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MINIMIZING THE IMPACT OF SCR CATALYST ON TOTAL GENERATING COST THROUGH EFFECTIVE CATALYST MANAGEMENT

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ABSTRACT

For coal-fired boilers equipped with Selective Catalytic Reduction (SCR) NOx reduction technology, direct catalyst cost contributes to a major operating expense. Decisions regarding catalyst management have other significant impacts to generating cost, including outage time and frequency and parasitic load. Strategies for minimizing the impact to total generating cost while preserving system performance - generally referred to as catalyst management – are receiving greater attention. Approaches to managing catalyst can vary widely. Therefore, analysis of catalyst management strategies requires accurate predictive tools for assessing SCR system performance that have the flexibility to address a wide range of scenarios. These predictive tools may also be used to investigate performance issues that facility operators may encounter. However, until recently, operators have not had access to these tools, except through catalyst suppliers or consultants.

In this presentation, various catalyst management strategies will be examined. Using an analysis tool recently adopted by several power plant operators and SCR technology suppliers, we will illustrate how such a tool can be used to optimize a catalyst management strategy to minimize the total cost of generation. Comparisons of model results to measured SCR performance at operating facilities will be presented. The model will be used to show operating trade offs for SCR operating parameters, such as NOx reduction, ammonia slip, catalyst outage frequency, catalyst usage, and parasitic load under a variety of scenarios. We will also discuss how the tool can be used to diagnose operating problems.

INTRODUCTION

With more coal-fired power plants operating with Selective Catalytic Reduction (SCR), catalyst management is a topic that has gained increased interest. In this paper, the topic of catalyst management will be explored along with a tool that can be useful for analysis of catalyst management strategies.

As discussed in Reference 1, a comprehensive approach to catalyst management goes far beyond simply planning for the next catalyst addition or replacement and performing the associated catalyst testing. It also extends beyond the objective of minimizing catalyst consumption over the plant lifetime. A comprehensive catalyst planning effort involves minimizing the catalyst costs while simultaneously optimizing the operation of the facility to achieve the lowest cost to produce power. As a result, it involves making trade-offs between catalyst consumption, the frequency and duration of outages taken for catalyst work, ammonia slip, NOx reduction, baseline NOx, parasitic pressure loss, and, of course, comparing catalyst regeneration versus catalyst replacement.

Assessing these trade-offs in an efficient manner requires an interactive tool. Some of the trade-offs that can be assessed with such a tool are discussed below:

- Ammonia Slip – If your plant can tolerate a higher ammonia slip from the SCR than originally anticipated, it may be possible to reduce catalyst loading, extend the time between catalyst replacement events, or to increase the amount of NOx reduction that is possible from the facility.

- NOx reduction – With NOx allowances having a marketable value, increasing the NOx reduction of the SCR may be worth exploring. However, increased NOx reduction comes at a price of increased ammonia slip, increased ammonia consumption, increased frequency of catalyst replacement, increase catalyst loading, or increased pressure loss.

- Baseline NOx level – If the baseline NOx level is increased, this may have benefits to the boiler or improve ash LOI, but it this may necessitate higher costs associated with operating the SCR at a higher reduction level or it may have other adverse affects, such as higher ammonia slip. Alternatively, reducing NOx from the furnace to the SCR inlet can help reduce ammonia consumption, reduce ammonia slip, and permit longer times between outages.

- Catalyst Loading – It may be possible to extend time between catalyst outages further through increasing the catalyst loading beyond the initial design level. However, increased catalyst loading adds catalyst cost and increases parasitic loads due to pressure drop across the catalyst.

- Pressure Drop – In some catalyst management scenarios, some layers in the catalyst reactor are left empty. This approach has the advantage of reducing catalyst loading and pressure drop versus a traditional approach that fills the SCR reactor and later replaces catalyst as the catalyst loses activity.

Furthermore, there are other effects that may need to be reassessed after a period of plant operation. For example, if catalyst deactivation rates differ from what was originally expected, it may be necessary to modify the plans for catalyst replacement or regeneration. In this paper we will explore such a situation in detail.

