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Technical Paper

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W.K. Keslar, P.E. and M.S. Tittle, P.E.
The Babcock & Wilcox Company
Barberton, Ohio, U.S.A.

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Introduction

To comply with Title I guidelines from the Clean Air Act Amendments of 1990, coal-fired power plants in the United States were required to have significant reductions in their nitrogen oxides (NO_x) emissions by May 1, 2003. Many utilities have or are already planning the installation of Selective Catalytic Reduction (SCR) systems on operating units to meet these and future requirements.

Consumers Energy approached The Babcock & Wilcox Company (B&W) to engineer, fabricate and install Selective Catalytic Reduction (SCR) equipment at the Dan E. Karn generating facility, located in Essexville, Michigan. Karn 1 is a 255 MW CE tangential fired boiler; Karn 2 is a 260 MW B&W wall-fired boiler (Fig. 1).

After extensive evaluation of reagent suppliers, Consumers Energy contracted with Chemithon Corporation for their SafeDeNOx® process to convert urea to ammonia.

Both units are meeting Consumer Energy's NO_x reduction goal and have been in successful operation since the installation and startup of the SCRs (see Table 1). Karn 2 has been in service since June 2003; Karn 1 has been in service since May 2004. The SCRs currently operate during the ozone season (May-September). A flue-gas bypass system diverts the flow around the reactors when they are out of service.

The success of the Karn project included a strong project team; a design that considered constructability, reliability and flexibility of the system; the use of proven technologies and new applications for existing technologies; and construction techniques that avoid unplanned interruption of ongoing plant operations.

Fig. 1 D.E. Karn Units 1 and 2 during SCR installation

Project approach

Planning for an SCR system requires special attention to technical design and construction details to keep the overall cost of the project under control. At the beginning of the Karn SCR project, clear project objectives were established and a project team was formed to carry out the project objectives from the initial design decisions through final implementation and start-up of the system. The integrated project team included Consumers Energy's Title I Team that included members of their Engineering Services Department and plant personnel; The Babcock & Wilcox Company engineering, field service, and training departments; and representatives from key equipment suppliers. Chemithon, the supplier of the ammonia plant, and Cormetech, the catalyst supplier, played an important role as key suppliers.

The project key objectives included:

- Achieve maximum NO_x reduction
- Utilization of known and proven technologies
- Design to accommodate future modifications and year round operation

Description	Karn 1		Karn 2	
Coal Blend Percent Western	50	80	50	80
Inlet NO_X, lb/10^6 Btu	0.45	0.39	0.38	0.30
Outlet NO_X, lb/10^6 Btu	0.05	0.05	0.05	0.05
% Removal	88.9	87.2	86.8	83.3

Table 1- Karn SCR NO_X Reductions

- Economical solution to meet the performance objectives
- Minimal impact to plant operations during installation
- High availability during ozone season
- No compromise of ash sales and disposal

Maximizes reductions on key units

The Karn plant is located at the mouth of the Saginaw River in Essexville, Michigan. The base loaded units represent a reliable source of energy production for Consumers Energy. Karn units 1 and 2 burn a mixture of western and eastern bituminous coal. Karn 1 is a 255 MW CE tangential fired boiler with an inlet NO_x of 0.39-0.45 lb/10^6 Btu; Karn 2 is a 260 MW B&W wall-fired boiler with an inlet NO_x of 0.30-0.38 lb/10^6 Btu. The outlet NO_x goal, with the SCRs in service, is 0.05 lb/10^6 Btu. See Table 1.

Proven emission reduction technologies

The Babcock & Wilcox Company provided more than 135 years of experience designing, manufacturing, erecting, and commissioning power generation systems and servicing and retrofitting both its own boilers and those from other manufacturers. Over the past forty years, B&W has been helping utilities comply with their environmental control objectives by supplying engineered combustion and post-combustion emission control solutions.

B&W's approach to compliance planning is to take advantage of integrated NO_x solutions. This method allows utilities to apply the most cost effective NO_x control strategy. In 1998, B&W's DRB-XCL® burners and overfire air ports were put into service. This combination of technologies resulted in a lower cost SCR on unit 2.

New technologies

Due to the safety and environmental concerns related to anhydrous and aqueous ammonia being transported through a heavily populated area, the team had to look at other solutions to meet the ammonia reagent requirements. Anhydrous and aqueous ammonia are both classified by the Environmental Protection Agency (EPA) as regulated substances and are toxic to humans. The chemicals are an irritant and corrosive to skin, eye, respiratory tract, and mucous membranes. Exposure may cause severe burns, eye and lung injuries. Exposure can aggravate skin and respiratory related diseases.

