

NO_x Control Options and Integration for US Coal Fired Boilers

Quarterly Progress Report

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Abstract

This is the nineteenth Quarterly Technical Report for DOE Cooperative Agreement No: DE-FC26-00NT40753. The goal of the project is to develop cost effective analysis tools and techniques for demonstrating and evaluating low NO_x control strategies and their possible impact on boiler performance for boilers firing US coals. The Electric Power Research Institute (EPRI) is providing co-funding for this program. Refurbished corrosion probes were installed at Plant Gavin and operated for approximately 1,300 hours. This quarterly report includes further results from the BYU catalyst characterization lab and the in-situ lab, and includes the first results from a model suitable for comprehensive simulation codes for describing catalyst performance. The SCR slipstream reactor at Plant Gadsden operated for approximately 100 hours during the quarter because of ash blockage in the inlet probe.

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Executive Summary

The work to be conducted in this project received funding from the Department of Energy under Cooperative Agreement No: DE-FC26-00NT40753. Due to the recent provision of a six-month no-cost extension, this project now has a period of performance that started February 14, 2000 and continues through September 30, 2005.

Our program contains five major technical tasks:

- evaluation of Rich Reagent Injection (RRI) for in-furnace NO_x control;
- demonstration of RRI technologies in full-scale field tests at utility boilers;
- impacts of combustion modifications (including corrosion and soot);
- ammonia adsorption / removal from fly ash; and
- SCR catalyst testing.

To date, good progress is being made on the overall program. We have seen considerable interest from industry in the program due to our successful initial field tests of the RRI technology and the corrosion monitor.

During the last three months, our accomplishments include the following:

- A six-month no-cost extension was requested and granted.
- Refurbished electrochemical noise (ECN) corrosion probes were installed at Plant Gavin and operated for approximately 1,300 hours.
- This quarterly report includes further results from both the BYU catalyst characterization lab and the in-situ lab and includes the first results from a model suitable for comprehensive simulation codes for describing catalyst performance.
- The SCR slipstream reactor at Plant Gadsden operated for approximately 100 hours during the quarter because of ash blockage in the inlet probe.

Experimental Methods

Within this section we present in order, brief discussions on the different tasks that are contained within this program. For simplicity, the discussion items are presented in the order of the tasks as outlined in our original proposal.

Task 1 - Program Management

During the last performance period,

- Corrosion Probe:
 - The corrosion probes were refurbished, re-installed at Plant Gavin and successfully operated for about 1,300 hours.
 - Testing of the software that controls the flow of cooling air to the corrosion probes was successfully completed during the re-installation of the probes at Plant Gavin.
 - At the end of the quarter, REI personnel removed the 4 probes from the boiler and shipped them back to Salt Lake City. Profilometry will be performed on the plates in two of the probes.
- SCR:
 - The SCR slipstream reactor at Plant Gadsden operated for approximately 100 hours during the quarter because of ash blockage in the inlet probe.
 - This quarterly report includes further results from the BYU catalyst characterization lab and the in-situ lab, and includes the first results from a model suitable for comprehensive simulation codes for describing catalyst performance.

Industry Involvement

A technology update column that will highlight the RRI NO_x control technology demonstrated earlier within this project is scheduled to be published during the next performance period in a electric utility industry trade magazine:

- “Firm Will Develop Advanced NO_x Control”, to appear in the Update section (pg. 14) of Power Engineering, April, 2005 (<http://www.power-eng.com>).

A technical article that will highlight the RRI NO_x control technology demonstrated earlier within this project is scheduled to be published during the next performance period in a electric utility industry trade magazine:

- “AmerenUE Sioux Plant Approaching 90% NO_x Reduction Through In-Furnace NO_x Control,” to appear in Power, June, 2005.

A paper will be presented at the 30th International Technical Conference on Coal Utilization & Fuel Systems, April 17-21 in Clearwater, Florida:

- “Poisoning/Deactivation of V₂O₅/TiO₂ SCR Catalyst in Coal and Biomass-Fired Systems” by Xiaoyu Guo, Aaron Nackos, John Ashton, Calvin H. Bartholomew, William C. Hecker and Larry Baxter

Also during this quarter, one presentation of the current BYU SCR work was presented at the 2005 Annual Advanced Combustion Engineering Research Center (ACERC) conference on February 17 and another at Western State Catalysis Club (WSCC) meeting on February 25, the latter being awarded the first-place prize for the best paper presented at the meeting.

Task 3 - Minimization of Impacts

A Project Review meeting was held with OCDO (Howard Johnson), DOE-NETL (Bruce Lani), AEP (Tony Gerstenberger, Matt Usher), and REI (Kevin Davis, David Swensen, Bill Cox) personnel at the Gavin plant on Thursday, January 27, to provide an update on recent work and discuss the schedule for completing the remainder of the project. Because plant personnel were unable to attend the formal review meeting at the time scheduled, a pre-meeting was held with AEP (JJ Letcavits, Randy Schiedler, Tony Gerstenberger, Matt Usher) and REI (Kevin Davis, David Swensen, Bill Cox) personnel on Wednesday, January 26, to obtain plant feedback on the project, remaining tasks and project schedule.

During this quarter, REI completed fabrication of newly designed probe components, repaired signal conditioners, assembled probes for installation and modified control software to interface with the new controller. The newly designed probe was installed at Gavin plant in location "Main". The new embedded controller for probe temperature control was evaluated. The test was a success: the controller was able to maintain probe temp ± 2 °F. Fabrication and assembly of the remaining probes were completed and the probes re-installed at Gavin, including new embedded temperature controllers that are integrated with the Ethernet network.

Table 1. Operating time for corrosion probes in Quarter 1.

Probe No.	Hrs. in Q1
Main	1,344
1	---
2	336
3	1,344
4	---
5	1,008

The probes installed in January have operated for most of the quarter, as shown in Table 1. The probes functioned well and data have been collected since the installation date. The only exception occurred when one of the probes was disconnected from the control system. REI became aware of the problem immediately via the remote monitoring software in Salt Lake City. AEP was contacted and plant personnel corrected the problem. This problem caused approximately 1.5 weeks of data to be lost for one probe.

