

# Determining SCR Reactor Potential *In situ*

*Paper # 17*

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## ABSTRACT

To date, the U.S. utility industry has installed over 100 GW of selective catalytic NO<sub>x</sub> reduction (SCR) systems on coal-fired utility boilers<sup>1</sup>. In these coal-fired SCR systems, Catalyst Activity and Reactor Potential will gradually decrease over time, requiring the addition and/or periodic replacement of catalyst material.

Traditionally, Catalyst Activity is monitored by physically removing catalyst samples from the reactor and testing them in a laboratory. Most utilities are operating SCR systems on a five-month ozone season basis, and have ample sampling opportunities. However, for those utilities who currently operate on a year-round basis, or those who will need to switch to year-round operation in the future, opportunities to enter the reactor to obtain samples are reduced; hence, there is a need for new tools and approaches that allow informed catalyst management decision-making under these conditions.

This paper presents the results of a four-year field demonstration of a new system to measure Catalyst Activity and Reactor Potential *in situ*. The *in situ* measurement technique is similar to the traditional laboratory measurement but occurs within the SCR reactor, while the reactor is operating.

The *in situ* results from this demonstration are in agreement with laboratory tests of Catalyst Activity. In addition, the *in situ* tests were able to document the effect that vacuuming the catalyst between ozone seasons had on Reactor Potential at the demonstration site. Finally, the *in situ* system was able to track the changes in Reactor Potential during a short period when the SCR reactor sootblowers were temporarily inoperable.

## INTRODUCTION

To date, the U.S. utility industry has installed over 100 GW of selective catalytic NO<sub>x</sub> reduction (SCR) systems on coal-fired utility boilers.<sup>1</sup> In the SCR process, ammonia is injected ahead of a catalyst (composed primarily vanadia-titania based materials) where it reacts with NO<sub>x</sub>, forming nitrogen (N<sub>2</sub>) and water (H<sub>2</sub>O). In coal-fired SCR systems the Catalyst Activity will gradually decrease over time, primarily due to various constituents in coal flyash. Furthermore, these coal-fired SCR systems contain multiple catalyst layers and each layer can exhibit a different rate of activity decay. In addition to the decline in Catalyst Activity, with increasing operating hours the catalyst may become plugged with flyash, effectively reducing the active catalyst surface area. As the overall NO<sub>x</sub> removal capacity of the reactor decreases, a point is reached where the system may no longer achieve the designed level of NO<sub>x</sub> reduction without allowing an increased level of ammonia slip.

Ammonia slip can have detrimental impacts on equipment downstream of the SCR reactor. In particular, the ammonia can react in the air preheater with SO<sub>3</sub> resulting in ammonium bisulfate formation and air preheater pluggage. The ammonia can also contaminate the flyash at levels such that the flyash may no longer be sold. To avoid these impacts, ammonia slip is typically limited to less than 2 ppm in coal-fired SCR applications.

As the Catalyst Activity degrades and ammonia slip increases, a point is reached where either additional catalyst must be added to the reactor, or a portion of the existing catalyst replaced with new material. To deal with these issues, utilities have instituted catalyst management programs aimed at monitoring the activity of the catalyst layers within the SCR reactor. This typically involves experimentally monitoring the activity decay of each layer, as well as utilizing a software tool to help plan when catalyst must be added, or replaced.

Traditionally, Catalyst Activity is monitored by physically removing catalyst samples from the reactor and testing them in a laboratory. Many U.S. utilities are operating SCR systems on a five-month ozone season basis from May 1<sup>st</sup> through September 30<sup>th</sup>. Thus, the seven-month “off season” generally provides ample time to remove catalyst samples from the reactor, send them out for testing, receive the activity results, and if necessary, take corrective action by adding or replacing catalyst material prior to the next ozone season. However, some utilities operating on an ozone season basis cannot enter the reactor until an annual unit maintenance outage because the SCR isolation dampers are not considered man-safe. For these utilities, this is usually a spring outage that is scheduled just before the SCR reactor comes online in May, and thus the test results from any samples removed at this time are not available until after the ozone season has begun.

For those U.S. utilities who currently operate their SCR systems on a year-round basis, or those who will need to switch to year-round operation in the future, opportunities to enter the reactor to obtain samples are reduced. Furthermore, many utilities are extending the interval between major outages to 24 and even 36 months, further reducing the opportunity to obtain catalyst samples for activity testing. At the same time, shifting from seasonal to annual operation essentially means that the Catalyst Activity will be degrading approximately twice as fast over

the period of a calendar year. This increased annual rate of decay coupled with fewer opportunities to obtain samples for testing could reduce the utility's ability to make timely and informed catalyst management decisions. Hence, there is a need for the development of new tools and approaches to aid in the catalyst management process. This paper presents the results of a four ozone season demonstration of a system to measure Catalyst Activity and Reactor Potential *in situ*.

In addition to the impacts on the catalyst management decision-making process, during year-round operation the SCR reactors will experience more low-load operating conditions than during operation on strictly an ozone season basis. In many cases utilities may chose to operate their SCR reactors below the minimum operating temperature (MOT) recommended by the catalyst manufacturer. In this case Ammonium Bisulfate (ABS) can deposit on the catalyst, resulting in reduced Catalyst Activity and Reactor Potential. Fortunately, this process is generally reversible, as the ABS will sublime when the unit returns to full-load operation, given the proper conditions. The *in situ* measurement technique can be used to monitor this decrease in Catalyst Activity, and quantify the allowable operating time at low-load such that when the unit is returned to full-load there is sufficient Reactor Potential to meet the SCR's NO<sub>x</sub> removal and ammonia slip performance requirements.