Because of these many trade-offs, a tool that enables the owner's personnel to quickly and easily evaluate different scenarios should be very useful.

In the next section, we will review catalyst management basics. Then, we will discuss the key features of a tool that is used for catalyst management by a number of power plant operators and SCR technology suppliers. Finally, we will discuss an assessment of catalyst management alternatives at a utility boiler using SCR.

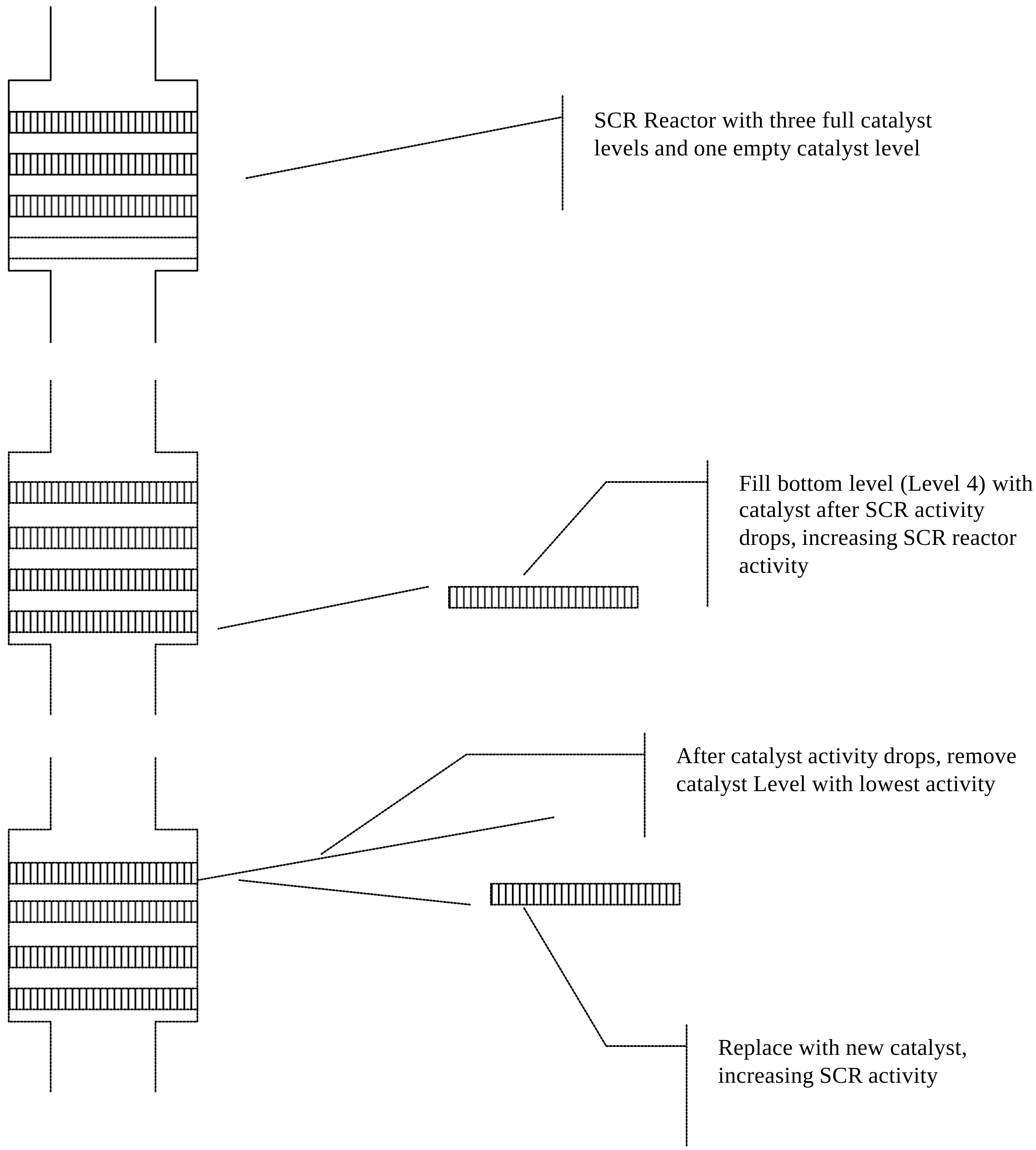
CATALYST MANAGEMENT BASICS

Although the physical size of catalyst should not significantly change over time, catalyst can be viewed as a consumable item. The catalyst has the ability to facilitate the NOx reducing reactions, and this quality is called "activity". Over time, impurities in the gas stream will deposit on the catalyst and block exhaust gas from reaching active sites within the catalyst. Some catalyst "poisons", such as arsenic, will chemically bond to the active vanadium pentoxide within the catalyst micropores. As more and more of these microscopic, active sites get blocked, the catalyst activity will gradually drop to a point where performance becomes unacceptable.

Each SCR reactor is designed to provide a minimum specified NOx reduction performance with a maximum ammonia slip under a given set of conditions after the catalyst has lost some portion of it's initial activity. Therefore, once catalyst activity drops below a level determined in the original design of the SCR system, it is necessary to replace some of the catalyst or add more catalyst to the reactor. SCR catalyst activity is regularly monitored by laboratory analysis of catalyst samples. This is normally done on an annual basis.