PI data have been received for 2002 through 2005 and are currently being analyzed. Data reduction has been initiated for 2004 corrosion data

The beginning of April will be the end of the testing period for the project. Prior to a scheduled outage at Gavin (April 4th), REI personnel removed the 4 probes from the boiler and shipped them back to Salt Lake City. Profilometry will be performed on the plates in two of the probes.

Task 4 - SCR Catalyst Testing

Selective catalytic reduction (SCR) represents the only commercially proven technology capable of achieving the relatively large NO_x reductions required to comply with the latest (amended) Clean Air Act requirements. SCR systems are being installed in most large-scale utility boilers. However, most long-term experience with SCR comes from Germany and Japan and most of this is based on high-rank coal combustion. Less experience with low-rank, subbituminous coals specifically Powder River Basin coals, appears in the literature. The literature also provides essentially no US and little foreign experience with systems co-fired with biomass. The purpose of this task is to provide both laboratory and field slipstream data and analyses, including computer models that fill this information gap.

Within this task there are for principal sub-tasks:

1. technology assessment and fundamental analysis of chemical poisoning of SCR catalysts by alkali and alkaline earth materials;
2. evaluation of commercial catalysts in a continuous flow system that simulates commercial operation;
3. evaluating the effectiveness of catalyst regeneration; and
4. develop a model of deactivation of SCR catalysts suitable for use in a CFD code.

Task 4.1 Technology Assessment/Fundamental Analysis

Items 1 and 3 are principally performed at Brigham Young University (BYU) under the direction of Profs. Larry Baxter, Calvin Bartholomew, and William Hecker. Methods and equipment have been described in previous technical quarterly reports. Progress during the last performance period on this task is described in the Results and Discussion section.

Task 4.2 Evaluation of Commercial SCR Catalysts for Power Plant Conditions

The work effort for items 2 and 4 is being performed by REI, with assistance from the University of Utah and BYU.

Biomass Co-firing Tests at Gadsden

The Gadsden Plant is located in Gadsden, Alabama, and has two 70 MW tangentially fired boilers. The slipstream reactor has been installed on Unit 1. The reactor started up the week of November 15, 2004. Fuel samples (coal plus sawdust) were taken from the inlet to the pulverizer. The reactor experienced ash blockage at the end of 2004. The reactor was cleaned and started up January 5, 2005. However, the inlet probe rapidly became blocked with ash, possibly because of cycling of load and low inlet temperature on the boiler. The blockage could not be cleared until the unit was in outage. Therefore, the slipstream reactor only ran for about 100 hours in January. The plant was not able to unblock the inlet pipe until an outage in March. Problems with the telephone line prevented REI from restarting the reactor in this quarter.

Results and Discussion

Discussion of Laboratory Study of Catalyst Activity

In-situ FTIR Study

Previous results from NH_3 adsorption and intrinsic kinetic investigations of NO reduction on fresh, lightly sulfated, and 24-hour sulfated 1% vanadia/titania catalysts indicate that sulfates increase catalyst NO reduction activity by increasing the amount of active sites on the catalyst surface without changing the reaction mechanism. This conclusion is based upon the pseudo-first-order intrinsic kinetic analysis results of a larger pre-exponential factor (an indication of the number of the active sites) on sulfated samples with the activation energy remaining the same (an indication of the mechanism) before and after sulfation, as well as a more intense but spectrally unshifted NH_3 adsorption band on the Brønsted acid sites on sulfated vanadia catalyst. These results also indicate that the Brønsted acid sites probably represent the active sites. Previous results also indicate that no statistically significant difference in NO reduction activity exists between lightly sulfated and 24-hour sulfated 1% vanadia catalyst. Moreover, NH_3 adsorption intensities on lightly and 24-hour sulfated 1% vanadia/titania appear the same, which is not consistent with the previous results that NH_3 adsorbs more strongly on a 24-hour sulfated sample than on a lightly sulfated sample. Therefore, NH_3 adsorption and NO reduction kinetic investigations were repeated on fresh, lightly, and 24-hour sulfated 1% vanadia/titania catalysts during this quarter.

In the following section, NH_3 adsorption results were reported first and then the kinetic study of NO reduction on vanadia catalyst.

NH_3 adsorption

During this quarter, NH_3 adsorption conditions remained the same as previous experimental conditions. During the experiment, 1000 ppm NH_3 (helium balance) was introduced into the sample at ~50 sccm for 1 hour at 323 K to ensure complete saturation of the sample. Physisorbed gas was removed by flushing the wafer with helium for another hour at 323 K. The NH_3 adsorption IR spectra were collected on fresh, lightly sulfated, and 24-hour sulfated 1% vanadia/titania catalyst, with results as shown in Figure 1. Catalyst temperature varied over the range relevant to commercial SCR catalyst applications.

