SCR maintenance fundamentals

The latest round of NO_X emissions rules may afford power plant operators more flexibility in meeting air-quality standards. But complying with the rules can be somewhat confusing. Because a selective catalytic reduction (SCR) system is the first line of defense against excessive NO_X emissions, its proper maintenance is critical. This article explains how to monitor an SCR system for ammonia slip and manage its catalysts in a way that optimizes the system's performance.

By Ken Wicker and Jim Staudt, PhD, Andover Technology Partners

Whenever the wind blows, America's eastern states receive unwelcome visitors from midwestern states: molecules of NO_X—a precursor of ozone—from large and small boilers and internal combustion engines. The EPA's response to this problem takes the form of new rules for industrial and utility boilers in 11 Rust Belt states. The rules are part of a new summertime emissions reduction program based on the EPA's NO_X State Implementation Plan (SIP) Call.

The proposed Interstate Air Quality Rule (IAQR) aims to reduce emissions of NO_X (as well as SO_2 and particulates) in 29 downwind eastern states and the District of Columbia. According to the EPA, the IAQR—one of the agency's Clean Air Rules of 2004—should be finalized by the end of the year. Its advent makes clear that, over the next few years, midwestern fossil-fueled utilities will have no choice but to continue buying and installing costly selective catalytic reduction (SCR) systems (see POWER, April 2004, page 32).

The EPA's NO_X SIP Call and associated NO_X Budget Trading Program were originally proposed under the authority of the 1990 Clean Air Act Amendments. The proposed IAQR shares many characteristics with the Bush Administration's Clear Skies Initiative, the mulipollutant control bill that failed to pass Congress last year. Under the proposed IAQR, the EPA will establish allowance budgets for affected states and authorize their regulators to allocate the allowances.

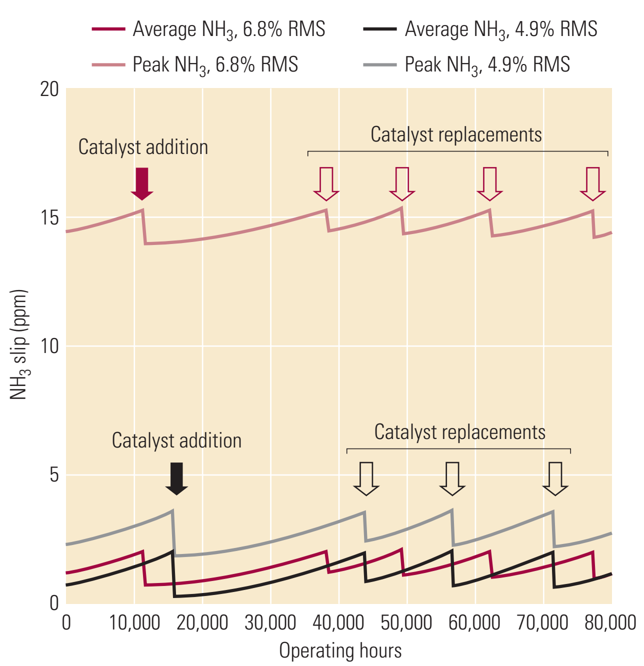
In some states targeted by the IAQR that already had NO_X requirements, an unprecedented level of investment in new NO_X controls has put power companies in a position to reduce their NO_X emissions by as much as a third below the level required in 2004. "This short-term overinvestment by industry will maintain downward pressure on NO_X allowance prices and lessen the impact on power markets," said Robert LaCount, director of Massachusetts-based Cambridge Energy Research Associates (CERA).

CERA, which is conducting an extensive study on the new rules, says that utilities have already announced more than $7 billion of planned investment in new NO_X and SO_2 pollution controls over the next decade. According to LaCount, this is just the beginning of what will be required under the new federal rules. Even more astounding, though, is that the next round of policies will force utilities to make even more complicated and expensive investment decisions than those for the projects announced thus far.

The new rules have far-reaching implications for which the utility industry needs to be prepared. According to LaCount, they include:

- Fundamental changes to SO_2 and NO_X emissions-credit markets that could alter the attractiveness of new investment and operating economics.
- Higher levels of industrywide pollution control investment over much shorter time periods than previously experienced in the U.S.
- Pressure on the profitability of much of the existing U.S. power generation fleet.

1. Average and peak ammonia slip. If a catalyst is replaced when average slip reaches 2 ppm (arrows show time of catalyst addition or replacement), better distribution (indicated by lower root mean square variation) will result in longer times between catalyst replacement due to the lower average ammonia slip. Better distribution will also result in much lower peak ammonia slip. *Source: Andover Technology Partners*



Note: RMS = root mean square

- Strategies for future capital availability, investment levels, fuel selection, and market location may have to be rethought.
- Increased complexity and expense in complying with more-stringent emissions standards.

