GT Emission Control and Exhaust systems

Route map and Summary for the Decision Guide and Gas Turbine Decisions

Uses of GT Emission Control and Exhaust system route map and summary

Initial Use

- Sent to potential attendees in advance and continually revised
- Updated version to be used in webinar on August 6
- Foundation for discussions which will expand the knowledge base
- Focus on what is new and not what is already in Gas turbine Combined Cycle Decisions
- High level discussion to help turbine owners choose the best products and services

Longer Term use

- The route map and the recording of the August 6 discussion will be permanently posted in the GTCC Emission control and Exhaust system Decision Guide
- The Decision Guide is a subsidiary website which is part of 59D Gas Turbine and Combined Cycle Decisions
- This service is provided at no charge to any turbine operator anywhere in the world

Table of Contents

Regulations

Regulatory requirements- Pollutant

Particulate, Nox, Ammonia, VOCs, CO, noise

Regulatory requirements- location

U.S, California, Netherlands, EU, Japan, Taiwan, S. Korea

Regulation requirements

- **SCR is BACT for Gas Turbines in the Netherlands**
- Mid sized gas turbines burning either liquid or gaseous fuel have to meet Nox emissions of 140 mg/Nm3. SCR is considered BACT
- **Air Pollution Control for Gas Turbines Webinar - Hot Topic Hour September 19, 2013**
- - Fossil Fuel 化石燃料, Haldor Topsoe, Mitsubishi Power Systems, Eneractive Solutions, Ammonia Injection Grid, Catalyst, SCR, Ammonia, Nox Control, Air Pollution Control

Particulate and ambient air Emissions

- **Fine PM Emission Factors for Gas Turbine Engines by Glenn England, Environ – Hot Topic Hour April 17, 2014**
- EPA Methods 201A and 202 (and similar methods) remain problematic for gas-fired sources. Dilution methods offer advantages for gas-fired sources.
- **Impact of Ambient Air Quality Rules on Fossil-fueled Boilers and Gas Turbines Webinar - Hot Topic Hour February 13, 2014**
- Over 20 utillity personnel signed up for the webinar. Four experts weighed in on the impact of existing and proposed NAAQS standards
- **Dealing with Implementation of the 1-Hour SO2 NAAQS: Challenges and Options by Brian Stormwind, AECOM - Hot Topic Hour February 13, 2014**
- Brian offered advice on "Dealing with Implementation of the 1-hour SO2 NAAQS - Challenges and Options"
- **Dark Skies Ahead: Modeling the New NAAQS by Richard Hamel, Environmental Resources Management - Hot Topic Hour February 13, 2014**
- The new 1-hour SO2 and NO2 probabilistic NAAQS, as well as the newly tightened annual PM2.5 standard and the already stringent 24-hour PM2.5 standard, have brought to the table a whole new set of challenges.
- **National Ambient Air Quality Standards (NAAQS) by Mack McGuffey, Troutman Sanders - Hot Topic Hour February 13, 2014**
- Mack conveyed the impact and status of the NAAQS
- **Understanding Today's CAA Permitting Programs: Air Quality Modeling Update by Gale Hoffnagle, TRC Environmental - Hot Topic Hour February 13, 2014**
- Gale enumerated problems related to obtaining permits under the new NAAQS

New Sources and non attainment areas require Nox reduction (Peerless)

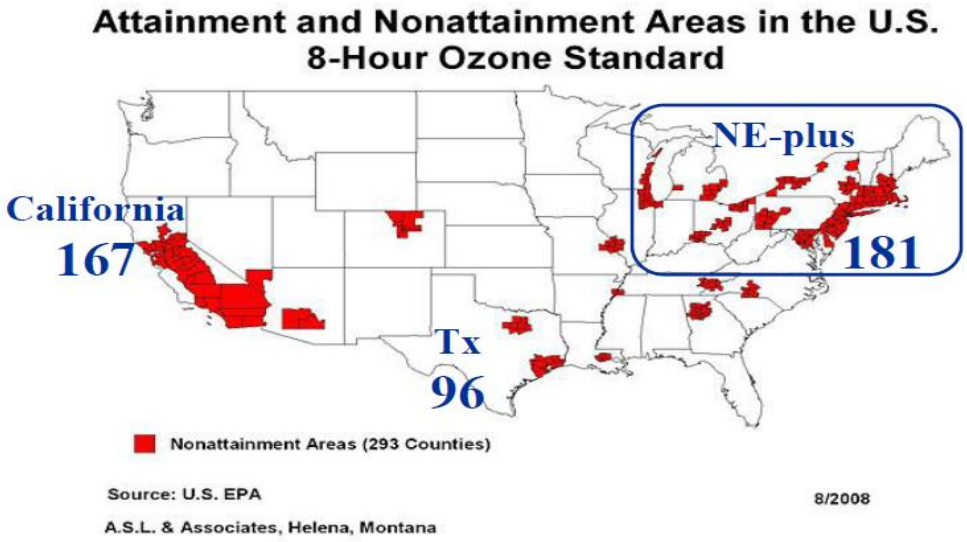
PEERLESS

Making Energy Safe, Efficient and Clean.

USA Requirements

Federal and State Regulations require very stringent NOx limits for new sources, especially in non-attainment areas for ozone – mostly California, Texas and Northeast USA

California has implemented retrofit rules to get further reduction on NOx emissions due to the severity of the problem, especially in San Joaquin Valley

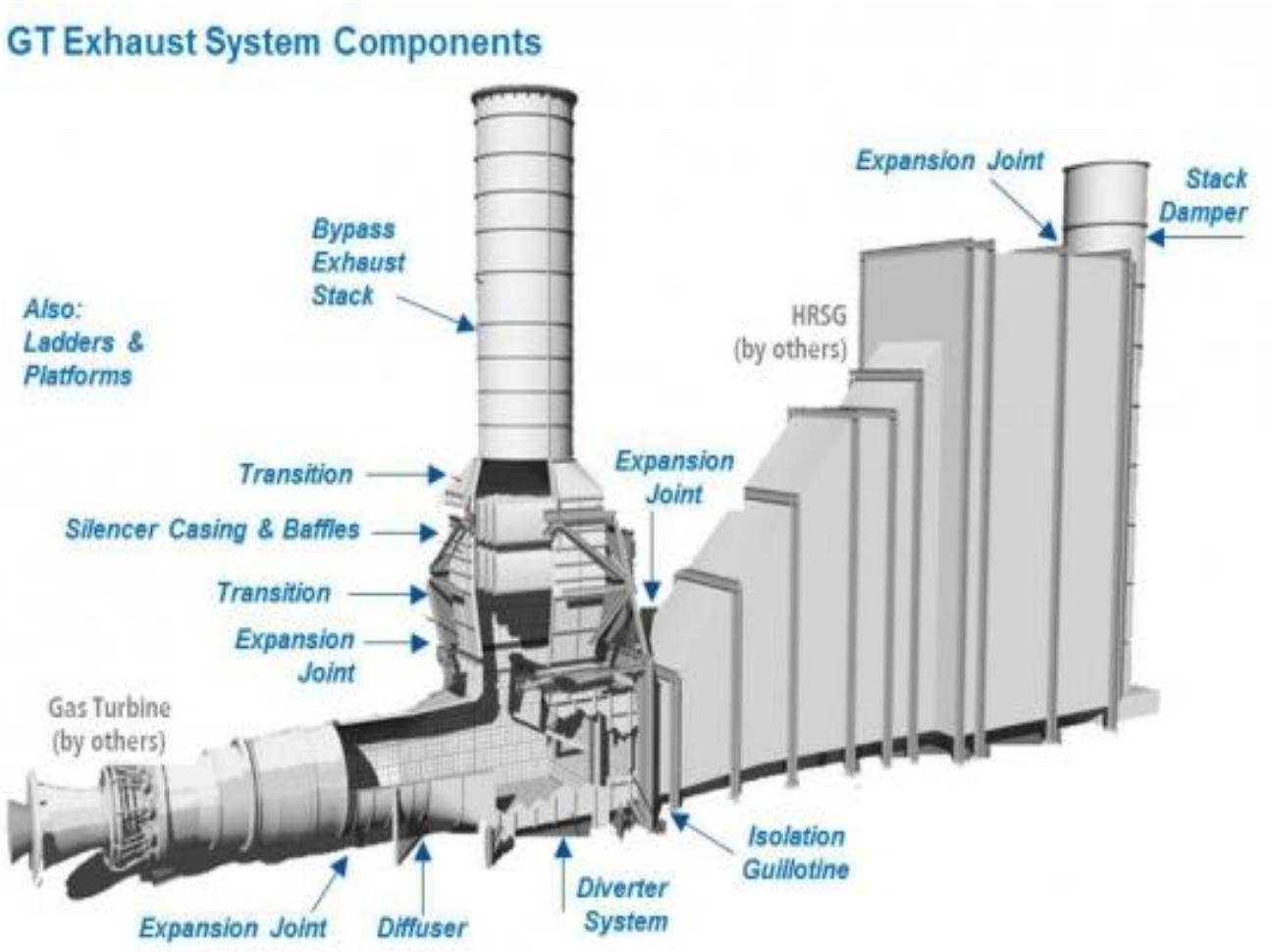


Exhaust systems

Includes the entire air flow but not steam (HRSG) for both simple cycle and combined cycle GT

GT Exhaust System

Clyde Bergemann



Clyde Bergemann exhaust systems

Clyde Bergemann gas turbine exhaust systems and components provide a "Balance of Plant" Island solution (exclusive of the turbine and HRSG-boiler).

- .

Exhaust systems provide all media handling and conditioning needs into and out of the gas turbine, including any exhaust bypass.

- Depending on specific requirements, systems may be supplied as entire homogeneous units, or as individual components:

Expansion Joints

- Gas Flow Diverter Systems
- Diffusers, Transitions, Equalisers
- Silencers and Casings
- Exhaust Stacks and Stack Dampers
- Isolation Guillotine Dampers
- Ladders, Platforms, and Supports

Features

- Exhaust systems for simple-cycle and combined-cycle
- Finite Element Analys (FEA) and 3D modeling of designs to ensure performance
- Systems may be supplied as entire units, or as individual components
- Custom engineering to accommodate unique requirements of each installation
- Experience and expertise with all types and sizes of turbines
-

- Benefits
- System integrity under high temperature, high velocity exhaust conditions
- Options available for easy and economical conversion to combined-cycle operation
- Experience and expertise from hundreds of installations around the world
- Reliable, cost-effective operation

Universal supplies complete exhaust systems

INLET SYSTEMS

- Inlet Silencers
- Pulse Filtration Systems
- Barrier Filtration Systems
- Anti-Icing Systems
- Inlet Cooling Systems
- Fogging Systems
- Transitions
- Ductwork
- Enclosures

EXHAUST SYSTEMS

- Exhaust Silencers
- Diverter Dampers
- Structural/Support Steel
- Emissions Packages
- Bypass and HRSG Stacks
- Platforms/Ladders
- Plenums
- Expansion Joints
- Oxidation Catalyst