## Catalyst Activity and SCR Reactor Potential

Before discussing the approach for the new *in situ* activity measurement technique, it is important to understand the parameters that dictate SCR performance. The parameters that are of most importance include: 1) Catalyst Activity, 2) Reactor Potential, and 3) Area Velocity. A one dimensional analysis of the SCR process leads to the following relationship for NO<sub>x</sub> reduction within a catalyst channel:

$$\Delta\text{NO}_x = 1 - e^{-K/A_v} \quad (1)$$

$\Delta\text{NO}_x = \text{NO}_x$  reduction expressed as a fraction  
(or multiplied by 100 to be expressed as percent)

$K =$  Catalyst Activity

$A_v =$  Area velocity, or flowrate through a catalyst passage  
divided by surface the area of the passage

The area velocity essentially defines the flue gas flowrate per unit catalyst surface area in the reactor:

$$A_v = \frac{Q}{A_{\text{cat}}} \quad A_v = \text{area velocity, m/hr} \quad (2)$$

$$= \frac{Q}{V_{\text{cat}} A_{\text{sp}}} \quad Q = \text{flue gas flowrate, m}^3/\text{hr at standard conditions} \quad (3)$$

$A_{\text{cat}} =$  catalyst surface area, m<sup>2</sup>

$V_{\text{cat}} =$  catalyst volume, m<sup>3</sup>

$A_{\text{sp}} =$  catalyst specific surface area, m<sup>2</sup>/m<sup>3</sup>

The overall reactivity of an SCR system is determined by a term referred to as the Reactor Potential (RP). The Reactor Potential is the Catalyst Activity multiplied by the total surface area of catalyst per unit of flue gas.

$$RP = \frac{K A_{sp} V_{cat}}{Q} = \frac{K}{A_v} \quad (4)$$

The Reactor Potential is a measure of the overall ability of the reactor to reduce  $NO_x$ . A specific amount of Reactor Potential is needed to achieve a defined  $NO_x$  reduction level while maintaining  $NH_3$  slip within the allowable limit.

For an SCR reactor with multiple layers, the overall Reactor Potential is the sum of the Reactor Potential of each layer.

$$RP = \sum_{i \text{ layers}} RP_i = \sum_{i \text{ layers}} \frac{K_i}{A_{vi}} \quad (5)$$

In actual application, some of the catalyst surface area for each layer is usually lost due to plugging by flyash, and therefore the area velocity term in Equation 5 may need to be modified to account for this blockage.

Traditionally, to determine the Reactor Potential, a utility will remove a sample of catalyst from each layer of the reactor. The samples are then sent to a laboratory for an activity measurement. This is accomplished by placing the sample in a device that allows a flue gas stream (real or simulated) to be passed through the sample at temperature,  $NO_x$ , and flow conditions representative of those for the full-scale SCR reactor. Ammonia is injected ahead of the sample at a  $NH_3/NO_x$  ratio of 1.0 or 1.2, and the  $NO_x$  reduction across the sample is measured. Formal laboratory testing protocols have been established for the testing of SCR catalyst material.<sup>2,3</sup> The Catalyst Activity for the sample is then calculated by rearranging Equation 1.

$$K = -A_v \ln (1 - \Delta NO_x) \quad (6)$$

Where  $A_v$  = the area velocity at which the laboratory test was conducted (generally corresponding to the design area velocity)

$\Delta NO_x$  = the  $NO_x$  reduction measured in the laboratory apparatus

Once the activity of each individual layer ( $K_i$ ) is calculated using Equation 6, the Reactor Potential can be calculated from Equation 5, where the area velocity for each layer is modified to account for blockage. Generally, this is accomplished by conducting a visual inspection of the full-scale reactor, or by inferring the blockage from a change in pressure drop across each catalyst layer within the reactor.

Currently, many U.S. utilities operate their SCR systems only during the five-month ozone season. In most cases, the seven-month “off-season” generally provides ample time to remove catalyst samples from the reactor, send them out for testing, receive the activity results, and if necessary, take corrective action by adding or replacing catalyst material prior to the next ozone season. However, this best-case scenario still only allows one data point per layer, per year to provide input into future catalyst management decisions. For these U.S. utilities, as well as those already operating SCR systems on a year-round basis, the trend of stretching the scheduling of major outages out to as far as 24 to 36 months, will result in far fewer opportunities to go inside the reactor to remove catalyst samples for activity analysis, as well as to assess the blockage of the catalyst layers.

### ***In situ* Measurement of Reactor Potential and Catalyst Activity**

Fossil Energy Research Corp. (FERCo) has developed a new device (U.S. patent pending)<sup>4</sup> that allows Reactor Potential and Catalyst Activity to be determined *in situ*. With this new approach to catalyst testing, the Reactor Potential and activity can be measured at any time the SCR is in operation, independent of the scheduling of unit outages. With multiple devices, each layer can be measured independently and if desired, a number of individual measurements can be made across a single catalyst layer.