Consumers Energy selected Chemithon Corporation to supply their SafeDeNOx® process shown in Fig. 2. Chemithon began designing and fabricating chemical process equipment in 1954. Based on Chemithon's extensive experience in designing and supplying chemical process equipment and visiting the SafeDeNOx pilot plant in Seattle, Washington, the project team was confident that the Chemithon solution was the proper choice for the Karn project.

The process, developed at the Chemithon Research & Development facility in Seattle Washington, satisfied the demand for a safer, cost effective alternative to storing ammonia on site. The Karn plant has the first commercial SafeDeNOx® Urea-to-Ammonia Process which went into service in May 2003. The process generates ammonia by melting urea (Fig. 3) and metering molten urea and steam into a vessel where they are reacted in the presence of a catalyst (Fig. 4) to produce gaseous ammonia (NH_3) and carbon dioxide (CO_2). The vessel is operated at constant temperature and pressure resulting in a constant ratio of ammonia, carbon dioxide and water vapor in the gas stream from the reactor. The overall reaction for converting urea to ammonia is:

$$NH_2CONH_2 + H_2O \text{ (steam)} \longrightarrow 2\ NH_3 + CO_2$$

The resulting ammonia product is transported to the SCR through a steam jacketed piping system.

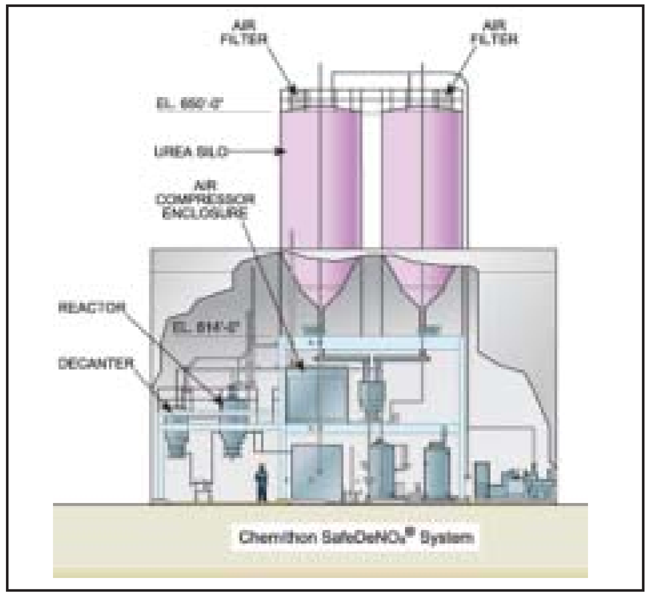

Fig. 2 Chemithon Corporation's first commercial installation of the SafeDeNO_x® system began operation in May 2003 at Consumers Energy's Karn plant.

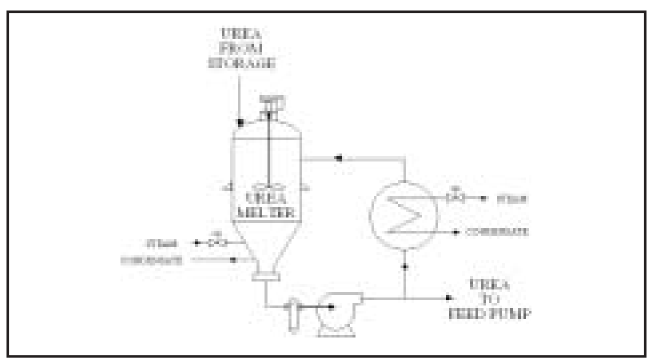

Fig. 3 Urea melter.

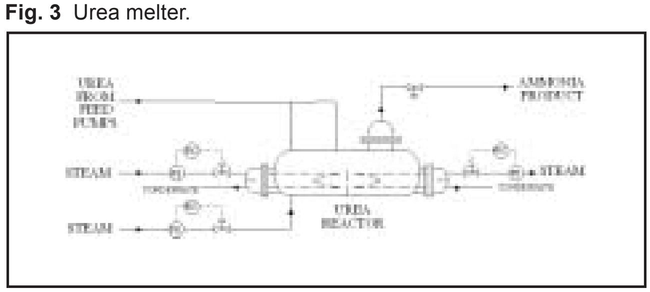

Fig. 4 Urea reactor.