Braden has furnished more than 1500 exhaust systems

- Braden Manufacturing, LLC is a market leader in Exhaust Bypass, Simple Cycle, Exhaust Diffuser, and Exhaust Expansion Joint applications.
- Braden has developed the floating liner system that provides internal system stability in high turbulence/high temperature environments such as F class machines. Additionally, each design is evaluated for internal pin spacing, pin size, liner plate thickness, and clamping system positioning to ensure system integrity. Many of the critical welds are robotically conducted to provide weld integrity and proper weld penetration. Braden has implemented stringent QA processes to ensure that the designs created in the office are properly implemented in the manufacturing facilities.
- In house acoustical capabilities, backed up with extensive laboratory and field measurements, allow tailored solutions for noise control requirements. Designs have been created to meet noise requirements in the far field, near field, stack exit, total system sound power, low frequency emissions and more. Silencer baffles have been extensively modeled and tested to survive the harshest conditions created by modern turbines. This includes a new baffle design optimized for the fast turbine startups of the F class machines.
- Braden has more than 1500 exhaust systems in operation worldwide, including exhaust systems for every major turbine OEM. The company can utilize low cost local country fabrication to reduce your shipping cost

Aarding supplies exhaust systems and components

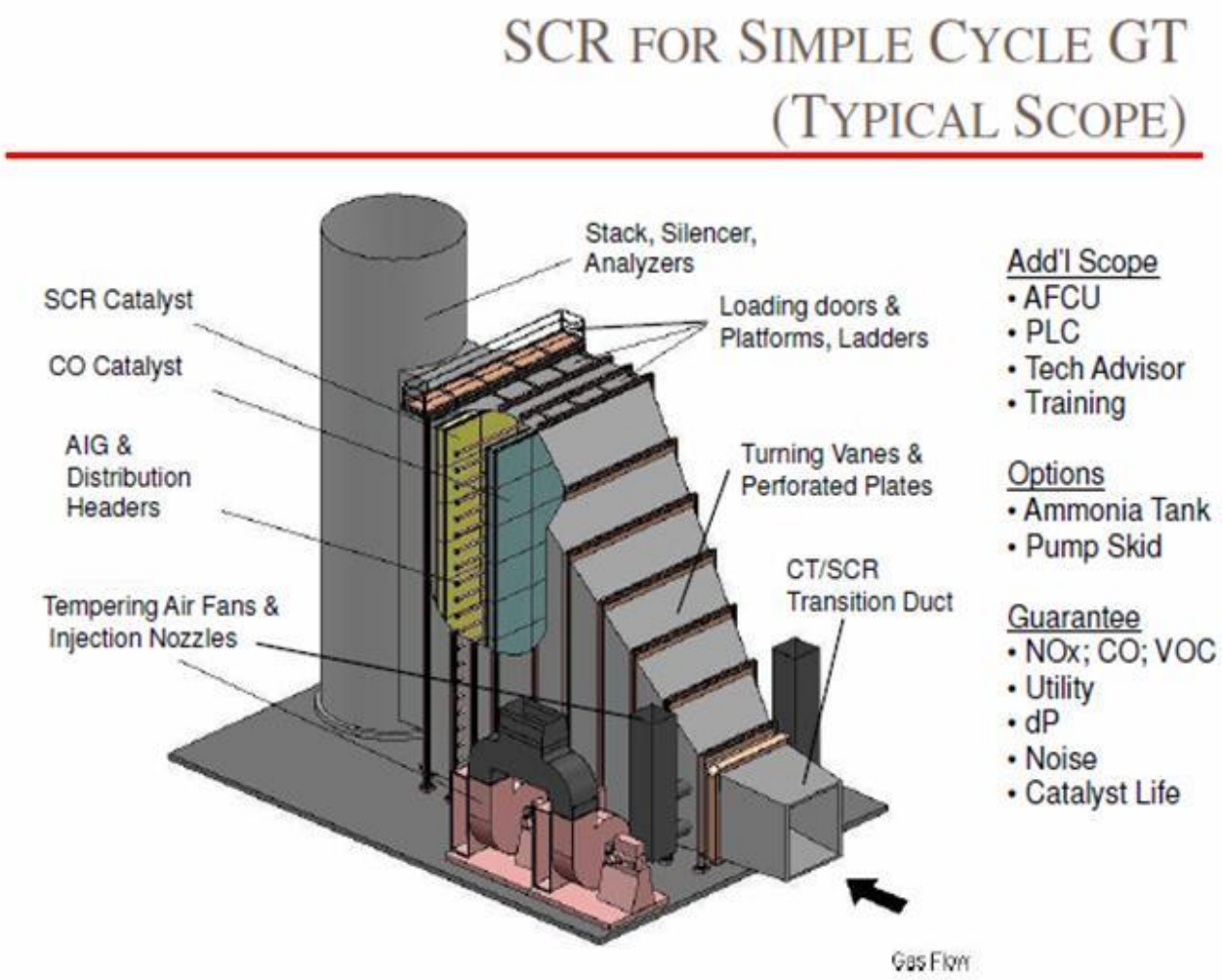
- Aarding provides diffuser ducts, diverter dampers, silencers, internal insulation, bypass stacks, steel structures including ladders & platforms and necessary auxiliary equipment such as aircraft warning lights and expansion joints. These systems may be supplied on a turn-key basis supported by in-house engineering, project management and on-site installation supervision.
- Diffusers / Plenums
- Gas turbine exhaust ducts
- Single Cycle Exhaust Systems
- Bypass exhaust systems
- Exhaust Stacks
- Internal Insulation
- Boiler Internals

Nox Control

Nox Control system design

- **Gas Turbine Emission Control Overview by Bill Gretta, Eneractive Solutions - Hot Topic Hour July 17, 2014**
- Bill Gretta, Eneractive Solutions discussed several problem installations. The operating temperature increases over time. In one case the rise of some 20°F was sufficient to cause emissions to increase above the permit limits and require some adjustments
- **Engineered solution improves SCR performance significantly**
- Getting gas-turbine inlet air and exhaust gas to flow where and how you want it to in powerplant ductwork is akin to herding cats. The problem, as described by industry veterans Jim Carlton, president, Granite Ridge Energy LLC, and Larry Hawk, plant engineer, Granite Ridge Energy, operated by NAES Corp, was that the plant had been challenged by an underperforming NOx catalyst since commissioning. However, routine destructive sampling of the catalyst showed reactivity at or above expectations. And testing confirmed that the ammonia injection grid was properly balanced. What to do?
- **NOx Control for Gas Turbines - Hot Topic Hour February 14, 2013**
- NOx control for specific gas turbines, NOx control technology and new technologies being developed.
- **Vogt Power Emission Control Solutions by Kelly Flannery, Kristen Cooper and Andrew Heid - Hot Topic Hour February 14, 2013.**
- Kelly covered three product lines for emissions control from combustion turbine exhaust.
- **SCR DeNOx Systems by Robert (Bob) McGinty, Mitsubishi Power Systems - Hot Topic Hour February 14, 2013**
- Bob reviewed reliable control of NOx from simple cycle and combined cycle gas turbine applications.
- **SCR for Gas Turbines - InterWEBview™ with Chris Ferguson, Honeywell-UOP**
- This 21 minute interview with Chris Ferguson, product manager for Honeywell-UOP, addresses SCR systems for turbines and other applications.

Simple cycle SCR



Hot SCR

- **Hot SCR Reference Project, Marsh Landing by Mitchell Krasnopoler, Kiewit - Hot Topic Hour March 19, 2015**
- Mitch prepared a presentation on Hot SCR System at Marsh Landing.
- **Simple Cycle SCR Designs by Bill Gretta, Eneractive Solutions - Hot Topic Hour September 19, 2013**
- Bill provided advice for single cycle SCR purchasers

Single Cycle SCR tempering

Marek A. Buzanowski, Ph.D. Peerless Mfg. Co., Dallas, TX, USA

- a new compact exhaust system and efficient arrangement of the tempering air system for simple cycle power plants includes transitioning hot exhaust flue gas into pre-oxidation section of the exhaust system, passing hot exhaust gas through the oxidation catalyst for the CO emissions control, injecting tempering air stream into the post-oxidation section of the exhaust system, and passing cooled flue gas through the reduction catalyst for the NOx emissions control. The resultant benefit of this newly designed process is a more effective use of catalysts and a smaller exhaust footprint.
- http://www.peerlessmfg.com/assets/pmfg/files/learning-center/2011-Buzanowski-State-of-the-Art-Nitrogen-Oxide-Removal.pdf

Peerless has supplied more tha 500 GT SCR systems

PEERLESS

Making Energy Safe, Efficient and Clean.

Peerless – Environmental Systems

Supplying Emission Control Systems (SCR/CO) for over 20 years

800 Emission Control Systems totaling more than 100,000 MW

- More than 500 Combustion Turbine related projects
- More than 240 "F" Class CT experience
- More than 85 simple-cycle SCR/CO systems
- Complete systems integration with focus on low installed and life-cycle cost
- Expertise in retrofit SCR/CO systems minimizing downtime

SCR Retrofit for Gulf Coast Refinery Cogen

MPS design parameters

KEY CONSIDERATIONS FOR GAS TURBINES SCR

Service life – Hours & Years (customer requirement)	Ammonia slip
Exhaust gas temperature	Catalyst temperature
Turbine exhaust NO_X , CO, VOC levels	Reactor duct configuration
Required NO_X CO, VOC removal & stack exit	Flue gas flow/temperature distribution
Pressure loss allowance	SO2 to SO3 Conversion
Volumetric flow rate	NH_3/NO_X distribution

MITSUBISHI POWER SYSTEMS

MPSA has more than 600 systems

SUMMARY

- MPSA has established SCR design considerations for gas turbine fired applications and can ensure long-term and continuous system operation on gas or liquid fuels.
- Mitsubishi has supplied SCR systems for combined cycle and simple cycle gas turbines globally, and is a "Proven" technology provider with over 600 SCR systems worldwide.
- MPSA has a team of qualified experts in Newport Beach and Lake Mary Office with access to more experts at MHI Nagasaki and MHI R&D. We can offer support with feasibility studies, with project execution, and with long term maintenance of your valuable investment.

