Optimization of SNCR Systems with Continuous Measurement of Ammonia Slip at Constellation Energy's Crane Units 1 and 2

By

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ABSTRACT

Constellation Energy operates power plants in the Baltimore, Maryland area that are subject to Maryland's Healthy Air Act. This piece of legislation required NOx, SO_2, and Hg reductions from Constellation's Maryland plants. In response to those requirements, Constellation installed SNCR systems on three of its coal-fired units, Wagner 2, Crane 1 and Crane 2. The urea-based SNCR systems provide NOx reductions that contribute to Constellation's overall system-wide cap.

A unique aspect of these systems is the use of continuous ammonia analyzers. These analyzers work on the principle of tunable diode laser (TDL) spectroscopy and provide continuous, real-time indication of ammonia slip in the duct. Application of the TDL analyzers to these units required overcoming several application challenges that in the past have plagued the use of TDL technology in coal-fired power plant applications. Using this PAT.- PEND. approach, the TDL instruments provided reliable, real-time indication of ammonia slip, even under changing loads and conditions. The value of using these analyzers is that they have enabled optimization of the SNCR system with respect to NOx emissions, urea consumption, and ammonia slip, with lower ammonia in fly ash. This paper will discuss this project, the technical challenges, approaches used for addressing these challenges, and the results of the optimization program for Crane units 1 & 2 and operating experience to date.

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Project Background and Technical Description

Constellation Energy's Baltimore plants are subject to a system-wide cap on NOx, SO_2 and mercury emissions as a result of Maryland's Healthy Air Act. To address NOx emission needs Constellation selected Selective Non Catalytic Reduction (SNCR) for application at C. P. Crane units 1 and 2 and Wagner 2. This paper will focus on the CP Crane SNCR systems, which were particularly difficult applications.

C. P. Crane station has two cyclone boilers, units 1 &2, rated at 200 MWg and 205 MWg, respectively. Each unit has four cyclones – two on the front wall and two on the rear wall. At the time of the SNCR system start up the boilers were firing a blend of eastern bituminous coal with PRB at a blending ratio of roughly 75%/25% Bailey/PRB by weight. Table 1 summarizes key characteristics of the CP Crane units.

Table 1. CP Crane Units 1 & 2 Description

	Unit 1	**Unit 2**
Rated Capacity MWg	200	205
Boiler Type	Cyclone 2 front wall 2 rear wall	Cyclone 2 front wall 2 rear wall
OFA	yes	yes
Internal Wing Walls	No	Yes
Coal Blend (approx. by wt.)	75% Bailey 25% PRB	75% Bailey 25% PRB
Combustion Optimizer	Emerson IVY	Emerson IVY
Baseline NOx (approx)	0.45 lb/MMBtu	0.45 lb/MMBtu
Air Preheater	Tubular	Tubular
PM Control	Fabric Filter	Fabric Filter

Project Team

Constellation assembled a project team to evaluate technologies and execute the program. The project team members included the following organizations and their responsibilities.

The SNCR Project Team included the following organizations

1. Constellation Energy – Overall Capital Project Management
2. CP. Crane Station – Plant support, controls and instrumentation integration
3. Andover Technology Partners – Constellation's technology and startup/optimization consultant
4. Tourgee & Associates, Inc – Engineering and Construction Management at CP Crane

SNCR system selection

Constellation evaluated offerings from different technology suppliers. High Energy Reagent Technology (HERT) technology from Advanced Combustion Technology, now part of Fuel Tech, Inc., was selected to supply SNCR for both Crane units. The reagent, urea, is stored on site in a 50% by weight aqueous solution. Before being injected into the furnace it is diluted to about 5% by weight. The dilution rate is largely determined by the necessary flowrate/pressure to achieve good atomization for the injectors.

The HERT systems are similar for both units, and include four zones of injection, numbered 500, 600, 700, and 800 - from uppermost to lowermost injection zones, as shown in Figure 1.

- The lowermost injectors (zone 800) inject urea into the boiler at the 65 foot elevation above the cyclones but below the OFA for Rich Reagent Injection. These ports were formerly used for gas injection when gas reburn was employed.
- The next zone (700) injects urea through the OFA ports at the 91 foot elevation.
- The 600 zone injects reagent into the upper furnace at the 102 foot elevation,
- And the 500 zone injects reagent slightly above the nose arch at the 120 foot elevation.

The HERT system is different from other SNCR systems in that, rather than air-atomized nozzles, for each injector it uses a pressure-atomized nozzle within a larger tube (about 2 inches) which is supplied with blower air that provides the motive air to inject the atomized urea into the furnace. For zone 700 the OFA provides the motive air. Zones 500 and 600 are fed from a common dilution water header and chemical injection pump. Flow distribution between levels is controlled by on/off motor operated valves and by selection of atomizing nozzles. Zones 700 and 800 are fed from a common dilution water header and chemical injection pump. Flow distribution between levels is controlled by on/off motor operated valves and by selection of the pressure atomizing nozzles. Nozzles were installed during acceptance testing and were adjusted during optimization.

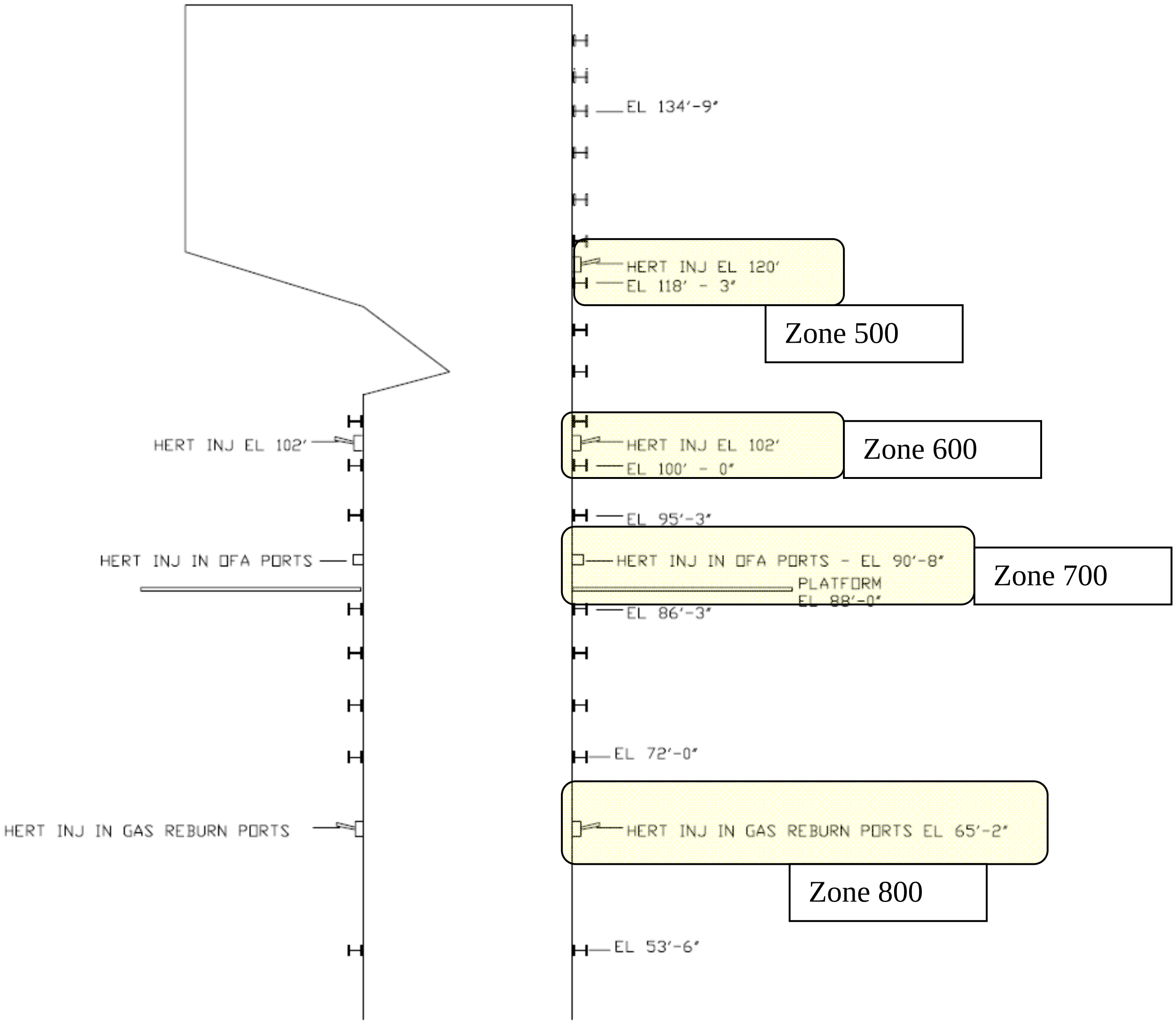
Control of the SNCR systems is directly from the DCS. The plant controls group performed all controls programming based upon input from the technology supplier, ACT.