Most SCR reactors are designed with up to four available levels of catalyst. In some cases each level may hold more than one layer (two layers of catalyst essentially stacked on top of one another). When the system is new, with fresh catalyst, at least one level is typically empty, as pictured at the top of Figure 1. When the SCR catalyst activity drops to a point where ammonia slip increases to an unacceptable point, then new catalyst is added to level 4, as shown in the middle part of Figure 1. In the case of Figure 1, only one catalyst layer is in each level. But, in some cases two layers are in each level. In that case, one layer (half of a level) would be added to level 4 and then at a later time when SCR total activity is low enough, a second layer (half of a level) would be added to level 4, filling level 4 and the SCR reactor.

FIGURE 1. NORMAL ADD AND REPLACE SEQUENCE



After the SCR reactor is full, it is necessary to replace catalyst levels with new or regenerated catalyst to increase total SCR catalyst reactor activity. This is shown at the bottom of Figure 1. Since the top level usually loses activity faster than the others, it is normally the first catalyst level to be replaced.

Another approach to managing catalyst is to regenerate the catalyst. One approach, shown in Figure 2, requires that one level of catalyst always be empty. This permits the removed catalyst to be off site for regeneration. When total SCR catalyst activity drops to a minimum acceptable point, regenerated catalyst is added to the empty catalyst level and the catalyst level with the lowest activity is then removed for regeneration, as in Figure 2. When using this regeneration approach and two layers of catalyst are installed in each level, then it is necessary to remove the top layer for regeneration in one outage before removing the bottom layer during the next. Of course, regenerated catalyst must be first added to empty layers on the bottom before being added to the top. This approach, described in Reference 2, is currently being used at PG&E National Energy Group's Indiantown Station.

The advantages of a regeneration approach such as this are:

