

January 5, 2004

Dear Power Generation Customers:

On this, the tenth anniversary of the development of the SCONOx technology, we at EmeraChem have prepared a white paper outlining the performance and commercial status of SCONOx (EMx), which has proven to be an effective multi-pollutant emission reduction technology for dual fuel turbines and internal combustion engines, both stationary and mobile.

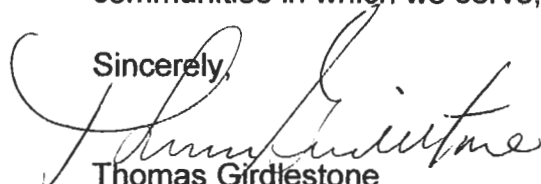
The last ten years have been extremely challenging for all of us at EmeraChem as we entered alone into a new science of catalysis and surface chemistry, a scientific path that others are now following. This new science has raised the bar of catalytic excellence, and has altered the definition of clean power generation in the United States. With the advent of SCONOx, electric power generating plants, in addition to many forms of transportation, can be ultra clean and environmentally friendly when burning natural gas and diesel fuels, including future fuels such as hydrogen.

As our nation continues to search for the ultimate energy source, EmeraChem continues to improve its commercial products for stationary turbines and internal combustion engines, yielding clean energy options at the lowest possible cost.

We at EmeraChem are proud of our scientific achievements and the commercial success of the SCONOx technology. What makes us even prouder is the positive impact we are making in numerous communities around the country by improving air quality while our customers generate more cost effective electricity.

As we take our technologies further into the power generation markets, in addition to new and more challenging applications, the knowledge and expertise gained by our employees in the past ten years will immeasurably benefit our customers and the communities in which we serve, both now and in the future.

Sincerely,



Thomas Girdlestone
Chief Executive Officer

Multi-Pollutant Emission Reduction Technology For Stationary Gas Turbines and IC Engines

Revision 1, January 5, 2004

High-Performance Technology Reaches Commercial Maturity

by Steven DeCicco, Boris Reyes and Tom Girdlestone

EmeraChem, LLC

UNRIVALED HIGH-PERFORMANCE

EMx™ (the second-generation of the SCONOx™ NOx Absorber technology), is a multi-pollutant control technology. NOx, CO, VOC and fine particulate matter are simultaneously destroyed using a single catalyst system. This is a unique feature setting EMx™ technology apart from all others.

With eight (8) years of operating history in commercial power generating plants, EMx™ systems have demonstrated the ability to reduce gas-fired NOx emissions to less than 1.0 ppm, release undetectable levels of carbon monoxide (CO), reduce VOC emissions by >90% and reduce fine particulate matter by 30%. EMx™ also has the capability of reducing sulfur emissions by 95%. In fact, the U.S. EPA has twice used EMx™ technology to establish new Lowest Achievable Emission Rate (LAER) standards for gas turbines.

EMx™ is characterized by low environmental impact across all media. EMx™ does not require the use of hazardous reagents such as ammonia, does not produce hazardous air emission byproducts such as ammonia and fine particulate matter, and does not become a hazardous solid waste at the end of its service life.

ENHANCEMENTS BRING COST REDUCTION

The emission reduction distinction between EMx™ technology and conventional SCR technology has always been significant. Now, advances in catalyst formulation and process improvements have brought EMx™ technology into a more cost competitive position with other mature technologies in the marketplace such as SCR technology.

Continuous improvements in catalysis and surface chemistry have dramatically improved the EMx™ catalyst formulation. A major increase in emission reduction capacity has brought a reduction of almost 40% in the required catalyst volumes. In addition, design and process improvements have yielded another 20% cost reduction in system components. Combining these advances, the total system cost has been significantly reduced while maintaining the highest emission performance in the market.

1. These technology improvements and cost reductions become particularly evident in Best Available Control Technology (BACT) analyses that evaluate EMx™ in comparison with SCR technology. Here is where the multi-pollutant capability of EMx™ shows a strong economic advantage. The “economic gap” between EMx™ and SCR has been closed with regards to quantitative NOx removal rates (\$/ton) even when these BACT analyses ignore additional SCR costs such as ammonia tanks, ammonia handling equipment, Federal ammonia permits, increased fine particulate emissions and hazardous solid waste disposal. It has also been shown that in many regions of the United States, the capabilities of the EMx™ technology reduced upfront NOx offsets when building a new power plant in addition to the opportunity to generated ERCs in retrofit applications.