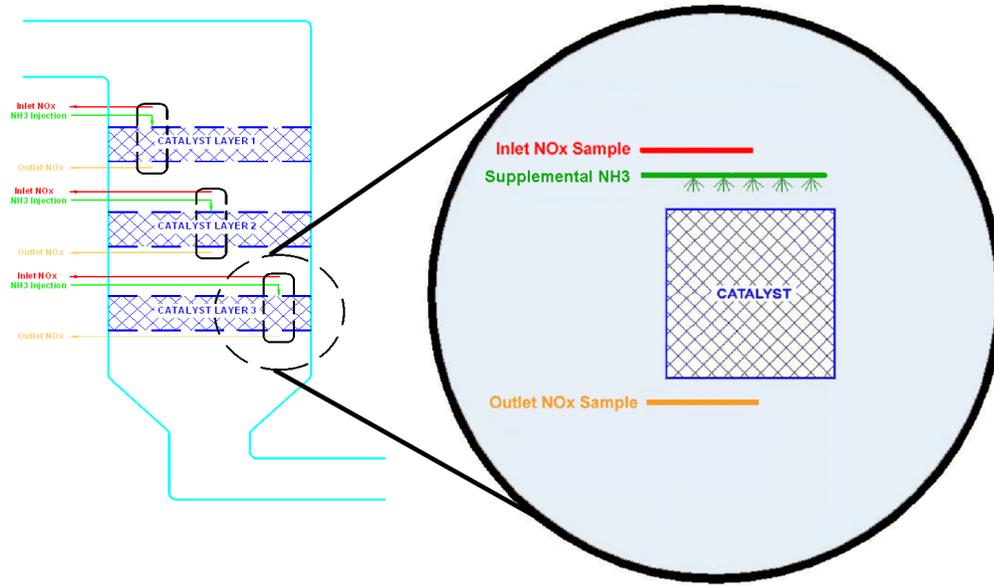
Unlike the laboratory approach that measures the activity (K) and then uses the design area velocity ( $A_v$ ) with an estimate of the blockage to calculate the Reactor Potential, this new device provides a direct measurement of Reactor Potential. The *in situ* measurement technique is similar to the laboratory measurement. A small auxiliary ammonia injection grid (AIG) is located above the section of catalyst to be tested. To make the measurement, ammonia is added such that the local  $\text{NH}_3/\text{NO}_x$  ratio exceeds 1.0, and the maximum  $\text{NO}_x$  reduction across the test section is measured. This is illustrated in Figure 1 where these individual test modules are incorporated on each catalyst layer. Incorporating previous expressions for Reactor Potential and Catalyst Activity, the following expression indicates that Reactor Potential can be directly determined by measuring the  $\text{NO}_x$  removal across the *in situ* test module.

$$\text{RP}_i = \ln (1 - \Delta\text{NO}_{xi}) \quad (7)$$

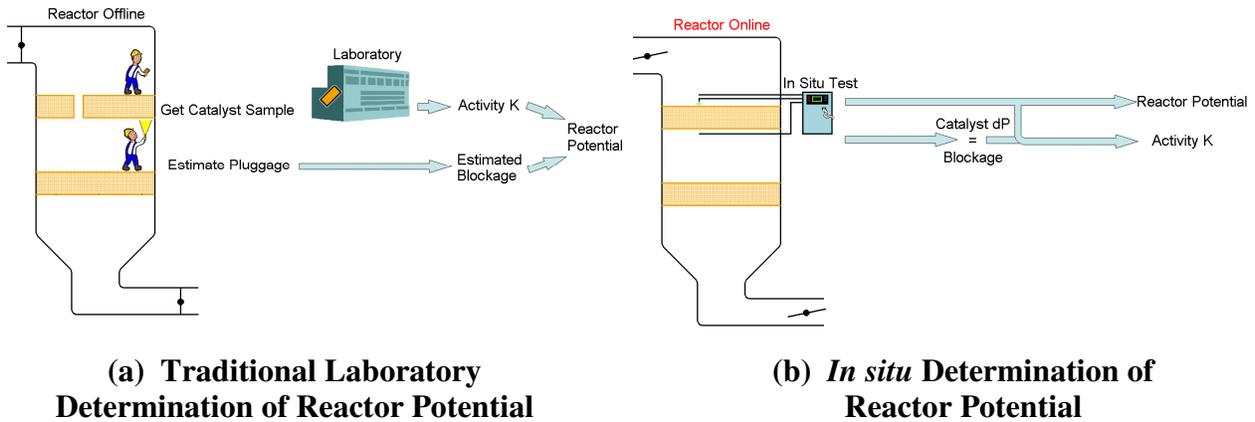
It is important to emphasize that this is a measurement of the true Reactor Potential value accounting for the actual flue gas flow rate and blockage values, not a calculated quantity based on the design area velocity and an estimate of the blockage.

The differences between the *in situ* and laboratory measurements are illustrated in Figure 2. To make informed catalyst management decisions, one needs to know the Reactor Potential at the conditions at which the SCR system is actually operating. In the traditional approach (Figure 2a), a laboratory measurement is made of the Catalyst Activity (K). The Reactor Potential is then calculated using an estimate of the blockage of each layer along with the design area velocity. If the estimate of blockage is inaccurate, or if the actual flue gas flowrate differs from the design value, the calculated Reactor Potential will be in error.

**Figure 1. *In situ* Determination of SCR Reactor Potential**



**Figure 2. Laboratory and *In situ* Determination of Reactor Potential**



On the other hand, the *in situ* approach provides a direct measurement of the actual Reactor Potential (Figure 2b). This measurement inherently accounts for the actual flue gas flowrate, the actual blockage of the catalyst layer being tested, and the actual Catalyst Activity.