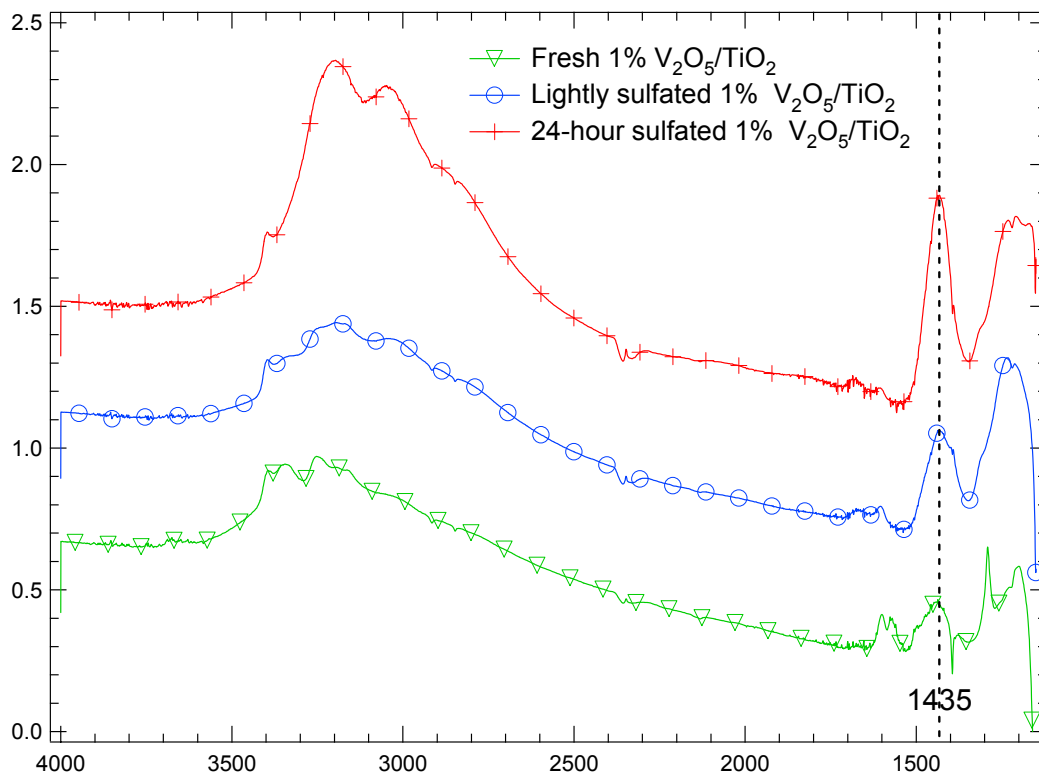


Figure 1. NH_3 adsorption on fresh, lightly sulfated, and 24-hour sulfated 1% $\text{V}_2\text{O}_5/\text{TiO}_2$.

The IR peak at $\sim 1435 \text{ cm}^{-1}$ represents the stretching mode of NH_3 adsorption on the Brønsted acid sites. The broad IR feature in the $2800\text{--}3400 \text{ cm}^{-1}$ range represents a combination of the bending vibrations of NH_3 adsorption on both the Lewis and Brønsted acid sites. As indicated, ammonia adsorption intensity increases with increasing extent of sulfation, indicated here by sulfation time. Moreover, an obvious difference appears between ammonia adsorption intensities on lightly sulfated and 24-hour sulfated vanadia catalysts. NH_3 adsorbs most strongly on the 24-hour sulfated sample, followed by the lightly sulfated sample, and still adsorbs, though least strongly, on the fresh 1% vanadia/titania catalyst. This indicates that the sample we had presumed to be lightly sulfated in the previous experiments was in fact completely sulfated. These data indicate that NH_3 adsorbs on lightly sulfated catalyst to an extent that is intermediate between the fully sulfated and the unsulfated samples. However, the adsorption energy, indicated by the vibration frequency of the band, appears essentially identical for all three samples. For example, the position band at $\sim 1435 \text{ cm}^{-1}$, which represents adsorbed ammonia in stretching mode on Brønsted acid site, remains at the same position before and after sulfation. This result indicates that sulfation increases the number of the acid sites on the catalyst surface without changing the Brønsted acid site acidity.

NO reduction activity investigation

Previous results showed no statistically significant difference between NO reduction activities on lightly and 24-hour (fully) sulfated 1% vanadia catalysts. Since the data on the amount of ammonia adsorption reported last quarter were found to be in error (that is, both samples appear to have been fully sulfated), we repeated the catalyst activity experiments on fresh, lightly sulfated, and 24-hour sulfated 1% vanadia/titania catalyst. The experimental conditions remain the same as before. These investigations involved 700 ppm NH₃ and NO, 5% O₂ and balance helium. A total of 3 flow rates (93, 121, and 187 ml/min) provided a range of space velocities. The temperature ranged from 250 °C to 350 °C. Both conversion and kinetic activity data derived from mass-spectrometer-based analyses of reactor effluent streams provide quantitative measures of the impact of sulfation on activity. The kinetic data require knowledge of film and pore diffusion impacts in addition to conversion results. Means of estimating these impacts are discussed prior to the kinetic parameter determination below.

Pore diffusion limitation

SCR tests on 5 and 2 % V₂O₅/TiO₂ catalysts at 350 °C resulted in NO conversions of about 80% and 72% respectively, which indicates that increasing vanadia content enhances NO reduction activity. However, at conversions as high as 80 and 72%, pore diffusion resistance could be dominant. For example, the calculated Thiele modulus (M_T) for 5% V₂O₅/TiO₂ is 1.06, substantially exceeding the 0.4 upper limit for M_T customarily accepted for negligible pore diffusion resistance. In addition, the Weisz modulus (M_W) for 5% V₂O₅/TiO₂ is 1.13, exceeding the 0.13 upper limit for M_W customarily accepted for negligible pore diffusion resistance.

$$M_T = L \sqrt{\frac{(n+1)}{2} \frac{k''' C_{As}^n}{D_{eff} C_{As}}} \quad (1)$$

$$M_W = \frac{L^2 (-r''')_{obs}}{D_{eff} C_{As}} \quad (2)$$

$L = Z/2$ for flat plate, Z = thickness

$L = r/2$ for cylinders, r = radius

$L = r/3$ for spheres

n = reaction order

D_{eff} = effective diffusivity

C_{As} = reactant concentration on catalyst surface

Pore diffusion impacts the kinetic reaction rates in these cases. Operation in regimes without such impacts provides more accurate intrinsic kinetic data. Therefore, NO reduction was tested on 1% V₂O₅/TiO₂ at 18% conversion with temperatures of about 250 °C and a 30% conversion at temperatures of 300 °C. These conditions correspond to a Thiele modulus (M_T) of about 0.25 (250 °C) and 0.34 (300 °C), respectively. Both are smaller than 0.4. Therefore the pore diffusion effects can be neglected.

Film diffusion limitation

Both theoretical and experimental results show that film diffusion can be neglected during SCR tests on 1% V₂O₅/TiO₂ at temperatures up to 350 °C and under the conditions of these experiments.

Film diffusion resistance is determined according to

$$K_c = \frac{1-\phi}{\phi} \left(\frac{D_{AB290}}{d_p} \right) Sh' \quad (3)$$

ϕ = void fraction of packed bed

D_{AB} = gas-phase diffusivity, m²/s

d_p = particle diameter, m

Sh' = Sherwood number

The calculated result indicates that the film resistance accounts for about 0.3% of the total resistance (combined resistance of film diffusion and kinetic resistance).