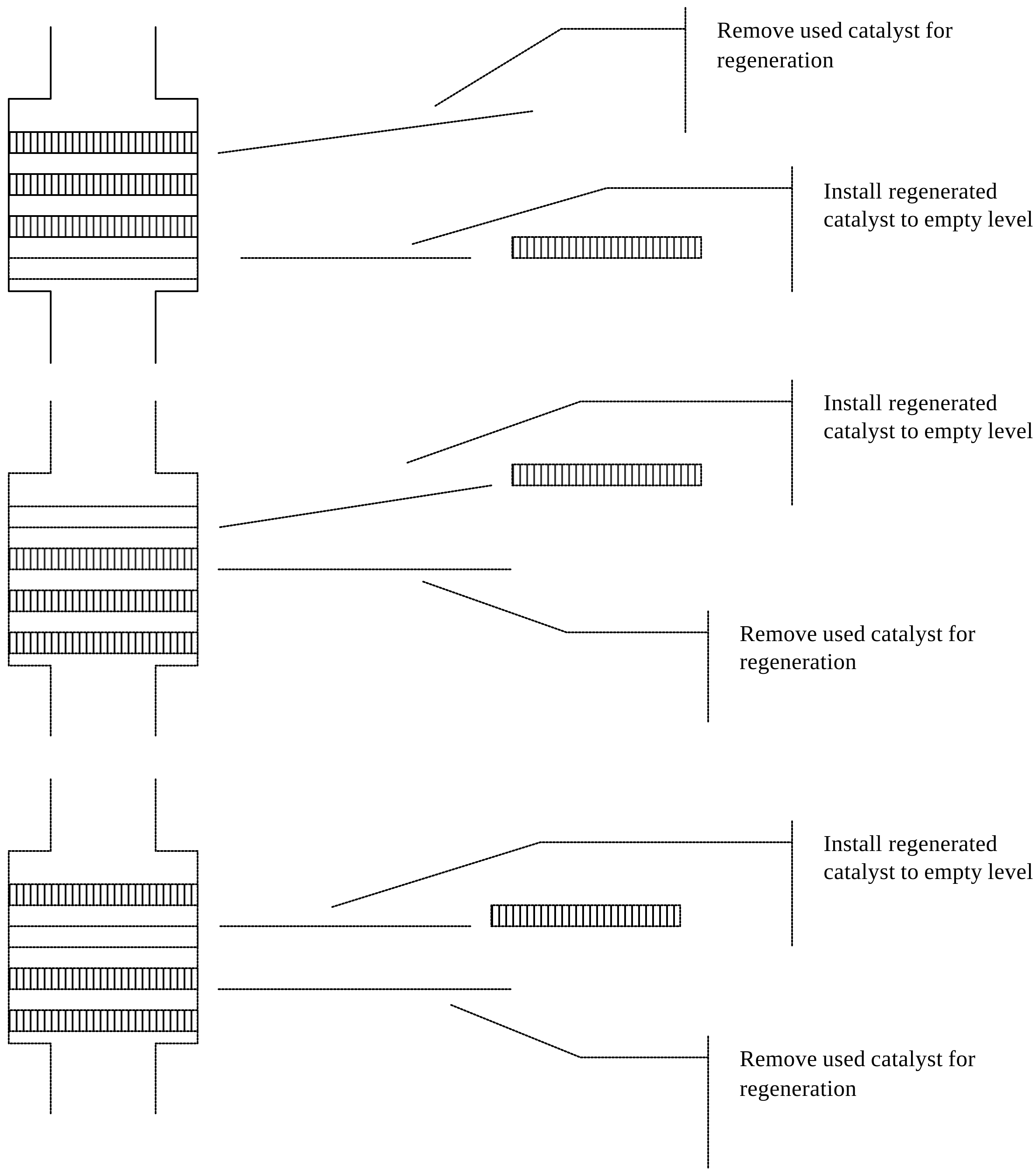
- If the catalyst is physically intact, it is not necessary to purchase new catalyst. And, since regeneration of a unit of catalyst is typically less expensive than buying new catalyst, savings are possible.
- Pressure drop across the SCR reactor is less than add-and-replace approaches that fill the SCR reactor, reducing the associated parasitic losses.
- Depending upon SCR reactor access and available staffing, shut downs for catalyst regeneration may be shorter in duration than for a catalyst level replacement because as one layer is removed for regeneration it may be possible to simultaneously install regenerated catalyst on another level.

There are some disadvantages of this regeneration approach with respect to a normal add-and-replace approach, such as:

- Shut downs for catalyst changes will typically be more frequent.
- A catalyst that is reactivated with new active material may not behave in the same way with respect to SO_2 to SO_3 oxidation and with respect to deactivation as the original catalyst because the active component (V_2O_5) may not be distributed throughout the catalyst in the same manner.
- If the catalyst is badly eroded, or otherwise physically damaged, regeneration cannot be performed and replacement with new catalyst is necessary.