MITSUBISHI POWER SYSTEMS

Catalyst

Nox

CO and VOC

Ammonia slip

SCR Components (Peerless)

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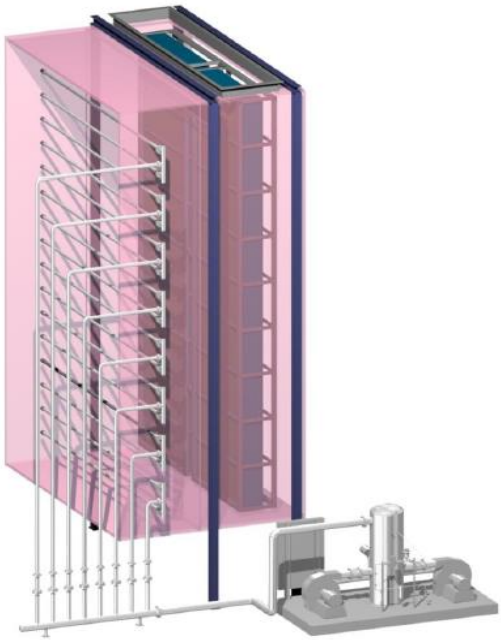
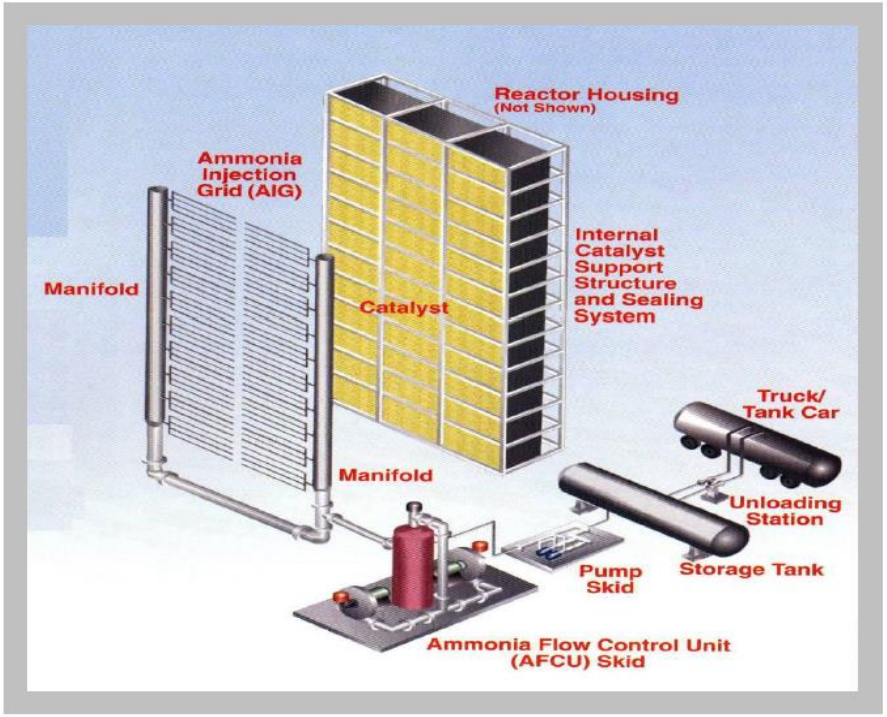
Major Components of SCR





SCR catalyst

- **Gas Turbine Emission Control by Greg Holscher, CERAM Environmental (IBIDEN) - Hot Topic Hour July 17, 2014**
- Greg Holscher, Sr. Applications Engineer, CERAM Environmental, Inc. displayed a V shape configuration with reduced pressure drop.
- **Integrating HRSG & Catalyst Design for High Performance & Low Cost by Joshua D. Gillespie, EmeraChem - Hot Topic Hour July 17, 2014**
- Joshua Gillespie, EmeraChem made some observations based on the supply of CO catalyst to more than 40,000 MW of turbines and engines. He pointed out that VOC removal performance varies with the compound and the emissions therefore are a function of the mix between difficult to remove and easy to remove compounds
- **Air Pollution Control Catalyst and Technology by Craig Sharp, Haldor Topsoe - Hot Topic Hour September 19, 2013**
- Craig introduced a new catalyst.

Catalyst activity vs temperature

(peerless)

SCR Catalyst Activity

Conventional Catalyst (normal V2O5)

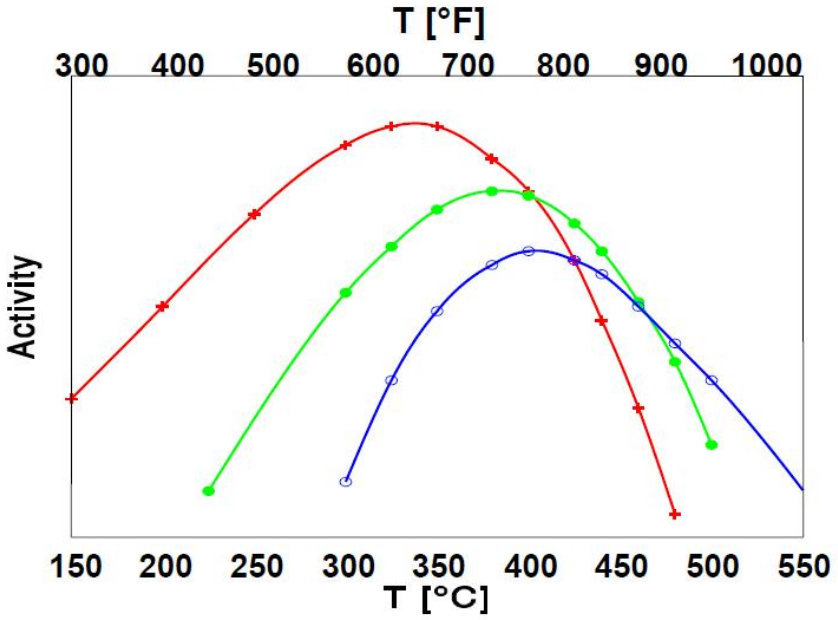
- Up to 425C
- 370C Optimum
- 6+ vendors
- HRSG Applications

Medium Temperature (reduced V2O5)

- Up to 470C
- 3+ vendors
- Simple-Cycle CT

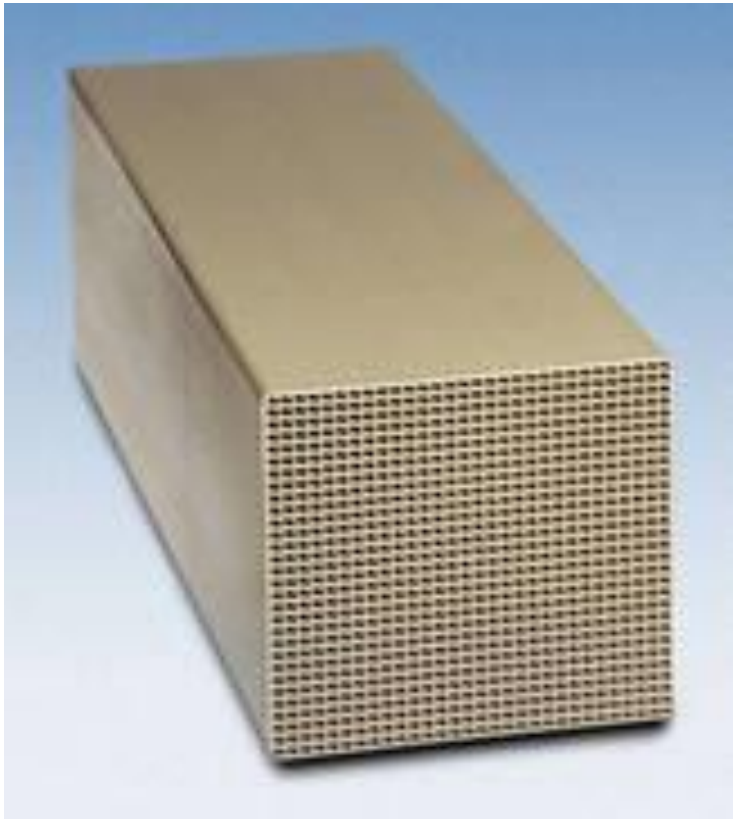
High Temperature (zero V2O5)

- Up to 510C
- 2+ vendors
- Simple-cycle "peakers"



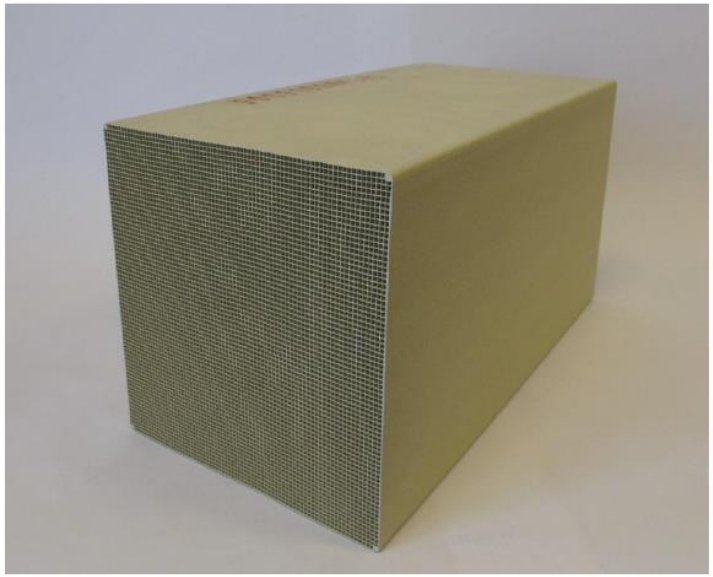
Johnson Matthey Concat SCR Catalyst

- Concat GT SCR catalyst provides a honeycomb structure that gives high performance NOx reduction with less catalyst required. The result is a smaller catalyst package and lower pressure drop across the catalyst. This gives turbine owners/operators and SCR system engineers greater flexibility in system design



Ceram GT honeycomb catalyst

Catalyst for Gas Turbines



75 x 75 Cells Gas Catalyst

- Free cross sectional area: 79 %
- Low pressure drop
- Low catalyst volume
- Flexible catalyst module arrangement
- Total flexible module design for optimal assembly of HRSG cross section

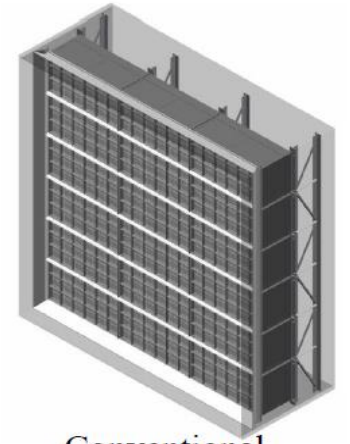
CERAM

IBIDEN

Angled catalyst arrangement reduces power consumption (Ceram)

Pressure Drop Optimized Catalyst Arrangement

POCA V-Type



Conventional Arrangement

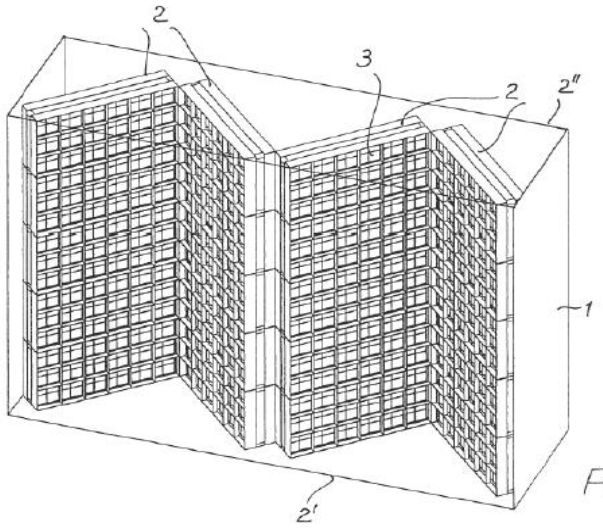
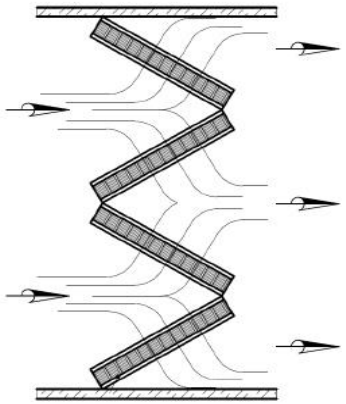


Fig.1



- CFD Indicates ΔP Decreases ≈35 - 55% Compared to Conventional Arrangement
  - Dependent on…
    - Module angle installation
    - Reactor depth
    - Flow correction needs