Experimentally, film diffusion investigations on SCR catalysts (1% V₂O₅/TiO₂) involved three different flow rates (93, 121, 187 ml/min). This range of space velocities in the catalyst provides significant variation in the boundary layer thickness along the catalyst surface and therefore should result in different conversions if film resistance plays a significant role in NO reduction. Similar NO conversions (17.6% at 93.3 ml/min, 18% at 121 ml/min, and 17.4% at 187ml/min at 250 °C) resulted from each experiment, consistent with the mathematical expectation of negligible impact of film resistance. Therefore, the following SCR reactions were investigated on 1% V₂O₅/TiO₂ catalysts with 700 ppm NH₃ and NO, 5% O₂ and balance helium with a total flow rate of 187 ml/min and at a temperature range of 250-350 °C, where both film diffusion and pore diffusion resistance can be neglected. This investigation involved catalyst reacting in the intrinsic kinetic range.

During NO reduction activity tests, the NO conversion is measured by comparing the changes in the NO³⁰/Ar³⁸ ratio of the MS signal intensity before and after reaction. Using this technique, the apparent NO conversion increased with time, frustrating attempts to collect repeatable data. Improved normalization of the data with one of the MS measurement parameters that measures background intensity improved the results.

Kinetic parameter calculation

Since NO reduction experiments did not involve film or pore diffusion, kinetic parameters depend directly on NO conversion based on the following equation (assuming the surface reaction is first-order in NO concentration):

$$K = -\frac{Q_0}{W_{cat}} \ln(1-X) \quad (4)$$

K = reaction rate coefficient

Q_0 = total gas flow rate, ml/min

W_{cat} = catalyst weight

X = NO conversion

And also

$$K = A \exp\left(-\frac{E_a}{RT}\right) \quad (5)$$

A = pre-exponential factor

E_a = activation energy

R = gas constant 8.314 J/mol·K

T = temperature, K

A series of reaction rate coefficients (K) and temperatures result from measuring NO reduction as a function of temperature (Table 2). Non-linear, least-squares fits of these data determine the parameters A and E_a and their confidence intervals. Figure 2 illustrates the estimated results of previous and repeated A and E_a for fresh, lightly sulfated, and fully sulfated samples.

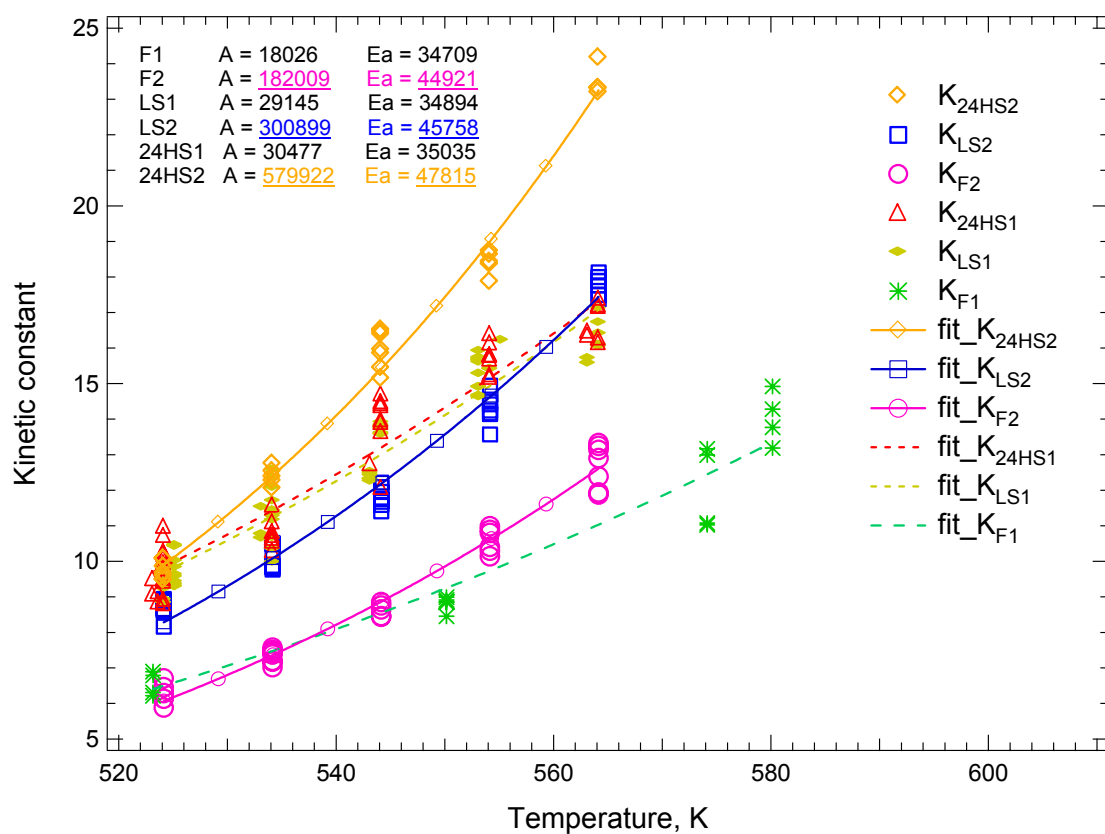


Figure 2. Kinetic parameter (A , E_a) estimations of fresh, lightly sulfated, and 24-hour sulfated 1% V_2O_5/TiO_2 .

In Figure 2, the indicated symbols represent measured NO conversion data from fully (24-hour exposure) sulfated, lightly sulfated, and fresh 1% V_2O_5/TiO_2 SCR catalysts. The solid lines represent the curve fits of replicate experimental data based on the non-linear least squares algorithm for each conversion data set, and the dashed lines represent the same curve fits of the previous experimental data.

K values of the replicated experiments appear generally higher than those of the previous experiments. The difference probably arises from subtle differences in sample preparation that impact various physical characteristics such as surface area or vanadia dispersion.