To determine the Catalyst Activity from the *in situ* measurement of Reactor Potential, an estimate of the blockage and the design area velocity would be used to calculate  $K_i$ , as shown in Figure 2b.

## Field Demonstration

### *Host Site*

The field demonstration of the *in situ* Reactor Potential measurement methodology was conducted over the 2005, 2006, 2007, and 2008 ozone seasons at Alabama Power Company's Plant Gorgas Unit 10.

Plant Gorgas Unit 10 is a 700 MW tangentially-fired boiler that started operation in 1972 and burns primarily an Alabama bituminous coal. The unit was retrofit with an SCR system that began ozone season operation in May of 2002. The Plant Gorgas Unit 10 system is a 3 + 1 design with two separate reactors (A and B). Three layers of extruded honeycomb catalyst were initially installed in each reactor, with room for a spare layer below. Prior to the start of the 2006 ozone season, a new layer of plate catalyst was installed in the top layer, and the "used" top layer was moved down to the fourth (spare layer) location in the other reactor. In this move, the original top layer in the A reactor was moved to the bottom layer in the B reactor, and vice versa. During the field demonstration, *in situ* Reactor Potential measurements were made only on the B reactor. Additionally, physical access to the outlet of the fourth layer was limited, and thus an outlet flue gas sample probe could not be located in a position to yield valid data. Therefore, *in situ* Reactor Potential measurements during the field demonstration were limited to the upper three catalyst layers.

The *in situ* measurements began at the start of the 2005 ozone season. At this time the original three layers of honeycomb catalyst in each reactor had accumulated nominally 11,500 hours of operating time. The *in situ* measurements are continuing through the 2008 ozone season which will correspond to an accumulated operating time of nominally 26,000 hours.

### *Measurement Hardware*

The hardware designed for the field demonstration consists of two cabinets, as shown in Figure 3. The cabinet on the right side of the photograph, with the external air conditioning unit attached, accepts all of the sample lines from the test modules located within the SCR reactor, and provides the ammonia supply lines to the small supplemental AIGs. This cabinet also contains the computer-controlled valves utilized to switch from one test module to another.

The smaller cabinet on the left of Figure 3 contains a dual channel NO<sub>x</sub>/O<sub>2</sub> measurement system consisting of a pair of chemiluminescent NO analyzers and a pair of zirconium oxide O<sub>2</sub> analyzers. This arrangement allows the simultaneous monitoring of the inlet and outlet of the module being tested. This cabinet also houses the sample conditioning system, an ammonia mass flow controller, and the data acquisition and control system hardware.

The dual cabinet arrangement shown in Figure 3 is commercially intended for a site with multiple SCR reactors. In this case, a valve cabinet like the one on the right side of Figure 3 would be located at each SCR reactor. A single analysis/control cabinet (left side of Figure 3) could then be moved from reactor to reactor, or from unit to unit. This should reduce overall costs for a site with multiple units as only one set of analyzers would have to be purchased. For

**Figure 3. *In situ* Measurement Hardware**



a site containing a single SCR, both cabinets shown in Figure 4 would be incorporated into a single enclosure.

### ***Field Results***

The *in situ* measurement of Reactor Potential for each catalyst layer is performed under the actual operating conditions of the full-scale SCR reactor. This is accomplished by creating a small region on each layer where the  $\text{NH}_3/\text{NO}_x$  ratio is greater than 1, thereby allowing the measurement of the maximum  $\text{NO}_x$  removal across the catalyst, and thus the direct determination of the Reactor Potential for that particular layer (recall Equation 7). While the host-unit boiler is not in any way controlled during these tests (i.e. load blocked), the tests are run during full-load operation in order to best emulate the SCR design conditions (i.e. the design  $A_v$ ).

As indicated above, since the *in situ* Reactor Potential measurements are performed on the full-scale SCR, the results reflect the true operating conditions and  $\text{NO}_x$  removal performance of the SCR reactor accounting for the effects of catalyst deactivation, blockage of the individual catalyst layers, and the actual flue gas flowrate through the reactor.

One significant difference between the *in situ* and laboratory methods is that the *in situ* technique is not as controlled or spatially well-defined. In the laboratory, it is relatively easy to set an  $\text{NH}_3/\text{NO}_x$  ratio of 1.0 or 1.2 since the gas flowrates are all well controlled and catalyst test sample is completely enclosed within the test apparatus. With the *in situ* test module, there are no walls to prevent the additional  $\text{NH}_3$  injected via the test module AIG from diffusing out from the test area. Thus, simply setting the test  $\text{NH}_3/\text{NO}_x$  ratio to 1.0 based upon the bulk flue gas flowrate and the  $\text{NO}_x$  concentration at the inlet of the test section, does not guarantee the point of

maximum NO<sub>x</sub> removal will be achieved. Furthermore, there will be excess, unreacted NH<sub>3</sub> from the host unit's AIG that has passed through the catalyst layer above, and is now entering the test region on the layer below. For these reasons, the NH<sub>3</sub> flowrate required to achieve the maximum NO<sub>x</sub> removal point cannot be calculated, but rather must be determined experimentally for each individual *in situ* test location.

The test protocol for the *in situ* determination of Reactor Potential is straightforward. First, the NO<sub>x</sub> removal across the test module is measured without any additional NH<sub>3</sub> injection through the test module AIG. Once this baseline NO<sub>x</sub> removal is characterized, NH<sub>3</sub> is added incrementally via the test module AIG and the NO<sub>x</sub> removal monitored until the point of maximum NO<sub>x</sub> removal is achieved. Once the maximum NO<sub>x</sub> removal is determined, the Reactor Potential for the catalyst layer is calculated using equation 7.