Ammonia Monitoring

A major concern for the plant was ammonia slip and its impact on fly ash. With tubular air-preheaters, air-preheater plugging is less of a concern at Crane than if the air-preheaters were of a rotary design. However, Constellation wanted to assure that fly ash ammonia levels remained low. Because of this concern Constellation considered the installation of ammonia slip analyzers.

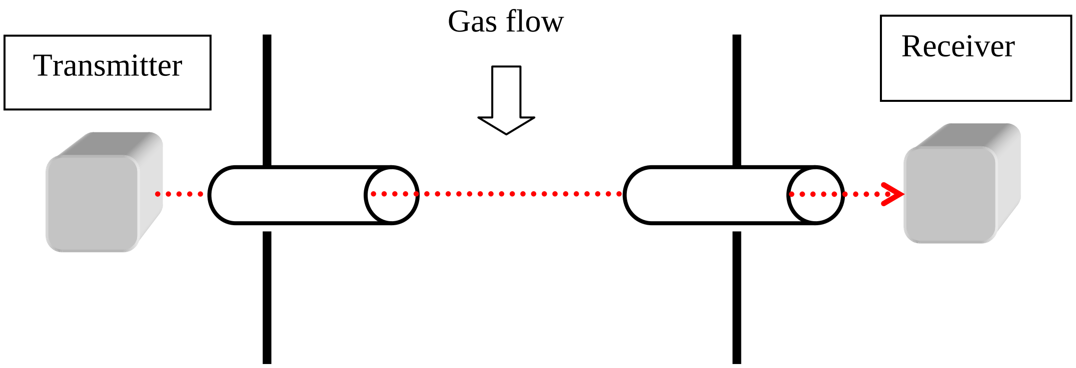
The project team examined several approaches for monitoring ammonia slip and determined that tunable diode laser absorption spectroscopy (TDLAS) technology offered the greatest chance of success; however, the situation at Crane offered several challenges to using the TDLAS approach. TDLAS ammonia instruments measure the number of ammonia molecules across an optical path using the principle of the Beer-Lambert law as in Figure 2. In this manner it provides an indication of the average concentration along the line of sight. This is done with a solid-state laser light source that scans across near infra-red absorption wavelengths for the gas that is being measured (in this case, ammonia). It is suitable for remote sensing, for in-situ, real-time measurements, and can be used in high temperature environments. It does not require sample transport to an analyzer, which avoids concern regarding preservation of sample

Figure 1. Crane 1 and 2 HERT SNCR Injector Locations



integrity. In large ducts this approach gives a good indication of the average concentration across the duct.

Figure 2. Cross Duct TDLAS measurement with spacers to limit path length



Experience with the TDLAS method on coal power plants has had mixed success – and unfortunately, far more failures than successes. As an optical method, the TDL approach is extremely sensitive to instrument alignment and particle dust loading. Flue gas ducts flex as load and gas temperature change, which affects alignment with the instrument mounted on the duct. And, for a dust-laden stream such as a coal plant, there is a challenge to achieving adequate sensitivity (which is related to optical path length) and maintaining an adequately strong signal. Suppliers of TDLAS instruments have developed means to address the problem of misalignment – at least to a degree – by having beams that expand (think of a shotgun rather than a rifle). But, this weakens the optical beam density and for dust-laden gases optical signal can get too weak to maintain adequate signal-to-noise ratio. There are systems under development to actively align the instruments. But, at the time Constellation was making a decision, we were not yet confident that this approach would be ready in the time we needed. Some suppliers offer instruments with probes – which solves the problem of misalignment and the effect of dust. But, because ammonia slip can be quite stratified, having a representative ammonia slip measurement on large ducts is not practical with current probe-based TDLAS systems.

The problem with dust loading can be mitigated with spacers that shorten the path length. But, this will impact the minimum detectible limit and will mean that parts of the duct will not be measured for ammonia.

For both Crane units the available duct locations between the economizer and the air preheater offered path lengths of close to 20 feet – or about 6 meters. The duct also has turns upstream and downstream – which further limits access and impacts flow within the duct. Moreover, the Crane units cycle in load, which means that the duct will flex as temperature changes over the changing load. Substantial flexing was measured, and this flexing would make alignment of cross-duct TDLAS optical paths impossible across the load range if the optics were mounted to the duct walls. Fortunately, the dust loading at Crane, with roughly a 60/40 split between fly ash and bottom ash,[1] is not quite as high as it would be for a pulverized coal unit, but is not as low as might be expected for a cyclone boiler.

Flow testing was performed in the portion of the duct where there was access to mount instruments to determine the best location for the optical paths. As expected, the gas flow was highly stratified – with regions of very high velocity and regions of very low velocity. The optical paths (two per duct, one duct per unit, and four optical paths altogether for both Crane units) locations were selected to cover the regions of highest gas flowrate – at least within the limitations of where access was available.

To address the problem of TDLAS alignment across these large ducts, an instrument mounting assembly (PAT.PEND.) was designed to independently mount the instruments from the duct. The instrument mounting assemblies were mounted to the platforms that provided maintenance access for the instruments.

The instrument mounting assemblies provide independent mounting of the instrument, a flexible spool coupling the instrument optics with the boiler duct, and design features that allow for hot or cold installation, adjustment and air purging of the flexible spool coupling. It also has the ability to reduce the optical path using inserts in situations where the dust loading is too high for the beam to cross the full duct width while also addressing the thermal lensing that is problematic for positive pressure ducts. The instrument mounting assembly can be used on either positive or negative pressure ducts. By assuring alignment with the instrument mounting assembly, the beam diameter can be reduced, which increases TDLAS beam intensity and improves the signal to noise ratio of the instrument.

The project team selected the Unisearch TDLAS instrument from CEMTEK for application at Crane (and also at Wagner). This instrument has a controller that houses the laser, laser controls, an optical multiplexer, and signal processing electronics. Each optical path is comprised of an optical transmitter and optical receiver. Optical fiber transmits the light output from the laser to the optical transmitter. Coaxial cable transmits the signal from optical receiver to the controller. Each Crane unit has a controller and two optical paths. The optical multiplexer in the controller alternates the output from the laser between the two optical paths. The advantage of this instrument at Crane versus some of the other TDLAS instruments that were evaluated is that it permits installation of electronics in a controlled environment and installation of the optics, which are less sensitive to temperature, on the duct. It also reduces the size of the

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[1] Based on 2005 EIA Form 767 data

hardware that is mounted on the duct compared to other TDLAS products that have the laser and electronics mounted on the duct, which is an advantage when space is limited.

Crane 1 & 2 SNCR System Acceptance Testing

The performance guarantees required that the SNCR system meet an average emission reduction of 50% at two load points of 67% MCR and 100% MCR with ammonia slip at or below 5 ppm and and average urea flowrate of 190 gph. According to the contract with ACT the ammonia slip was to be measured using extractive FTIR because that was the method that ACT was familiar with from previous experience. The TDLAS analyzers were operating during acceptance testing; however, they were not used for determining compliance with the SNCR contract guarantees.

The acceptance test results are summarized in Table 2. The baseline NOx levels were lower than expected. Nevertheless, with both units averaged, the SNCR system met its NOx reduction and ammonia slip guarantee requirements. Slip by FTIR was below the limit of 5 ppm, although the TDLAS instruments indicated higher slip. Notably, during acceptance testing zone 700, which injects through the OFA ports, was found to be ineffective. So, these results were achieved without Zone 700 in operation. Also, during acceptance testing the IVY combustion optimizer was taken out of service in order to assure that combustion conditions did not change during a test.

Table 2. SUMMARY OF C. P. CRANE SNCR ACCEPTANCE TESTING

	Unit 1 Low Load	**Unit 1 High Load**	**Unit 2 Low Load**	**Unit 2 High Load**
Injection Test Time	12/16/2008 17:10-18:10	12/16/2008 09:15-10:15	12/17/2008 20:30-21:30	12/17/2008 16:45-17:45
Baseline NO_x (before), lb/mmBTU	0.3394	0.4112	0.3160	0.3708
Urea Injection NO_x, lb/mmBTU	0.1554	0.2342	0.1289	0.2133
Baseline NO_x (after), lb/mmBTU	0.3376	0.4164	0.3213	0.4031
Average Baseline NO_x, lb/mmBTU	0.3385	0.4138	0.3186	0.3869
NO_x Reduction	54.1%	43.4%	59.5%	44.9%
Average Reduction (both Units)	**50.5%**			
Average Urea Consumption	**192**	**gph**		
Ammonia Slip During Injection (ppm)				
FTIR (average)	0.50	2.79	3.69	0.30
TDLAS Slip Meter Channel 1	6.03	18.48	19.93	10.26
TDLAS Slip Meter Channel 2	6.35	0.45	17.42	6.05
OFA (%)	24.9	25.0	21.0	26.9
IVY Optimizer Status	OFF	OFF	OFF	OFF
Load (MW)	135	200	135	201

Comparison of FTIR and TDLAS ammonia results

The TDLAS instruments and the FTIR instrument showed significant differences in the slip being measured, with the TDLAS instrument often being higher than the reported FTIR measurement. This was particularly so when the TDLAS instrument ammonia concentration was high. But, the FTIR raw data did also show some very high spikes.