Both the previous and replicated results indicate that sulfated vanadia catalysts possess higher NO reduction activity than those of fresh catalysts. However, the replicated data indicate that NO reduction activity on fully sulfated samples significantly exceeds activity of the partially sulfated samples, consistent with the adsorption data discussed in the previous section. By contrast, the original data indicate that fully sulfated and lightly sulfated vanadia catalysts have the same activity. Figure 3 demonstrates the statistical comparison of activities K of fresh, lightly sulfated, and fully sulfated samples in the replicated experiment.

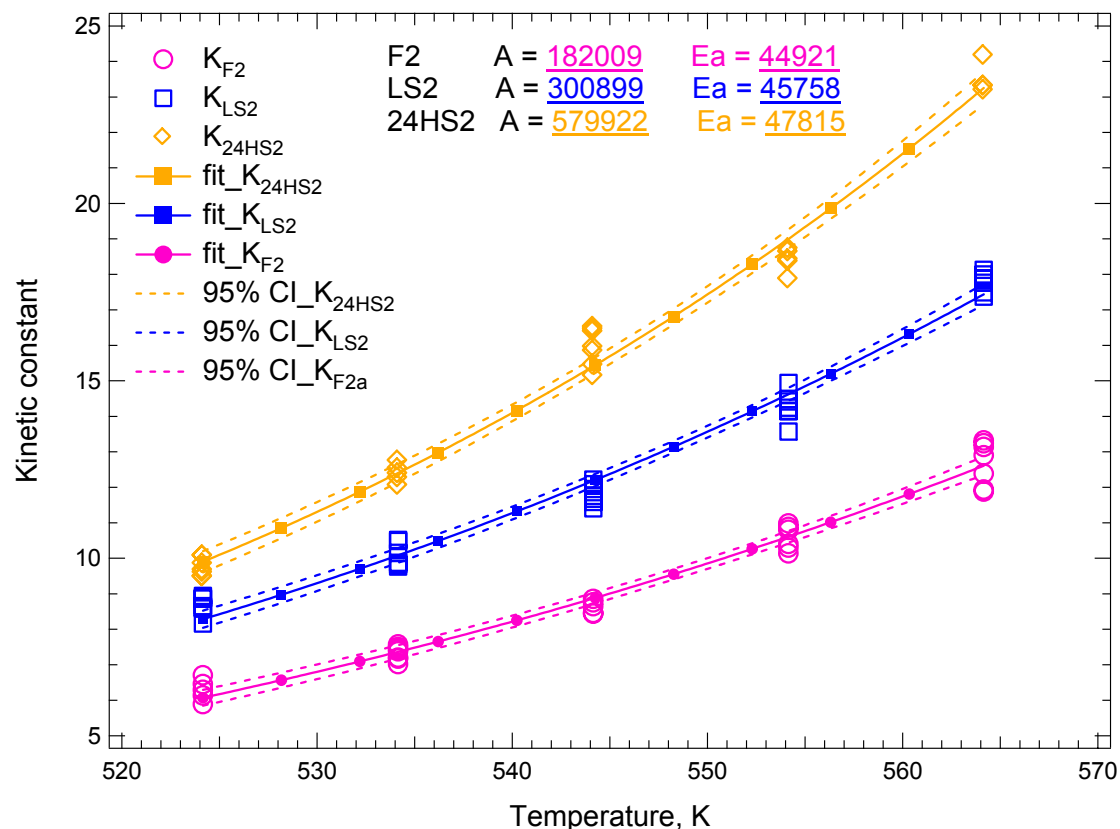


Figure 3. Kinetic parameter (A , E_a) estimations with confidence intervals of fresh, lightly sulfated, and 24-hour sulfated 1% V_2O_5/TiO_2 .

In Figure 3, the indicated symbols represent measured NO conversion data from fully (24-hour exposure) sulfated, lightly sulfated, and fresh 1% V_2O_5/TiO_2 SCR catalysts. The solid lines represent the curve fits based on the non-linear least squares algorithm for each conversion data

set. The upper and lower dotted lines indicate the 95% confidence interval for activity (K) at a given temperature. The results indicate that differences observed among the samples are statistically significant. Typically, sulfation increases intrinsic activity by about 40% in these tests. Furthermore, although K increases significantly upon catalyst sulfation, the activation energy E_a remains statistically unchanged for sulfated and non-sulfated samples, with E_a in the range of 44921 to 47815 J/mol. The differences in the rate coefficient arise from the pre-exponential factor, A . Results of curve fitting show that sulfated samples have larger pre-exponential factors ($A = 300000$ and $580000 \text{ cm}^3/\text{g s}$) than fresh samples ($A = 182000 \text{ cm}^3/\text{g s}$). This is consistent with the in-situ spectral results that indicate sulfation does not impact the vanadia grains on the catalyst. As indicated by the spectra, surface sulfation impacts the ammonia absorption on the surface, providing more opportunities for $\text{NH}_3\text{-NO}$ interaction, thus increasing the interacting frequency, which is related to A .

Table 2. Statistical 95% confidence intervals for the new data.

Sample	A	Interval for A	E_a	Interval for E_a
Fresh	182009	$\pm 1.56\text{e}05$	44921	± 2370
Lightly sulfated	300899	$\pm 1.16\text{e}05$	45758	± 2930
24-hour sulfated	579922	$\pm 1.10\text{e}06$	47815	± 3560

Tests of Monolith Catalysts from REI Slipstream Reactor

During this quarter, tests continued on samples from the commercial monolith catalysts M1 and M2. For each catalyst type, tests were run on two samples cut from the upstream end of catalyst that had been exposed for 3800 hours in the slipstream reactor. The 3800 hour exposed catalysts had significant channel plugging, but samples came only from unplugged areas. Sample size and flow conditions for each test were the same as those tests run on the fresh catalysts and catalysts exposed for 2063 hours (flow of 1000 sccm comprised of 2% O_2 , 10 % H_2O , 900 ppm NH_3 , 900 ppm NO and the balance He ; temperature varied between 275 and 325 °C).