EMx™ FIELD INSTALLATIONS AND PERFORMANCE

The EMx™ technology has been commercially demonstrated on natural gas and dual-fuel turbine installations presented in Table 1:

TABLE 1

Turbine & Fuel	Facility	Location	Start-up Date	NOx Performance
5 MW Solar Taurus 60 dual-fuel ¹ turbine	Wyeth BioPharma cogeneration facility Unit #2	Andover, MA	September 2003	Permit Limit: 2.5 ppm on gas 15.0 ppm on oil Actual: 0.3 ppm on gas 1.5 ppm on oil
5 MW Solar Taurus 60 dual-fuel ¹ turbine	Montefiore Medical Center cogeneration facility	Bronx, NY	June 2002	Permit Limit ² : 2.5 ppm on gas 15.0 ppm on oil
45 MW Alstom GTX100 gas turbine	Redding Electric municipal plant	Redding, CA	June 2002	Permit Limit ² : 2.0 ppm on gas
Two 15 MW Solar Titan 130 gas turbines	University of California cogeneration facility	San Diego, CA	July 2001	Permit Limit ² : 2.5 ppm on gas
5 MW Solar Taurus 60 dual-fuel turbine	Wyeth BioPharma cogeneration facility Unit #1	Andover, MA	1999	Permit Limit ² : 2.5 ppm on gas 15.0 ppm on oil
32 MW GE LM2500 gas turbine	Sunlaw Federal cogeneration facility	Vernon, CA	1996	Actual ³

¹ Dual-fuel: pipeline natural gas and low-sulfur diesel fuel oil.

² Actual values on gas typically below 1.5 ppm, with substantial periods below 1.0 ppm.

³ Below 2.0 ppm for nearly all of the plant’s operating hours in 2000 and 2001, below 1.5 ppm performance for 97% of those operating hours, and below 1.0 ppm for over 90% of the hours.

Wyeth BioPharma Unit #2 Cogeneration Facility

This installation, which came on line in September 2003, incorporates the new EMx™ catalyst formulation and the most advanced hardware and process enhancements. The enhancements were so effective and successful that within 2 weeks of installation the system was fully commissioned, the operators were trained, and the process was optimization to produce the cleanest fossil fuel power currently available on the market today.

The newest EMx™ patented catalyst formulation almost triples the standard NOx sorption capacity and enhances its tolerance to sulfur masking. This installation also incorporates the increased sulfur-handling capacity of the SCOSOx® catalyst; improved distribution of regeneration gas to increase catalyst efficiency; improved seals on isolation dampers to minimize loss of regeneration gas; improved catalyst handling systems; heavy duty butterfly isolation dampers and actuators; Class 6 shutoff valves on the regeneration gas headers for better control of gas distribution; and improved steam reforming process to produce higher hydrogen concentrations with less natural gas consumption in a robust, straightforward process. It also uses the latest version of the EMx™ system PLC program and other process and mechanical improvements.

Emission performance has set a new standard for clean fossil fuel power production:

100% load, natural gas fuel, catalyst operating temperature approximately 625°F

- 0.3 ppmvd NOx @ 15% O₂
- 0.4 ppmvd CO @ 15% O₂

100% load, low sulfur diesel fuel, catalyst operating temperature approx. 625°F

- 1.5 ppmvd NOx @ 15% O₂
- 0.3 ppmvd CO @ 15% O₂

Of course, ammonia slip and PM₁₀ were non-existent.

Montefiore Hospital Cogeneration Facility

Like the two Wyeth BioPharma installations (the second one discussed below), this EMx™ installation operates on either natural gas or low-sulfur diesel fuel. Catalyst operating temperature is approximately 525°F. The permit limits for NOx emissions on gas and fuel oil are 2.5 and 15.0 ppm, respectively. This system has been operational since June 2002 and has twice succeeded in passing rigorous New York State EPA stack emissions tests on both turbine fuels.

Redding Electric Municipal Cogeneration Plant

An EMx™ system serving a new cogeneration turbine for the city of Redding, CA reached operational status in June 2002. Catalyst operating temperature is approximately 525°F. The NOx limit for this installation is 2.0 ppm. Data collected during the first months of operation indicate consistent NOx performance below 1.0 ppm, with levels achieved as low as 0.25 ppm.

University of California San Diego (UCSD) Cogeneration Facility

The EMx™ systems installed at the two 15 MW UCSD cogeneration units have been in operation since July 2001. Catalyst operating temperature is approximately 425°F. This natural gas fired installation also operates under a 2.5 ppm NOx limit. Like the Wyeth BioPharma facility before it, this system consistently produces NOx levels below 1.5 ppm, with substantial periods below 1.0 ppm. These EMx™ systems are equipped with water-cooled gas condensers to recover condensate from spent regeneration gas and reduce boiler feed water consumption.

Wyeth BioPharma Unit #1 Cogeneration Facility

The Wyeth BioPharma plant was the first EMx™ system to operate on a dual-fuel turbine firing either natural gas and low-sulfur fuel oil, with automatic changeover capability. Catalyst operating temperature is approximately 625°F. This system has been operational since 1999, and over the years several system improvements and modifications have been implemented to enhance performance.