Whether replacing catalyst or regenerating catalyst, it is important to identify the layer with the lowest activity and replace or regenerate that layer. This is because the ***net*** activity addition to the SCR reactor is the activity of the new or regenerated catalyst minus the activity of the catalyst that is removed. The greatest net activity addition will occur if the catalyst with the lowest activity is replaced or regenerated. In most cases, the top level of catalyst (in a down-flow reactor) loses its activity at the fastest rate. This is because it tends to be exposed to the highest concentration of impurities. However, there may be some cases where activity is lost at the same rate or faster in other layers. So, regular catalyst testing is an important part of any catalyst management program.

FIGURE 2. SEQUENCE FOR REGENERATION OF SCR CATALYST



MODELING CATALYST MANAGEMENT PLANS

Analyzing the various trade-offs and approaches to catalyst management is best done with a computational modeling tool that can quickly estimate the effects of a different approach on facility operation and forecast the future sequence of events and the associated costs. As a result, the model needs to be both accurate and flexible. A list of important features is shown below.

The model should be able to:

1. Model either add-and-replace or regeneration approaches easily, predicting the sequence and time of future catalyst events for several years.
2. Model seasonal catalyst operation, annual catalyst operation or initially operating the SCR seasonally and then switching to annual operation.
3. Allow modeling initial load of catalyst of any type from any manufacturer.
4. Model changes in catalyst manufacturer or type over time.
5. Determine the need for catalyst changing based upon user-selected preference of either time periods or reaching an ammonia slip or activity limit.
6. Properly select the catalyst layer to be removed and replaced under a wide range of scenarios.
7. Model at least four for more levels of catalyst with up to two layers of catalyst per level.
8. Model different deactivation rates per level, as top levels often lose activity faster than lower levels.
9. Model time-variant catalyst deactivation rates, as deactivation rates can vary with time.
10. Model different catalyst deactivation rates for regenerated or replacement catalyst versus original catalyst, as regenerated or replacement catalyst may behave differently than the catalyst it replaces.
11. Accurately predict ammonia slip over time.
12. Model the effects of maldistribution of the ammonia injection on ammonia slip. This is especially important for very high NOx reduction SCR systems where the risk of ammonia break-through can be high.
13. Model changes in catalyst loading for each layer from the initial SCR reactor design, because experience may make such a change in catalyst management plant necessary (an example will be discussed later).
14. Model new SCR systems or systems that have been in use for some time.
15. Permit updating of catalyst conditions and deactivation rates as data becomes available.
16. Calculate the costs of future catalyst changing events and make long-term cash-flow projections.
17. Accurately model the effects of changes in inlet or outlet NOx on ammonia slip and the catalyst management plan.
18. Model the impact of the catalyst management plan on draft loss and associated parasitic power costs.
19. Perform Net Present Value analysis of the plan over a period of time.

Costs associated with a catalyst management plan include the cost of catalyst itself and the labor associated with removing used catalyst and adding replacement catalyst. Additional costs that must be considered are costs associated with parasitic power, costs associated with lost production when the boiler must be shut down for catalyst changing events, procurement and other overhead costs, and monitoring and testing costs. Thus, the cost is not strictly proportional to the catalyst volume affected, but there are costs that may be considered "per event" costs and costs that may be incurred continually (such as parasitic power). Furthermore, since a catalyst management plan has implications that will extend for many years, the effects of escalation and cost of money should be considered such that Net Present Value analysis can be performed.

In addition to the above features, in order for the model to be most useful for the typical user, a computer program should run on a Windows-based PC, have a familiar user interface, and be well documented. Fortunately, modeling software with all of these features was recently made available to users with the release of CAT MANAGER™.[1] Several owners of SCR plants and SCR technology suppliers are currently licensed to use CAT MANAGER™ version 3.0 or the earlier version 1.0. In the following section, we will discuss the modeling

[1] CAT MANAGER™ is a trade mark of Andover Technology Partners

of various situations with CAT MANAGER™ version 3.0.