Reduced ΔP Will Increase Power Output

CERAM

IBIDEN

Cormetech catalyst in simple cycle

- For simple cycle gas turbine applications, the SCR reactor is located in an expanded outlet duct immediately downstream of the turbine (Figure). The duct size is optimized to accommodate the SCR catalyst reactor performance. The short transition section from the turbine outlet to the SCR inlet poses challenges with the system design. The turbine exhaust flue gas temperature is often too hot to be efficiently treated by the SCR system. Many units rely on the injection of tempering air to cool the flue gas down to exhaust temperatures below 900F (±25F). An economic evaluation considering a number of design and operational parameters is performed to determine if tempering air or a high-temperature catalyst is the best selection. The evaluation must consider factors such as the capital and operating costs, operating hour limits, volume of catalyst, duct size and back pressure, purge fan versus tempering air fan cost, cost of the air distribution equipment, and so on

Haldor Topsoe has close to 400 turbine SCR catalyst installaitons

Catalyst Performance

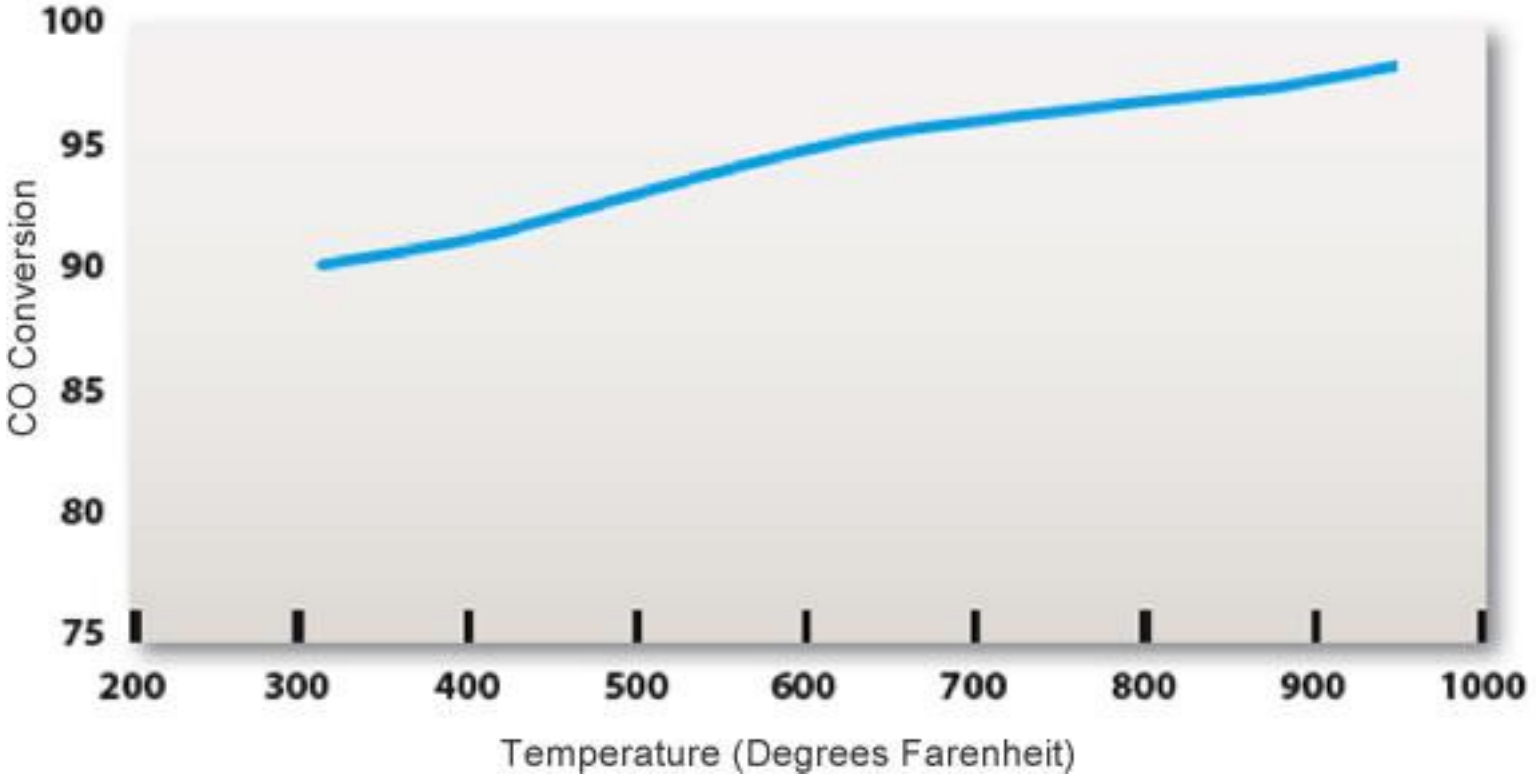
Alabama Combined Cycle Siemens 501F
DNX-929 Catalyst Installed (2010)

Test		Before Brand X Catalyst Replaced	Guarantees	Current
Outlet NOx	ppmvdc	3.5	3.5	3.5
NH_3-slip	ppmvdc	20	10	< 3
SCR Inlet Temp.	deg. F	600 - 650	-----	600 - 650
29% NH_3 Injection Rate	gph	> 500	394	266
SCR Draft loss	in. wc	> 2.75	1.6	< 1.4
Service Life	Hours	-----	40,000	4,380
Power Generation	MW	156.4	-----	160.1

- ✓Power Output increased by 3.7 MW
- ✓Ammonia usage decreased by over 50%

HALDOR TOPSOE

Johnson Matthey Oxidation Catalysts provide high CO Conversion

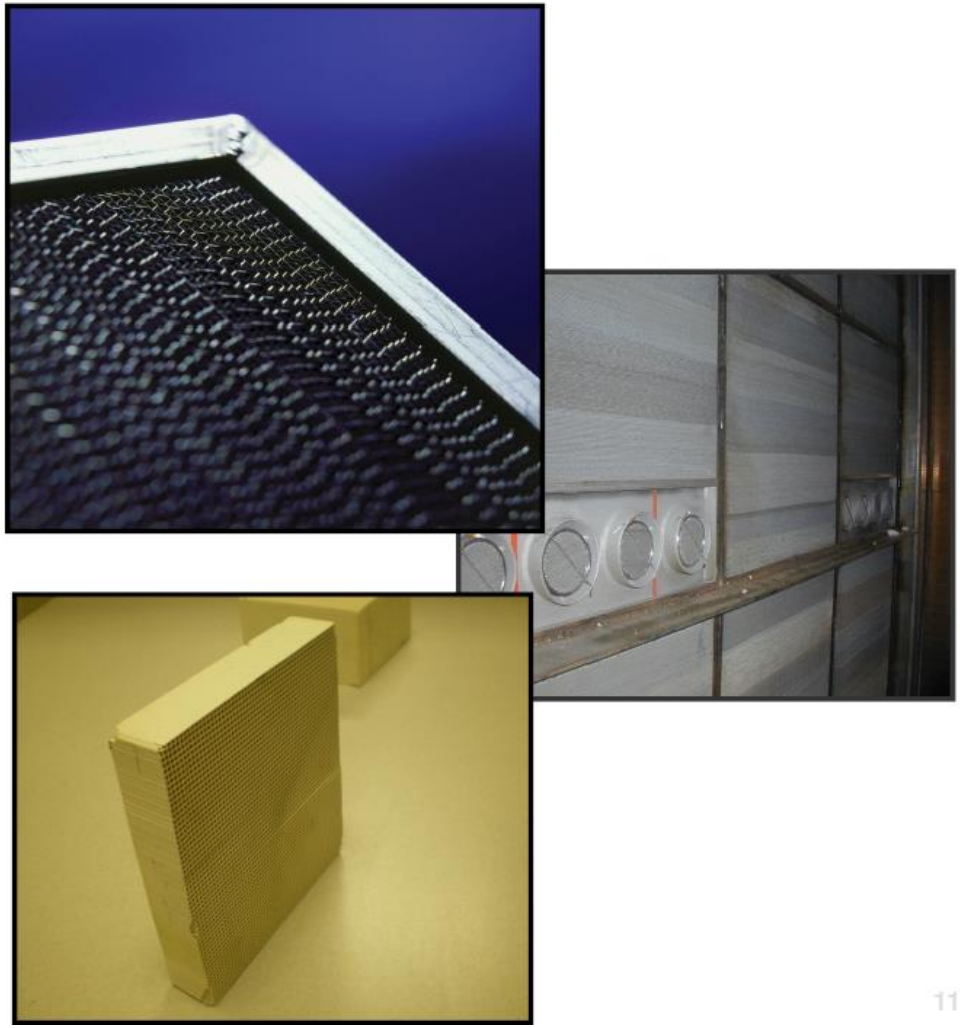


Oxidation Catalysts have an established durability of 10 or more years of continuous operation.
Catalytic performance can be easily maintained or restored through washing

MPS catalyst for CO & VOC

CO & VOC CATALYST

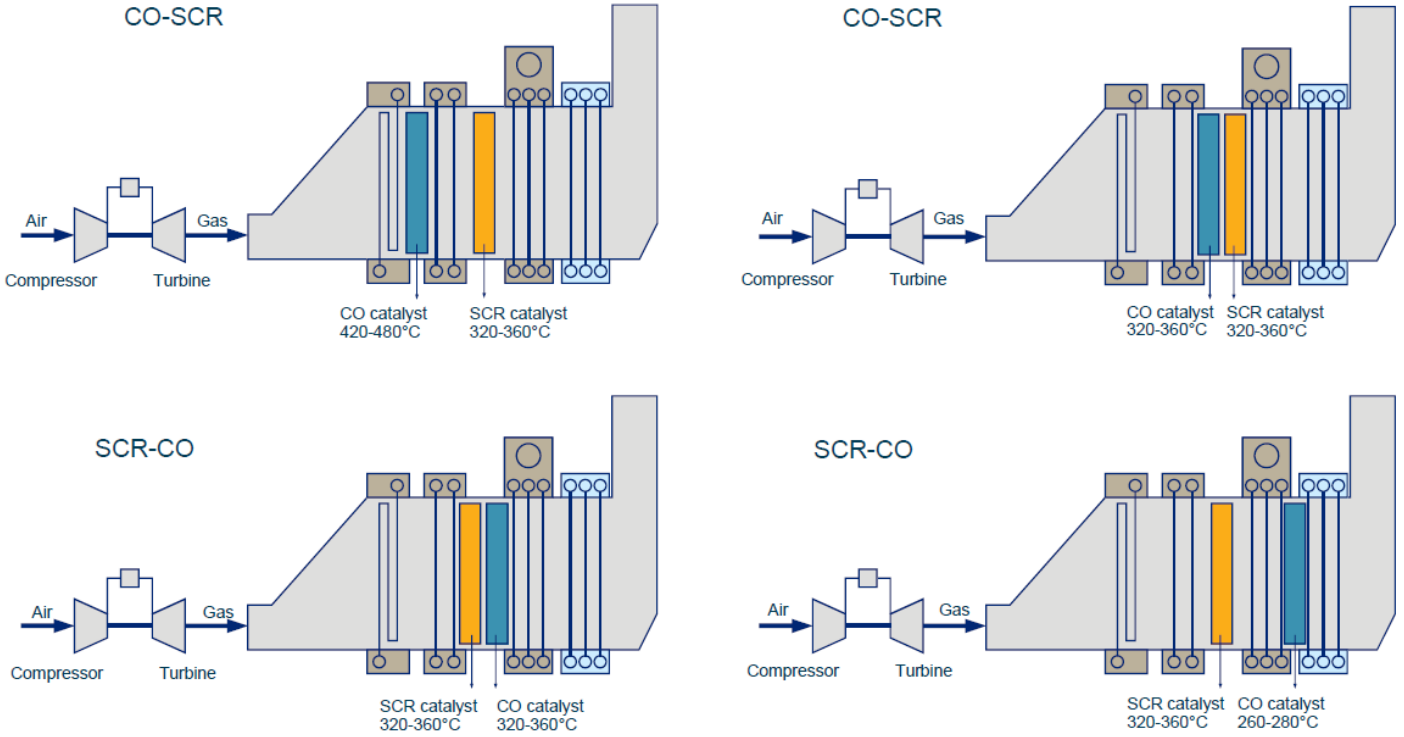
- Platinum or other PGM promotes CO to CO_2 oxidation.
- Brazed joint corrugated metallic foils, stacked corrugated foil or ceramic cells to provide high surface area per cu.ft. of catalyst
- Oxidation occurs on "surface" of catalyst.
- Pressure drop is directly dependent on catalyst depth and compactness



