Gas Turbine & Industrial SCR Systems

Lessons Learned Firing NG and ULSD in Large Frame Simple Cycle Gas Turbine Hot SCR Systems

Bob McGinty Senior Product Manager
PRESENTATION OVERVIEW
Gas Turbine & Industrial SCRs

Corporate Qualifications
Drivers Impacting GT Emission Control Market
SCR Systems, Controls & Catalyst
CFD & Isothermal Reactor Modeling
Tempering Air Systems
SCR Systems Constructability
MHPSA Key Facilities

MHPS Canada

MD&A

MHPS de Mexico

MH Power Systems de Venezuela

Savannah Machinery Works

Houston Repair Center

U.S.A.

Canada

Mexico

Venezuela

Brazil

Orlando Service Center

MHPS Americas Energy and Environment

MHPS Americas

Mechanical Dynamics & Analysis

CBC

MHPS Puerto Rico

Office

Office with manufacturing
Gas Turbines, Steam Turbines, and Emerging Products

Products
- Gas turbines (30MW to 327MW)
- Steam turbines (30MW to 1,600MW)
- Gas engines (300kW to 15MW)
- Combined cycle systems
- Combined heat and power (CHP)
- Organic Rankine Cycle (ORC) systems (200kW to 15MW)
- Balance of plant equipment (chiller systems, boilers, electrical aux.)
- Portable power MegaNinja system

Engineering
- Project evaluation & planning
- Testing & project implementation
Solid Fossil Fuel Services & AQCS

Sales Service & Engineering
- SCR for simple cycle gas turbines
- SCR for Industrial fired applications
- SCR for coal-fired applications
- Flue Gas Desulfurization (FGD)
- Fabric Filters
- Lox NOx Burner (LNB)
- Catalysts
- Enhanced All-Dry Scrubber (EAD)
- Waste Spray Dryer (WSD)

Repair Services
- Engineering studies for emission reduction
- Fuel conversions
- Catalyst testing, optimization & replacement
- ESP to fabric filter conversions

Upgrades
- Catalyst
- Low NOx burners
- Scrubbers
- AQCS upgrades on dry and wet systems
MHPSA – Global Solutions for SCR Systems

Installations Worldwide – An Original Pioneer Of SCR Technology

Over 400 SCRs Installed on Gas Turbines
86 SCRs Installed for Simple Cycle applications

<table>
<thead>
<tr>
<th>MHPSA</th>
<th>Japan, Asia, North &amp; South America</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>173</td>
</tr>
<tr>
<td>Oil</td>
<td>103</td>
</tr>
<tr>
<td>Gas</td>
<td>52</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>423</td>
</tr>
<tr>
<td>Diesel Engine</td>
<td>224</td>
</tr>
<tr>
<td>FCC &amp; Refinery</td>
<td></td>
</tr>
<tr>
<td>Heater</td>
<td>48</td>
</tr>
<tr>
<td>Total Units</td>
<td>1023</td>
</tr>
<tr>
<td>Installed</td>
<td></td>
</tr>
</tbody>
</table>

Over 40 years of first hand experience
# High Temp SCR Reference Units

<table>
<thead>
<tr>
<th>Project</th>
<th>K-Point</th>
<th>SMUD McClellan</th>
<th>TEPCO Yokosuka</th>
<th>Carson IceGen</th>
<th>NRG Marsh Landing</th>
<th>Calpine Mickleton</th>
<th>Calpine Carll's Corner</th>
<th>PNM La Luz</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>M701F</td>
<td>GE 7EA</td>
<td>M701DA</td>
<td>LM 6000</td>
<td>SGT6 5000F</td>
<td>W501AC</td>
<td>P&amp;W FT 4 TwinPac</td>
<td>LM6000</td>
</tr>
<tr>
<td>Gas Temp Deg. F</td>
<td>1112</td>
<td>1020</td>
<td>986</td>
<td>875</td>
<td>1146</td>
<td>900</td>
<td>900</td>
<td>&lt;900</td>
</tr>
<tr>
<td>DeNOx Eff.</td>
<td>86%</td>
<td>90%</td>
<td>60%</td>
<td>90%</td>
<td>87%</td>
<td>75%</td>
<td>76%</td>
<td>&gt;94%</td>
</tr>
<tr>
<td>Operating Hours</td>
<td>3,000</td>
<td>&gt;1000</td>
<td>4,081</td>
<td>25,000</td>
<td>&gt;2500</td>
<td>&gt;300</td>
<td>&gt;250</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Tempering Air Fan</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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# Environmental Market Drivers For Simple and Combined Cycle Gas Turbines