The NOx emission limits for this installation for gas and fuel oil are 2.5 and 15.0 ppm for gas and oil respectively. When firing natural gas, this plant is currently producing NOx levels consistently below 1.5 ppm, with substantial operating periods below 1.0 ppm. Four years after start-up the original catalyst is still performing to rigorous Massachusetts regulatory criteria. Furthermore, the owner reports that the reliability of this early EMx™ system has been good. EMx™ maintenance has always taken place during scheduled turbine outages.

Sunlaw Federal Cogeneration Facility

The Sunlaw Federal cogeneration facility, a natural gas fired plant, represents the first commercial application of EMx™ technology, in 1996. This configuration is currently considered to be old technology. It was data gathered from this facility that formed the basis for the U.S. EPA's Lowest Achievable Emission Rate (LAER) determination of 2.0 ppm NOx for gas turbines.

According to Sunlaw operating data, this EMx™ installation achieved NOx levels at or below 2.0 ppm for nearly all of the plant's operating hours in 2000 and 2001, and below 1.5 ppm performance for 97% of those operating hours. Furthermore, the plant demonstrated NOx levels at or below 1.0 ppm for over 90% of the plant's operating hours.

EMx™ SURPASSES COMMERCIAL BARRIERS TO ENTRY

Perceived Barriers to Entry

SCR has been the conventional method for controlling NOx in the power industry. For 10 years EMx™ technology has been advancing and maturing as installations increased and applications broadened. All the while, industry debated whether EMx™ was an appropriate LAER technology for electric power applications. The debate has centered around three fundamental issues:

- Performance - The ability of EMx™ to consistently achieve NOx reductions similar to, or better than, those produced by SCR technology.

- Feasibility and Availability - The viability of constructing and operating EMx™ technology on large power plants (in excess of 50 MW).
- Resource minimization - The ability of EMx™ technology to minimize, recover and reuse water from spent regeneration steam.

Performance

Operating records from numerous commercial installations continue to demonstrate that EMx™ technology consistently demonstrates NOx emissions well below 2.0 ppm. Operating data also support the claim that EMx™ can achieve NOx abatement levels below 1.0 ppm for a significant portion of plant operating time. SCR technology, on the other hand, has simply not demonstrated NOx control below 2.0 ppm.

From a broader environmental and health impact standpoint, EMx™ does not use or emit hazardous reagents. SCR inevitably generates byproduct air pollutants from ammonia slip – inherently unhealthy, yet unavoidable. These emissions increase as the incoming NOx concentration decrease, which suggests that SCR is misapplied in facilities where new Dry Low-NOx Combustor (DLNC) technology is applied or in areas where low ammonia emissions are required.

A comparison of SCR and EMx™ performance is summarized in Table 2 and discussed later in this paper.

TABLE 2
PERFORMANCE COMPARISON

	SCR	EMx™
Additional catalyst system required for CO and VOC reduction	yes; SCR reduces NOx only	no; EMx™ is a multi-pollutant catalyst
NOx emission @ 15 - 25 ppm NOx inlet	2 - 5 ppm	less than 2 ppm
NH ₃ slip @ 15 - 25 ppm NOx inlet	3 - 6 ppm	zero; NH ₃ not used or emitted from process
NOx emission @ <10 ppm NOx inlet	2 - 5 ppm	0.5 - 1.5 ppm
NH ₃ slip @ <10 ppm NOx inlet	2 - 10 ppm	0
Additional catalyst required when NOx inlet <10 ppm	yes	no
Fine Particulate (PM ₁₀)	SCR generates PM ₁₀	EMx™ reduces PM ₁₀
Disposition of spent catalyst	hazardous solid waste	non-hazardous; recover value for platinum precious metal

LAER involves the most stringent emission limitation available. The purpose of the regulation is to attain the greatest degree of emissions reduction for a criteria pollutant –

specifically NO_x in this case. From a permitting perspective, therefore, it is important to note that, when applied to commercial gas turbines:

- Where NO_x reductions are required to be 2.0 ppm or below and multi-pollutant emission reduction is required, EMx™ is the only commercially available technology able to achieve those limits on a consistent basis.
- Where DLNC turbines are the NO_x source, and ammonia emissions must be minimized to 2 ppm (or less), EMx™ is the only commercially available technology able to simultaneously achieve ultra-low NO_x emissions and ammonia emissions less than 2 ppm (i.e., zero).
- From an overall environmental, safety and health standpoint, EMx™ is clearly the lowest impact technology. EMx™ eliminates issues such as ammonia slip, the formation of airborne particulate matter, hazardous solid waste disposal, ammonia transportation and on-site storage, and difficult costly permitting.

It is interesting to note that most of the commercial installations achieve NO_x emissions below the federal LAER standard of 2.0 ppm, although none were specifically designed to do so. In fact, operating records show NO_x emissions below 1.0 ppm, for substantial periods of time.

Had these EMx™ systems been specifically designed using a NO_x emission target of, say 1.5 ppm (a 25% reduction in the current LAER), it is clear that such an emission target could be achieved continuously in operation.

