirements: If the actual plant performance requirements are more severe than the design performance requirements, actual life will be less than design life. An example of this would be a unit that is required to achieve a higher NOx reduction than the unit was designed for.

Operating Conditions: Flue gas flow rate, inlet NO_X levels, temperature, oxygen content, and water content impact catalytic potential. If the catalyst is at an operating condition where the potential is lower than design, actual life will be less than design life.

Scale-Up Factors: The full NO_X reduction potential of the catalyst is not attained in the field due to non-ideal flow distribution, temperature distribution, ammonia to NO_X molar ratio distribution,

catalyst blockage, and/or flue gas bypass. Collectively, these non-ideal conditions are accounted for with 'system scale-up factors'. If the overall actual system scale-up factors are more severe than the design scale-up factors, then the potential of the SCR system to meet a given performance requirement is reduced.

Catalyst Deactivation Rate: Catalytic potential decreases over time. This catalyst deactivation rate has a direct impact on actual life. If the deactivation rate is more than design, then actual life is effectively reduced. If the deactivation rate is less than design, the actual life is effectively increased.

If the performance requirements, operating conditions, and/or scale-up factors are more severe than the initial design, less margin remains for catalyst deactivation. Therefore, actual life will be less than design life.

At any given time and operating condition, the SCR system performance is dictated by the NO_X reduction potential of the catalyst and the system scale-up factors. These factors reduce performance from the catalytic potential to the performance achievable in the operating SCR system.

Performance tests are purposefully conducted in a controlled environment, free from the scale-up factors that adversely affect SCR system performance, and at repeatable operating conditions, so that changes in catalytic potential may be evaluated accurately. Catalyst deactivation is determined by testing the field catalyst sample at the same operating conditions as the fresh sample.

In conjunction with performance test results, analysis of field SCR system performance data can confirm the field performance requirements, the plant operating conditions, and actual system scale-up factors.

Cormetech's SCR catalyst design and testing experience enables analysis of the actual versus design values of performance requirements, operating conditions, system scale-up, and catalyst deactivation to predict future catalyst performance.

FACILITY OPERATIONAL HISTORY

The SCR system at the GenConn Middletown Unit 15 consists of 1 layer of CM21MHT™ 70 cell catalyst. The unit was originally put into service on May 2011.

On October 21, 2019 one catalyst sample was removed from the field sampler at GenConn Middletown Unit 15 and returned to Cormetech for laboratory testing. At the time the sample was removed, the audited element had accumulated 640 operating hours. The results of the December 18, 2019 audit are summarized in this report.

PROCEDURE OVERVIEW

1. One catalyst sample was removed from the field sampler module at the GenConn Middletown Unit 15 SCR and was shipped to Cormetech's laboratory. Operating history was recorded by the plant and forwarded to Cormetech.

2. The physical condition of the catalyst was documented by Cormetech.

3. The catalyst was prepared and loaded into an Activity Test Apparatus and then evaluated at the original design conditions for the SCR. The Performance Test Standard Procedure is included in Appendix 3.

4. The results include catalyst potential expressed as NO_X removal efficiency at a constant 5 ppmvdc ammonia slip.

5. Test results were compared to design expectations and to the results of the fresh reference. Expectations of catalyst deactivation were determined by the time on-line and experience data of similar gas-fired facilities.

6. A catalyst life prediction is based on the above testing and analysis.

7. Additional data submitted by the plant was reviewed for the field performance of the SCR system.

FIELD SAMPLING AND UNIT OPERATING CONDITIONS

Field Sampling

One SCR catalyst sample from GenConn Middletown Unit 15 was removed and sent to Cormetech's Laboratory for evaluation. The sample retrieval location is shown in Appendix 1.

Operating Status

Field records supplied by GenConn Middletown are summarized in the table below. The field records are reproduced in Appendix 2.

First Gas-In Date with Catalyst Installed	5/2/2011
Sample Removal Date	October,21 2019
Total Operating Hours On Catalyst Sample	640
Primary Fuel Fired	Ultra-Low Sulfur Kerosene
Hours Burning Primary Fuel	569
Secondary Fuel Fired	Natural Gas
Hours Burning Secondary Fuel	72
Number of Starts and Stops since catalyst was installed	282

LABORATORY PERFORMANCE TEST CONDITIONS

A performance test was conducted on the sample received using the conditions below. These conditions reflect the original design conditions for which there is fresh catalyst test data available for direct comparison.