MITSUBISHI POWER SYSTEMS

CO catalyst can be located after SCR

What's New - Basic HRSG layouts

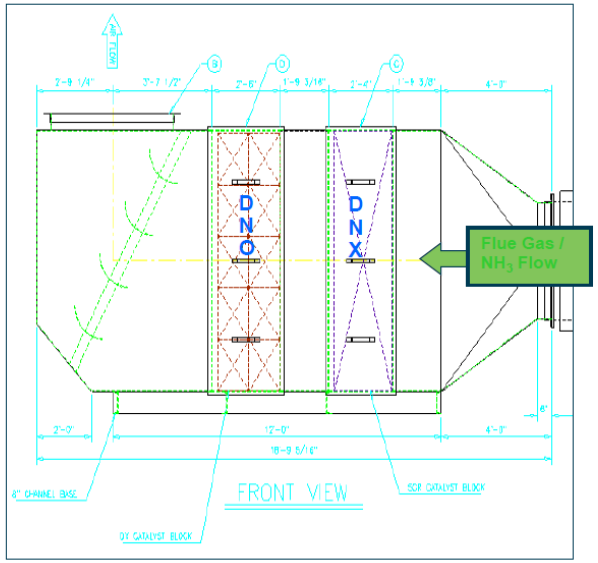


HALDOR TOPSOE

Haldor Topsoe has successful SCR and then CO catalyst installation

New Developments for CO (DNO) Catalyst

Pennsylvania Plant: NOx Catalyst (DNX-929), CO Catalyst (DNO-1920) Installed (April 2011)



DeNOx Guarantees:

12.24 lb/hr Outlet NOx

90% DeNOx @ 10-ppmvdc NH_3 slip

2-yrs life

CO Guarantees:

98% Outlet CO Conversion

41% Outlet VOC (C6+) Conversion

2-yrs life

HALDOR TOPSOE

Johnson Matthey's ammonia slip catalysts are designed to prevent ammonia breakthrough

- The ideal ratio of ammonia (NH_3) to NOx is 1:1 based on having ammonia available for reaction of all of the exhaust NOx without ammonia slip. However, SCR efficiency can be less than ideal at low temperatures (potential low SCR activity), and at higher temperatures with high exhaust flow rates (high space velocities).
- Optimizing the ammonia to NOx ratio is shown to lead to potential improvements in overall NOx conversion efficiency with little additional ammonia slip. Ammonia slip past an SCR catalyst can be oxidized to NOx or it can be selectively oxidized to nitrogen. Johnson Matthey's ammonia slip catalyst (ASC) is highly selective to N_2 and can convert the NH_3 to >90% N_2 depending on the operating conditions. Johnson Matthey's ASC have achieved < 5 ppm ammonia slip on diesel engines operating with very rapid changes in engine load

Haldor Topsoe is developing new ammonia slip catalyst

Selective ammonia slip catalyst enabling highly efficient NOx removal requirements of the future

Milica Folić, Lived Lemus, Ioannis Gekas and Andreas Vressner

HALDOR TOPSØE

Operation and Maintenance

SCR components

- **Tenaska Lindsay Hill Generating Station Ammonia Pump Problem**
- The facility's anhydrous-ammonia forwarding pumps did not allow for double-valve isolation during maintenance. These pumps are only required for use on very cold days. This requires additional maintenance and laying them up for periods of non-use. The system had single-valve isolation from the ammonia storage tank to the suction of the pumps, a potential safety risk for the O&M team.Solution. Plant management decided to install double-block-and-bleed capabilities to the liquid suction line from the storage tank and liquid return line to the storage tank
- **AIG Tuning, Catalyst for Life Forecasting**
- Many gas-turbine "bubble" units installed between 2000 and 2004 are operating with their original charge of SCR catalyst. These units have outlived the original catalyst warranty (typically three years) and have benefitted from a combination of conservative design and good luck. However, as these systems reach the decade mark, the design margins have diminished because of gradual (and inevitable) deactivation of the catalyst with age. As the catalyst nears its end of life, ammonia slip begins to increase exponentially. There are practical steps operators can take to avoid this scenario

Catalyst replacement advice from Cormetech.

- When the SCR catalytic potential has degraded and can no longer meet the plant's needs, the entire SCR reactor bed must be addressed. In that situation, the options are usually full replacement, partial replacement, integrated reuse with new, or regeneration. Each method has its advantages and disadvantages that must be considered within the context of a given unit, plant, and fleet.
- Logistics of individual unit replacement and integration within a given outage period must be considered at each plant. Early trials to prove long-term durability and applicability are recommended. Partial reuse may be applied by integration with an advanced module design, which can result in lower total pressure loss. Regeneration is the process of cleaning catalysts that are fouled by contaminants that are removable by a special aqueous-based chemical solution. This option may be considered if the catalyst deactivation mechanism indicates reliable recovery by the regeneration method and proven long-term performance can be guaranteed.
- Every plant's operations are unique, so a single catalyst cost estimate is not possible. Instead, take a fleetwide view and manage the life-cycle cost of SCR catalysts. This approach will keep catalyst costs low over the operating life while reliably meeting air quality limits. And don't forget that routine audits and inspections will help ensure a long catalyst life.

Ferco analyses improvement options in Mcilvaine webinar-

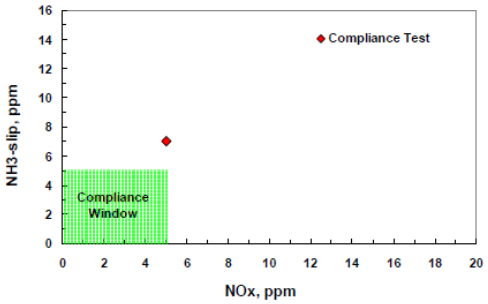
Why?

Catalyst Activity (K)?

- F(material, geometry)
- Condition of active sites

Reactor Potential?

- Ability of the catalyst bed to reduce NO_x
- $RP = K * A_{sp} * V_{cat} / Q_{fg}$



Poor NH3/NOx Distribution?

- Uniform NH_3/NO_x profile is critical
- Local $NH_3/NO_x > 1$ creates NH_3 slip

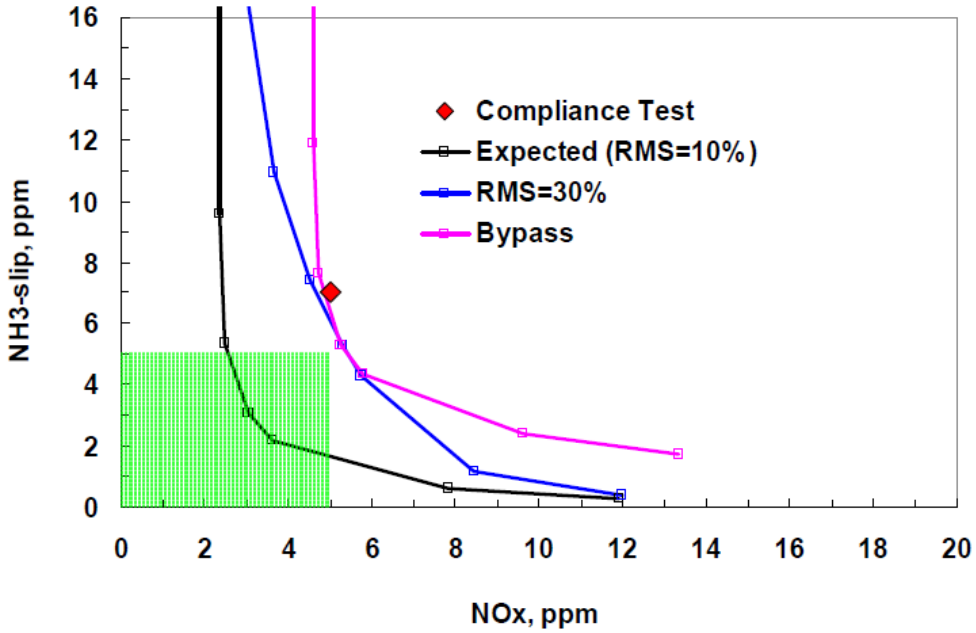
Flue Gas Bypass?

- Any leakage around the catalyst increases stack NO_x & NH_3

Process models used to identify problems

Activity, NH3 Distribution, or Bypass?

- FERCo utilizes a process model to compare expected SCR performance to actual performance (see curves below)
- A single data point is not sufficient for identifying the problem



Sample grid needed for optimization

Sample Probe Grid Expedites Tuning

A sample grid is especially important for larger units (e.g., more than 30' wide)

325MW combined cycle SCR with a 36-point sample grid (6 x 6)

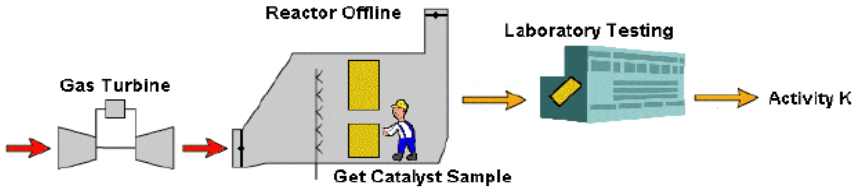
Measure catalyst activity cointinuously

In Situ Catalyst Activity Measurement*

Traditional Lab Measurement
- Typically one per year
- Currently no test protocol

$K_{Lab} = -A_{Vdesign} \ln(1-\Delta NO_x)_{Lab}$

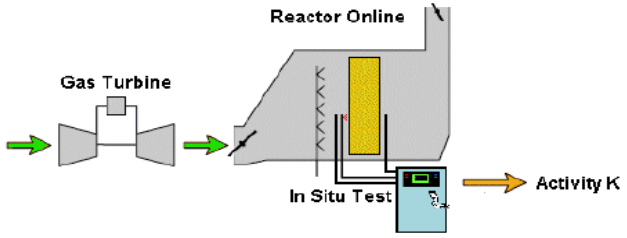
@NH3/NOx=1-1.5



FERCo's **CatalysTrak®***
- *in situ* measurement
- No outage required

$K_{In\text{-}situ} = -A_{Vactual} \ln(1-\Delta NO_x)_{full\ scale}$

@NH3/NOx>1 locally



*** Patented Process**

EMIT Catalyst Maintenance

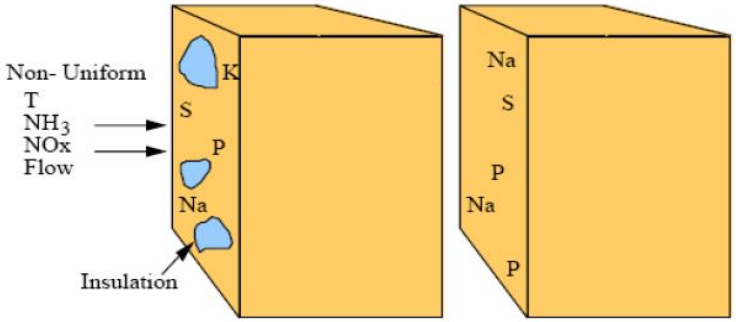
- EMIT Technologies' Catalyst Maintenance Program is customized to meet each customer's needs. With wash bays strategically located across the US, refurbishment capabilities and stocked replacement elements at each location, EMIT has the hardware and services to support any company's Catalyst Maintenance requirements.
- Catalyst Washing and Refurbishment.
- Catalyst Stocking and Replacement Elements
- Catalyst Asset Tracking and Maintenance Notifications
- Turnkey Catalyst Maintenance Services
- Catalyst Recycling and Cash Back

Performance impacts on removal efficiency (Peerless)

PEERLESS

Making Energy Safe, Efficient and Clean.