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Status</th>
<th>Pollutant Targeted</th>
<th>Compliance Options</th>
<th>Expected Date of Compliance</th>
<th>Market Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonattainment New Source Review</td>
<td>Affect All New Gas Turbines</td>
<td>CO, NO₂, O₃, PM, SO₂</td>
<td>SCR, Low NOx Combustors</td>
<td>All new permits and ongoing SIP Review of existing sources</td>
<td>Gas turbine and gas fired boiler – All new plants or expansions</td>
</tr>
<tr>
<td>National Ambient Air Quality Standards Ozone limit - 70ppb October 2015</td>
<td>Final 8 hr Ozone Rule issued Oct. 2015</td>
<td>CO, Pb, NO₂, O₃, PM, SO₂ and VOCs</td>
<td>SCRs and ULNBs for Gas Turbines, Industrial Boilers &amp; Process Heaters</td>
<td>Compliance begins 2018 through the next 20 years</td>
<td>Gas turbine and industrial gas fired boilers, heaters May affect existing sources</td>
</tr>
<tr>
<td>FERC Ruling Increased Generation Reliability in PJM June 2015</td>
<td>Requires dual fuel or face significant penalty for fail to provide generation during NG curtailment</td>
<td>NOX, CO</td>
<td>ULSD Fuel Addition will require SCR Systems for gas turbine plants in PJM</td>
<td>2018/2019 Affects all existing and new sources after Aug 2015</td>
<td>Power Generation Gas turbines all sizes SC and CC</td>
</tr>
<tr>
<td>FERC Ruling Docket No.: ER14-500-000 January 2014</td>
<td>Enacted = Favored Economic Consideration to Frame Simple Cycle Gas Turbine</td>
<td>NOX, CO, VOC and PM</td>
<td>SCR Systems or reduced capacity factor preferential evaluation to Frame GT w/SCR</td>
<td>All new permits for peaking plant applications after January 2014</td>
<td>Utilities - economic analysis for Recips, SC, CC Frame and Aero GTs</td>
</tr>
</tbody>
</table>

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**The NAAQS Ozone Rule will require more SCR’s on Gas Turbines in 515 Counties**

**The FERC Secure Fuel rule will affect all gas turbines in Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and District of Columbus**
Utilizing Frame Simple Cycle with SCR (No Operating Limitations) results in the most cost effective peaking application.

No operating limitation of frame with SCR outweighs the $86/kW increase in CAPEX.

**FERC January 2014 Ruling**

“We find that NYISO’s proposal to use the F class frame unit with SCR technology peaking unit for developing the capital cost estimate for NYC, LI, and the G-J Locality is reasonable.”
MHPSA Solution for Simple Cycle Gas Turbine SCR

Project Features
- Four (4) F Class CTG’s
- GT Peaking plant nominal 750 MW
- Max operating temp: 1,146°F

Emission Limits (15% O₂ Dry Basis)
- NOx & CO 2.0 ppm
- VOC 1.0 ppm

COD May 1, 2013 on schedule
- As of 12/2015, AOH : 633, 562, 555, 533 = 2283
- As of 12/2015, Starts : 119, 95, 102, 85 = 401

Many 1st in class technologies
- Patented tempering air injection
- Hybrid hot gas/electric heated vaporization skids
- Self mixing high density ammonia injection
- Triple Loop NOx control over ramp conditions
- Process ammonia trim back TDL

NRG Marsh Landing
SCR for Large Frame Simple Cycle

Additional Frame Experience List

<table>
<thead>
<tr>
<th>Project</th>
<th>GT Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-Point</td>
<td>M701F</td>
</tr>
<tr>
<td>SMUD McClellan</td>
<td>EA Class</td>
</tr>
<tr>
<td>TEPCO Yokosuka</td>
<td>M701DA</td>
</tr>
<tr>
<td>Calpine Mickleton</td>
<td>W501A</td>
</tr>
</tbody>
</table>
Gas Turbines for Peaking/Load Following Applications

**Project Features**
- Two (2) F7 MS-7001-B CTG's
- GT Peaking plant nominal 100 MW
- Max operating temp: ~975°F

**Emission Limits (15% O₂ Dry Basis)**
- NOx NG 2.5 ppm / ULSD 4.2 ppm
- CO 5.0 ppm
- VOC 50% removal

**2005/2006 Retrofit SCR COD**
- Unit 1 - 1,512 fired hours predominantly on ULSD
- Unit 2 - 1,943 fired hours predominantly on NG