Temperature	442°C (828°F)
Entrance Gas Velocity	3.76 Nm/s
O_2	14.4 vol% dry
Inlet NO_X	46.0 ppmvd @ 14.4% O_2 (42.0 ppmvdc @ 15% O_2)

RESULTS

Sample Visual Inspection

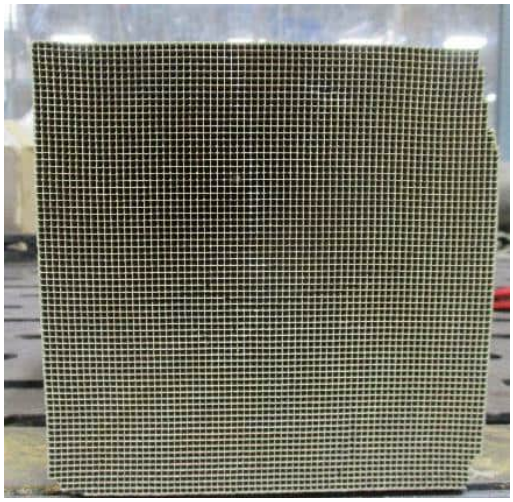
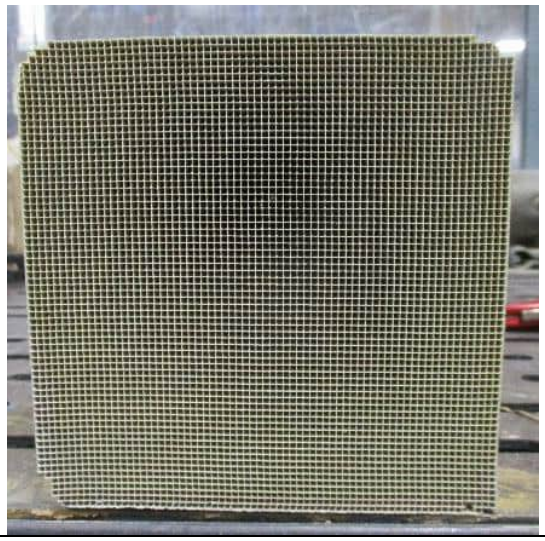
One field sample was received from the GenConn Middletown Unit 15 SCR.

Below are photographs of the flow entrance face and the flow exit face of the element with an as received inspection report.

Element ID	2389-1021-0340

Box Markings	NA
Sample Markings	GenConn Middletown Unit 15
Flow Direction Marked	Yes
Other Markings	None

Visual Inspection Notes	Element condition is good
Product Description	CM21MHT^{tM}
Length, mm	447
Blocked Cell Count, as received	0
Blocked Cell Count, after light cleaning	0

Flow Entrance	*Flow Exit*
	

Results of Laboratory Tests

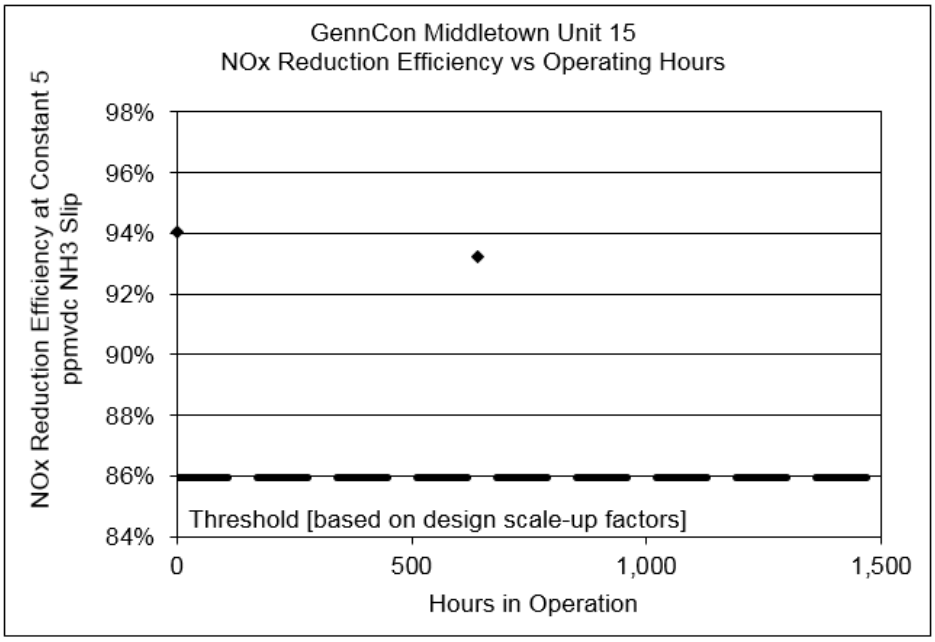
The catalyst performance below is reported under constant 5 ppmvdc ammonia slip and design operating conditions.