Equally significant, the CO output levels at all of these installations have been measured below the NO_x emission levels. At the Sunlaw Federal Cogeneration Facility, Formaldehyde and Benzene emissions were assessed by the U.S. EPA as MACT (Maximum Available Control Technology).

EMx™ Feasibility And Scale-Up

For LAER applications, the argument is often made that EMx™ technology scale-up is technically infeasible, and so the application must default to conventional SCR. The cost and risk of EMx™ relative to SCR are also typically cited to support this lack of technical feasibility.

Technically Feasible Processes

A process may be said to be technically feasible when it has the following characteristics:

1. The basic chemistry is well understood, demonstrated and documented.
2. The process can be scaled to any size with identical results (scalability).
3. Systems can be constructed with commercially available components.
4. Commercial installations are operating or under construction.
5. The system itself is commercially available for purchase.

These characteristics apply to a wide variety of technologies in the chemical process and petroleum industries. Even with mature, well understood technologies, variations in system size may present different engineering or construction challenges. The

application and management of these characteristics is no different in the electric power generating industry.

EMx™ chemistry is the product of years of research and development. The chemistry and the process are well understood and documented, and are the subject of numerous U.S. patents. At present, seven gas turbine EMx™ systems are installed in the US, representing 112 MW of power generating capacity.

The process is scalable. Alstom Power, one of the EMx™ licensees, engineered and installed the technology on one of their GTX100 gas turbines. This size and design is a reproducible module that would be replicated multiple times for larger installations. Alstom has already produced preliminary designs for several standard size plants that match standard sizes of large turbines.



As further testimony to the feasibility of EMx™, U.S. EPA Region 1 issued its own opinion of EMx™ technology. In a December 20, 1999 letter to the Massachusetts Department of Environmental Protection (MDEP), USEPA Region 1 stated that it had “... concluded that our earlier technical concerns about EMx™ have been resolved, and that there are no known scale-up concerns with EMx™. Consequently, it is our view that EMx™ is a technically feasible control option for large combined cycle power plants.”

Additional testimony comes from satisfied customers. For example, Wyeth BioPharma of Andover, MA demonstrated their confidence when they placed a purchase order for an additional EMx™ unit in 2002 after a comprehensive technical and economic comparison with SCR technology.

Technically Optimal Processes

A process may be said to be technically optimal when it has the following characteristics:

1. The mechanical installation is fully refined.

2. The technology is available throughout the marketplace from multiple vendors and costs are competitive.
3. System contingencies are well understood and predictable.
4. Risk is minimized due to a larger and growing installation base.

Many processes that are technically feasible may not be technically optimal (or mature) because the installed base is so small. These include such commercially available technologies as solar power systems, coal gasification, and electric powered vehicles. None of these technologies can be considered mature, but all are installed and operated reliably on the basis of sound engineering and construction principles.

Given the growing number of permitted and operating EMx™ installations and the engineering, purchasing, and manufacturing skills of EMx™ licensees, the technology is rapidly approaching a point where costs and risks are consistent with system size.

EMx™ hardware has matured as licensees have applied their engineering and manufacturing experience. All the vessels, piping, instruments, and controls are standard, commercially available industrial components.

It is therefore reasonable to conclude that the current EMx™ technology can be applied with predictable results. This conclusion is consistent with the U.S. EPA determination cited earlier and validated by the experience with the newest EMx™ installation. The system was delivered ahead of schedule and within budget. The latest catalyst, process and hardware enhancements were so effective and successful that within 2 weeks of installation the system was fully commissioned, the operators were trained, and the process was optimized to produce the cleanest fossil fuel power currently available on the market today.

Water Conservation And Waste Steam Recovery

One final argument in the EMx™ / SCR debate involves the perceived consumption rate of water. The EMx™ process requires the use of steam to produce regeneration gas (see Catalyst Chemistry below). Smaller units discharge this spent regeneration gas (composed mainly of steam) to the exhaust stack. For large-scale facilities, once-through water usage becomes impractical and indeed unnecessary.

Steam condensation and recovery is a standard industrial process that can be applied to the spent regeneration gas. Water recoveries of 80% are attainable using the following measures:

1. Low leakage isolation damper seals to minimize steam losses during the regeneration process (already incorporated in the latest system design).
2. Uniformly distributed regeneration gas supply and exhaust to minimize chamber pressures and steam losses during regeneration (already incorporated in the latest system design).
3. Active chamber pressure control and spent regeneration gas removal by use of a vacuum exhauster, which also serves to reduce the dependence of the process on the effectiveness of damper seals (already incorporated in the latest system design).

4. Water recovery by use of a standard water-cooled condenser, with the condensate returned to the plant condensate system (already incorporated in one of the installed systems).