The FTIR instrument was used to measure ammonia at multiple discrete points in the duct. These locations were adjacent to, but not exactly where the TDLAS instruments were located. The sample is extracted through a heated probe. It then passes though a trap to remove particle matter, through a heated sample line up to about 200 feet long and into the trailer where the FTIR analyzer is located.

The TDLAS instrument, on the other hand, provides the average ammonia along a line of sight across the duct. The ammonia measurement is made in-situ, which means that a gas sample does not need to be drawn from the duct and transported to an analyzer.

Because of the differences in measurement method and somewhat different locations, the same results should not be expected from both methods. However, ideally there would have been better correspondence between the results of the two methods. Figures 3 and 4 show ammonia slip from the TDLAS instruments (taken from the plant PI system), from FTIR raw data for ammonia slip (provided by the testing company) and urea injection rate (in gph/10) for December 16 for Unit 1 and December 17 for Unit 2 plotted versus time. The two acceptance test periods are highlighted in yellow. It is uncertain how well synchronized the time of the test company raw data is with the reported time in the PI data. But, it is reasonable to expect that there should not be more than a few minutes difference. The actual reported FTIR values for the purpose of the acceptance test are discrete points that fall along the FTIR line 5 minutes after the probe is moved to the sample point (it is not possible tell from this data when the probe is moved, except possibly each “jump” is a different point). The most remarkable characteristics of these plots are:

- The FTIR shows spikes above 10 ppm and even up to 60 ppm although all of the reported results were well below those values.
- There are occasional times when slip is high by both methods even when no urea is being injected.
- In most situations, the TDLAS instruments seem to respond to urea injection more consistently (this might be due to the fact that every 10 minutes or so the FTIR probe is moved to a different location)

Figure 3. Crane Unit 1 Ammonia Slip and Urea flow, December 16, 2008

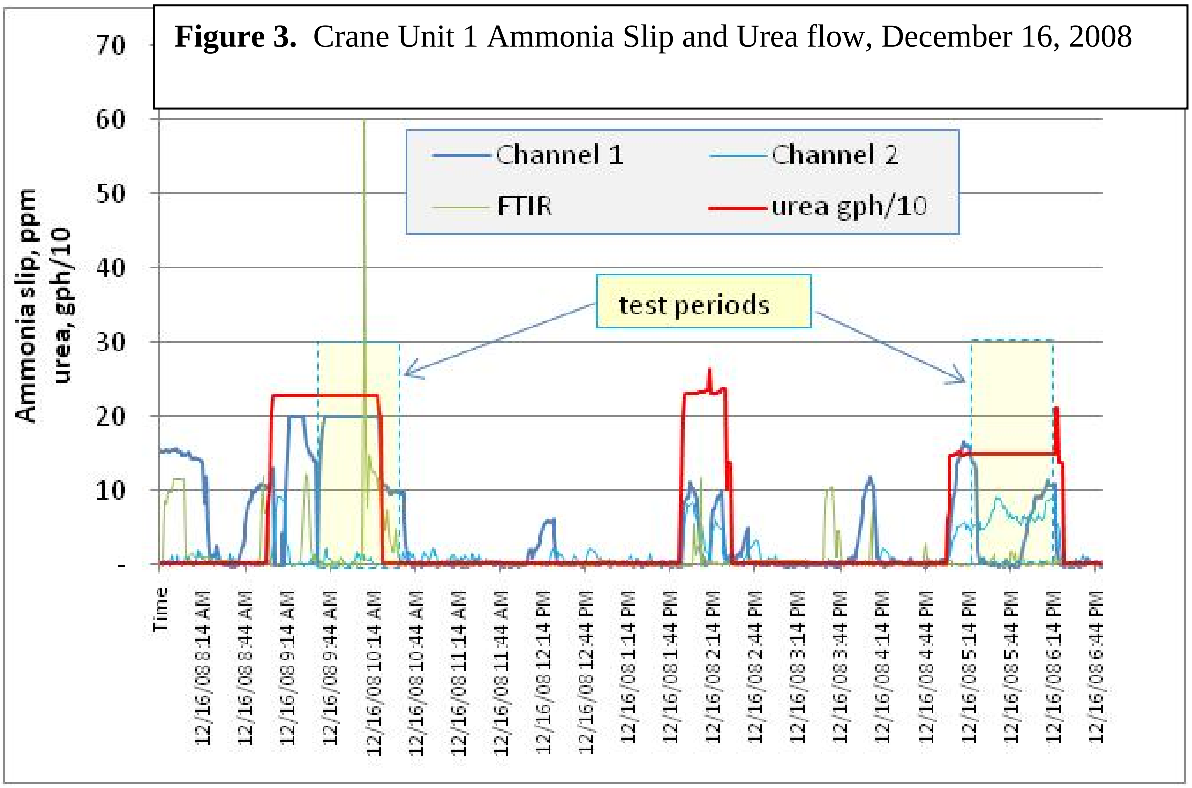
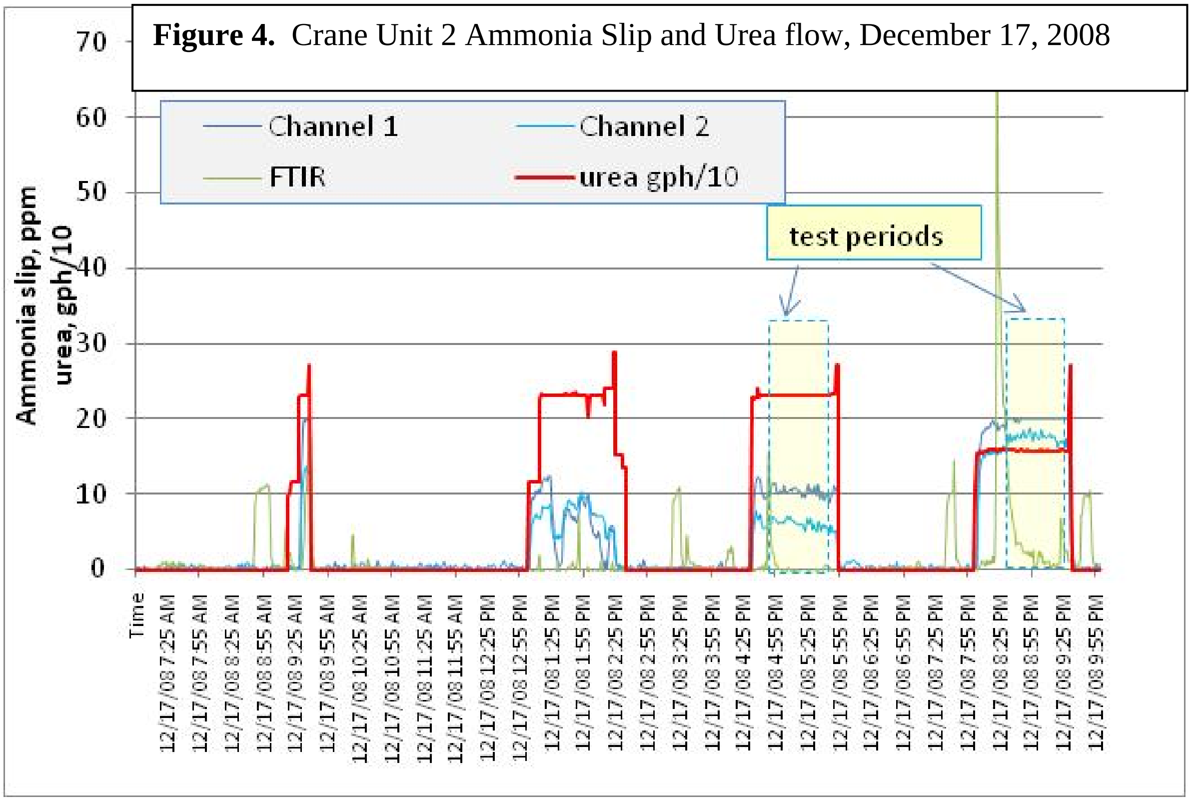


Figure 4. Crane Unit 2 Ammonia Slip and Urea flow, December 17, 2008



Most concerning is the first bullet point – particularly the very high spikes to 60 ppm. It does not seem likely that ammonia slip in the duct is peaking quickly to values like 60 ppm and then dissipating since it would likely be picked up on the TDLAS instruments. Another explanation is that perhaps ammonia may be collecting in the FTIR probe or sample line only to be released suddenly, perhaps when the probe is moved or after enough ammonia has built up. When the test company was asked about this while on site, they did not have an explanation except that when the FTIR does see the ammonia spikes, there is definitely ammonia present.