Functional design basis - flexibility

The Karn 1 and 2 SCRs are designed for future flexibility, including:

- Universal reactor – ability to accommodate catalysts from major suppliers; Catalyst modules interchangeable between both units
- Reactors and flues designed for 100% Powder River Basin (PRB) coal
- SCR bypass system/catalyst protection system

To allow maximum flexibility in the future, B&W designed a "Universal Reactor" which would accommodate catalyst from four different major suppliers - Babcock Hitachi, Haldor Topsoe, Cormetech, and Frauenthal. The universal reactor approach required that the reactor design be flexible enough to accommodate the differences associated with the supplier product. The catalysts from the suppliers varied significantly in type (plate or honeycomb), geometry, weight, and functional performance. The number of catalyst layers and the reactor cross sectional area were set to allow for a minimum of one spare level of catalyst when the reactor went into service for the first time. The stage height allows adequate space for sonic horns, catalyst support beams, and the tallest catalyst block. The supporting structure design can handle the heaviest load, multiple block sizes and support arrangements.

If Consumers Energy elects to convert the units to 100% western fuel (PRB) firing in the future, the cross sectional area of the reactor and flues and the induced fan are designed to accommodate the increased flow.

Both Karn 1 and Karn 2 SCRs are identical units, allowing additional flexibility with interchangeable catalyst blocks and other equipment.

During the non-ozone season, an SCR bypass and Catalyst Outlet Protection System (COPS) is in operation. The bypass diverts flue gas around the reactor. The COPS uses hot secondary air to the reactor to keep the reactor environment above the dew point. Both features provide for longer catalyst life.

Flow modeling

B&W evaluated the SCR arrangement by using advanced Computational Fluid Dynamics (CFD) models for each unit (Fig. 5). A physical flow model (1:12 scale) by the catalyst supplier provided verification of the CFD model (Fig. 6).

Flow modeling of the reactor and connecting flues is important for determining the flow distribution devices required.

Catalyst suppliers typically specify, as a condition for their performance guarantees, several criteria. These include velocity profile at the face of the catalyst, temperature profile at the face of the catalyst, and ammonia-to-NO_x mole ratio profile at the face of the catalyst.

The use of the flow models for the reactor and connecting flues provided valuable design information for the configuration and placement of flue geometry, flow distribution devices, static mixers, and ammonia injection grid. To help meet the catalyst vendor requirements, the Karn units are designed with two separate static mixing devices.

Popcorn ash

The use of an economizer ash deflector (Figs. 7 and 8) and screen at the economizer exit minimized the amount of large particle ash (sometimes referred to as "popcorn ash") from making its

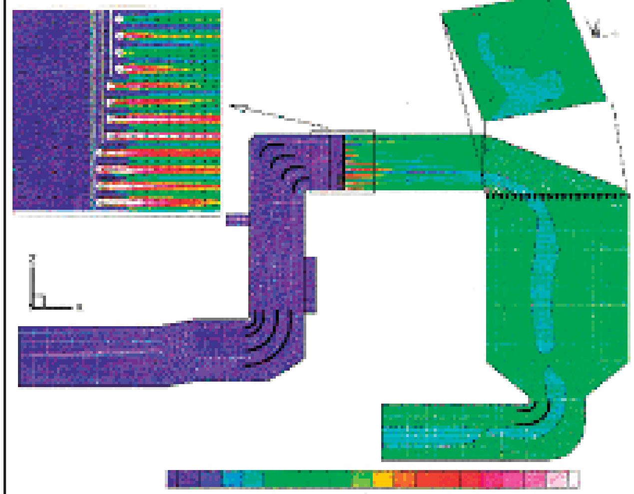

Fig. 5 Modeling activities for Karn SCRs ensure proper flue gas distribution NH_3 mixing.

Fig. 6 Typical physical SCR model.

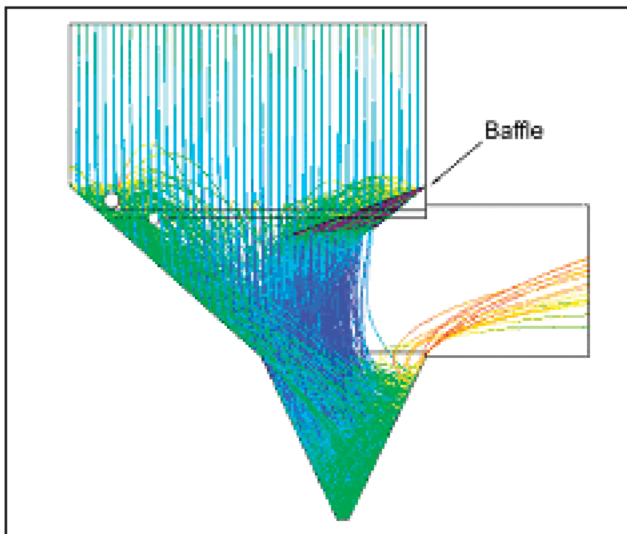

Fig. 7 B&W modeled and installed a baffle system to improve large particle capture.