The lab performance threshold represents the design NO_X removal efficiency, as measured in lab apparatus, at which the actual *field* performance at *design* operating conditions is expected to reach end-of-life. Field performance is based on a design performance requirement of 85.9% NO_X removal efficiency and 5 ppmvdc ammonia slip.

In field scale (actual) operation, flow, temperature and ammonia/NOx non-uniformities exist. In the highly controlled laboratory environment these non-uniformities do not exist; therefore, the lab results must be scaled-up to reflect expected field performance. The scale-up factors limit achievable NO_X reduction performance in operating SCR systems. The performance threshold value is based on design values for the scale-up factors. The *actual* threshold may be lower if actual scale-up is less severe, or higher if more severe.

	Element ID	**Time On-Line** (Hours)	**NOx Removal Efficiency, %** at 5 ppmvdc NH_3 Slip
Fresh Reference	# 2389-2026-0403	0	94.06
October 2019 Audit	# 2389-1021-0340	640	93.21
Threshold (based on design scale-up factors)			85.9

The figure below shows the trend in catalyst performance.



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- Plugged/ poorly performing Ammonia Injection System resulting in poor mixing of the NH_3 prior to the catalyst.
- Flue gas flow velocity maldistribution.
- Flue gas flow bypass around the catalyst.
- Plugged catalyst.

Below is a table that compares the field data provided by GenConn Middletown Unit 15 SCR against the design criteria for the installed SCR catalyst:

Parameter	Design Value	Field Value (oil)	Field Value (gas)
Flue Gas Temperature (°F)	828	812	769
Flue Gas Flow Rate (lb/hr)	1,088,460	287,389 DSCFM	291,163 DSCFM
Inlet NOx (ppmvd @ 15% O_2)	42	42 (estimated)	25 (estimated)
Outlet NOx (ppmvd @ 15% O_2)	5.9	1.74	1.36
NOx Reduction Efficiency (%)	85.9	95.8	94.5
NH_3 Slip (ppmvd @ 15% O_2)	5 (end of life)	3.5	4.82
NH_3 Flow Rate (lb/hr)	180 (end of life)	146.2	73.7
NH_3 Supply Concentration (wgt %)	19	19	19
Flue Gas O_2 Conc. (% vol dry)	14.4	15	15.1
Catalyst Pressure Drop (in. wg.)	5.1	4.9	4.7

Permit Limit

Outlet NOx = 5.9 ppmvd @ 15% O_2 (ULSK), 2.5 ppmvd @15% O_2 (Gas)
Ammonia Slip = 5 ppm

Based on the provided operational data, GenConn Middletown Unit 15 is operating well in the field and meeting permit limits. The measured ammonia slip and flow rate are lower than expected given the other parameters and lab measured activity of the catalyst, indicating good performance.

In both oil fired and gas fired conditions, the outlet NO_x is being driven well below the permit limit. This increases the NO_x reduction efficiency resulting in a higher level of performance than the design of the catalyst. As the catalyst deactivates over time the outlet NO_x will need to be maintained closer to the permit requirements to maintain ammonia slip under 5 ppmvdc.