Performance Impacts



Non-uniform Gas Flow
- result due to change in flow direction
- cause a variance in contact time

Non-uniform NOx/NH_3
- result due to heterogeneity in burner and operation of duct burner
- cause variance in NOx conversion

Non-uniform Temperature
- due to heterogeneity in burner and operation of duct burner
- cause selectivity changes

Catalyst Deterioration
- poisoning K, Na, P, Ca, SO_2
- fouling from dust and insulation
- thermal phase change

Plant Operation
- Insulation blockage
- Moisture exposure (some catalysts)

reagents

reagents

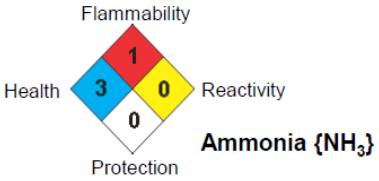
- **An Economical Alternative for HRSG SCR Reagent Supply by Stewart Bible, Fuel Tech - Hot Topic Hour February 14, 2013.**
- Stewart offered an economical alternative for HRSG SCR reagent supply.
- A number of liquid urea injection systems have been installed on gas turbine SCR systems
- Offers safety advanatages and more available than aqueous

Urea has advantages (Fuel Tech)

REAGENT CONSIDERATIONS

Anhydrous Ammonia

- Least Expensive (Coming in the Gate)
- Extremely Hazardous
- Requires RMP and Extensive Safety

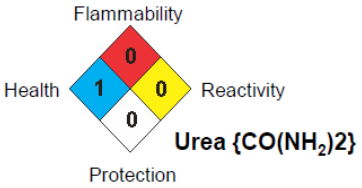


Aqueous Ammonia

- 29% Conc. – Limited Availability
- 19% Conc. – Requires Greater Heat Input for Vaporization

Urea for On-Site Ammonia Generation

- Significant Safety Advantages
- Worldwide Commodity



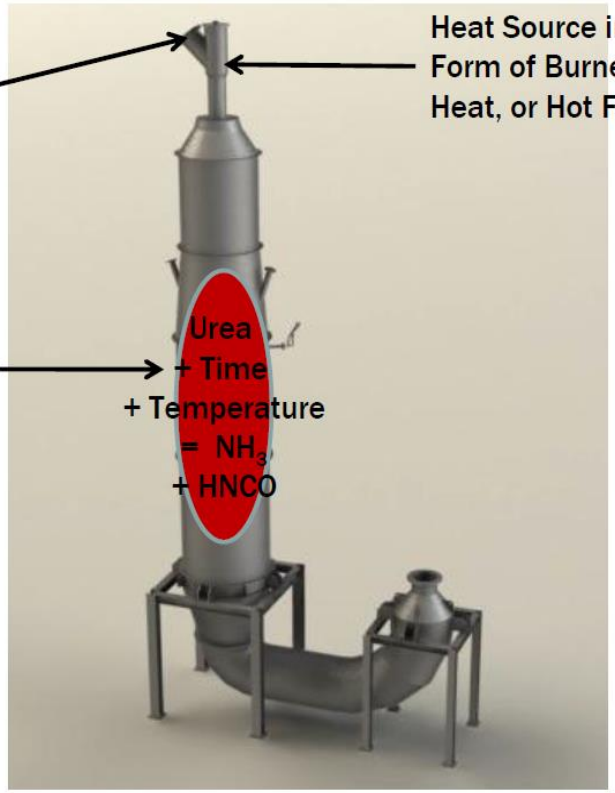
Liquid Urea injection (Fuel Tech)

THERMAL DECOMPOSITION OF UREA

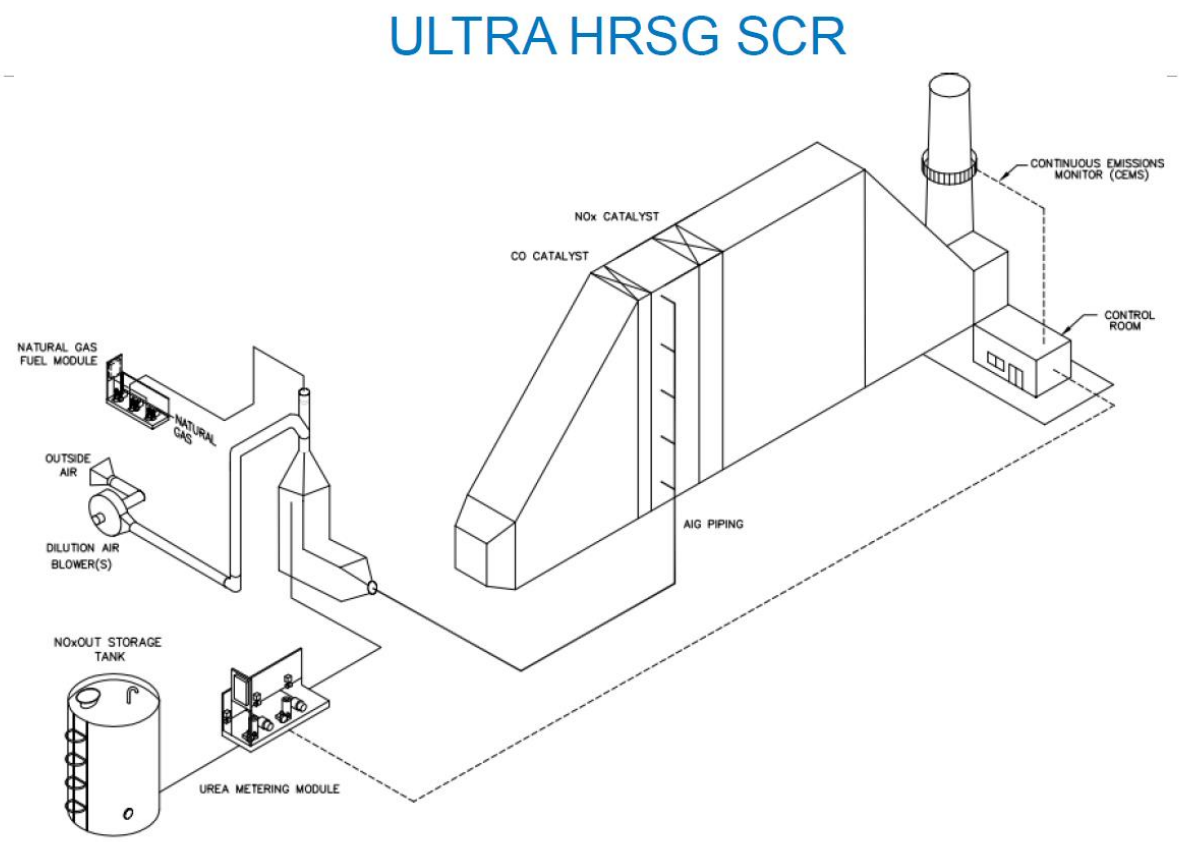
Carrier Medium: Ambient Air, Clean Flue Gas

Heat Source in the Form of Burner, Electric Heat, or Hot Flue Gas

Injection of Aqueous Urea in Temperature and Time Dependent Chamber – Fast Load Following Capabilities



Liquid Urea injection for GT SCR



Yara supplies eragents and complete reduction services

- Yara leverages its technology and reagent capabilities to provide a complete NOx reduction service package to industrial sites. These services include:
- Plant optimization
- Safety audits and training packages
- Storage and handling solutions
- Spare parts support
- Technical Support
- Maintenance
- Catalyst management & regeneration
-

Wahlco has supplied over 50,000 MW of ammonia injection systems

- Having supplied over 50,000 Megawatts of Utility, IPP, and Industrial Power ammonia systems, WAHLCO understands the critical nature and reliability requirements of ammonia handling and injection equipment for SCR Applications. WAHLCO supplies virtually all commonly used types of ammonia unloading, storage, vaporization and handling systems, from industrial applications of a few pounds per hour to Utility Boiler Applications requiring up to 4,000 pounds per hour of ammonia. WAHLCO approaches each project as a team member, insuring the equipment will correctly integrate within the overall SCR system and is uniquely qualified to meet all project requirements of ammonia handling

Ammonia Injection systems

Turbulence generating AIG improves efficiency (2007 R&D study)

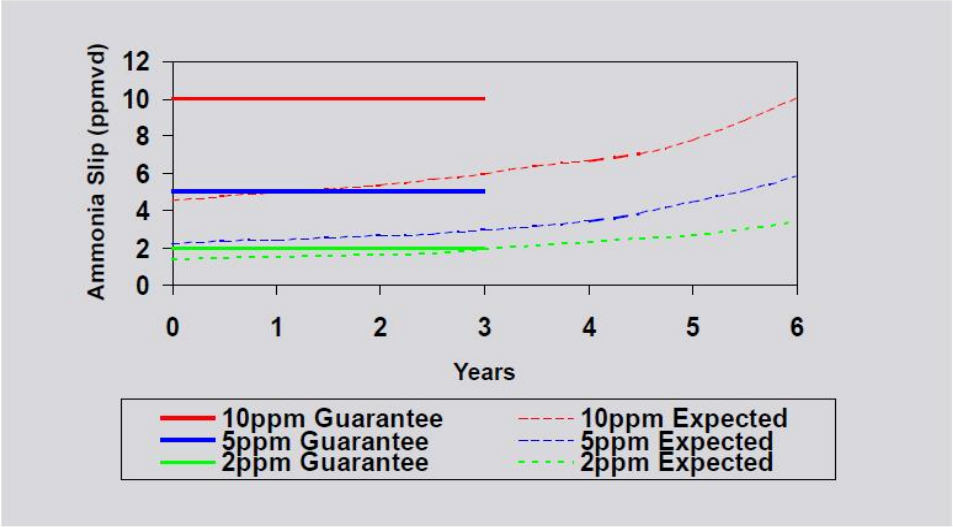
- Ammonia injection grid (AIG) is used to introduce vaporized ammonia (NH3) into an exhaust gas stream for nitrous oxide (NOx) reduction in selective catalytic reduction (SCR) systems. Computational and experimental studies on the AIG resulted in significant improvements in the turbulence mixing between the injected ammonia and the exhaust gas. Improved mixing is instrumental to maximize catalyst performance, extend catalyst life time, minimize catalyst volume, decrease system pressure drop, minimize reagent use and ammonia slip, minimize the overall size of the SCR system, and minimize risks associated with designing the SCR system. It is found that an AIG with a turbulence-generating edge dramatically increases the mixing efficiency and, therefore, reduces the mixing distance required to obtain acceptable distributions of the NH3 to NOx ratio. Results indicate over 50% reduction of the required mixing distance due to the turbulence generating edge. This work summarizes the obtained results from computational CFD simulations for two-dimensional and three-dimensional models, however the proposed arrangement of the injection grid has been successfully tested in laboratory experiments and applied to several commercial power generating systems. The commercial performance results will be reported in the subsequent publications
- http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1594029

Ammonia slip can be limiting factor on operation (Peerless)

Ammonia Slip

What is Ammonia Slip?