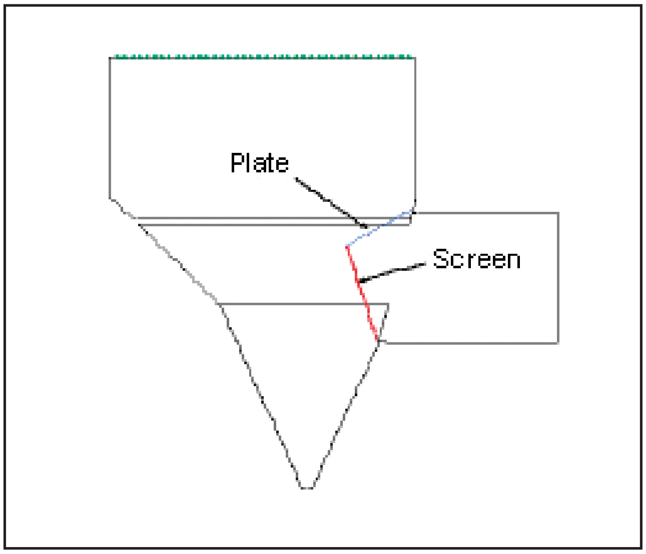

Fig. 8 B&W added an ash screen to capture the remaining large particle ash.

Fig. 9 Karn SCR units were designed to handle large particle (popcorn) ash, if it is ever encountered.

way to the SCR. Popcorn ash (Fig. 9) is light kidney bean shaped material that normally forms in the furnace or on the leading edges of superheater surface. Most of the ash falls down the furnace and exits the unit through the bottom ash system. It becomes problematic when it carries into the horizontal convection pass and begins plugging the gas pass or carries through the back pass and out the economizer exit potentially plugging the air heater surface or SCR catalyst.

There seems to be some correlation of coal ash properties to the formation of popcorn ash. B&W has observed that popcorn ash is more prevalent in PRB fired pulverized coal units. One explanation for this is PRB firing tends to have elevated furnace exit gas temperatures (above eastern bituminous coal fired units) and the convection pass on PRB fired units is more difficult to keep clean.

Reasons why popcorn ash might carry through the convection pass include:

- Elevated convection pass gas temperatures due to higher furnace exit gas temperatures or heat transfer surface fouling, causing popcorn ash to form further back where its only path out of the unit is to the rear then down through the horizontal convection pass.
- Gas velocities being high due to convection pass surface plugging or high load which sweeps this material back.
- A buildup on the flat floor of the pendant convection pass that creates a combination of higher gas velocities and an ash slope to the rear or "snowdrift."

Once popcorn ash has been formed and carried through the horizontal convection pass, it can be carried out of a standard design economizer exit arrangement. Hopper design and ash removal frequency play an important role in how much popcorn ash is carried out of a unit.

Various collection devices have been used in the economizer hopper area. The effectiveness of these depends on the following:

- A fully functioning economizer hopper ash removal system.
- Proper gas velocities at the economizer exit gas turn.
- Aerodynamics of the popcorn ash particles.

CFD modeling set the angle of the economizer ash deflector to minimize the amount of popcorn ash hitting the ash screen.

Constructability/plant operations

Because project and plant operation costs can be significantly impacted by installation, the project team focused on constructability and plant operations.

In most cases, the SCR is going to be located directly behind the existing steam generator. Since the majority of the installations are retrofit projects, the design considers potential obstructions (overhead and underground) from existing equipment and utilities, construction techniques, and plant operation concerns (unit trips and outage span). See Figs. 10 through 16.

The major objectives of installing the SCR included: keep the unit running during construction, avoid unit trips, and minimize the tie-in schedule. A soft-dig technique is used to avoid unnecessary unit trips. Conventional digging techniques have a much higher probability to disturb or even break underground services in the area, resulting in potential for plant trips or dangerous contacts with energized or pressurized lines.