RECOMMENDATIONS

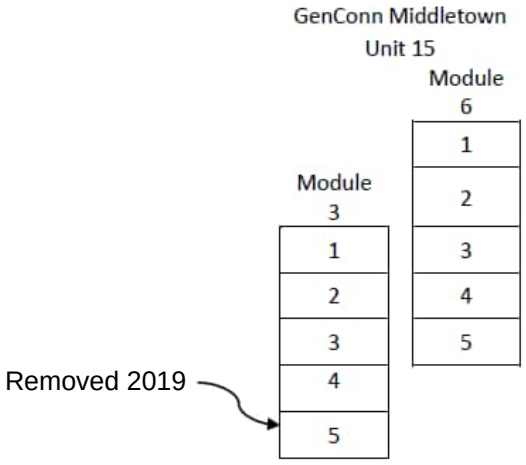
Regular laboratory catalyst testing is recommended to refine the accuracy of the remaining catalyst life prediction. The next audit should occur after an additional 600 hours of operation or three years, whichever is first, from the time the sample for this audit was removed.

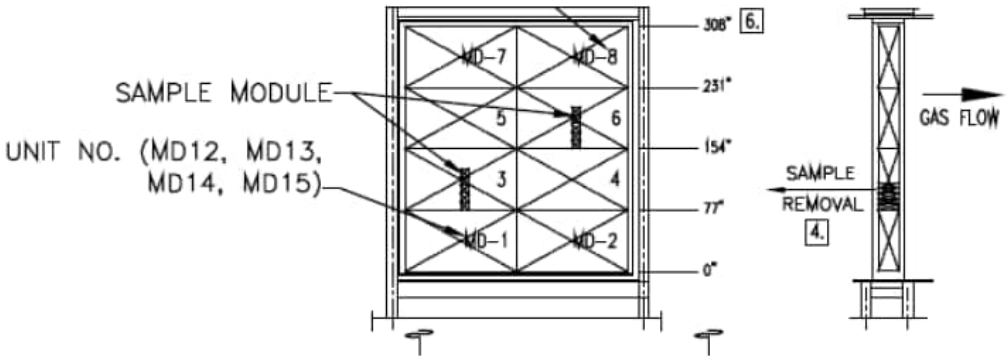
Continued review of field test data to accurately confirm actual performance requirements, operating conditions, and system scale-up factors, and thereby the appropriate laboratory scale performance threshold is recommended.

APPENDIX 1: Location of Sample Retrieval

The sample retrieval location for GenConn Middletown Unit 15 is shown in the following schematic.

Data Sheet for Unit 15





APPENDIX 2: Field Records

Field records received from GenConn Middletown are reproduced below

Facility Information	
Facility Owner	NRG
Facility Name	GenConn Middletown
Facility Street Address	1866 River Rd
City, State, Zip Code	Middletown, CT 06457
Unit Designation	Unit 15

Contact Information	*Person completing form*	*Person report goes to*
Name	Keith Shortsleeve	Keith Shortsleeve
Title	Environmental Engineer	Environmental Engineer
Telephone Number	860-638-3102	860-638-3102
E-mail Address	Keith.Shortsleeve@nrg.com	keith.shortsleeve@nrg.com

Sample Operational History		
Catalyst Installation Date	2/15/2011	
First Gas In Date	5/2/2011	
Sample Removal Date	10/21/2019	
Sample Removal Position *Indicate sampling position: Circle, Mark with 'X" or Note sampling position here* ***Unit 15 Module 3 Slot 5*** *View from Upstream Side*	See Page 4	
Removed Sample Element Serial Number, stamped on element	238910210340	
# Starts and Stops on Catalyst	Oil = 260, Gas = 22 (Total = 282)	
Operating Hours by Fuel Type	*# Operating Hours burning this fuel*	*Type of Fuel*
Primary Fuel	568	ULSK
Secondary Fuel	72	Natural Gas
Total # Operating Hours	640	

Important: Write directly on the removed sample element: the plant name and unit designation along with a gas flow directional arrow; permanent marker (preferred) or pencil okay.