Figure 4 shows the results of a typical set of NO<sub>x</sub> removal measurements utilizing the test protocol outlined above. For each of the three test locations, the NO<sub>x</sub> removal is presented as a function of the test module NH<sub>3</sub>/NO<sub>x</sub> ratio, which is calculated based upon the additional NH<sub>3</sub> injected through the test module AIG only (i.e. does not include the NH<sub>3</sub> already in the flue gas from the SCR reactor's full-scale AIG). The Plant Gorgas Unit 10 SCR system is typically operated at 85% NO<sub>x</sub> removal overall. Figure 4 shows that under this condition, in 2005 with three catalyst layers installed, the baseline NO<sub>x</sub> removal levels across layers 1, 2, and 3 were nominally 68%, 42%, and 8%, respectively. These variations in removal through the reactor are expected as the full-scale AIG is located ahead of the first layer, and while the NO<sub>x</sub> levels decrease as the flue gas moves through the reactor, the amount of unreacted NH<sub>3</sub> decreases at a faster rate. Thus, the NH<sub>3</sub>/NO<sub>x</sub> ratio decreases as the flue gas passes through the reactor. Note the baseline NO<sub>x</sub> reduction measurements of 68%, 42%, and 8% across layers 1, 2, and 3 correspond to an overall NO<sub>x</sub> removal of 83%.

As the NH<sub>3</sub>/NO<sub>x</sub> ratio is increased at each test location by injecting additional NH<sub>3</sub> via the test module AIG, the NO<sub>x</sub> removal for that test location is seen to increase and eventually level out at a maximum value. For the particular set of tests shown in Figure 4, the maximum NO<sub>x</sub> removal rates are nominally 77%, 87% and 91% for layers 1, 2 and 3, respectively. In multiple-layer, full-scale SCR systems burning bituminous coals, it is expected that the catalyst deactivation rates will be higher for the "upstream" layers in the reactor, and the maximum NO<sub>x</sub> removals shown in Figure 4 confirm this expectation. Recall that both K and RP are a function of the relationship:  $-\ln(1-\Delta\text{NO}_x)$ . Thus, as the maximum NO<sub>x</sub> removal increases, both the Catalyst Activity and Reactor Potential for that layer increase.

Figure 5 presents the typical repeatability of the NO<sub>x</sub> removal measurements made at each test location. The tests for each catalyst layer were conducted over a time span of one to two hours, and results indicate very little variation in the NO<sub>x</sub> removals measured over that period of time. The average NO<sub>x</sub> removals measured for catalyst layers 1, 2, and 3 were nominally 73%, 80% and 86%, respectively. The specific set of data shown in Figure 5 was collected at the end of the 2005 ozone season, and it can clearly be seen that the average maximum NO<sub>x</sub> removals for each layer have decreased from the levels measured early in the 2005 ozone season (i.e. Figure 4), indicating that both the Catalyst Activity and Reactor Potential for each layer had decreased.

Figure 4. *In situ* NO<sub>x</sub> Removal as a Function of NH<sub>3</sub> Injection Rate