MODELING CHANGES IN CATALYST MANAGEMENT PLANS

At times actual catalyst behavior does not correspond to expected performance. This will normally cause the facility owner to reevaluate their catalyst options. In such a situation, there is a benefit to having a tool that enables the owner to quickly reassess various options in light of new information on catalyst performance. Orlando Utilities Stanton Energy Center Unit #2 is an example of how the owner found it necessary to revise their catalyst management plan after a few years of experience. As a matter of disclosure, neither OUC nor the catalyst supplier used CAT MANAGER™ to perform the analysis for any decisions made thus far, although both have since licensed CAT MANAGER™. In this paper, our intention is to compare the results of modeling catalyst performance with CAT MANAGER™ against experience at an actual facility and demonstrate how this tool can be effective in helping make catalyst management decisions for the future.

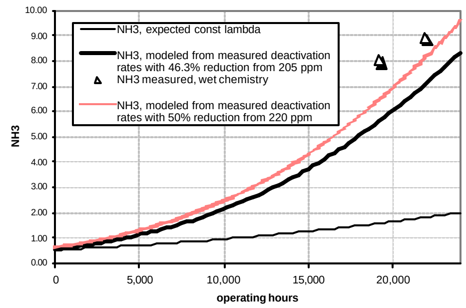
Orlando Utilities Stanton Energy Center Unit #2 is a 468 MW Babcock & Wilcox dry bottom boiler that went into service in June of 1996. The unit is equipped with low NOx burners, overfire air, an SCR, ESP and a wet scrubber for emissions control. The SCR uses Argillon (formerly Siemens) plate catalyst. Based upon an expected coal analysis that had adequate free CaO (over 2.5%), a moderate level of arsenic in the coal, and no fly ash reinjection, a low gaseous arsenic condition was believed to exist and the catalyst management plan was developed accordingly. However, as documented in References 3, 4 and 5, Stanton Unit #2 experienced more rapid catalyst deactivation than originally anticipated. This was determined to be a result of arsenic deactivation due to actual coal mineral conditions being different than those originally planned for the SCR catalyst design. Specifically, actual CaO in the coal was lower than originally anticipated, which contributed to increased deactivation from arsenic. As a result, actual catalyst additions were greater than originally planned, as shown in Table 1. In order to maintain a three-year period between catalyst changing events while preserving acceptable boiler and SCR performance, OUC, with input from the catalyst supplier, modified their catalyst management plan to allow up to 4 ppm of ammonia slip and increased catalyst loading. At the end of 2002, the entire OUC SCR reactor had been filled. The reason that more catalyst was added to level 4 than to level 3 was because the manufacturer had changed their standard module size in the time between 1999 and 2002. At this point it is important to reiterate that the decisions made so far regarding catalyst management at OUC were made without the use of CAT MANAGER™ and were based upon the analysis of the catalyst supplier and OUC. OUC has not yet determined if levels 1 through 3 will be replaced with 185 cubic meters of catalyst, 231 cubic meters of catalyst or whether another approach will be used.

TABLE 1. CATALYST ADDITIONS AT OUC STANTON [6]

	Expected	Actual
1999	92.5 m3 (level 3)	185 m3 (level 3)
2002	92.5 m3 (level 3)	231 m3 (level 4)
-All four layers are full at this time -Revised allowable slip to 4 ppm from originally planned 2 ppm -Enables 3-year interval on replacement -Revised catalyst plan determined by OUC and catalyst manufacturer		

Going forward, OUC planned to evaluate different options. To verify that CAT MANAGER™ would be useful as a performance-predicting tool, it was benchmarked against measured SCR system performance. Reference 6 showed results of a benchmark of ammonia slip predicted by CAT MANAGER™ against actual ammonia slip measured by wet chemical methods. As shown in Figure 3, the predicted ammonia slip based upon measured catalyst deactivation and operating conditions corresponds closely to the ammonia slip measured by wet chemistry methods. Figure 3 also slows that the expected ammonia slip (if the catalyst had deactivated as originally expected) was much lower than what was actually experienced. These results provided OUC confidence that catalyst management plans determined with this tool would be useful.

Figure 3. NH3 for OUC (Ref. 6)
measured with wet chemistry and modeled with CAT MANAGER(tm)



Catalyst activity information from the April 2002 catalyst samples, which corresponds to 47,294 operating hours on levels 1 and 2, 23,614 operating hours on Level 3 and 0 hours on newly-installed Level 4, were used to establish initial conditions for modeling future SCR management strategies. Assumptions were also made about future catalyst deactivation and SCR operation. With this information, modeling with CAT MANAGER™ predicted the outcomes of Table 2 for various future catalyst management scenarios.