Data Sheet for Unit 15

Present Operating Conditions				
	Units [Circle correct unit or change as required]	Value	Continuously monitored?	Measurement Method [1]
Flue Gas Temperature (at SCR)	°F or °C	Oil=812 Gas=769	Y	Stack Measurement
Flue Gas Flow Rate	Lb/hr wet dscfm	Oil= 287389 Gas=291163	N	4/26/16 CK Stack Test
SCR Inlet NOx	ppmvd @__15__% O_2	Oil==42 Gas=25	N	Estimated
SCR Outlet NOx	ppmvd @_15___% O_2	Oil=1.74 Gas=1.36	N	6/22-6/23/16 CK Stack Test
NH_3 Slip	ppmvd @__15__% O_2	Oil=3.5 Gas=4.82	N	6/7/16 TRC Stack Test
NH_3 Flow rate	lb/hr	Oil=146.2 Gas=73.7	N	
NH_3 Supply Concentration	wgt %	19-19.5%	N	Supplier Analysis
Flue gas O_2 Concentration	Dry Volume %	Oil=15.0 Gas=15.1	N	6/22-6/23/16 CK Stack Test
Flue gas H_2O Concentration	Volume %	Oil=8.0 Gas=12.42	N	6-7-6 TRC Stack Test
Catalyst Pressure Drop	iwg or mm Hg	Oil=4.9 Gas=4.7	Y	CEM Data

[1]Method of measurement and accuracy should be provided for all measured values, i.e., flow (boiler load signal or stack measurement), NOx (dilution method chemiluminescence), NH_3 (chemiluminescence subtr

action method, ammonia flow gpm/± 5%, etc.).

Permit Limits	(List units as appropriate)
NOx Out	[Gas 4.4 lb/hr; 2.5 ppmvd@15% O_2][OIL 10.5 lb/hr; 5.9 ppmvd@ 15% O_2]
NH_3 Slip Out	3.27 ppmvd@ 15% O2 (OIL) 4.6 ppmvd @ 15% O2 (GAS)
NOx Removal	95%

APPENDIX 3: Performance Test Standard Procedure

Purpose

The *laboratory performance testing* for SCR catalyst is conducted to determine the catalytic potential of a representative sample of SCR catalyst at conditions that closely match the actual operating conditions of the SCR system. The sample should represent a typical cross section of the SCR, and the operating history should be known. The test is conducted in a controlled, laboratory environment on custom-built, rigorously validated SCR catalyst test apparatus allowing accurate determination of performance and comparisons of the sample catalytic potential to the system requirements previously tested catalyst(s).

Test Equipment Description

The Cormetech Laboratory SCR test reactors consist of three basic systems:

- Simulated flue gas generator
- SCR catalyst test chamber
- Measurement system

The purpose of the simulated flue gas generator is to provide a stable controlled supply of heated gas with the required mix of gases at the required flow rate and temperature to the SCR catalyst test chamber. It consists of a bulk flue gas generator, a flue gas modification system, a flue gas heater, a reactive gas injection system, and a flue gas mixer.

Bulk Flue Gas Generator -The bulk flue gas is produced by either the combustion of air in a natural gas fired water-cooled combustion chamber, the extraction of nitrogen from air via a membrane system, or the delivery of nitrogen from liquefied nitrogen. This system is adjusted to achieve the overall flue gas flow rate required for the specified test.

Flue Gas Modification System – The gas stream produced by the bulk flue gas generator is modified by the addition of oxygen/air and water/steam to achieve the targeted concentrations of water vapor and oxygen in the flue gas stream.

Flue Gas Heater – The flue gas stream is heated to the target test temperature by an electric pre-heater.

Reactive Gas Injection System – Calibrated mass flow controllers are used to deliver SO_2, SO_3, NO_2, NO, and NH_3 into the flue gas stream.

The table below summarizes the range of process conditions that can be produced by various apparatus in Cormetech's laboratory. Cormetech's laboratory maintains multiple testing units, each with varying capabilities for temperature, flow, and gas composition. The unit selected for a given test will depend on the specific requirements for the sample tested.