CATALYST CHEMISTRY

EMx™-Catalyst Operating Cycle

Being a multi-pollutant catalyst, the EMx™ catalyst simultaneously oxidizes CO to CO₂, VOCs to CO₂ and H₂O, and NO to NO₂. The NO₂ is absorbed onto the catalyst surface through the use of a potassium carbonate (K₂CO₃) absorber coating. These reactions are referred to as the “Oxidation/Absorption Cycle”.

EMx™ is classified as a “trap” technology. During the oxidation/absorption cycle, the potassium carbonate coating chemically bonds and traps the nitrogen oxides (NO₂) to form potassium nitrites and nitrates, which are held on the surface of the catalyst. Before the potassium carbonate on the surface of the catalyst becomes saturated with nitrogen oxides, the catalyst enters a regeneration cycle.

During the regeneration cycle the reactor chamber is isolated from the engine exhaust and a small flow rate of reducing gas, consisting of steam, carbon dioxide (CO₂), and a dilute concentration of hydrogen (H₂), is passed through the catalyst. The H₂ and CO₂ react with potassium nitrites and nitrates to form water vapor, elemental nitrogen and potassium hydroxide. The resulting water vapor and elemental nitrogen are exhausted to the stack.

CO₂ in the turbine exhaust reacts with potassium hydroxide to form the potassium carbonate – the absorber coating on the surface of the catalyst before the oxidation/absorption cycle began. This cycle is referred to as the “Regeneration Cycle.” The rates of these oxidation, absorption and regeneration catalytic reactions are a function of temperature, i.e., higher temperatures produce faster reactions. Catalyst operating temperatures in the range of 500 to 700°F are fast and require the least amount of catalyst.

Sulfur Guard

Sulfur compounds are present in natural gas and fuel oil and produce sulfur dioxide (SO₂) in the engine exhaust. Over time, the SO₂ forms potassium sulfate on the EMx™ catalyst, masking and degrading EMx™ catalyst’s capacity to absorb NOx. The potassium sulfate is not removed from the EMx™ catalyst during the normal regeneration cycle, but can be removed by washing the catalyst in a chemical solution.

The lifetime and efficiency of the EMx™ system are extended when used in conjunction with the SCOSOx[®] catalyst system. SCOSOx[®] catalyst is a sulfur management technology that protects the EMx™ catalyst from the masking properties of sulfur compounds. SCOSOx[®] catalyst is placed upstream of the EMx™ catalyst where it acts like a filter and removes most of the sulfur from the exhaust gas stream before it reaches the EMx™ catalyst. During the regeneration cycle the sulfur compounds are liberated from the SCOSOx[®] catalyst and concentrated in the small flow of spent regeneration gas. The sulfur compounds can be scrubbed out or returned to the stack downstream of the EMx™ reactor. SCOSOx[®] reduces EMx™ catalyst washing to once or twice per year.

EMx™ PROCESS DESCRIPTION

Absorption/Regeneration Cycle

The EMx™ reactor is constructed in modules with five catalyst chambers – large systems combine multiple modules. At any given time four of the five chambers are in the oxidation/absorption cycle and one is in the regeneration cycle. A regeneration cycle initially is set to last for approximately five minutes, so each section is in the oxidation/absorption cycle for twenty minutes.

EMx™ Reactor

To provide an oxygen-free environment during the regeneration cycle, the catalyst chamber undergoing regeneration is isolated from turbine exhaust gases using a set of isolation dampers – one upstream of the chamber being regenerated and one downstream. During the regeneration cycle, these isolation dampers close and two regeneration gas valves open – one delivering regeneration gas to the chamber and the other exhausting spent regeneration gas from the chamber.

The incoming regeneration gas is directed through a number of internal distribution passageways or plena that provide uniform flow across the face of the catalyst. The regeneration gas flows through the EMx™ catalyst, through the SCOSOx[®] catalyst, and into an outlet plenum. As it does, it displaces oxygen and turbine exhaust gas and creates a chemically reducing environment. Spent regeneration gas flows through an exhaust header and into the duct downstream of the EMx™ reactor.



Advances in isolation damper design, and the selection of special high-integrity metallic seals around the isolation dampers provide a durable and effective barrier against leakage.

Regeneration Gas Production

Regeneration gas is produced in either one of two simple, well-proven industrial processes. If a small quantity of low-pressure superheated steam is available the regeneration gas is produced by steam reforming natural gas (or propane) over EmeraChem's low-temperature steam reforming catalyst. The active constituents in regeneration gas are hydrogen (2 to 4 percent nominal) and carbon dioxide. Steam acts as the carrier gas.

The mass flow rate of steam is set at approximately one percent of the turbine exhaust flow rate. The mass flow rate of natural gas to the steam reformer is then controlled to maintain a set ratio of natural gas to steam (on the order of one percent).

The conversion of the hydrocarbons in natural gas into hydrogen is strongly dependent upon the operating temperature of the steam reformer. With a steam temperature of 800 to 900°F the conversion efficiency is over 90 percent.

If superheated steam is not available, a partial oxidation process with water-gas shift reactor is used to produce regeneration gas. Both technologies are well proven industrial processes.