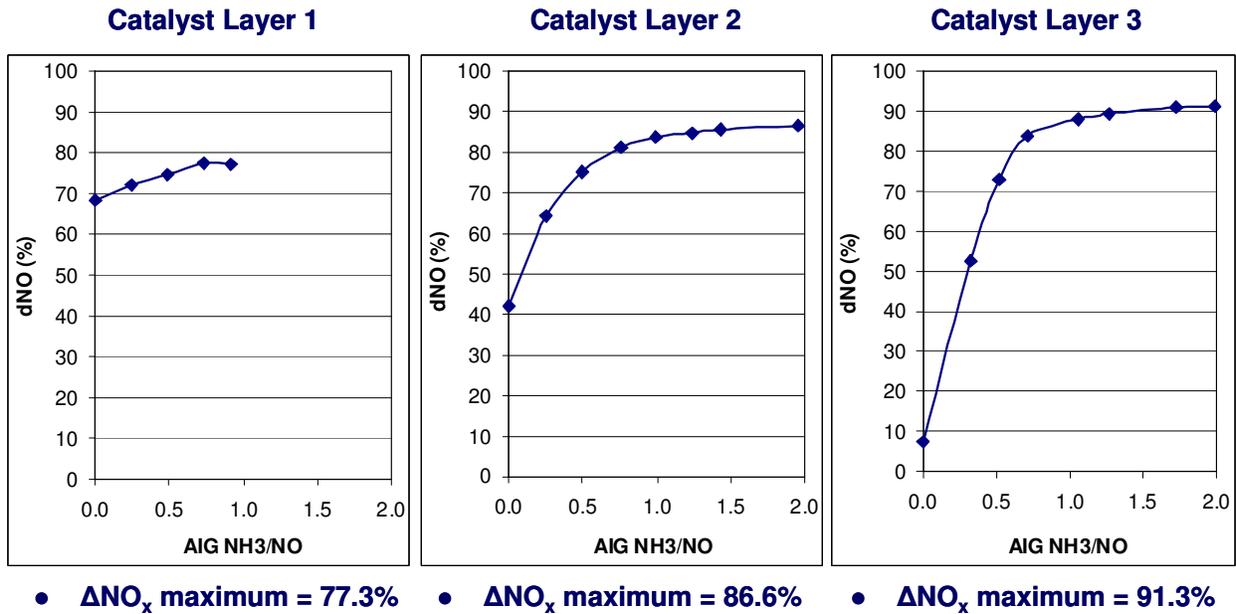


Figure 5. Typical Repeatability of *In situ* NO<sub>x</sub> Removal Test Results

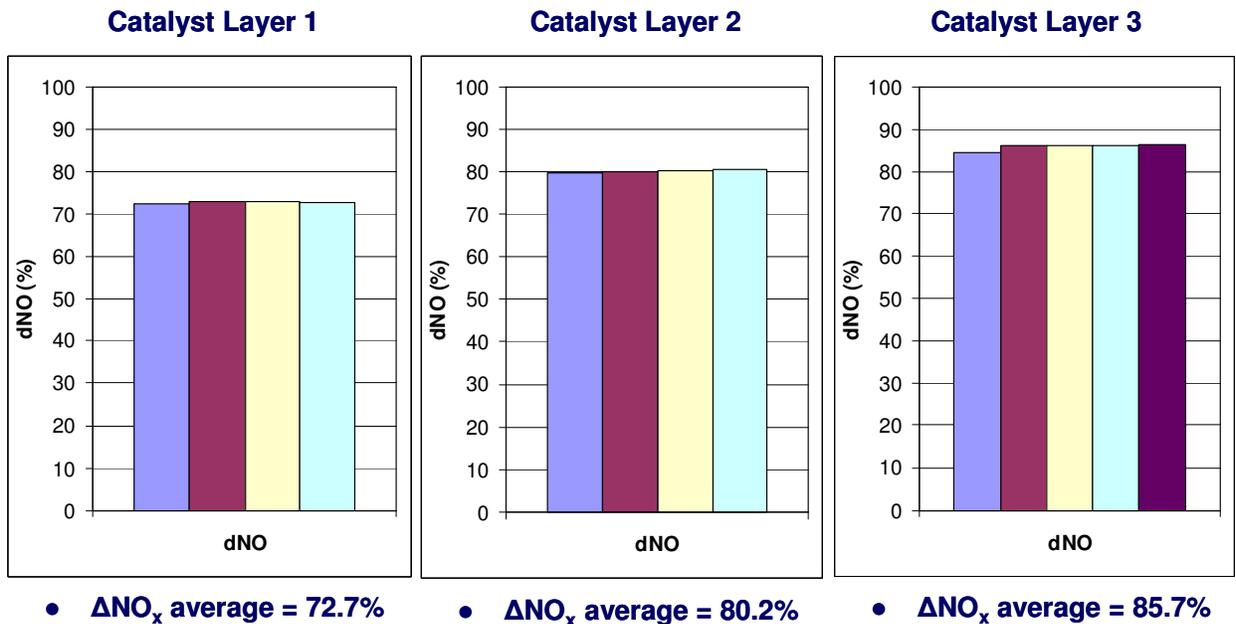
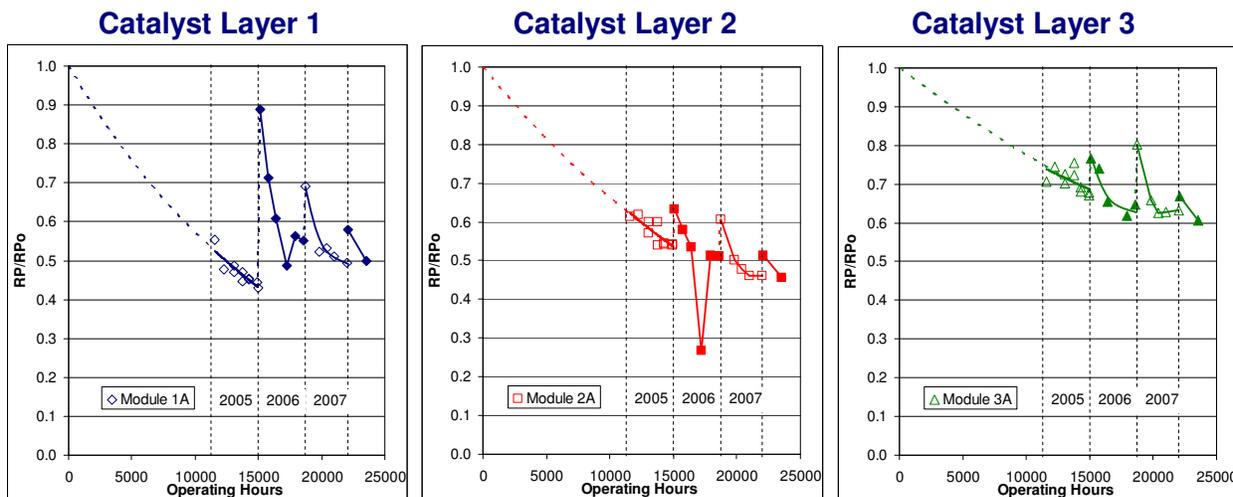


Figure 6 shows the Reactor Potential results for the individual catalyst layers for the four ozone seasons, and Figure 7 shows how the measurements on the individual layers can be combined to show the overall Reactor Potential of the SCR system. Looking at the results for the 2005 ozone season, the results are as would be expected for a multi-layer SCR reactor system. The Reactor Potential for first layer is the lowest, and the Reactor Potential for the third layer is the highest.