- Affected by Velocity and Temperature Profile and Ammonia Distribution at the Catalyst and catalyst sealing system
- Slowly Increases Over Time due to Catalyst Degradation
- Guarantees Based on End-Of-Life of Catalyst



Miscellaneous

Stack testing and CEMS

Diverters

Noise Control

2014 GT turbine emissions measurement recording

- **Measurement of Gas Turbine Emissions Including NH_3** 95 minutes
  You will need to enter your name and email address after clicking link to view recording.

Nox emission measurement

- **CEMS for Calabas Landfill Gas CEMS by Len Richter, Cisco - Hot Topic Hour April 17, 2014**
- Clsco supplied the CEMS for this California land fill gas project which uses Solar Turbines. NO_x is 7 ppm and CO is 3 ppm
- **Predictive Emissions Monitoring is an option for gas turbine NOx measurement**
- **Thomas Eisenmann**, **Durag** is presenting a paper at CEM 2014 which explains why predictive monitoring is an option for the primary monitoring of gas turbines and duct burners or as a secondary measurement tool. PEMS offer significant cost benefits with lower capital expenditures as well as much lower operational and maintenance cost than CEMS. PEMS and DAHS require for operation very little or no plant manpower. CEM 2014 - The 11th International Conference and Exhibition on Emissions Monitoring will take place in Turkey in the country's financial and cultural capital, Istanbul, from the 14th – 16th May 2014
- **Emerson Continuous Emissions Monitoring Systems (CEMS) for gas turbines and other applications**
- With over 3,000 CEMS installations in the field worldwide, Rosemount Analytical combines the expertise and field-proven technologies with the most rugged sample conditioning and extraction systems in the industry to provide superior measurement accuracy and repeatability. Designed in consideration of CEM regulations as specified in clean air laws around the world, including U.S EPA 40 CFR Part 75 and 40 CFR Part 60, we help you meet data reporting requirements, maintain emissions compliance, and ensures certification and compliance with your local and international regulatory agencies.
- ***Revision Date:*** 4/15/2014

Testing (EMIT)

SLIPSTREAM Environmental was founded as a wholly owned subsidiary of EMIT Technologies to act as an independent testing company providing services to the Natural Gas Engine Marketplace. Utilizing the latest technology, SLIPSTREAM has the ability to break down the molecular structure of an engine's exhaust to provide the most accurate emissions diagnostics available. The FTIR (Fourier Transform Infrared) method provides real time and simultaneous gas analysis and provide several benefits over the conventional FID (Field Ionization Detectors) method:

- Requires minimum calibration
- Increased accuracy and consistent analysis
- Best method for measurement of formaldehyde
- More cost effective, all inclusive analysis tool
-

Ammonia Measurement

- **Measuring Ammonia from SCR or SNCR Systems by James Staudt, Andover Technology Partners - Hot Topic Hour April 17, 2014**
-
-
- There is a comparison of NO_x differential, UV photometry, TDL and IR as options for NH_3 measurement. Successful control of SNCR and TDL is chronicled.
-
- EPA Methods 201A & 202 (& similar methods) remain problematic for gas-fired sources
-
- —Lack sufficient sensitivity
- —Blank levels are significant – not due to reagent contamination!
- —New Method 202 reduces but doesn't eliminate artifacts.
-
- Dilution methods offer advantages for gas-fired sources.
- —Greater accuracy due to absence of SO_2 and VOC artifacts and greater analytical sensitivity.
- —Resulting $PM_{2.5}$ emission factors are ~1/10 or lower of those based on hot filter/cooled impinger methods e.g., AP-42.
- **California Analytical Instruments FTIR Training presented by Thomas McKarns - Hot Topic Hour April 17, 2014**
- FTIR can measure NH_3 along with a number of other gases. Advantages include long laser life, no liquid N_2 required, no sample pressure restrictions, easy to maintain, makes repetitive tasks
- **NH3 Slip Measurement by Donald Wyatt, Yokogawa – Youtube Presentation**
- Overview of tunable diode lasers for measuring ammonia slip and other gases

Diverters and Dampers

Effox Flextor Diverter Damper

- **Effox-Flextor** has extensive experience in the design and supply of toggle-type and pivot-type diverter dampers for HRSG, Waste Heat recovery, natural gas turbine, and other systems that require diversion of the gas stream. We have designed and installed diverter dampers in systems ranging from small turbine units to the largest turbines in the world such as the GE Frame 7.

Braden has supplied more than 250 Diverters

Braden has designed and manufactured diverter isolators since 1985. The bulk of diverter experience is in combined-cycle gas turbine power plants, where extreme and sudden thermal changes necessitate thorough design foresight Over 250 diverter dampers have been supplied. Features include.

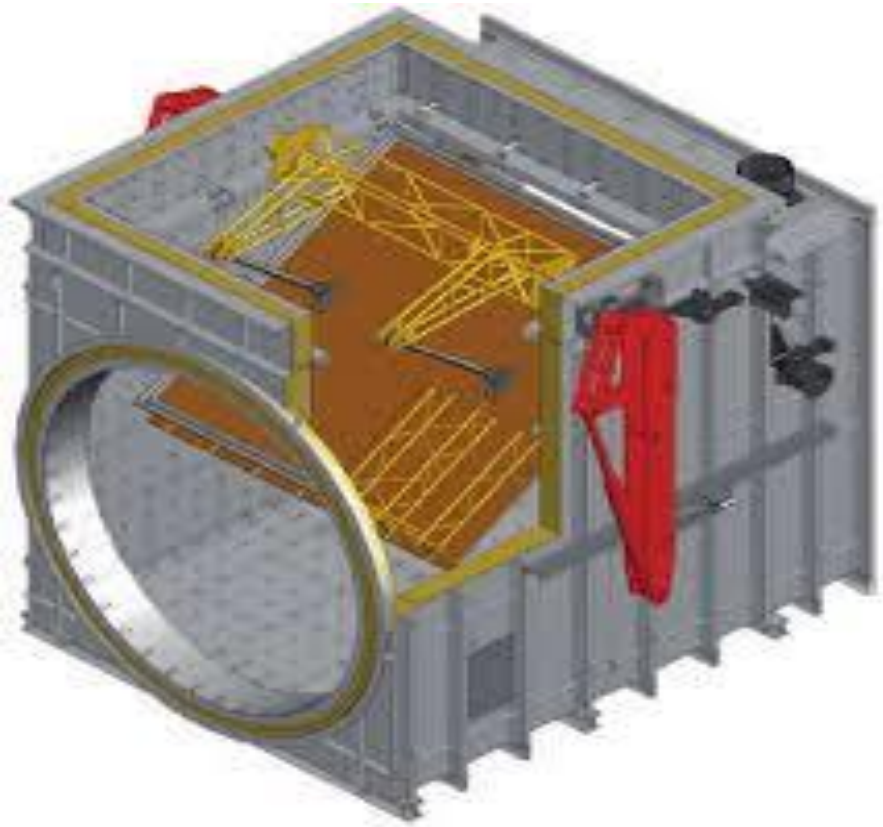
- Flexible Inconel® seal elements
- Toggle or pivot drive system operation
- Thermal stress-free blade design
- Internal casing insulation
- Delivery in one piece or split into sections as per transportation limits
- Hydraulic power units with HRSG protection mode

Boldrocchi Diverter for GT Exhaust

New diverter blade design from RAUMAG-JANICH

- RAUMAG-JANICH has developed and patented a new diverter blade design for combined cycle gas turbine plants,.
- It has proved itself already in a wide variety of installations. By means of computer simulations it's behaviour under varying service conditions is exactly predictable in advance.
- In combination with the new NICROFLEX-HIPERFORM DBP, sealing system distinguished by it's high resilience and stability when exposed to high gas velocities, this design concept provides, especially for very large damper dimensions, an advantageous solution.

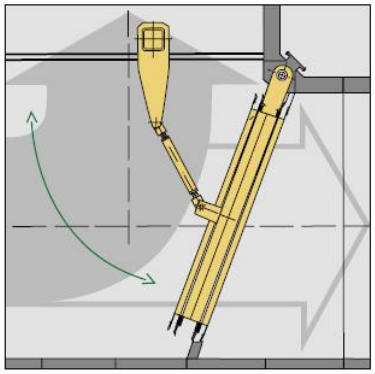
RAUMAG-JANICH DIVERTER WITH NEW TOGGLE ACTUATOR

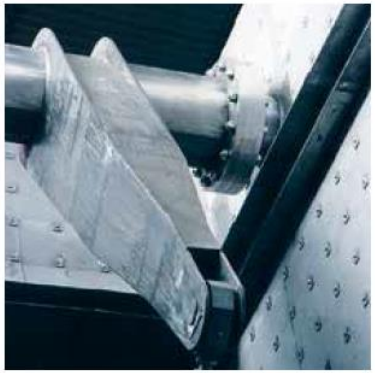


New actuation method for GT Diverters from RAUMAG-JANICH

- RAUMAG-JANICH has developed a unique new external dual toggle lever actuation method for diverters which provides for a turning angle of 180 degrees. This offers a number of advantages for the damper operation and its reliable function. Large sized diverters are designed with an internal toggle lever system. With this it is of advantage to apply the actuation forces at the blade centre in order to obtain symmetrical loads on the blade and its seals. Also, in the blade end positions, when the blade is subjected to the highest differential pressure and the seals make contact with the landing bars, the toggle lever system provides for an effective conversion of drive torque into high closing force. Hydraulic cylinders acting with single or double levers can, on account of the geometry of the lever system, attain only relatively small turning angles. To overcome this, the position of the main drive shaft is usually shifted towards the pivoting point of the blade. This however, results in an insufficient utilisation of the internal toggle lever system in the end positions of the blade when the acting differential pressure is greatest and the seals are pressed down firmly onto the landing bars. Consequently, the cylinders have to be dimensioned for higher forces. The required torque in the end positions is also higher. Generally, the whole drive system will have to cope with heavier loads. The n3.

Camfil Diverter





Claimed Advantages of Camfil Diverter

The advantage of diverter dampers from Camfil Power Systems is the flexible operation possibility with multi function hydraulic units. Ouick start of the gas turbine via bypass, then regulated slow heating of the heat recovery steam generator and emergency opening to bypass operation during full load of the gas turbine are available.

The position of the flap itself is infinitely controllable. Besides completely shut, the blade can be positioned into preferred intermediate positions.

The drive system can completely open and shut the flap within 60 seconds or 20 seconds in emergency case. It is then possible to mechanically lock the flap in this position.