EM_xTM EQUIPMENT DESCRIPTION

EM_xTM Reactor

The core EM_xTM reactor module has five catalyst chambers stacked one above another. Above each chamber is an internal manifold that carries regeneration gas to the chamber and carries spent regeneration gas from the chamber. Each reactor chamber has a catalyst access door used to load and unload catalyst modules. Each reactor chamber is equipped with louver dampers on the inlet and outlet to isolate the chamber from turbine exhaust during the periodic regeneration cycle.



The specific dimensions of the reactor are based upon the boiler gas path dimensions, the room arrangement, and the turbine exhaust gas flow rate. The construction material is externally insulated carbon steel.

EM_xTM and SCOSO_x[®] Catalyst Modules

EM_xTM and SCOSO_x[®] are platinum-based catalysts applied to a ceramic substrate. The ceramic substrates are housed in 304 stainless steel modules that provide structural rigidity and ease of handling. The specific dimensions of the modules, the number of modules, and number of rows of modules are based upon the reactor size, turbine exhaust gas composition, and performance requirements.



Steam Reforming Regeneration Gas System

The steam reformer vessel is constructed of 304 stainless steel. It is typically rated for 15 psig. The vessel is equipped with catalyst supports and a large access lid for installing catalyst. Catalyst can be washed in-situ and nozzles are installed for filling and draining catalyst wash solutions. The specific dimensions of the vessel are based upon regeneration gas requirements for each application.

The steam reformer catalyst is a precious-metal based catalyst applied to a crimped stainless steel substrate. The catalyst module is a ring-shaped cylinder. The diameter and depth of catalyst modules, and the number of modules are based upon the regeneration gas requirements for each application



Piping on the steam reformer skid carries natural gas, superheated steam, and condensate. Steam piping and valves are made of 304 stainless steel and rated for the design steam

temperature. Natural gas piping and valves are carbon steel. The header and valves that supplies regeneration gas to each reactor chamber are 304 stainless steel. The spent regeneration gas header and valves are carbon steel. Instruments, controls, valves, and actuators are all standard reliable industrial components.

Isolation Dampers

The damper frame is constructed of structural steel designed to resist all loads imposed by shipping, handling and installation, as well as resist all loads imposed by operating conditions. The blades are reinforced and aerodynamically shaped to minimize pressure loss. To assure blade integrity deflection is designed to be minimal at operating temperature and pressure. The blades are sized to absorb thermal expansion without binding or interference. The blade shafts are of 304 stainless steel for long bearing and packing life. The bearings are pedestal mounted, permanently lubricated and self-aligning sleeve bearings. The bearings are located to minimize deflection.

The isolation dampers have flexible metal spring seals constructed of high temperature Inco 625 alloy material. These seals minimize leakage and maintenance. These fully self-adjustable metal to metal seals allow thermal growth and misalignment to be absorbed.

EMx™ ADDRESSES LIMITATIONS OF CONVENTIONAL SCR

Selective Catalytic Reduction (SCR)

In the electric power generating industry, selective catalytic reduction (SCR) is considered a mature technology and is generally the accepted method of controlling NOx from power plants. SCR has been applied to natural gas, oil, and coal fired combustors.

As the name implies, selective catalytic reduction (SCR) involves the reduction of NOx compounds in the gas stream to nitrogen gas and water vapor by means of a catalyzed chemical reaction. The reducing agent is ammonia.

Anhydrous ammonia can be stored in tanks, vaporized, and injected into the hot turbine exhaust gas. Alternatively, an aqueous ammonia solution can be vaporized into an air stream and blown into the exhaust gas. A third alternative is to inject liquid urea into the exhaust where it vaporizes and converts to ammonia.

When the turbine exhaust and ammonia flow through the catalyst, the nitrogen and hydrogen in the ammonia combine with the nitrogen and the oxygen in the NOx to produce nitrogen gas (N₂) and water vapor (H₂O). The process requires that the ammonia supply be continuously adjusted, based upon the measurement of incoming and outgoing NOx concentrations.

Single- versus Multi-Pollutant Catalyst Technology

SCR is a single-pollutant catalyst technology. Where SCR is employed, separate catalytic systems are required for CO and VOC destruction. EMx™ is a multi-pollutant catalytic control technology. NOx, CO, VOC and fine particulate matter are simultaneously destroyed using a single catalyst system. This is a unique feature setting EMx™ technology apart from all others.

Byproduct Ammonia Emissions

In general, the NH₃/ NO_x molar ratio depends on the amounts of NO and NO₂ present in the exhaust gas. There are at least five (5) documented reactions that take place between NH₃ and NO_x and the theoretical ratios of ammonia reagent to NO_x vary from 0.66 to 2.0. While SCR system suppliers recommend or target a 1:1 ratio the experience of SCR operators shows that excess NH₃ is required to compensate for the unpredictable chemical stoichiometry and practical limitations in uniformly distributing and mixing ammonia into the exhaust gas stream. This excess supply is known as “ammonia slip,” which shows up as an additional source of air emissions for the plant and results in the formation of fine particulate emissions.