The second bullet point suggests that perhaps during SNCR purge cycles or other conditions, urea was being admitted to the furnace although the urea pumps were not running. And, the third bullet indicates that the TDLAS instruments are responding to ammonia as expected.

In any event, for the purpose of the performance guarantees of the SNCR contract, FTIR is the ammonia measurement that was used. However, the results observed here raise questions about the FTIR method and reliability of the data when using FTIR.

SNCR Optimization

Optimization of the Crane SNCR systems was necessary because concern about fly ash ammonia content makes it necessary for the SNCR system to be operated at more stringent conditions with respect to ammonia slip than allowed by the performance guarantees.

The objective of the optimization was to establish parameters and setpoints to minimize NOx emissions across all operating conditions (ideally at or below 0.27 lb/MMBtu) while maintaining NH_3 slip at or below 2 ppm. Optimization was intended to:

1. Explore the operating range of the SNCR system at expected operating conditions that may be outside the range of the guaranteed load conditions and establish setpoints for operation under such conditions that minimize NOx emissions while also maintaining slip below 2 ppm.
2. Evaluate the performance of the system during expected operating transients and establish operating setpoints that minimize NOx emissions during transients while also maintaining slip below 2 ppm
3. Identify adverse secondary effects of the SNCR system and develop means to mitigate these effects.

Although the goal from the outset was to keep slip below 2 ppm, the decision was made to work toward keeping slip below 1 ppm but recognizing that 2 ppm might be necessary at some loads. This shift toward lower slips was made because:

- It was determined during optimization that it was possible to achieve the emissions rate of 0.27 lb/MMBtu or less while keeping slip below 1 ppm for most loads on both units. High loads are more difficult.
- It became apparent that there would be periodic transients in slip that might increase slip. So, keeping slip a little bit lower to begin with would be beneficial in reducing those slip excursions and the average slip over a day.
- Most utility SNCR systems are on boilers with ESPs, and there is much less experience with baghouses. Because unit 2 had experienced some difficulty maintaining pressure drop adequately low near full load, care was necessary to ensure that the SNCR did not contribute to increased baghouse pressure drop.

The low ammonia slip requirements are primarily intended to minimize ammonia in the fly ash. Although there are other benefits to reducing ammonia slip, ammonia in the fly ash is the most limiting factor. At Crane, there are two factors that make ammonia concentration on fly ash higher than for other units, and therefore ammonia slip of increased concern.

- As cyclone units, less of the ash is in the form of fly ash than for a dry-bottom boiler, which will concentrate the ammonia over less fly ash, raising the concentration on the fly ash over what would be expected for a dry bottom boiler.
- Having a tubular air preheater (APH), accumulation of ammonium bisulfate (ABS) in the APH is less of an issue than for a regenerative air preheater. While this means that APH plugging is less of a concern, this means the bisulfate is more likely to end up being collected downstream on the fly ash in the baghouse.

The SNCR system optimization was performed with plant personnel and supported with ATP on site during the weeks of January 5 through January 16, 2009.

In the following sections, we will discuss:

- Cyclone trips and load regulation
- Pre- and post- optimization comparisons
- Optimization at Full Load

Cyclone trips and load regulation

There are two transients of particular interest that were evaluated during the two weeks of testing. These are: SNCR operation during a cyclone trip; and regulation of loads.

Cyclone Trip

Because there is a risk of high ammonia slip during such a transient as the furnace cools from the reducing load and because the operator will be very busy working to stabilize the unit to a safe condition, it was decided that the SNCR system should trip off line in the event of a lost cyclone. Once the operator has determined that the unit is stable, then the operator can bring the SNCR system back on the line. A trip of the SNCR system on loss of a cyclone was programmed into the SNCR system. Unplanned cyclone trips showed that the programmed trips worked as intended. It is possible to restart the SNCR system with only 3 cyclones in operation. However, the intent is for the operator to do this when he has determined that the unit is stable.

Load Regulation

The two Crane units typically regulate load to meet the demand. Therefore, performance during load regulation was evaluated. Temporary peaks in ammonia slip were observed during

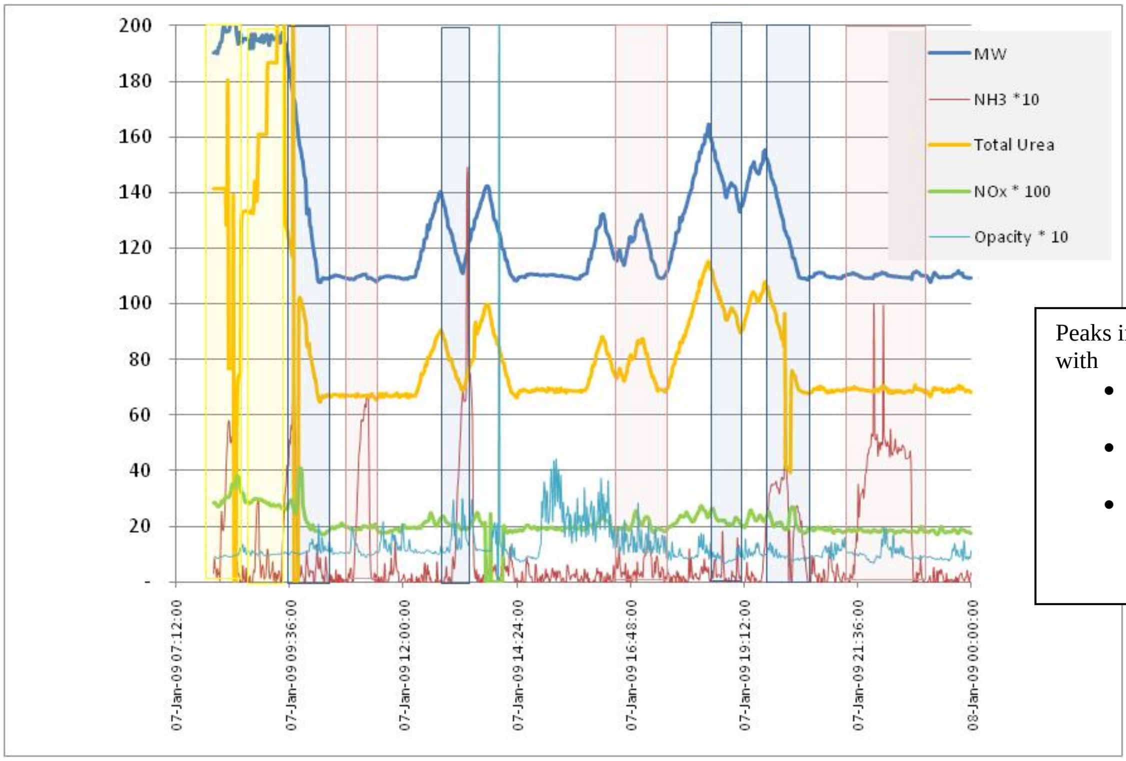
- Reductions in load
- Use of some soot blowers (in some cases coinciding with increases in opacity)
- Increases in urea injection

Figures 5 and 6 are plots of MWg, NOx, total urea flow, ammonia slip and opacity for Unit 1 and Unit 2, respectively on January 7, at a very early period in the optimization program. Peaks in slip associated with load reductions highlighted in blue, peaks that occur with increases in opacity highlighted in pink and increases in slip that occur with increases in urea injection are highlighted in yellow. There are large increases in opacity that do not correspond to increases in slip. These opacity increases are most likely associated with baghouse cleaning transients, which would not be expected to impact ammonia slip.

An objective of optimization was to address these brief high slip conditions that might, over time, result in excessive ammonia in the fly ash.

Examining the behavior during a period after optimization on a day with high variation in load showed that these transients had, for the most part, been addressed. As shown in Figures 7 and 8, on January 22, 2009, which was a day with frequent load changes, the SNCR system maintained NOx generally at or below 0.25 lb/MMBtu (except when urea was shut off) for both units 1 and 2 while maintaining ammonia slip at a low level. For both units there were brief periods where slip reached about 2 ppm but then dropped off. These were both periods where urea injection was increasing – either due to increasing load or due to the SNCR system being placed back in service after a period of being secured. The results in these figures indicate that the SNCR systems are capable of tracking load while keeping NOx controlled to 0.25 lb/MMBtu with ammonia slip at acceptably low levels while also changing loads. There may be room to improve the ammonia slip some more to eliminate these brief spikes altogether. But, overall, the spikes in ammonia slip were substantially reduced.