Parameter	Units	Range
Gas Temperature	°C	200 – 600
Flow rate/Entrance velocity	Nm/s	1.25 - 7.05
O_2	volume % dry	1 – 20
H_2O	volume %	1-20[1]
NO	ppmvd	0 - 2,000
NO_2	ppmvd	0 - 2000[2]
NH_3	ppmvd	0 - 4,000
SO_2	ppmvd	0 - 2,000
SO_3	ppmvd	0 – 25

1: Some apparatus have the capability to control water concentration. Other units supply water as a product of combustion. When water concentration is not controlled, Cormetech corrects the results to the target concentration with a standardized correction factor.
2: NO_2 addition capability is not available on all test units.

Flue Gas Mixer – Following the reactive gas injection, the gases are mixed using a high efficiency static mixing element.

The simulated flue gas next enters the SCR test reactor where the SCR test sample or samples are located. Each sample is sealed tightly to the walls of the test chamber to ensure that all of the flue gas passes though the sample[s]. Along the length of the test chamber there are electric heating elements that maintain the specified test temperature. There are test ports located at the entrance to the test reactor and at the exit of each sample layer to extract a sample of flue gas for analysis, measure the static pressure of the flue gas, and monitor the temperature of the catalyst samples and the flue gas.

The process conditions of the SCR catalyst under test are monitored by the measurement system:

Gas Flow Rate – The flue gas flow rate is measured by an averaging pitot tube in the exit of the simulated flue gas generator. The flow rate is also calculated from the mass flow controllers for the various gas constituents as they are added. Finally, an annubar is installed in the exhaust of the reactor which allows another cross-check of the flow rate. For the testing to be determined valid, the flow rate must be within the allowable limits from the target flow rate.

Gas Temperature – The temperature of the gas and the catalyst samples is measured by a series of thermocouples throughout the test reactor. For the testing to be determined valid, both the spatial and temporal variability must be within the allowable limits from the specified set point.

Component Concentration – The components of the flue gas are determined by the methods described below. Different systems may not have every type of sampling measurement system.

- *NOx* – Chemiluminescent NOx Analyzer / Infrared Spectroscopy. Average value at each sampling point recorded for each sampling cycle
- NH_3 – Ion Chromatography/infrared spectroscopy
- SO_2 – Precipitation Method/infrared spectroscopy
- SO_3 – Controlled Condensation; Collective Precipitation Method
- O_2 – Micro-fuel cell and Paramagnetic O_2 Analyzer

Procedure Description Summary

The following stepwise description is a guideline to understand how an audit proceeds from sample receipt to reported results.

1. Upon receipt, each sample is inspected for condition and photographed. The sample dimensions are recorded.
2. The Test Plan is prepared based on the needs of audit. The appropriate test apparatus is selected based on the test requirements and the test is scheduled.
3. Each sample is prepared for testing. [This process includes cleaning the sample, and cutting to the required test sample size.]
4. The reactor is opened, inspected, and prepared for operation.
5. Each catalyst sample is loaded according to the Test Plan and sealed in the reactor.
6. An equipment leak test is performed.

7. The Bulk Flue Gas Generator is started and the test conditions are set for O_2%, temperature, and bulk flow rate.
8. NO and NO_2 injection is started and then adjusted in order to meet the test conditions.
9. Ammonia, SO_2 and SO_3 injection is started and then adjusted in order to meet the test conditions.
10. The catalyst is allowed to equilibrate at the test conditions specified.
11. A calibration check is run for the analyzers.
12. For each sampling cycle, the following measurements are taken, as required:

Item	Location Measured	Frequency
NO_X Concentration	Multiplexed to measure NO_X at each sampling point	Average value at each sampling point recorded per each sampling cycle
NH_3 Concentration	At exit of sample[s]	Depends on test method [Multiple analyses recorded]
SO_2 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
SO_3 Concentration	Entrance and at each sampling port	When SO_2 oxidation performance is measured
O_2 Concentration	Exit of combustion chamber and multiplexed with NO_X Analyzer	Continuously controlled and monitored
Gas Flow	Exit of combustion chamber	Continuously controlled and monitored
Gas Temperature	At each sampling port	Inlet continuously controlled
Pressure Drop	Entrance and at exit of testing chamber	Continuously monitored, recorded as required

13. The results are recorded and checked per Quality Assurance requirements and compared to the Test Plan.
14. The results are reported.