The amount of ammonia slip may seem trivial. But consider that even if SCR could meet a 2 ppm ammonia emission limit, a 500 MW cogeneration facility would still emit 45 tons per year or more of ammonia into the atmosphere and surrounding areas. This is clearly against the desires of those regions where airborne ammonia is regulated under an air toxic policy.

In contrast, EMx™ technology does not use ammonia. Consequently, ammonia is not emitted as a byproduct from the process.

Formation of Fine Particulate Matter as a Byproduct

The unreacted amounts of ammonia (ammonia slip) can react with the sulfur present in the turbine exhaust gas and the uncontrolled NO_x to produce fine particulate matter (PM₁₀). This particulate fouls boiler tubes and is ultimately emitted into the atmosphere as small respirable airborne pollutants, which are of particular health concern.

EMx™ technology does not use ammonia. Consequently, ammonia-based fine particulate matter is not generated or emitted from the process. Furthermore, EMx™ technology actually reduces the amount of particulate emitted by the turbine.

Achieving Low NO_x and Low Ammonia Slip Simultaneously

SCR NO_x control performance is known to vary significantly as dynamic changes occur with turbine load, exhaust gas flow rate, and incoming NO_x concentration. This variability is due to the complexity and sluggishness of dynamically measuring, controlling and balancing the proportions of ammonia and NO_x.

Currently, there is no published information available to confirm the performance of SCR for NO_x abatement of 2.0 ppm or below for significant periods of time. From available information, most sources generally describe successful SCR installations as those achieving NO_x emissions in the 3 - 10 ppm range. Although power industry trade journals often cite SCR performance potential as being “...below 3.0 ppm”, or “...as low as 2.0 ppm”, there are no apparent references or testimonials confirming SCR control as an available technology for NO_x levels at or below 2.0 ppm.

In some cases, SCR has reduced NO_x levels down to 2.5 ppm but required the trade-off of releasing excess ammonia into the atmosphere (ammonia slip). Historically, SCR NO_x control has been demonstrated to be effective for NO_x inlet concentrations of 15- 25 ppm, when 2 - 10 ppm of ammonia slip can be tolerated.

While SCR technology has been permitted in several combined cycle applications as LAER for NO_x at 2.0 ppm (most notably in Massachusetts, with 2.0 ppm ammonia slip), none have yet been constructed. Several California facilities using SCR control have demonstrated NO_x emissions in the 2.4 - 2.5 ppm range, although ammonia slip allowances are 10 ppm. Facilities that are known to be currently operating at NO_x emission levels of 2.5 ppm do so with an ammonia slip concentration in the range of 5-10 ppm.

No trade-off is required with EMx™ technology. EMx™ produces extremely low NO_x emissions without the use ammonia. Consequently, ammonia is not emitted as a byproduct from the process.

When the inlet NO_x concentration is low, such as from new generation Dry Low NO_x combustors, these difficulties increase. DLNC can produce NO_x concentrations of less than 10 ppm. If an SCR is required to control NO_x down to 2 ppm (or lower), then higher catalyst volumes and higher ammonia usage are required. Higher ammonia usage results in higher ammonia slip, which is a precursor to fine particulate matter (PM₁₀). To date, SCR systems have not demonstrated they can simultaneously achieve high NO_x removal efficiencies and low ammonia slip for low inlet NO_x applications.

In contrast, EMx™ performance is not a function of inlet NO_x concentration and does not require the precise control of any reagents. The newest generation of EMx™ catalyst achieves ultra-low emissions from gas and oil-fired turbines regardless of turbine load, exhaust flow rate, and inlet NO_x concentrations.

EXPANDING COMMERCIAL APPLICATIONS FOR EMx™

The future of EMx™ technology is very exciting. Cummins Engine Company, one of EmeraChem's equity investors, has helped EmeraChem apply the technology to internal combustion (IC) engines – particularly diesel engines. EmeraChem has invested many years and millions of research and development dollars adapting the EMx™ technology to these applications. The investment has paid off.

Transportation Market: EmeraChem's proprietary catalyst is currently the only catalytic technology that has demonstrated the required durability to meet the 2007 U.S. EPA diesel engine emission mandate. EmeraChem is currently collaborating with automotive exhaust companies to complete on-vehicle integration of the catalytic system in preparation for 2007-2010 production requirements.

More significantly, the EmeraChem technology is applicable, and is even more effective when applied to internal combustion engines burning “fuels of the future,” such as hydrogen, compressed natural gas (CNG), and methane mixtures. Compared with diesel and gasoline these fuels produce less carbon monoxide and hydrocarbons and little particulate. However, NO_x emissions still require after treatment.