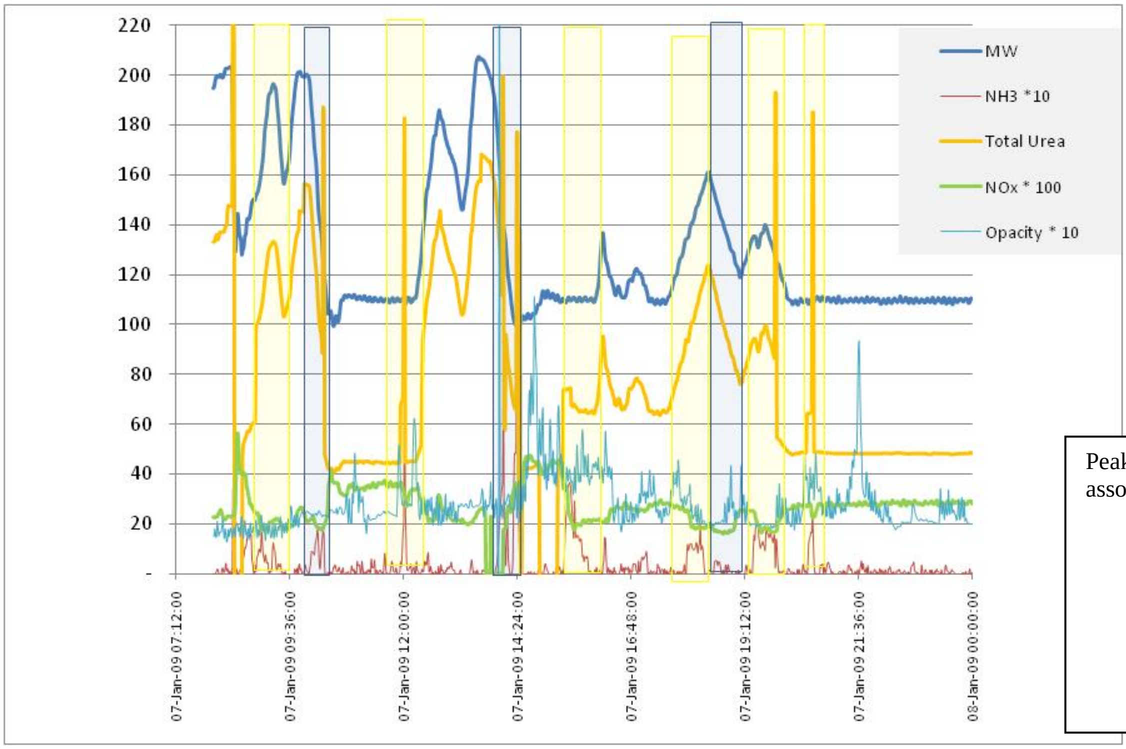
Figure 5. Unit 1 SNCR Operation 7 January, 2009



Peaks in Ammonia Slip associated with

- Load reduction highlighted in blue
- Increasing urea highlighted in yellow
- Opacity peaks highlighted in red

Figure 6. Unit 2 SNCR Operation 7 January, 2009



Peaks in Ammonia Slip associated with

- Load reduction highlighted in blue
- Increasing urea highlighted in yellow
- Opacity peaks highlighted in red

Figure 7. Unit 1 SNCR operation on January 22, 2009

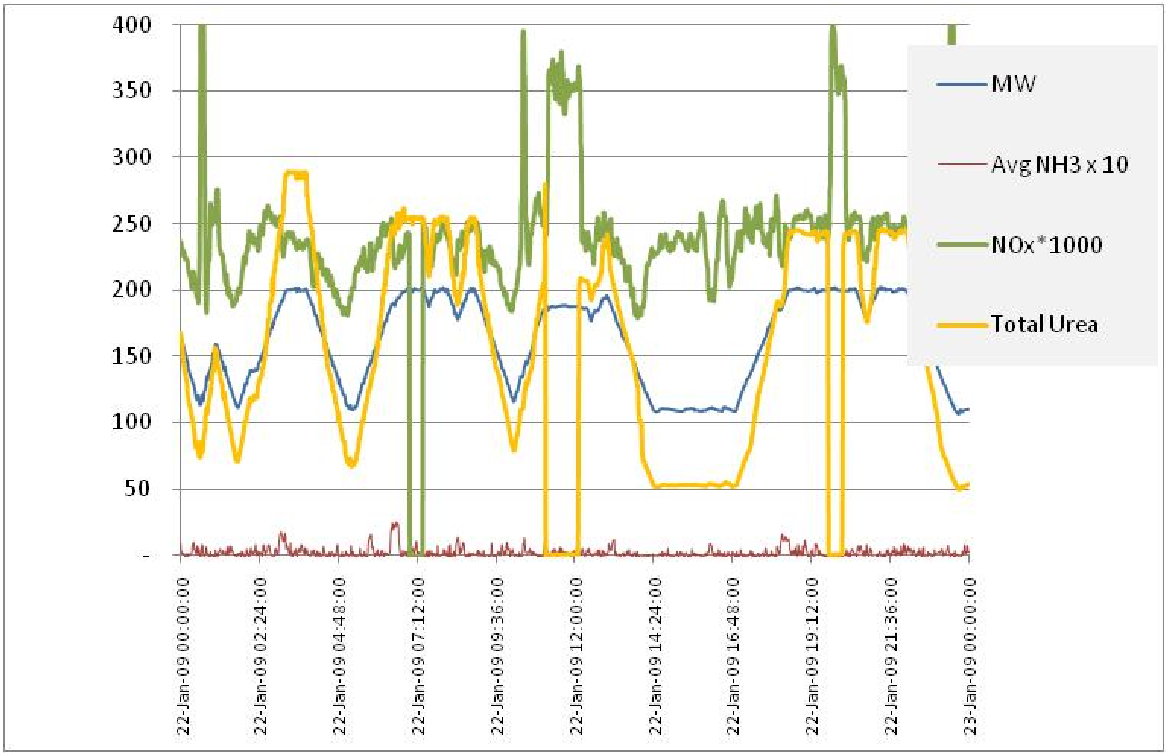
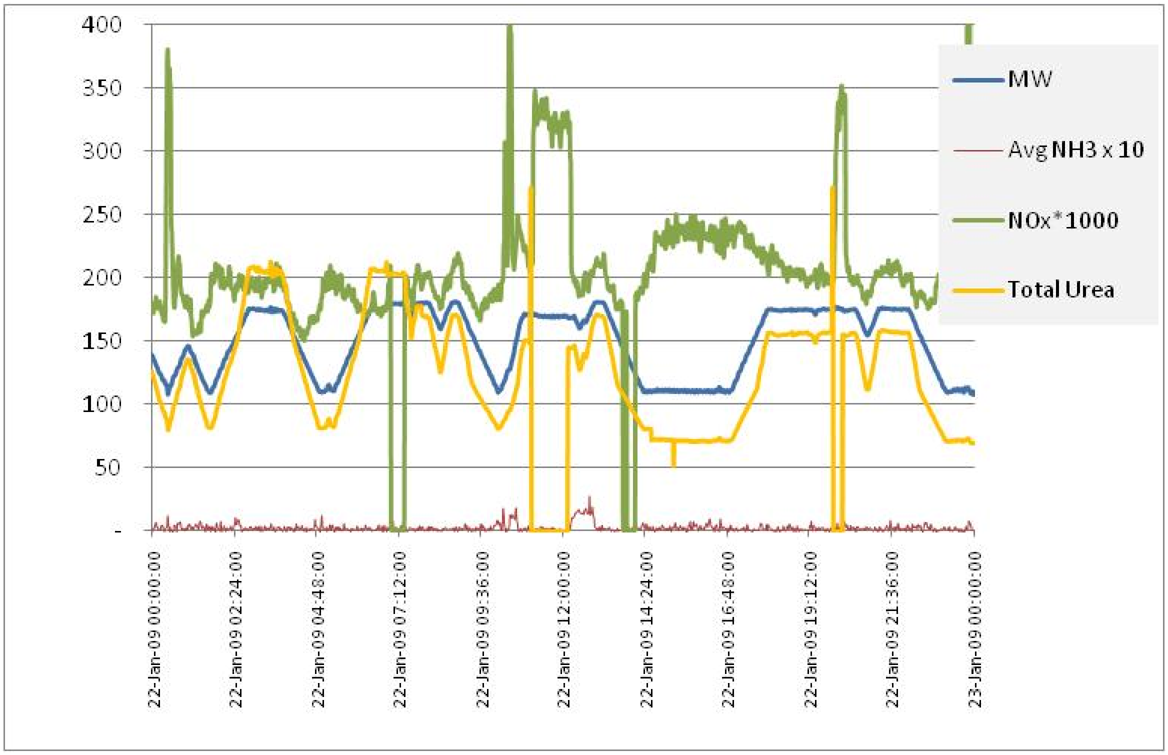


Figure 8. Unit 2 SNCR operation on January 22, 2009



The periods shown in Figures 7 and 8 when NOx equals zero are when the NOx analyzer is in calibration and the data was removed from the analysis, and the spikes in NOx that appear when urea is being injected are during brief jumps in oxygen or an imbalance in main air pressure.