The Chen model, developed to describe monolith catalyst deactivation in SCR [1], provides a quantitative means of tracking deactivation and a potential means of incorporating such deactivation in a combustion simulation code. The results presented below do not properly account for bulk diffusion resistance to the catalyst surface and are therefore not complete but are included here to illustrate the application of the model to data of this type. The kinetic parameters described in this section of the report are not accurate as the samples experienced considerable bulk diffusion resistance. However, the kinetic parameters described in the next section of the report (*in situ* reactor) are accurate. The model comparisons between the activity of the exposed catalysts and the fresh catalysts appear below. The Chen model predicts NO conversion (X_{NO}) of an exposed catalyst through the equations:

$$X_{NO} = 1 - \exp \left(- \frac{\sigma_{cat} L}{u A_{cs}} \frac{1}{\frac{1}{k_m} - \frac{1}{\frac{1}{(D_e k a)^{1/2}} \frac{\exp(-2\phi) + 1}{\exp(-2\phi) - 1}}} \right) \quad (6)$$

where

$$\phi = \left(\frac{h^2 k a}{D_e} \right)^{1/2} \quad (7)$$

σ_{cat} = perimeter length of a monolith cell

L = monolith length

u = linear gas velocity in cell

A_{cs} = cross-sectional area of a cell

k_m = mass-transfer coefficient

D_e = effective diffusivity of NO

k = first order reaction rate constant

a = activity

Φ = Thiele modulus

h = wall half-thickness

To compare the activities, the reaction rate constants (K) were found over a range of temperatures for each of the fresh catalysts by setting activity (a) equal to one. The pseudo-first-order Arrhenius' reaction rate pre-exponential factor (A) and activation energy (E_a) for each sample resulted from non-linear least-squares analyses of the measured reaction rate coefficients and temperatures. (Igor Pro[®] was used to fit the data):

$$k = A \exp \left(- \frac{E_a}{RT} \right) \quad (8)$$

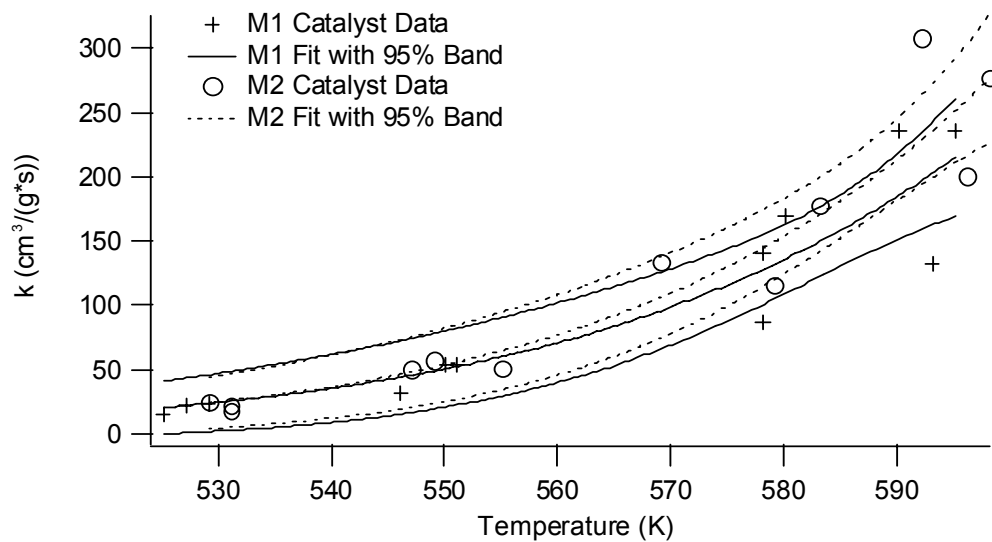
R = ideal gas constant

T = temperature

The results appear in Table 3 and the comparisons of data and model predictions appear in Figure 4.

Table 3. A and E_a values.

Catalyst	A ($\text{cm}^3/(\text{g}\cdot\text{s})$)	E_a (kJ/mol)
M1	$1.06 * 10^{10}$	87.7
M2	$2.65 * 10^{10}$	97.4

**Figure 4. Arrhenius-law fit for M1 and M2.**

By holding the reaction rate coefficients constant, conversion data from the exposed catalysts determine values of the activity factor (a) in the Chen model. These values appear in Table 4. Figure 5 and Figure 6 compare the Chen model fits to the actual data.

Table 4. Activity Factor Fits for Exposed Catalysts.

Catalyst	2063 hr Exposure	3800 hr Exposure
M1	1.029	1.152
M2	0.533	0.413

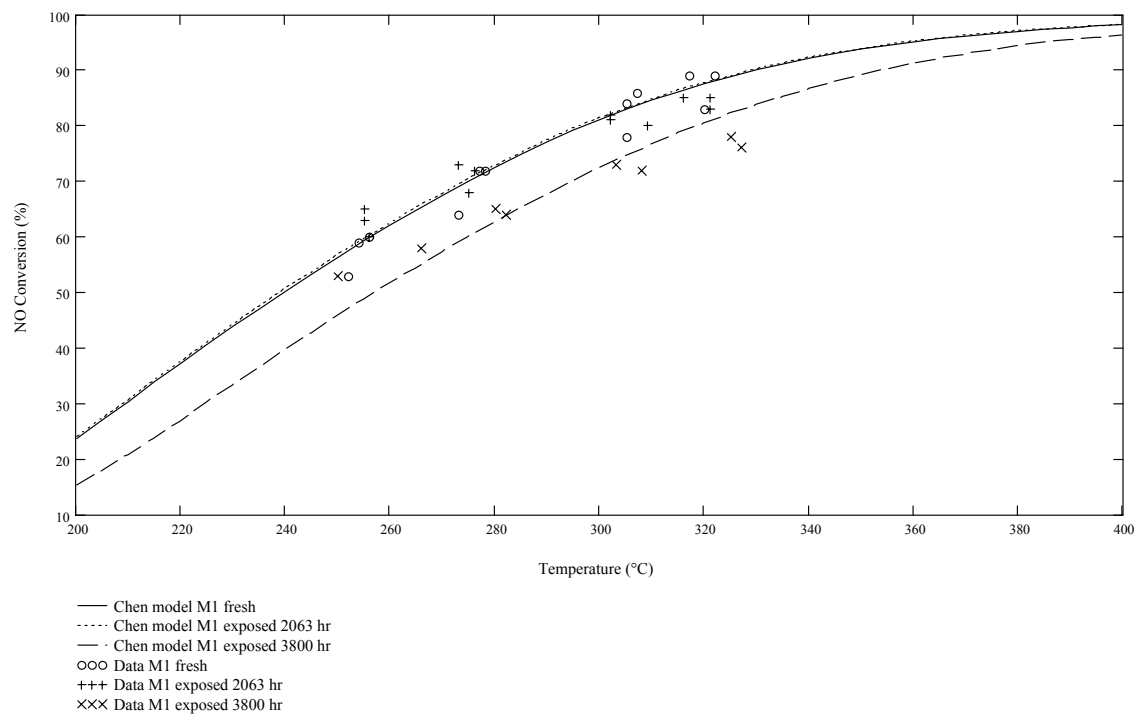


Figure 5. M1 comparison of data to Chen model prediction.