Considerable engine development work to reduce emissions has been done using exhaust gas recirculation (EGR). While EGR does reduce emissions somewhat it does so at the expense of fuel efficiency, power, and durability. An optimal approach would be to design and tune engines for superior engine performance and use a small, high-performance catalyst solution to achieve ultra-low emissions.

Stationary Diesel Engines: In the new distributed power markets in the United States, Europe and parts of Asia, an ultra-clean catalytic technology such as EMx™ will enable further acceptance of the diesel engine as a stationary power source. These diesel engines are highly reliable and operate at a much higher efficiency than any other small stationary power source and therefore will be in much greater demand when they can be operated in a clean manner. In addition, existing stationary diesel engine owners (most of whom are restricted in the number of hours per year they may operate), can apply EMx™ and capitalize on underutilized assets during peak power demand.

Industrial Boilers: New and existing industrial and institutional facilities are experiencing significant expansion throughout the country. A great percentage of these facilities are located in densely populated areas, thus driving the need for clean and efficient industrial boilers for the generation of steam and hot water. Also, as States race to meet the required the U.S. EPA ozone standards by 2007 (and in some cases by 2005), local authorities have identified the need to better control emissions from industrial boilers. The first pilot plant using EMx™ for this application reduced emissions by over 95%. An opportunity exists to set a new Best Available Control Technology (BACT) standard using EMx™ technology.

CONCLUSIONS

In light of the information currently available for both EMx™ and SCR NOx abatement, the following conclusions can be drawn.

2. EMx™ has demonstrated its ability in commercial operation to meet the current requirements of Federal LAER for NOx – in fact, the EMx™ technology has twice established the U.S. EPA LAER standard for gas turbines. In addition, EMx™ has been certified by the California EPA for 2.0 ppm NOx abatement as being “technically feasible”.
3. Commercial EMx™ installations have demonstrated NOx removal to levels lower than 2.0 ppm, and below 1.0 ppm on a consistent basis. Early and recent installations continue to demonstrate performance in this range.
4. EMx™ addresses the limitations of SCR technology. Where NOx control to 2.0 ppm or less is required, EMx™ is the only “available” and “technically feasible” NOx control option. There is no data available to support the claim that SCR technology can be installed and operated to achieve NOx control of 2.0 ppm or less; it is neither “available” or “technically feasible”.
5. EMx™ can simultaneously achieve ultra-low NOx emissions and zero ammonia slip. There is no data available to support the claim that SCR technology can be installed and operated to achieve 2.0 ppm (or less) NOx, while simultaneously achieving ammonia slip levels as low as 2.0 ppm. This limitation becomes even more daunting when applied to DLNC turbines.
6. For large combined cycle plants, SCR technology even in the most optimistic scenario of 2 ppm ammonia slip, can emit up to 45 tons per year or more of ammonia. In contrast, EMx™ technology does not use ammonia; ammonia is not emitted as a byproduct from the process.

7. From an overall environmental, safety and health standpoint, EMx™ is the lowest impact technology. EMx™ does not require the use of hazardous reagents such as ammonia, does not produce hazardous air emission byproducts such as ammonia and fine particulate matter, and does not become a hazardous solid waste at the end of its service life. The EMx™ catalyst subsequent residual value at the end of its useful life is used to offset the cost of future catalyst purchases in addition to operating and maintenance costs of the system. EMx™ eliminates issues such as ammonia slip, the formation of airborne particulate matter, ammonia transportation and on-site storage, and difficult costly permitting.
8. EMx™ hardware has matured as licensees have applied their engineering and manufacturing experience. All the vessels, piping, instruments, and controls are standard, commercially available industrial components. The most recent installation, which came on line in September 2003, incorporates the new EMx™ catalyst formulation and the most advanced hardware and process enhancements. These enhancements were so effective and successful that within 2 weeks of installation the system was fully commissioned, the operators were trained, and the process was optimized to produce the cleanest fossil fuel power currently available on the market today.
9. The scalability of the EMx™ process makes it “technically feasible” for large applications. Alstom Power, one of the EMx™ licensees, engineered and installed the technology on one of their GTX100 gas turbines. This size and design is considered a reproducible module that would be replicated multiple times for larger installations. Alstom has already produced preliminary designs for several standard size plants that match standard sizes of large turbines.
10. In December 1999 the U.S. EPA Region 1 made a favorable determination by stating the technology was “technically feasible”.
11. Where site water resources are a concern, EMx™ systems can be equipped to recover 80% of the steam used in the catalyst regeneration process. This process is a proven one.
12. Where applicable, the cost of NOx offsets can be minimized when building a new power plant in addition to the opportunity to generate ERCs in retrofit applications.
13. The EMx™ technology is available to achieve ultra-low emissions for other combustion sources such as stationary diesel engines, mobile diesel engines and industrial boilers. Furthermore, EMx™ technology will play a key role in clean fuels of the future such as internal combustion engines fueled by hydrogen, compressed natural gas, and methane mixtures.

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