To accommodate site constraints and avoid unnecessary plant disruptions, the project team selected micro-pile technology. Micro-piles are sometimes referred to as pin piles, mini-piles, or root piles. Micro-piles were developed in the 1950s in Europe, and began to see use in North America in the 1970s. The micro-piles for Karn are based on a patented design by Dywidag-Systems International (www.dywidag-systems.com). The GEWI® Pile (Rock-Socketed) is a drilled micro-pile with a steel center made with the GEWI® THREADBAR® system. The design transfers load by friction between the bedrock and the cement grout.

The Karn project is based on modular construction to optimize the installation time and minimize construction costs**.**

Ash sales – not compromised

The SCR is designed for ammonia slip of less than 2 ppmdv @ 3% O_2 DV. This design condition allows Consumers Energy to sell ash in the future.

Reliability – high availability

The units were successfully put into operation on schedule (2003 Karn Unit 2; 2004 Karn Unit 1). The long-term operation experience indicates that the units met or surpassed the project goals without any adverse effects on unit operation. See Figs. 17 through 20.

Fig. 10 The Badger Hydro-Vac “soft-dig” excavation technique safely exposes underground obstructions.

Fig. 11 Underground exposed obstructions during Hydro-Vac excavation.

Fig. 12 Typical micro-pile installation.

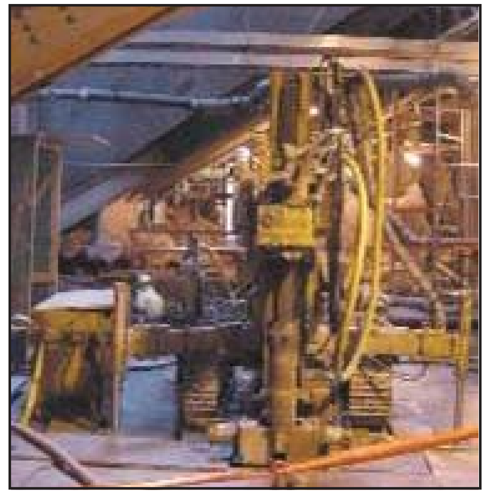

Fig. 13 Micro-piles being installed in a limited access area.

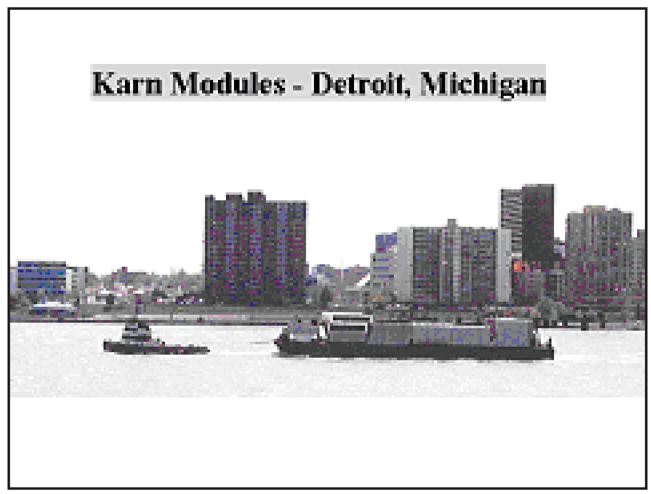

Fig. 14 Pre-assembled modular SCR components were transported by barge to the Karn station.

Fig. 15 Pre-assembled SCR flue shown during installation, complete with insulation and lagging.