Pre and Post Optimization Comparison

Performance was compared for the two periods before and after optimization. Arguably, there was also a period while optimization was in progress. However, for simplicity SNCR performance in the period of January 5, 2009 and prior is evaluated as the pre-optimization period against the period January 6, 2009 through January 25, 2009 as the post-optimization period with the following metrics:

- Ammonia slip
- NOx emissions
- Urea consumption – measured in gallons of urea per MWh

Daily averages over these two periods were evaluated for trends. As shown in Figures 9 a, and b, daily averages of NOx on Unit 1 remained roughly the same while ammonia slip trended downward over the period. Average daily load (MWg) and urea consumption (in gallons/MWh) for unit 1 are shown in Figure 9c. Urea consumption in gal/MWhr clearly is related to load. Figures 10 a, b, and c show similar results for unit 2 over the same period. Unit 2 was shut down for a large part of January 24th and 25th, which affects the NOx level because the SNCR system is shut down when the unit is in the process of being shut down or started up, and over these days the unit spent several hours below 100 MWg with the SNCR system turned off.

Figures 11 a and b show average urea consumption in gallons/MWghr and average ammonia slip in ppm for unit 1 versus MWg. As shown, there is a clear relationship. Urea consumption was reduced sharply (by about 50%) at low load conditions through optimization but increased somewhat (about 20%) at high load conditions through optimization. However, across the load range ammonia slip was reduced significantly. So, the slight increase in urea consumption at high loads on unit 1 was the price for reducing ammonia slip. As shown on Figures 12 a and b, on unit 2, urea consumption was reduced at all loads except full load; however, ammonia slip was reduced across all loads, and particularly at full load.

Since ammonia slip is of particular concern because of its impact on ammonia on fly ash, trends in fly ash ammonia concentration were evaluated. As shown in Figure 13, there has been a sharp drop in fly ash ammonia concentration that occurred as a direct result of optimization. This low ammonia slip performance has been sustained since January, with average slip of 1.0 and 1.3 ppm year to date on Units 1 and 2, respectively.

Figure 9a. Unit 1 average daily NOx.

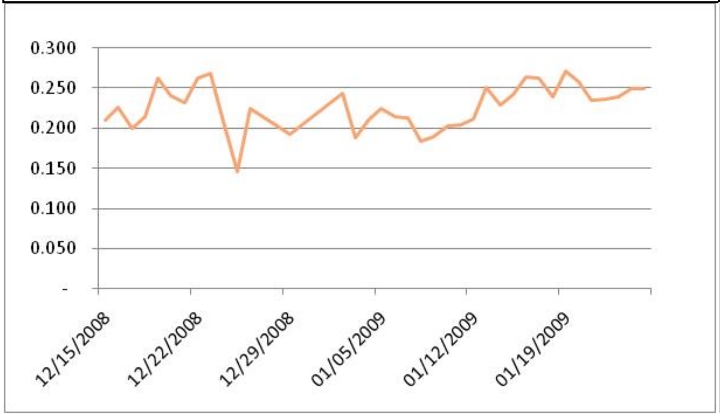
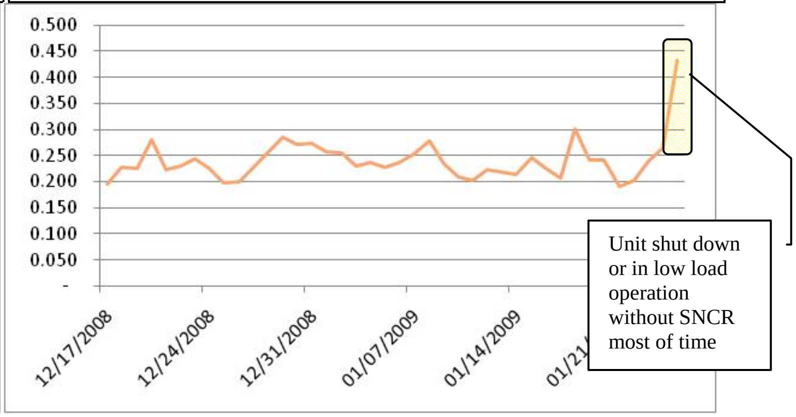


Figure 10a. Unit 2 average daily NOx.



Unit shut down or in low load operation without SNCR most of time

Figure 9b. Unit 1 average daily ammonia slip

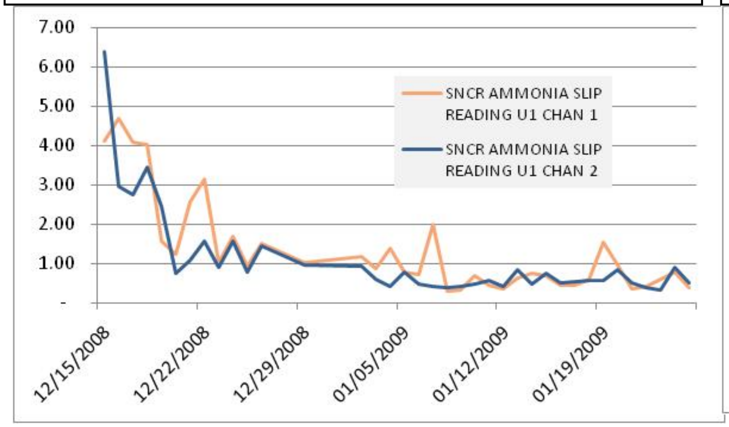


Figure 10b. Unit 2 average daily ammonia slip

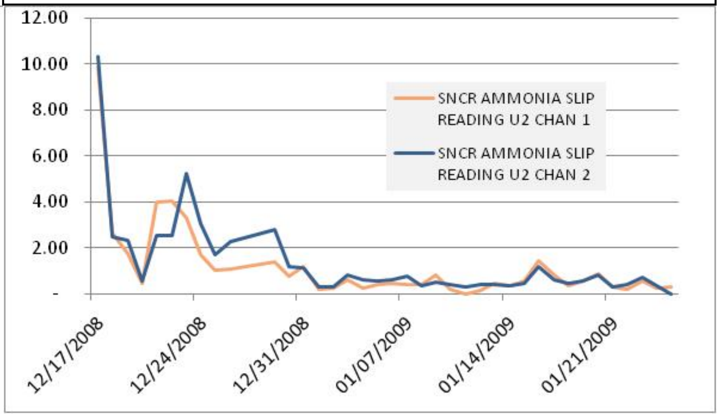


Figure 9c. Unit 1 average daily urea consumption (gal/MWh) and load (in MW).

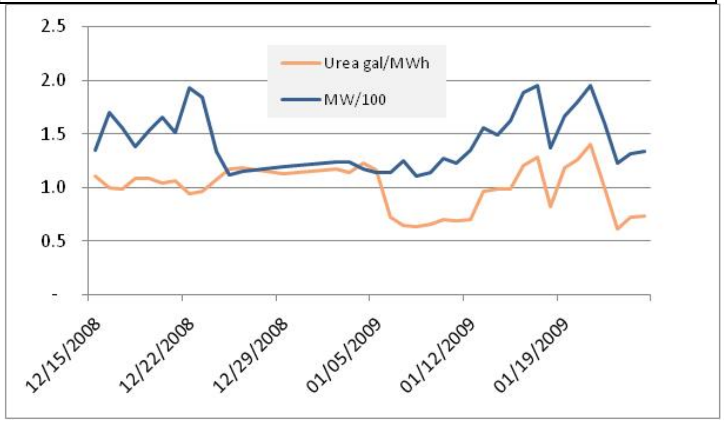


Figure 10c. Unit 2 average daily urea consumption (gal/MWh) and load (in MW).