**Figure 6. Summary of *In situ* Reactor Potential Results for 2005-2008 (Individual Layers)**

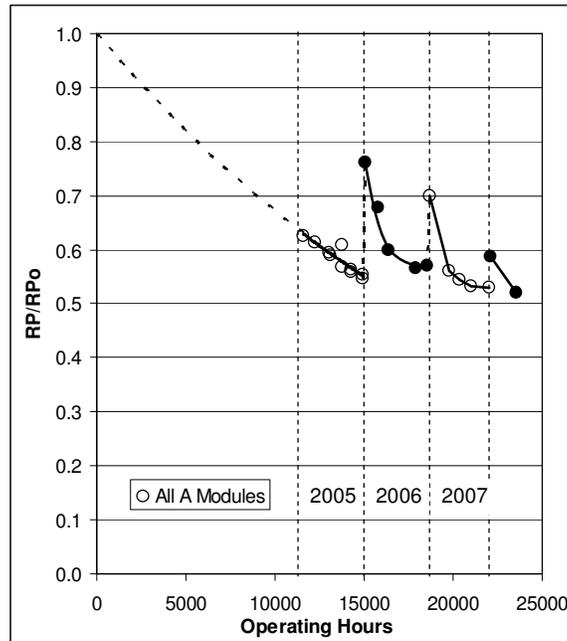


While the results for each catalyst layer exhibit some scatter, the trends for each layer are clear. All three layers show an obvious decline in Reactor Potential over the course of the 2005 ozone season. On an overall basis (Figure 7), the results show the potential for the entire reactor decreased from nominally 0.62 to 0.55 during the five-month test period in 2005. This ending Reactor Potential number (55% of the value when new) may seem low considering SCR vendors generally define end-of-life for the catalyst as  $K/K_0$  (or sometimes  $RP/RP_0$ ) equal to 0.60 or 0.65. However, it is interesting to note that Southern Company chose to add the new fourth layer of catalyst to the Plant Gorgas Unit 10 reactor during the outage between the 2005 and 2006 ozone seasons. This decision was not based on the *in situ* measurements, but rather based on the results of the annual third-party laboratory Catalyst Activity tests.

Between the 2005 and 2006 ozone season the honeycomb catalyst in Layer 1 was replaced with a new layer of plate catalyst. As can be seen from the first *in situ* test of the 2006 ozone season (Figure 6),  $RP/RP_0$  of the first layer has increased from 0.45 to 0.89. Note,  $RP_0$  is taken to be the reactor potential of the original new honeycomb layer. Because of the lower specific surface area of the plate catalyst, the Reactor Potential of this new layer is lower than that for the original honeycomb catalyst.

At the start of the 2006 ozone season, one of the three sootblowers on each of the layers in the B reactor of the Unit 10 SCR system was inoperable for a short period of time. This led to significant blockage of the catalyst and a rapid drop in Reactor Potential, particularly for the 1<sup>st</sup> and 2<sup>nd</sup> layers. When the sootblowers became operable mid-way through the 2006 ozone season, they were able to remove some of the accumulated ash and an increase in Reactor Potential resulted. However, for Layer 1 it appears that there has been some rapid deactivation as  $RP/RP_0$  only increased to 0.55 compared to 0.89 when it was first started up (i.e., 38% deactivation). For the Plant Gorgas Unit 10 SCR system it is known that Arsenic is the main catalyst poison.

**Figure 7. Summary of *In situ* Reactor Potential Results for 2005-2008 (Overall Reactor)**



There are a number of interesting observations that can be made from the *in situ* measurements shown in Figures 6 and 7. First, as expected, the first layer activity (or Reactor Potential) has decreased the most, followed by the second and third layers, respectively. As mentioned previously, while catalyst was installed in the fourth layer between the 2005 and 2006 ozone seasons, due to physical access, the outlet  $\text{NO}_x$  sampling probe could not be located so as to obtain a valid measurement. Therefore, it should be noted that the overall Reactor Potential results shown in Figure 7 for 2006 to the present time, only account for the upper three catalyst layers in the reactor.

An interesting phenomenon that was observed during the *in situ* test program is an increase in Reactor Potential is seen to occur between the end of one ozone season and the start of the next ozone season. This can be seen for layer 1 between the 2006/2007 seasons and 2007/2008. For Layers 2 and 3, this increase occurred between all seasons tested (2005/2006, 2006/2007, 2007/2008). At first it was thought that this was due to the plant's O&M procedure of vacuuming the catalyst layers between ozone seasons, which was thought to remove ash that was blocking a portion of the catalyst passages. However, no change in pressure drop across each layer was noted between the end of one ozone season and the start of the next ozone season after the vacuuming occurred. Thus, this activity increase does not appear to be due to the removal of any gross deposits in the reactor. It may be that vacuuming removes deposits from the catalyst channel walls that don't necessarily increase the pressure drop through the catalyst passages but do interfere with the mass transfer within the passages. Removal of these deposits may then result in an increase activity.