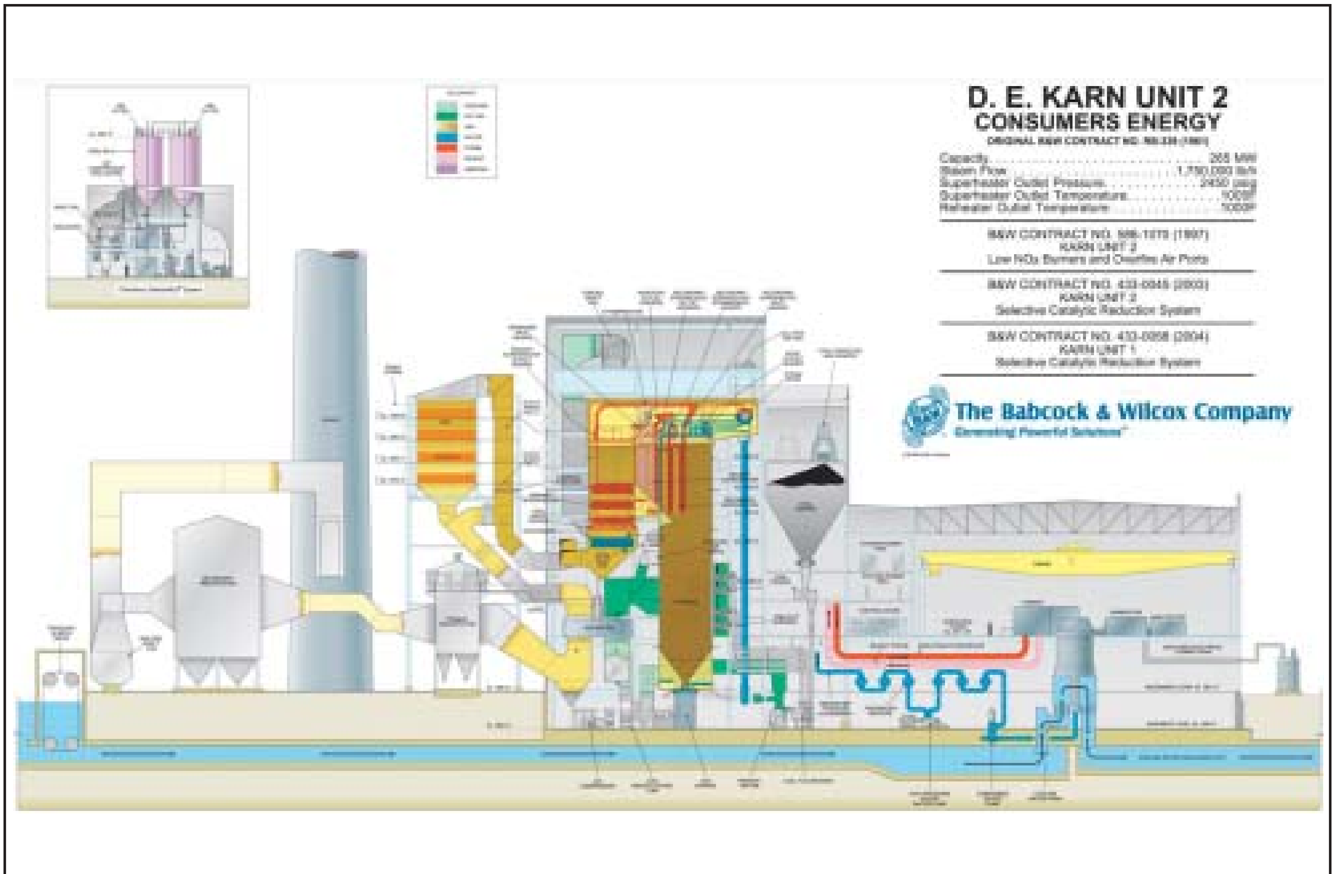

Fig. 16 Consumers Energy SCR System – Karn 2 – Plant sectional sideview showing new SCR unit and connecting ductwork.