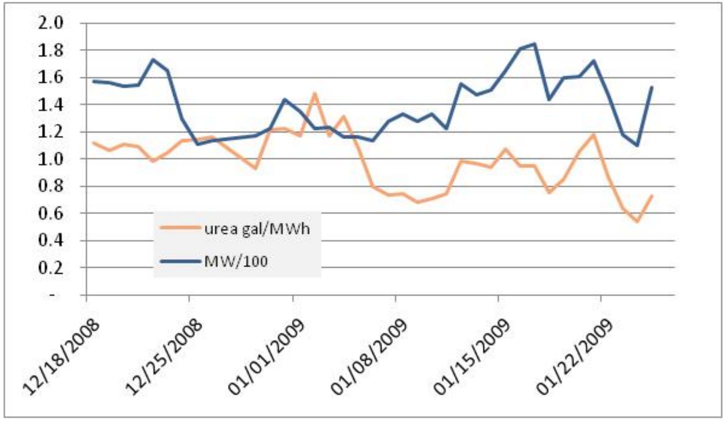


Figure 11a. Unit 1 daily avg urea consumption in gal/MWhr versus avg load in MWg

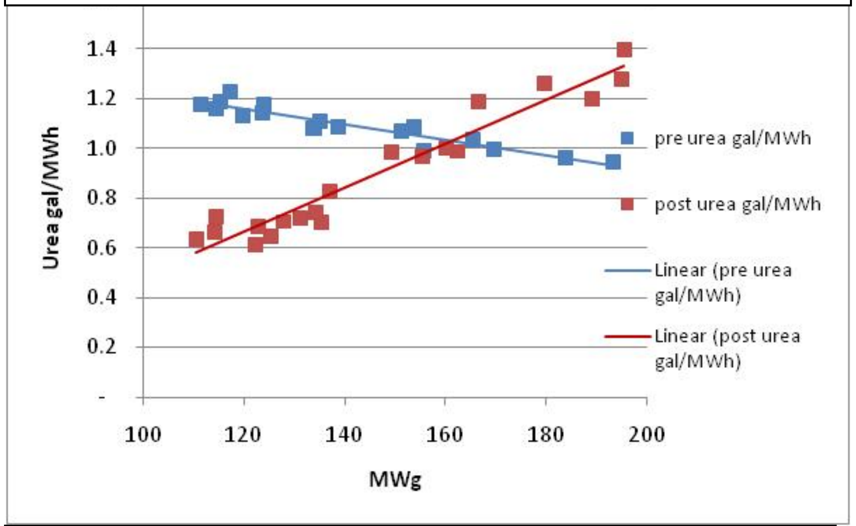


Figure 12a. Unit 2 daily avg urea consumption in gal/MWhr versus avg. load in MWg

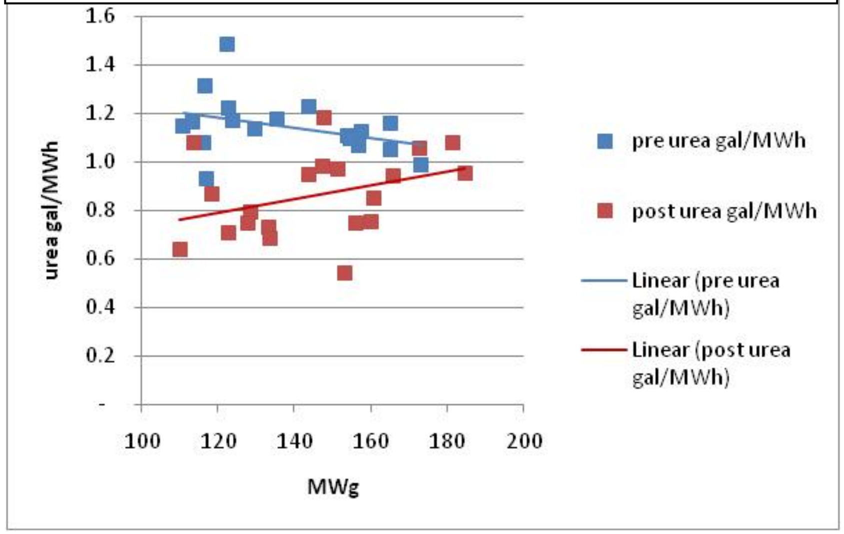


Figure 11b. Unit 1 average daily ammonia slip v avg load in MWg

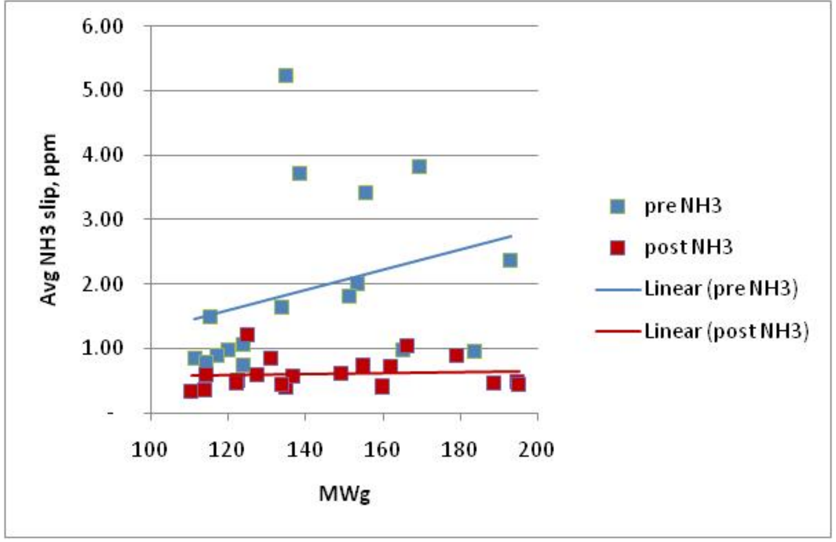


Figure 12b. Unit 2 average daily ammonia slip v avg load in MWg

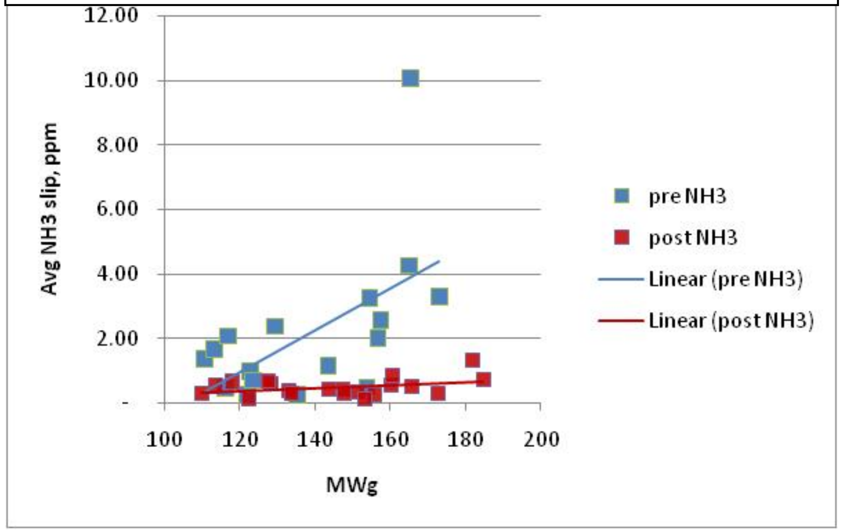
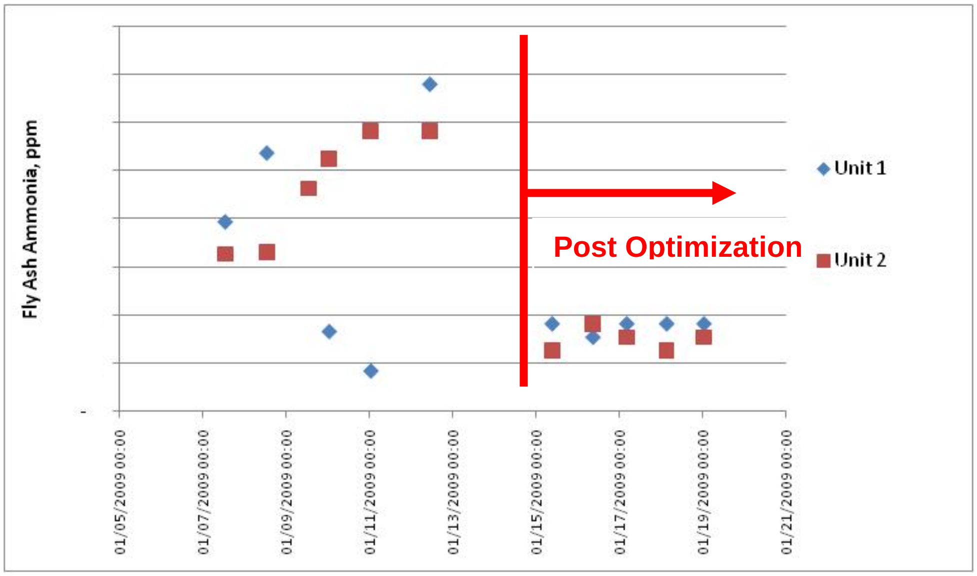


Figure 13. Ammonia in Fly ash (mg/kg)



Optimization at Full Load

Full load optimization proved to be more difficult with respect to NOx reduction performance than at other conditions. Both Crane units normally operate with the IVY combustion optimizer in operation and optimization was performed with the intention of optimizing the plant in the manner that the operators are accustomed to operating it. Therefore, IVY was in service during optimization. Under some full-load conditions it became very difficult, or not possible to achieve the target NOx level of 0.27 lb/MMBtu. Analysis of data showed that the SNCR NOx reduction performance at full load is extremely sensitive to combustion parameters that are controlled by IVY. This is to be expected due to the sensitivity of the SNCR process to furnace conditions, particularly at the high furnace gas temperatures that occur at full load. Analysis of combustion data showed that Unit 1 performance at or near full load was very sensitive to both main air pressure and the balance between the two main air pressure supplies. Performance on unit 1 was best with main air pressure above about 44 iwc and with both main air pressure supplies well balanced (difference of zero). Figure 14 shows NOx emissions versus main air pressure difference at near full load and with urea injection within a flow range of 290-310 gph. Furnace oxygen on unit 1 was fairly well controlled during optimization and did not appear to have a major impact. For unit 2, performance at full load appeared to be most impacted by furnace exit oxygen. Figure 15 shows the impact of furnace exit oxygen on NOx at full load with urea flowrate between 240-260 gph. The effect of oxygen on the NOx formed during combustion is well known. With Rich Reagent Injection the impact of oxygen on stoichiometry and NOx formation is likely to be greater due to the increased amount of nitrogen introduced into the combustion zone.