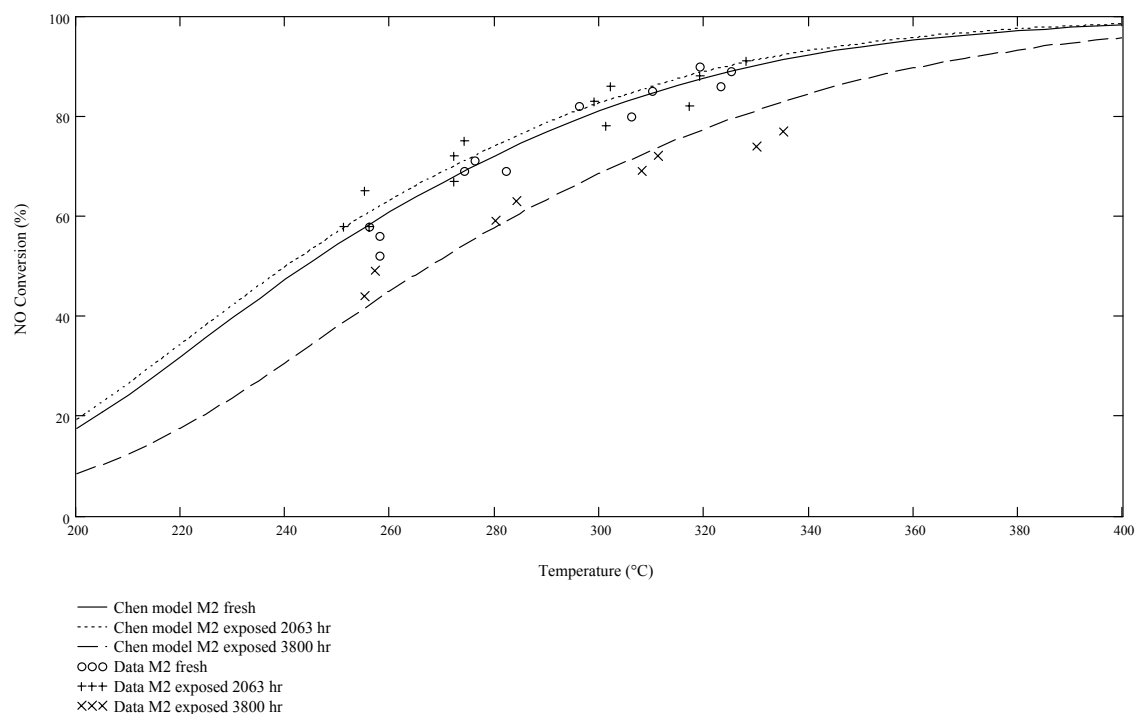


Figure 6. M2 comparison of data to Chen model prediction.

Values of a , from the Chen model, indicate that activity increases slightly after 2063 hours of exposure, presumably due to catalyst sulfation. However, after 3800 hours of exposure the a decreases significantly. It is unknown if this deactivation is caused by plugging, masking, poisoning, or a combination (see Figure 7).

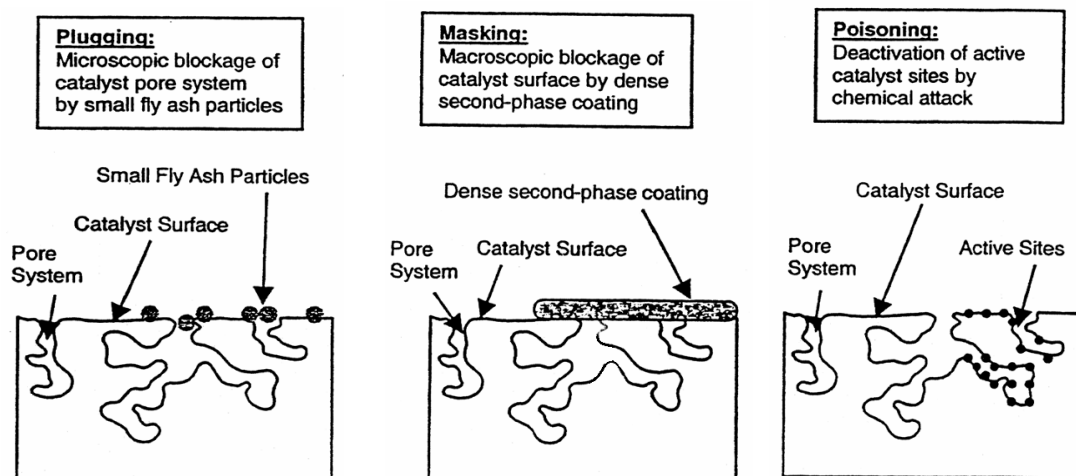


Figure 7. Comparison of deactivation mechanisms: plugging, masking and poisoning.

Currently, data are being collected for the P1 and P2 catalysts. Also the cause of the wide variation of k values (see Figures 5 and 6) is under investigation.

Discussion of the Slipstream Reactor Study

In the quarterly report for October through December, 2004 the mineral analysis of the fuel mix was reported. This quarter, more coal and ash data were received. Data from the plant PI system were also received this quarter.

The fuel sample contained approximately 5% sawdust by weight. A sample was taken at the pulverizer inlet. Table 5 gives the fuel composition. The flue gas composition can be estimated from the ultimate analysis, as shown in Table 6. The SO_2 content of the flue gas is moderately high.

Table 5. Fuel ultimate and proximate analyses.