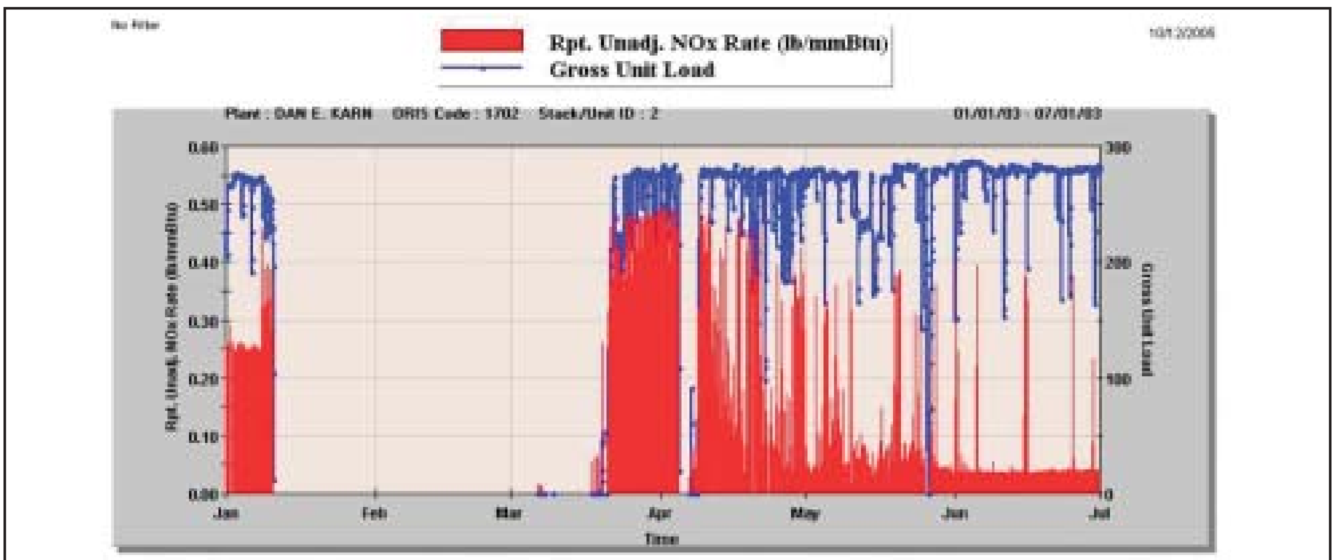

Fig. 17 EPA CEMS NO_X emissions, Karn 2 SCR startup – NO_X emissions were significantly reduced from pre-retrofit levels.

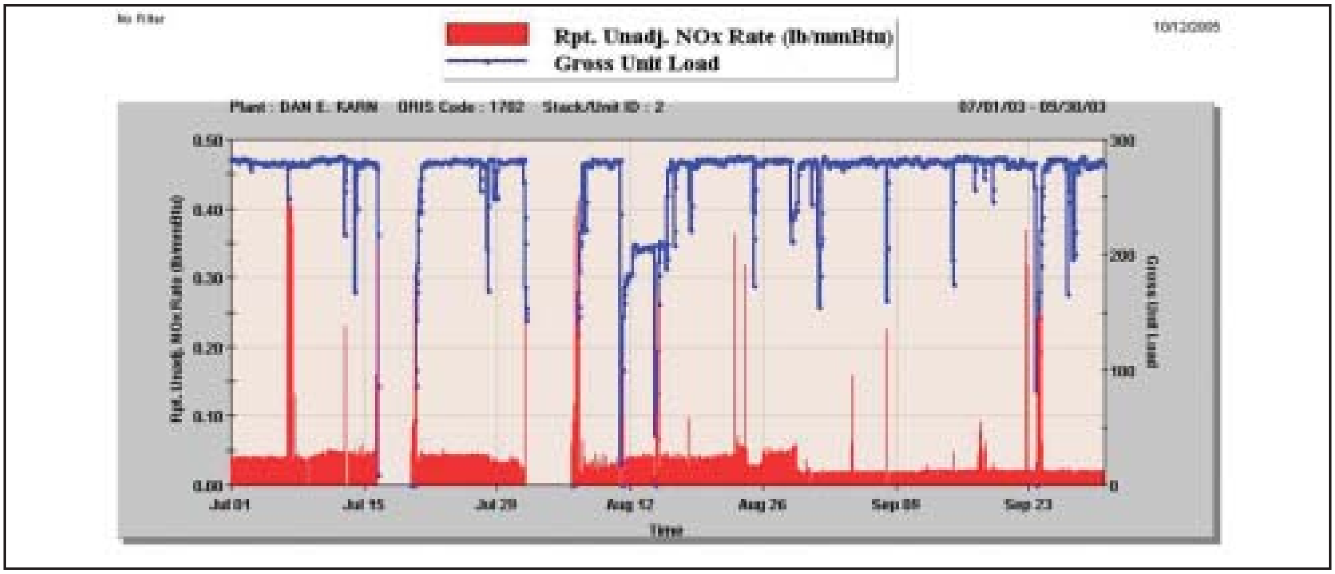

Fig. 18 EPA CEMS NO_X emissions, Karn 2 SCR first ozone season.