As shown in Table 2, it is not necessary for OUC to add 231 m^3 in order to maintain a 3-year replacement period. However, the 231 m^3 replacement approach would potentially allow longer times between catalyst replacement while maintaining slip below 4 ppm. Table 2 also shows that a policy of regeneration can be performed, but more frequent outages are necessary. The number of additional outages (and the amount of catalyst needed) is dependent upon whether full levels or half levels are regenerated and whether the catalyst is regenerated to its original full activity when new. As a result, OUC would not be able to maintain the 3-year period originally desired if it regenerated catalyst. However, the increased number of outages may be acceptable depending upon the difference in cost between regeneration and replacement with new catalyst. For the simulations conducted to generate the results of Table 2, it was assumed that the regenerated catalyst deactivated in the same manner as new catalyst. CAT MANAGER™ is capable of using different deactivation rates for regenerated catalyst if a different deactivation rate is expected.

TABLE 2. OUC 15 YEAR ANALYSIS – SUMMARY [6]

	Per event	Total Catalyst	Outages
3-yr Replace	185 m3	925 m3	5
3-yr Replace*	231 m3	1155 m3	5
Regen (100%)	92.5 m3	1017.5 m3	11
Regen (100%)	185 m3	1295 m3	7
Regen (95%)	185 m3	1480 m3	8