**Advanced Technology Designs**
- High flow tempering air systems multi ported - reduced pressure drop design
- Fully cold flow modeled from turbine diffuser through turbine exhaust stack
- Fully integrated SCR controls into Turbine Control System
- Designed for dual fuel firing both independently and commingled fuel during transition
MHPSA SCR Hot Simple Cycle Frame Class Turbine

State of the Art – Advanced Class Technology

Add’l Scope
- AFCU
- PLC
- Tech Advisor
- Training

Options
- Ammonia Tank
- Pump Skid

Guarantees
- NOx; CO; VOC
- Ammonia Slip
- Parasitic Power
- Pressure drop
- Noise
- Catalyst Life

SCR Catalyst
Ceramic Honeycomb

Platinum CO Catalyst

Tunable AIG & Distribution Headers
Stainless

Patented Tempering Air System & Injection Nozzles

Performance Driven
Distinct Compact Reactor Designs

Lined Stack, Silencer & CEMS

Loading doors & Platforms, Ladders

High Performance Reactor complete with Turning Vanes & Perforated Plates

CT/SCR Transition Duct Low dP loss

Gas Flow
Typical SCR System Overview Screens
CATALYST MODULES & TEST COUPONS/BLOCKS

Sampling Cassette

Sampling Basket
**CATALYST SELECTION: TEMP. VS. ACTIVITY**

**Today’s Technology**

Large operating temperature range (350 - 1100°F)

- High temp catalyst: 900°F ~ 1,100°F
- Medium-high temp catalyst: 800°F ~ 900°F
- Medium (Standard) catalyst: 450°F ~ 800°F

At higher temps, reduce V:W ratio
- Stronger NH3 adsorption
- Lower NH3 decomp rate
- Higher DeNOx rate
- Lower sintering rate

Extruded catalyst consistently demonstrates uniform cell sizing and pressure drop prediction
## Catalyst Poisoning & Degradation Mechanism

<table>
<thead>
<tr>
<th>Degradation Source</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Temperature &gt; 930°F</td>
<td>Decreases available surface area by thermal sintering of ceramic material</td>
</tr>
<tr>
<td>Fine particulate</td>
<td>Reduces available surface area by masking surface and preventing diffusion into pre structure</td>
</tr>
<tr>
<td>Ammonia-sulfur compounds</td>
<td>Plugs pores and prevents diffusion</td>
</tr>
<tr>
<td>Alkaline metals, Na, K</td>
<td>Ion exchange with active sites</td>
</tr>
<tr>
<td>Alkaline earth metals, Ca, Mg</td>
<td>Typically in form of sulfates, bond with acid sites reducing the ability of catalyst to absorb NH₃ i.e. formation of CaSO₄</td>
</tr>
<tr>
<td>Halogen</td>
<td>May react with and volatilize active metal sites</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Gaseous arsenic diffuses into catalyst and covers active sites, preventing further reaction</td>
</tr>
<tr>
<td>V, Pt, Cr and Family</td>
<td>Deposit onto catalyst, increasing NH₃ to NO and/or SO₂ to SO₃</td>
</tr>
</tbody>
</table>
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.
CO Catalyst Failures at Turbine Sites

- Insufficient foil retaining devices
- High velocity flue gas flow
- Incorrectly installed catalyst
- Mechanical failure of catalyst substrate

*Perforated plate eliminated turbulent zones*
<table>
<thead>
<tr>
<th>Key Considerations for Gas Turbines SCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service life year/hours (customer requirement)</td>
</tr>
<tr>
<td>Exhaust gas temperature</td>
</tr>
<tr>
<td>Turbine exhaust NO(_x) levels</td>
</tr>
<tr>
<td>Required NO(_x) removal</td>
</tr>
<tr>
<td>Pressure loss allowance</td>
</tr>
<tr>
<td>Volumetric flow rate variable</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Maintenance Considerations</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Service life year/hours (customer requirement)</td>
</tr>
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<td>Exhaust gas temperature</td>
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<tr>
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</tr>
<tr>
<td>Required NO(_x) removal</td>
</tr>
<tr>
<td>Pressure loss allowance</td>
</tr>
<tr>
<td>NH(_3)/NO(_x) distribution</td>
</tr>
</tbody>
</table>

**FOLLOW RECOMMENDED MAINTENANCE EVOLUTIONS**
SCR System Design Considerations

- **Seismic and Wind Loads**
  - Thermal Growth
    - Metallurgical Stress

- **Catalyst Support & Sealing**
  - Accessibility (Internal and external components)
  - Thermal Insulation & Liner Systems