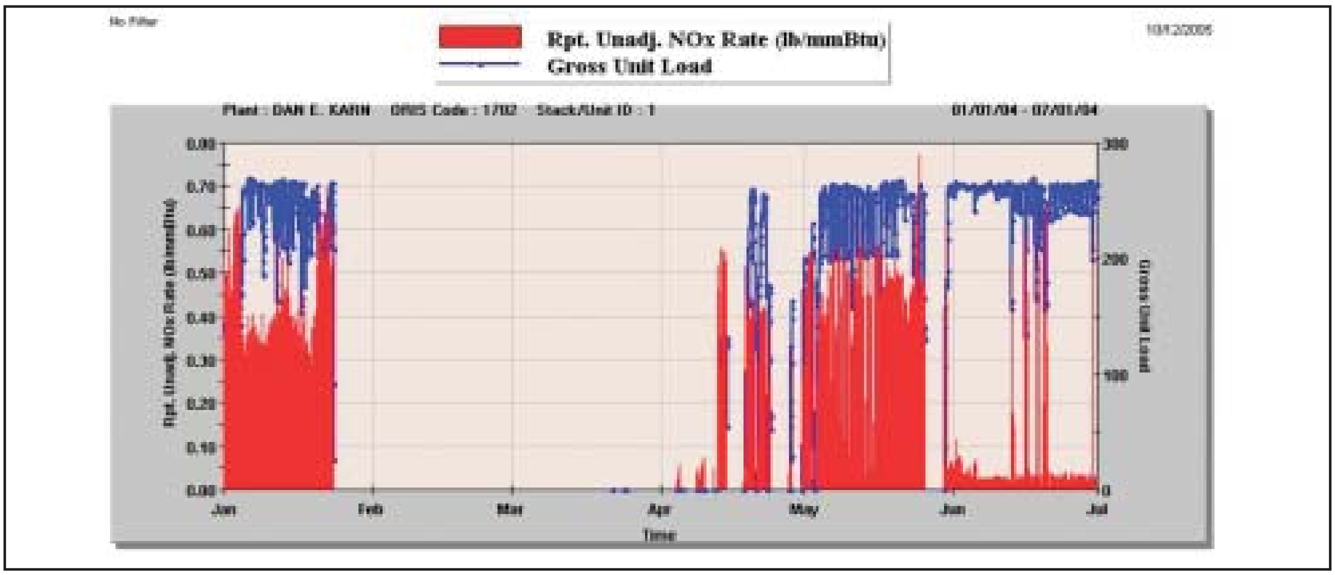

Fig. 19 EPA CEMS NO_X emissions, Karn 1 SCR startup.

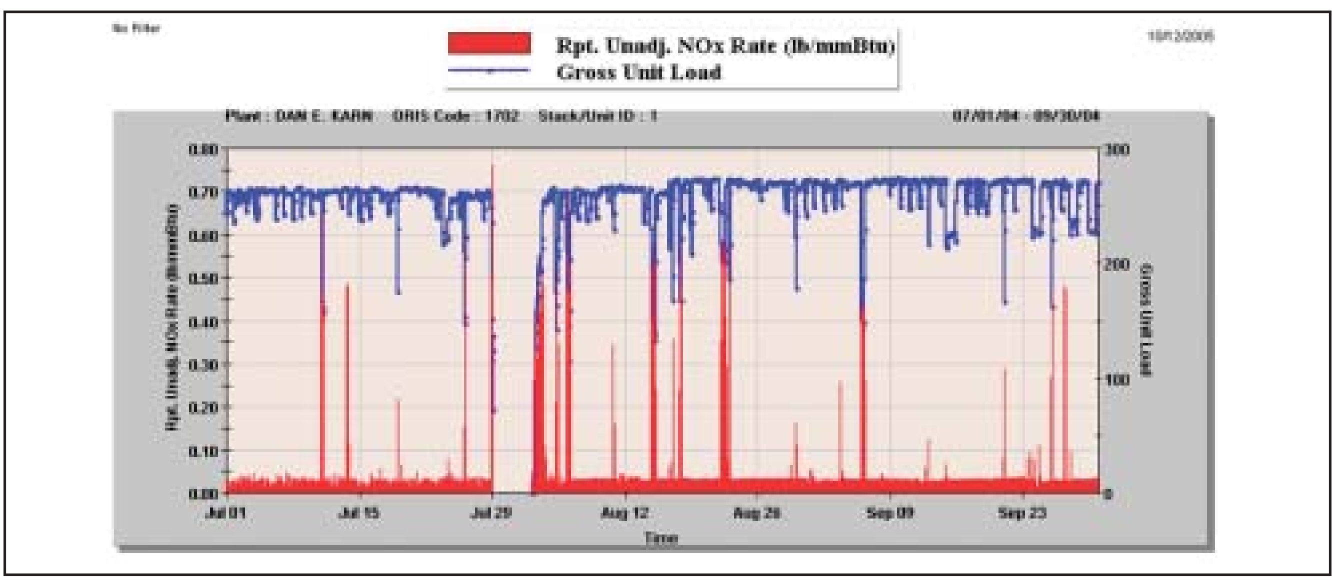

Fig. 20 EPA CEMS NO_X emissions, Karn 1 SCR first ozone season.