Alternately, Haldor-Topsoe has shown arsenic poisoning to be a pore-blockage phenomenon that is partially reversible when the gas phase arsenic concentrations are reduced<sup>5</sup>. Although the mechanism proposed by Haldor-Topsoe occurs at flue gas temperatures typical of normal SCR

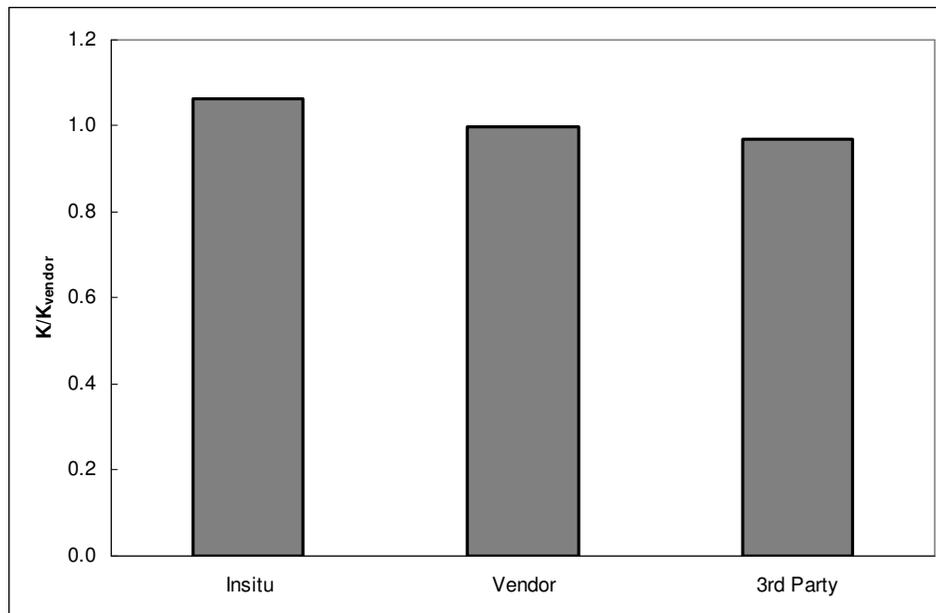
operation, and there is no data to support a similar mechanism at ambient temperatures, perhaps during the non-ozone season there is some loss of arsenic from the catalyst while the material is not exposed to flue gas.

### ***Comparison to Laboratory Catalyst Activity Measurements***

The installation of the new layer of plate catalyst prior to the 2006 ozone season provided an opportunity to quantitatively compare the results of the *in situ* measurements to 1) the activity provided by the catalyst vendor and 2) an activity test by Southern Company's third-party catalyst testing laboratory who tested an unused sample of catalyst. After installation of the new plate catalyst in Layer 1, the SCR reactor was put into service on May 1, 2006. The initial *in situ* measurement of the first layer was made on May 5, 2006, which represents approximately 120 hours of operation on the new catalyst.

The measured activity is compared to that reported by the catalyst vendor and third-party catalyst testing laboratory in Figure 8. The activities in Figure 8 have been normalized to the activity reported by the catalyst vendor. As can be seen, the results of the *in situ* activity measurements of the new plate catalyst are in agreement with the vendor's value of activity, as well as the third-party laboratory's measurements. The *in situ* measurements were 6% higher than the value from the vendor while the third-party laboratory's value was 3% lower than the vendor's reported activity. For the *in situ* measurement, this is considered very good agreement considering that the *in situ* determination needs to factor in the actual flue gas flow rate in order to determine the area velocity and then the activity. Furthermore, the *in situ* measurement is made at an  $\text{NH}_3/\text{NO}_x$  ratio  $> 1$ , whereas the vendor and third-party laboratory perform their laboratory measurements at  $\text{NH}_3/\text{NO}_x = 1$  per the VGB Guidelines<sup>2</sup>. This difference would tend to bias the *in situ* measurement to a slightly higher value.

**Figure 8. Measured Activity of New Plate Catalyst**



## SUMMARY AND CONCLUSIONS

The results of this test program over four ozone seasons successfully demonstrated a method to determine SCR Reactor Potential and Catalyst Activity *in situ* on a layer-by-layer basis. This methodology could become a valuable tool for utilities operating SCR reactors on coal-fired units as they transition from seasonal (ozone season; May 1 to September 30) operation, to year-round operation (if required). With year-round operation there will likely be fewer opportunities to obtain physical catalyst samples from the reactor for laboratory determination of activity.

The following conclusions can be drawn from the current study.

- The *in situ* technique directly measures the true Reactor Potential of the SCR system. The Reactor Potential is the parameter that determines the overall performance of the SCR reactor. With the laboratory Catalyst Activity measurement, an estimate of the catalyst blockage is needed to determine Reactor Potential.
- *In Situ* measurements can be made on a layer-by-layer basis within the reactor anytime the SCR system is in operation. This can provide a much larger data set upon which to quantify deactivation rates compared to once-a-year physical sampling.
- There was good quantitative agreement between the *in situ* and laboratory Catalyst Activity measurements of a new layer of plate catalyst installed at the start of the 2006 ozone season. Since the catalyst was new without any blockage, a direct comparison could be made without the need to assess blockage.
- The *in situ* measurements showed an increase in activity at the start of each ozone season relative to the end of the prior season. It is not clear if this is due to vacuuming that occurred between ozone seasons, as plant data indicate there was no reduction in pressure drop across each layer, and thus no increase in catalyst surface available to the flue gas.
- The *in situ* technique was also able to monitor the decrease in Reactor Potential during the 2006 ozone season when a number of the sootblowers in the SCR reactor were inoperable for a short period of time.

Both the laboratory and *in situ* test methodologies have advantages and disadvantages as discussed in this paper. Overall, an important point to note is that the *in situ* technique should not be thought of as a replacement for the laboratory analysis of catalyst samples, but rather a companion measurement.

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## KEY WORDS

NO<sub>x</sub>, SCR, Catalyst Activity, Reactor Potential, *In Situ*