- **Design Constructability**
  - Extent of prefabrication

- **Operation & Maintenance**
  - Standardized design
  - Operational philosophy
  - Modular design
  - Catalyst modules and loading system
  - Skid design (optimized to match site requirements)
  - Flexibility to design around plant specific restrictions and needs. Carry out flow studies, as necessary, to determine best layout and configuration
Why Flow Modeling Is Necessary

1) Develop flow distribution devices and injection ports to:
   a) Achieve acceptable velocity distributions through CO and SCR catalyst: (RMS) 15% to 20%
   b) Achieve acceptable ammonia distribution at the inlet to the SCR catalyst: (RMS) 5% to 10%
   c) Achieve acceptable temperature distributions at the catalyst inlets: (Mean Deviation) +/- 25 to +/- 50 deg F

2) To determine from model measurements the system pressure loss for the final configuration
   - Typical Boundaries: Gas Turbine Diffuser Outlet through Stack Outlet.
   - CFD and CFM results, validates ammonia injection design, ammonia mixing devices, tempering air distribution through injection ports, turning vanes, perforated plates and flow straightening devices.
Various SCR Failures at Turbine Sites

- Insufficient tempering air
- Poor tempering air mix into flue gas path
- Catalyst failure from higher temperature
- Poor AIG design - maldistribution
- Catalyst seal failures from sintering
- Insufficient ammonia injection capability
- Seal material issues from hot spots
Cold Flow Modeling (Isothermal)

• Cold flow modeling is the core method of determining complex flow fields.
• \(1/12\text{th}\) three dimensional scale model use.
• Geometrically similar to full size unit
• Construction uses \(\frac{1}{4}\)" clear Plexiglas
• Model extends from gas turbine outlet through cooling air duct, CO catalyst, AIG, SCR through silencer and stack
• All significant internal structures simulated
• Drawings and onsite inspection validates design
Flue Gas Path Management
(NH$_3$ Mixing - Cold Flow Model)

Simple Cycle Physical 1/12th Scale Model

Near Side

Center

Far Side
Sidewall Baffles & Horizontal Turbine Vanes
Tempering Air & Ammonia Mixing Challenges

- Major Design Concern;
  a) Short Distance Available to Mix the Air
  b) Conflicting requirement at the inlet duct

  Mix the air into flue gas (Turbulence)
  versus
  Uniform gas flow necessary at CO catalyst face.
  versus
  Homogeneous ammonia mix in flue gas at SCR catalyst face
  (Flow Straightening & Velocity Normalizing at Catalyst)

Challenging Turbine Exhaust Conditions – Typical

Flue gas exiting turbine diffuser up to ~140 FPS
Tempering air ~ 30% total flue gas volume
High exhaust gas temperature ~ 1200 deg.
Contrasting optimum catalyst temperature profiles
PERFORATED PLATE & TURNING VANES
High Density Ammonia Injection Grid

- Double entry balancing valves manifold to bias AIG
- Lance panels allows expedient optimization
- High density drilling, dense ammonia injection pattern
- Orifice flow measurements validate ammonia panel flow field balance
- Allows for future optimizing as catalyst ages or turbine performance degrades

Multi-Zone

Represents most responsive balancing approach, easy to adjust and fastest response, does require additional piping, valves and manifolds
Location & access of AIG balance valve array is generally lowest cost supply unless customer defined. Variations may affect price, real estate consumed and equipment sizing for transfer piping and fan size.
Plant A (Modular Construction)
Plant B (Panel Construction)
RIGHT - Solid Liner Plate System & Welded Stud Anchoring
WRONG - Expanded Metal Liner & Wire Welded Retainers
Catalyst Sealing Mechanism – Good & Bad
GT SCR & CO Catalyst Loading

Marsh Landing Super-module
Structurally engineered, up to 6” growth, all stainless construction
MHPSA - Experienced Technology Provider

- ‘Knowledge’ and ‘Expertise’ built over 40 years - Over 1000 SCR systems worldwide
  - (Original pioneer of SCR technology)

- Successfully completed the most difficult and challenging projects for Frame & Aero GT’s
  - Ultra Low NOx & Slip (< NOx 2ppm/NH3 2ppm)
  - Zero-Slip ammonia systems for gas turbines
  - High temperature SCR systems SCGT’s
  - Tempered air systems for SC Frame Turbines
  - More than 400 SCR systems for gas turbines

- Proven track record. (translates to Low Risk)
  - Have always met or exceeded performance guarantees
  - Only OEM supplier of SCR catalyst and SCR systems
  - We do not walk away

- Competitive offerings, high reliability systems
- Experienced US Design Build team, Japan R&D Centers
- Financial stability

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