Figure 14. NOx versus difference in main air pressure at full load on unit 1 with total urea flowrate from 290-310 gph

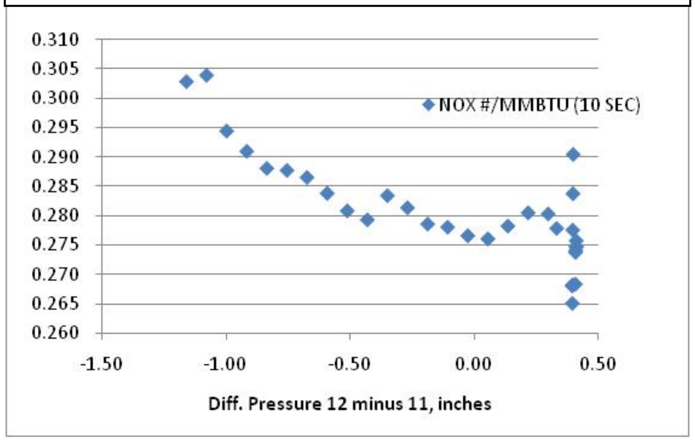
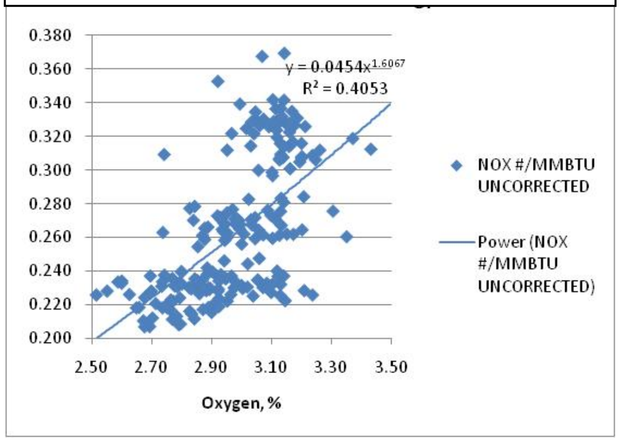


Figure 15. NOx versus boiler exit oxygen at full load on unit 2 with total urea flowrate from 240-260 gph



During optimization it was discovered that several Zone 700 injectors were damaged. These injectors could not be replaced easily because each one is designed for that specific OFA port and therefore they have different sizes. This may explain why zone 700 was found to be ineffective during acceptance testing.

Long Term Experience

Since optimization the plant has had an opportunity to gain some long-term experience with the SNCR system and the ammonia instruments.

Ammonia Instruments

The TDLAS paths have remained aligned since initial installation – over eight months – without any need for re-alignment. This is despite the substantial deflection of the flue gas ductwork with load changes. The PAT.-PEND. instrument mounting device has not experienced any leaks or failures of any kind.

It has been necessary to make upgrades to the initial software of the TDLAS instrument to address signal processing issues during periods of soot blowing and other times where signal to noise ratio is reduced, and these upgrades appear to have addressed concerns. Also, in the first months of operation some components needed replacing or adjustment; but, the supplier addressed that.

The ports for the optical path do need to periodically be purged with air. There is a constant purge on the optics to keep them clean. But material does occasionally build up in the port. The instrument mounting assembly has a purge connection that has facilitated periodic purging. Once the operators learned that this was necessary on a fairly regular basis, the instrument became far more reliable. It is planned that this will become an automated feature long term.

It has not yet been possible to perform a direct comparison of the TDLAS instrument measurements to wet chemistry measurements. A direct comparison with wet chemistry measurements may be performed in the future. Nevertheless, at this point in time the TDLAS instruments appear to be producing a reliable indication of ammonia slip. Ammonia in the fly ash is measured regularly, and it has remained low. Ammonia slip measured by the TDLAS instrument has also remained low.

SNCR System

SNCR experience will be divided between performance and reliability issues.

SNCR Performance

Since completion of optimization Crane has embarked on a program of coal test burns that included PRB coal as well as other coals. Over this period the SNCR system has had difficulty maintaining NOx emissions below the target rate although operators have attempted to make adjustments to control set points as conditions change. The problem is particularly severe at full load. It is likely that the different slagging characteristics of the test coals as well as different combustion characteristics of these coals have changed furnace conditions sufficiently that the most difficult condition – full load – has become far more difficult.

Ammonia slip, as indicated by the TDLAS systems and confirmed by fly ash samples, has remained low. This suggests that furnace temperatures may be higher since using the test coals.

The interaction of the IVY optimizer with the SNCR system was a serious concern early in the project. Experience has shown that this is not a major issue at reduced or mid loads. But, at full load conditions where the SNCR reactions are far more sensitive it is a significant concern. Crane personnel have been discussing with Emerson the interaction of IVY with the SNCR system in an effort to better understand this and develop a solution.

SNCR Reliability

Crane has experienced a number of issues regarding reliability of the SNCR system. These largely involve the injectors, dilution water quality and instrumentation.

- Boiler tube damage –Boiler tube damage was discovered in the vicinity of level 500 injectors on unit 1. This was determined to be caused by impingement of droplets on the inner wall of the air tube of the HERT injector. Relocation of the nozzle to be even or no more than ½ inch recessed from the HERT tube end appears to have corrected this problem. The plant has measured off the lances to ensure that in the future the nozzles are properly located within the HERT tubes, and added improved centering guides to the lances to prevent liquid impingement on the cooling guide tubes. The HERT injectors as originally supplied do not have stops to assure the correct nozzle position, and therefore must be carefully measured when inserting after each removal for periodic inspection. Crane is working with ACT to develop new HERT injector designs to address this concern.

- Zone 700 – Crane has yet to be able to use zone 700 since these injectors require re-design as well prior to implementation. It is hoped that this level will prove to be useful in the future.
- Injector plugging – The pressure atomized nozzles plugged frequently due to hardness deposits. The plant uses city water for dilution water and ACT did not expect that a water softener would be necessary. The plant has been utilizing a portable water softener for the dilution water and this has helped address the problem.
- Dilution skid plugging – Calcium deposits also fouled the injection dilution skid piping to the point that check valves in the dilute urea lines to the 600 and 800 levels of Unit 2 were plugged completely. Ultimately it was necessary to perform an organic acid cleaning of the piping to remove the deposits.
- Instrumentation and controls – Recent problems were discovered with automatic and manual valves leaking through in the dilution skid, along with "nuisance" trips of the system due to faulty instrumentation and/or interlocks. In another instance, a check valve failed to prevent reverse flow and allowed dilute urea to enter the plant air header. The plant feels it is necessary to perform a process hazards analysis to ensure a thorough understanding of the potential hazards associated with the system, especially with regard to automation sequences.

Conclusions

Constellation has installed SNCR on both Crane units 1 & 2 and at Wagner unit 2. These plants are unique in their use of TDLAS ammonia instruments for continuous monitoring of ammonia slip. The Crane installations were especially difficult applications for the TDLAS technology due to the duct dimensions and the nature of the Crane unit operations. Ammonia slip using the TDLAS technology was made possible at Crane units 1 & 2 as a direct result of a PAT-PEND approach for mounting the instrument optical paths to assure their alignment despite duct movement. The instruments have maintained their original alignment made over eight months ago without any need to adjust alignment and are continuously providing data that Constellation believes to be a good indication of ammonia slip. Although there were some teething issues relative to initial adjustment of the system and software upgrades, these were addressed.

The SNCR system did meet its contractual NOx and ammonia slip performance guarantees. However, optimization of the SNCR system to more stringent slip levels was necessary and improvement of reagent consumption rates was desirable. The availability of continuous ammonia slip data made it possible to improve SNCR system performance to reduce overall ammonia slip levels, reduce high ammonia slip transients, and reduce fly-ash ammonia concentrations while also improving reagent consumption under most conditions. The continued operation of these instruments provides assurance that operators can identify high ammonia slip conditions and therefore respond to them before the consequences of these conditions become problematic.

Experience with the SNCR system has shown that it is very sensitive to combustion conditions, especially at full load. Full load NOx reduction performance has been problematic under some furnace conditions and particularly since Crane embarked on coal test burns. There have also been a number of reliability issues regarding the SNCR system, and Crane personnel are working with ACT to implement design changes that hopefully will mitigate some of these issues in the long term.