* Could go longer than 3 years between catalyst events and stay under 4 ppm slip

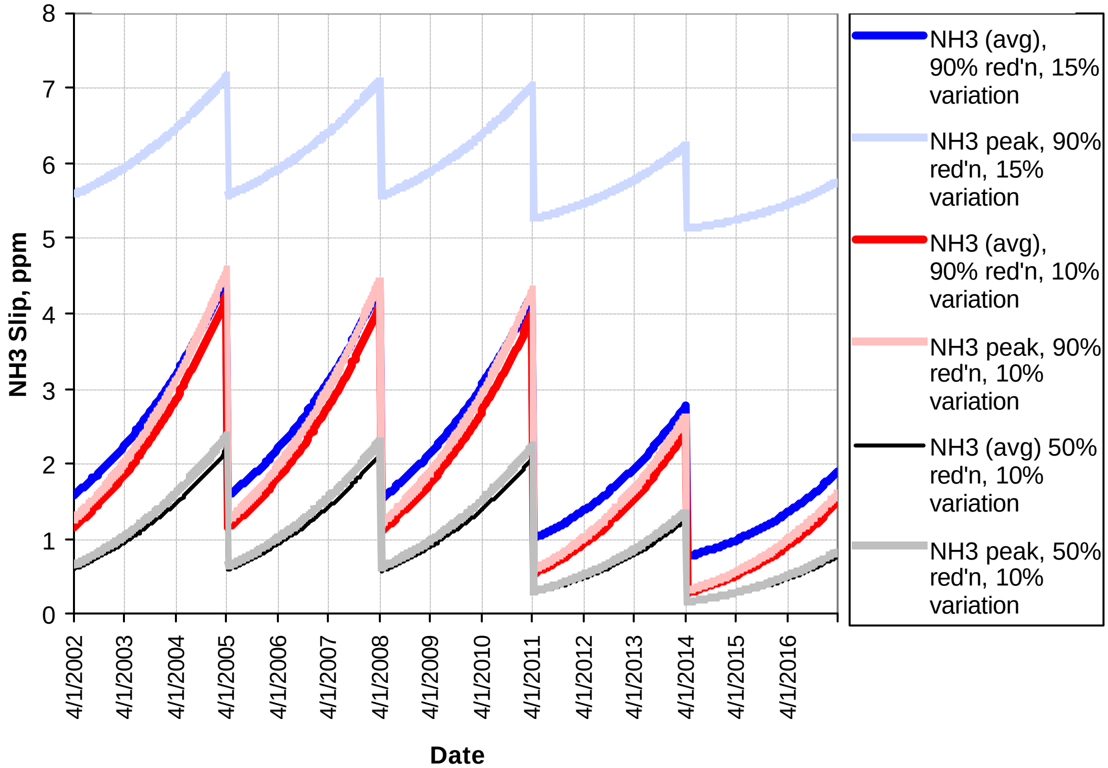
EFFECT OF CHANGING NOX REDUCTION AND EFFECT OF AMMONIA MALDISTRIBUTION

Depending upon a facility owner's needs, it may make sense to change NOx reduction levels. To investigate this effect, we modeled a reactor similar to that of OUC, except that the reactor had deactivation rates more typical of a low arsenic condition. We considered NOx reduction of about 50% from about 0.32 lb/MMBtu and also 90% NOx reduction from a similar NOx level. Figure 3 shows predicted ammonia slip for a three-year catalyst replacement frequency with three of four levels full at the beginning of the simulation and addition of half levels at 3 and 6 years before replacement of each full level.

As shown in Figure 3, an increase in NOx reduction from 50% to 90% is possible while keeping catalyst addition frequency at three years providing that ammonia slip can increase to 4 ppm. Figure 3 also showed the effect of an out of adjustment Ammonia Injection Grid (AIG). If peak deviation in ammonia to NOx molar ratio is allowed to increase from 10% to 15%, then the peak ammonia slip in the duct at 90% NOx reduction increases from about 4.5 ppm to about 7 ppm. Average ammonia slip increases somewhat as well. The results of calculations not shown on

Figure 3 showed that increases in deviation in ammonia to NOx molar ratio had little effect when NOx reduction was only 50%. Therefore, at high NOx reduction levels, proper adjustment of the AIG to match ammonia to NOx is far more critical than at low NOx reduction levels.

Figure 4. Predicted Average and Peak Ammonia slip for an Add-and-Replace approach with three-year intervals.
Effects of ammonia maldistribution and NOx reduction are shown



CONCLUSIONS

In this paper we described some features of a software tool that can help operators make decisions regarding catalyst management. In this paper we also discussed how at OUC Stanton it was necessary to modify the catalyst management plan because actual operating conditions and catalyst behavior were not as originally planned. Projections of possible future catalyst management scenarios were made with a software tool that was developed for this purpose. The following are key conclusions.

- Catalyst management involves optimizing a wide range of parameters, in addition to catalyst usage. Having a software tool to quickly evaluate different scenarios is very useful. The paper discussed several important features that such a tool should possess.

- Because of the many factors to consider, the most cost-effective catalyst management approach may not be the one that results in the lowest amount of catalyst usage or amount of catalyst regeneration over the period. Other factors, such as the cost of lost production during outages, cost of parasitic power and other effects need to be considered.

- In some cases operating conditions and catalyst behavior will differ somewhat from the actual predictions and it will then be necessary to reevaluate catalyst management options. This is what happened at OUC Stanton. In these situations a tool for evaluating future scenarios for catalyst management based upon the new information is very useful for SCR operators.

- A catalyst management tool that is licensed by OUC and others was benchmarked against actual data and provided reasonable correspondence with measured performance.

- Modeling of possible future catalyst management scenarios for OUC Stanton was performed. Scenarios that were assessed included future replacement of catalyst, future regeneration of catalyst, and variations of these approaches. This modeling provided valuable insights to the trade-offs between approaches and made analysis faster, easier and interactive.

- Regular measurement of catalyst activity provides important information for the model and will enhance predictive capability of the model, as was demonstrated with the modeling of the OUC SCR. Thus, having such a model is not a substitute for a regular catalyst testing. The model and the testing program enhance one another - with the testing providing useful information for the model and the model using that information as input for testing possible future scenarios.

- When NOx removal rates are high, proper adjustment of the AIG is much more critical for minimizing ammonia slip than at lower reduction levels. Peak ammonia slip in the duct can be much higher than the average slip and may lead to operating problems when the AIG is out of adjustment. Therefore, ability to address ammonia maldistribution is an important feature of a catalyst management tool.

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