So, what to do?

Today's SCR systems are designed to achieve about 90% NO_X removal and very low ammonia slip rates (typically less than 2 ppm). But those designs leave little room for error. Three areas in particular that have proven essential for maintaining top SCR performance are ammonia distribution, catalyst maintenance, and catalyst management.

Ammonia distribution. Uneven ammonia distribution is a frequent cause of poor SCR performance and may be mistaken for low catalyst activity. If the ammonia is not properly distributed throughout the exhaust gas, some parts will be overtreated, resulting in higher ammonia slip. Conversely, undertreating parts will result in poor NO_X reduction.

At high NO_X reduction rates, small maldistributions in ammonia can cause local peaks in slip and higher average rates (Figure 1). If average ammonia slip must be maintained below 2 ppm, poor distribution will necessitate more-frequent catalyst replacement. In fact, with even modestly poor distribution, peak ammonia slip can reach levels that are sure to cause problems. Why? Because at high NO_X removal rates, there is little margin for error in distribution. When parts of the exhaust gas have more ammonia than NO_X to react with, all of that excess ammonia will slip through the system.

Because NO_X distribution changes with boiler firing conditions, it is not possible to achieve ideal mixing under all conditions. Mixing devices—such as Babcock Power's Delta Wing (Figure 2)—help but don't totally solve the problem. Even if a mixing device is added, regular testing should be performed to confirm proper ammonia distribution. This can be done by measuring NO_X in a multi-point grid at the exit of the SCR system, and possibly between its internal levels. Proper ammonia distribution should show little variation of NO_X at the SCR exit grid. A high variation in NO_X measured at the exit grid means that poor distribution is likely.

Catalyst maintenance. Maintaining a properly working catalyst by on-line or off-line cleaning or regeneration is part of a larger catalyst management program. Such a program's other priorities would include periodic catalyst sampling and testing and replacement/exchange evaluations based on NO_X reduction efficiency, regular ammonia slip monitoring, the catalyst's physical condition, and unit outage schedules.

On-line catalyst cleaning can be performed on a regular basis with soot blowers or sonic horns. Off-line cleaning is typically done during outages but may become imperative if the catalyst becomes plugged. Keeping the catalyst clean is important for maintaining catalyst activity and for avoiding flow restrictions that can induce rapid erosion (Figure 3).

It is not uncommon for bituminous coal-fired units equipped with SCRs to experience severe catalyst plugging problems as a result of popcorn ash formation in the boiler (Figure 4) and carryover into the SCR

2. Mix it up. The Delta Wing being installed here on a new SCR uses large, angled disks to stimulate the mixing of NO_X, ammonia, and temperature throughout the SCR inlet duct. *Courtesy: Babcock Power Environmental Inc.*

3. SCR reactor with heavy ash. This picture shows a German SCR with heavy ash buildup from close spacing of catalyst levels and equipment located too near the catalyst face. *Courtesy: Argillon LLC*

Keeping arsenic from poisoning catalysts

Arsenic can be very troublesome for SCR catalysts. Arsenic trioxide gas released from burning coal reacts with the active vanadia in the catalyst to chemically deactivate it and "poison" the catalyst. Many American coals have adequate free calcium oxide (CaO) in their flyash to "scavenge" the arsenic down to safe levels—at least about 3% of the ash. In the presence of enough CaO, the arsenic trioxide reacts with the compound to form calcium arsenide, a solid that is collected with the flyash in the electrostatic precipitator or in the bottom ash.

However, some American coals with moderate to high levels of arsenic don't have enough CaO to scavenge the arsenic. One instance where this occurred was at Orlando Utilities Commission's (OUC) Stanton Energy Center Unit 2, which was commissioned in 1996. The 460-MW Unit 2 is powered by a Babcock & Wilcox boiler firing eastern bituminous coal.

Soon after Stanton Unit 2 went on-line, high ammonia slip was observed. It was determined through annual testing that the catalyst was losing its activity at a much faster rate than expected and that arsenic levels in the catalyst samples were higher than expected. After an investigation by OUC, the catalyst supplier, and outside consultants, it was determined that the fuel's CaO level was less than the SCR system design anticipated.

As a result, OUC had to revise its catalyst management plan. Now Stanton's operators add more than twice as much new SCR catalyst as originally planned—14,950 ft^3 versus 6,650 ft^3. According to Tony Engelmeyer, senior plant engineer, "OUC is evaluating approaches that may provide cost-effective alternatives for addressing our SCR catalyst needs."

There are other options for mitigating arsenic poisoning of the catalyst. One is to inject limestone into the furnace or add it to the fuel to provide the needed level of CaO. PP&L's Montour Station in Pennsylvania does it that way. Another option is to regenerate the SCR by chemically cleaning and reactivating the catalyst, as an alternative to replacing it.

reactor (see "Movie not included," page 56). When this happens, it is necessary to take the SCR off-line because of undesirable pressure drop increases.