Analyte	As-rec'd	Dry Basis
Cl	----	209 µg/g
<i>Proximate analysis</i>		
Total Moisture	4.88 wt. %	----
Moisture Air Dry	3.87 wt. %	----
Moisture Oven Dry	1.05 wt. %	----
Ash	14.22 wt. %	14.95 wt. %
Total Sulfur	2.02 wt. %	2.12 wt. %
Calorific Value	11,884 BTU/lb	12,493 BTU/lb
Volatile Matter	28.83 wt. %	30.31 wt. %
Fixed Carbon	52.07 wt. %	54.74 wt. %
<i>Ultimate Analysis</i>		
Total Moisture	4.88 wt. %	----
Ash	14.22 wt. %	14.95 wt. %
Total Sulfur	2.02 wt. %	2.12 wt. %
Carbon	70.08 wt. %	73.68 wt. %
Hydrogen	5.24 wt. %	4.93 wt. %
Nitrogen	1.44 wt. %	1.51 wt. %
Oxygen (by difference)	2.67 wt%	2.81 wt%

Table 6. Flue gas composition estimated from ultimate analysis.

Species	
O ₂	4.69%
CO ₂	12.88%
H ₂ O	6.19%
N ₂	75.99%
SO ₂ [ppm]	1,389
HCl [ppm]	13

A sample of the ESP hopper ash was taken at the same time as the fuel sample. Table 7 compares the mineral analysis of the fuel and the ESP hopper ash, normalized on a sulfur-free basis.

The ash is low in sodium and very low in calcium. However, the potassium content (2.65 wt%) is significant. The composition of the ESP ash corresponds well with the fuel ash composition. Sodium appears to be depleted in the ESP ash.

Table 7. Composition of mineral fraction in fuel and ESP hopper ash, normalized to a sulfur-free basis.

	Coal Ash	ESP Hopper Ash
Silicon Dioxide	53.14	54.86
Aluminum Oxide	25.52	26.86
Titanium Dioxide	1.23	1.25
Iron Oxide	14.24	11.31
Calcium Oxide	1.01	0.91
Magnesium Oxide	0.98	0.97
Potassium Oxide	2.65	2.76
Sodium Oxide	0.42	0.29
Phosphorus Pentoxide	0.41	0.42
Barium Oxide	0.26	0.26
Manganese Dioxide	0.04	0.03
Strontium Oxide	0.08	0.09

During the months of November and December, 2004 and January, 2005, the average sawdust content of the fuel was 3.85 wt%. Figure 6 shows the daily average sawdust content of the fuel, as reported by the plant. Daily CEM data were also received from the plant during this quarter and will be reported in the next quarterly report.

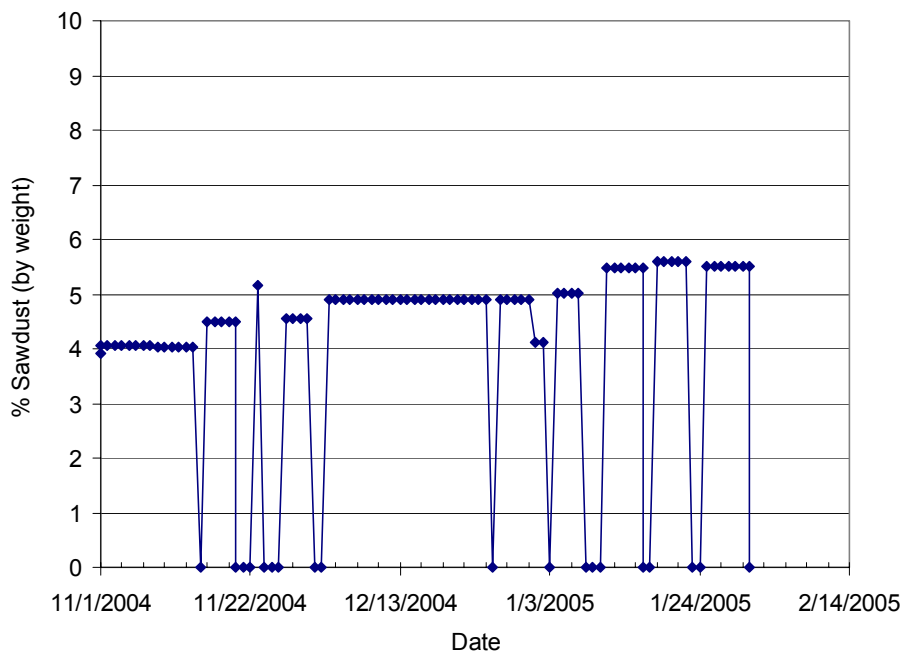


Figure 6. Sawdust feed rate at Gadsden Unit 1, in wt% of total fuel flow.

Conclusions

Good progress has been made on several fronts during the last three months. In particular:

- A six-month no-cost extension has been granted. The project will be completed on September 30, 2005.
- Refurbished ECN probes were installed at Plant Gavin and operated for about 1,300 hours.
- At the end of the quarter, REI personnel removed the 4 probes from the boiler and shipped them back to Salt Lake City. Profilometry will be performed on the plates in two of the probes.
- This quarterly report includes further results from the BYU catalyst characterization lab and the in-situ lab, and includes the first results from a model suitable for comprehensive simulation codes for describing catalyst performance.
- The SCR slipstream reactor at Plant Gadsden operated for approximately 100 hours during the quarter because of ash blockage in the inlet probe.

Plans for Next Quarter

Corrosion probe activity for the next quarter will focus on the following:

- Perform profilometry measurements on new probes.
- Request EPRI report on KEMCOP probe data taken earlier in program.
- Begin work on final reporting requirements for the project

Activity at BYU next quarter will focus on the following:

- Analysis of slipstream SCR samples from Gadsden.

SCR slipstream activity for the next quarter will focus on the following:

- The slipstream reactor will be removed from Plant Gadsden.
- Final data analysis will be completed.

References

1. Chen, Buzanowski, Yang, and Cichanowicz. (1990). "Deactivation of the Vanadia Catalyst in the Selective Catalytic Reduction Process." Journal of the Air & Waste Management Association **40**(10):1403-1409.