Senior Flexonics Pathway Metroflex bypass, stack and inlet isolation,

- Senior Flexonics Pathway Metroflex Stack Isolation dampers have been designed to help retain heat to the boiler during turbine shutdowns. This allows for faster restarts and less thermal shock to the boilers.
- **Features of the SFP – Metroflex Stack Isolation Dampers:**
- Robust “modified airfoil” blade design for greater strength and lower pressure drop
- Over-pressurization Escapement for fail safe operation
- Custom actuation packages to fit end user requirements
- Damper field “kits” for installation in existing stacks

Noise supression

Guadalupe Power Partners uses accurate diagnostics to solve noise problems

CCJ reported on a user group meeting where Craig Courter, maintenance engineer at Guadalupe Power noted that generators, particularly those installed during the "bubble" years, continue to report key-bar rattle events. Left uncorrected, the condition is conducive to deterioration of the generator stator.

The "rattle" can be detected with the Harmonic Noise Index (HNI), a test proprietary to GE that analyses acoustic data. It is a useful tool, the vice chair said, for identifying, prior to disassembly, what may be happening inside a generator.

Unit operating data indicated a slight uptick in vibration on the collector-end bearing. Operating temperature was normal and the low-frequency noise was heard only at base load. The sound was directional and there were no visual indications. Testing proceeded this way, Courter said:

- A generator load test verified that noise attributed to high deck vibration occurred only at base load.
- Onsite vibration analysis, based on a three-point test, identified the exciter end as having higher levels than the opposite end of the unit.
- A third-party vibration analysis confirmed the plant's findings.
- The harmonic content of the acoustic data was analyzed using HNI to determine the extent to which the 2/rev frequency and its harmonics were present in the overall noise level.

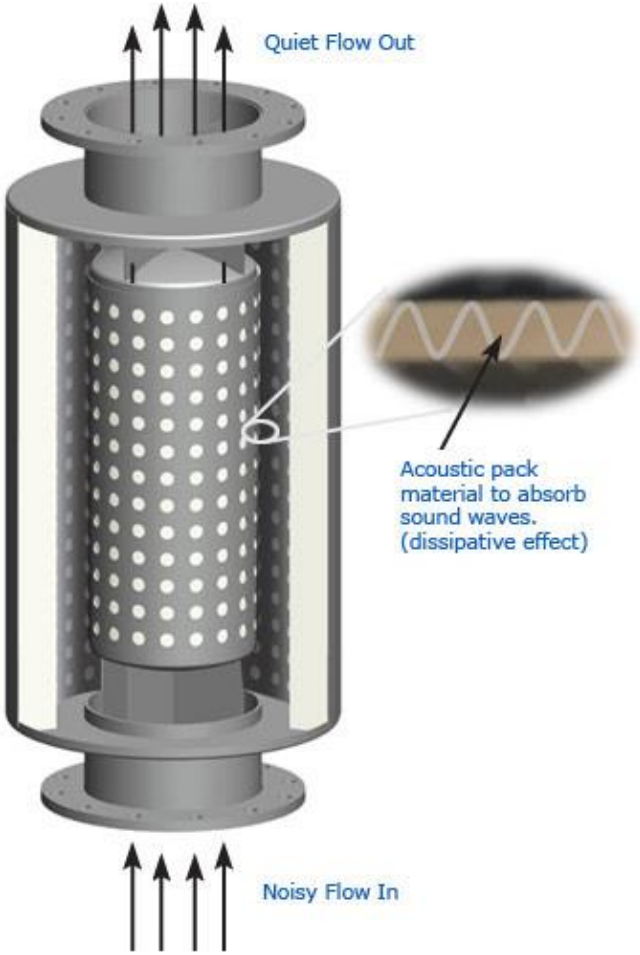
The HNI level calculated was higher than that of a normally operating hydrogen-cooled generator serving a 7FA gas turbine. It also was within an HNI range that suggested significant core/key-bar interaction The average sound pressure level at base load was the highest of all load points examined. Having accurate diagnostics, Courter said, allowed the plant to run until the next planned outage and to plan and obtain competitive bids for repairs with no exploration costs and no surprises.

Noise suppression-Aarding

- Aarding Thermal Acoustics Flue gas silencers are custom designed to keep noise emissions within acceptable levels. Current gas turbine operation requires the latest design, engineering and advanced material selections.
- Whether flue gas silencers are mounted in a silencer duct, a hot or cold stack or have to be able to operate in high flue gas velocities or elevated and fluctuating temperatures (start-stop mode), Aarding Thermal Acoustics can provides an effective solution in line with Gas Turbine output and Single cycle or bypass/HRSG design considering basic design criteria such as;
- Sound power level/noise output of gas turbine
- Noise requirement of power plant required dynamic insertion losses of silencer
- Pressure drop requirements
- Dimensions of duct/stack
- Other noise sources, e.g burners
- Other noise reducing parts of the system, e.g. boiler & elbow
- Maximum flow velocity

Peerless-Burgess Manning Noise reduction options

- Burgess-Manning Industrial Silencers typically fall into the following categories:
- **Absorptive** — High frequency noise applications. It is good for intakes and exhausts of gas turbines with noise reduction of 5-40dba
- **Reactive** — Low frequency noise applications such as blowers and pumps
- **Diffuser/Absorptive** — Combines absorptive and reactive designs to cover a broader range of frequencies to improve overall performance for turbine bypass or boiler start up purge
- **Inhibitive** — Pressure reduction applications typically encountered in vent or process piping systems, valves, and turbine bypass



dB Noise Reduction silencers

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- dB Noise Reduction provides standard and custom gas turbine silencers to control noise pollution in the most challenging applications. Gas turbine silencers are manufactured in any construction gauge, and in a variety of materials:
- Carbon steel
- Galvanized steel
- Stainless steel
- Other steels
- Gas turbine silencers from dB Noise Reduction are welded in accordance with AWS and CWB certified welding procedures, ensuring clean, strong joints, meeting the specifications necessary for the sensitive turbine environments. Custom sized straight through rectangular silencers, as well as elbow silencers are available for situations where there is very little available space for noise attenuation.

Expansion Joint Suppliers A-H

Gas Turbine Expansion Joint Companies, Products and Services				
Company	Metal	Non-metalic	After-market Sales	Installation Services
Aerosun-Tola Expansion Joint Co. Ltd.	x	x		
Bachmann Dampjoint	x	x		
Badger Industries	x	x	x	
BOA Group	x	x		
Clyde Bergemann Bachmann, Inc.	x	x	x	
DEKOMTE de Temple	x	x	x	x
Effox-Fextor	x	x	x	x
FlexCom	x	x	x	
Flexfab Niagara Inc.		x	x	
Frenzelit	x	x	x	x
Hesse Equipment	x	x	x	

Expansion Joint suppliers –H to Z

Gas Turbine Expansion Joint Companies, Products and Services				
Company	Metal	Non-metalic	After-market Sales	Installation Services
Holz Rubber		x	x	
Hyspan	x			
James Walker Townson		x	x	x
KE-Burgmann	x	x		x
Papco Industries		x		
Parker RE Dynex		x	x	
Senior Flexonics	x	x	x	x
U.S. Bellows	x	x	x	
WahlcoMetroflex	x	x		x
Zepco	x	x		x

Expansion Joints-Options

- **DEKOMTE Fabric Expansion Joint on Siemens Gas Turbine Outlet**
- A detailed case study analysis of a DEKOMTE fabric expansion joint design and installation on a Siemens gas turbine outlet. ***Revision Date:*** 11/22/2010 ***Tags:*** 221112 - Fossil Fuel 化石燃料, DEKOMTE, Expansion Joint, Exhaust Handling
- **Zepco Expansion Joint Retrofit at Florida Power Plant** Case study of a gas turbine power plant expansion joint retrofit by Zepco. ***Revision Date:*** 11/22/2010 ***Tags:*** 221112 - Fossil Fuel 化石燃料, Zepco, Expansion Joint, Exhaust Ductwork, Exhaust Handling, USA
- **Fabric Expansion Joints - Terms and Definitions**
- A glossary of terms prepared by the Quality Association for Fabric Expansion Joints. ***Revision Date:*** 11/22/2010 ***Tags:*** 221112 - Fossil Fuel 化石燃料, Expansion Joint, Exhaust Handling
- **Gas Turbine Expansion Joint Applications, an InterWEBview™ with Frenzelit**
- Bob McIlvaine's interview with Joe McFadden, the Expansion Joint Manager in the Gas Turbine Technical Department of Germany-based Frenzelit. The discussion focuses on expansion joints for gas turbine applications, including what materials to use. ***Revision Date:*** 11/22/2010 ***Tags:*** 221112 - Fossil Fuel 化石燃料, Frenzelit, Expansion Joint, Exhaust Ductwork, Exhaust Handling

Expansion Joints Options (2)

Analysis of Metal and Fabric GTX Expansion Joints

Deciding whether to use a metal or fabric expansion joint generally depends on the application specifications, according to this analysis prepared by EJS. ***Revision Date:*** 11/4/2010 ***Tags:*** 221112 - Fossil Fuel 化石燃料, Expansion Joint, Exhaust Handling

Design Criteria for Gas Turbine Exhaust Fabric Expansion Joint Assembly

Flexfab Niagara supplies fabric expansion joint assembly according to Specification from GE Schenectady's multi-disciplinary 6FA, 7F/A, 9F/FA Task Force, April 1996 ***Revision Date:*** 11/4/2010 ***Tags:*** 221112 - Fossil Fuel 化石燃料, Flexfab Niagara, Expansion Joint, Exhaust Handling

Problems & Solutions with Expansion Joints in Gas Turbine Exhaust Systems A white paper by James Walker Townson. ***Revision Date:*** 10/25/2010 ***Tags:*** 221112 - Fossil Fuel 化石燃料, James Walker Townson, Expansion Joint, Exhaust Handling

Suppliers of Gas Turbine Expansion Joint Products This is a summary of suppliers of fabric and metal expansion joints for gas turbine systems prepared by McIlvaine Company in 2010.***Revision Date:*** 10/21/2010 ***Tags:*** 221112 - Fossil Fuel 化石燃料, Zepco, DEKOMTE, Frenzelit, U.S. Bellows, Bachmann Dampjoint, Hyspan, Hesse Equipment, James Walker Townson, Clyde Bergemann, Effox-Flextor, KE Burgmann, WahlcoMetroflex, Flexider Flexider, Senior Flexonics Pathway Metroflex Dampers, Holz Rubber, Papco Industries, Parker RX Dynex, Badger Industries, Aerosun-Tola, BOA Group, Flexfab Niagara, FlexCom, Expansion Joint, Directory, Exhaust Handling

Expansion Joint Proper Design by Christopher Dyjak, Effox-Flextor - Hot Topic Hour February 24, 2011

Christopher L. Dyjak, Manager for Expansion Joints at Effox-Flextor, a CECO Environmental Company, emphasized the importance of utilizing proper application information in the initial design of expansion joints. One example is a joint in an FGD system. If the temperature could potentially drop to the dew point, then it is a more difficult application than if there were not the risk of acid corrosion. External insulation is recommended when the temperatures will never exceed the fabric limit and there is the potential for acid condensation.***Revision Date:*** 2/24/2011

Tags: 221112 - Fossil Fuel 化石燃料, Effox-Flextor, Expansion Joint