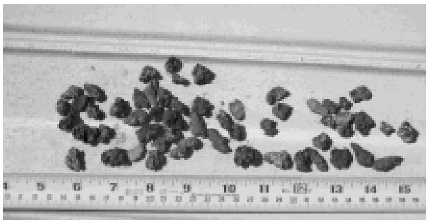
The exact reasons for the formation of popcorn ash in the furnace are still not completely known. But boiler operation and coal characteristics seem to play an important role. One popular theory is that large particles of ash develop from deposits on the boiler tubes and then harden, break off, and are carried into the SCR. It is desirable to have the popcorn ash fall out and be collected before it enters the SCR. Placing ash screens near the economizer outlet hopper can help.

Catalyst management. Catalyst management involves monitoring the catalyst's activity and then deciding whether to replace or regenerate it when it loses effectiveness. A catalyst's activity level will drop over time due to deposits of material that block active sites, by physical erosion and damage, and by chemical attack on its active components (see "Keeping arsenic from poisoning catalysts," page 54).

Timing is crucial here. SCR reactors are designed to maintain a minimum NO_X-reduction level under a given set of conditions even after the catalyst has lost some of its initial activity. But once catalyst activity drops below the level necessary to provide desired performance, it is necessary to replace some of the catalyst or add more catalyst to the reactor. SCR catalyst activity can be regularly monitored by laboratory analysis of catalyst samples.

Replacing an SCR system's catalyst is complicated and costly. At the very least, a comprehensive catalyst management program should minimize catalyst costs and simultaneously optimize plant operation to minimize the impact on generation. Often, such a program necessitates a number of trade-offs involving:

- **Outage timing and duration.** Ideally, outages for catalyst replacement can be timed to coincide with other work so they don't interfere with electricity production. But that isn't always possible. If the planned catalyst replacement doesn't coincide with an outage for other work, it may be necessary to choose among replacing catalyst early, taking an unplanned outage, or delaying catalyst replacement and risking higher ammonia slip.
- **NO_X reduction.** Now that NO_X allowances have a marketable value, increasing the NO_X-reduction level of the SCR system may be worth exploring. But doing so would come with a price: increased ammonia slip, increased ammonia consumption, and possibly increased catalyst demands.
- **Baseline NO_X level.** Reducing the amount of NO_X entering the SCR inlet can help reduce ammonia consumption, reduce ammonia slip, and lengthen the time between SCR-imposed outages.
- **Catalyst loading.** It may be possible to further extend the time between outages for catalyst replacement by increasing the catalyst loading beyond the initial design level. However, increased catalyst loading adds catalyst cost, increases the conversion of SO_2 to SO_3, 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 and avoids additional SO_2-to-SO_3 oxidation vis-à-vis a traditional approach that fills the SCR reactor and later replaces catalyst as the catalyst loses activity.
- **Regenerating the catalyst or buying a new one.** If it is in good physical shape, a catalyst can be cleaned and reactivated, eliminating the costs of buying a new catalyst and disposing of the old one. One newly available process being offered separately reduces the SO_2-to-SO_3 oxidation potential of previously exposed catalyst.



4. Popcorn ash. These photos of typical popcorn ash particles from a U.S. coal-fired power plant are of significant size (up to 1 in.) and specific gravity (between 0.2 and >1). *Courtesy: Southern Company*

A disciplined catalyst management approach that includes regular maintenance of instrumentation, controls, and major components (as well as periodic monitoring of ammonia distribution and catalyst condition) will usually enable operators to correct problems before they become large enough to seriously affect emissions performance. Accordingly, it is worthwhile to periodically review the catalyst management plan and catalyst tests to ensure that everything is on track for taking action during planned outages. Available software programs make assessments of trade-offs and planning ahead much easier.

Finally, be aware that emerging catalyst technologies and approaches to regeneration promise potentially significant savings of time and cost. It behooves users to follow developments in the vendor community so they can maximize the flexibility of their strategy. Locking into one approach or supplier could lock out some future options.

Level best

Most SCR reactors allow for up to four levels of catalyst. In some cases, each level may hold more than one layer of catalyst. When the system is new, with a fresh catalyst, at least one level is typically empty (Figure 8). When the SCR catalyst activity drops to a point where ammonia slip increases to an unacceptable point (typically >2 ppm), then new catalyst should be added to Level 4. After the SCR reactor is full, it is necessary to replace catalyst levels with new or regenerated catalyst to recover total SCR catalyst reactor activity (Figure 8). Because the top level usually loses activity faster than the others, it is normally the first catalyst level to be replaced.

Regeneration

As mentioned, another strategy for managing a catalyst is to regenerate it (Figure 9). This often requires that one level of catalyst always be empty when considering year-round SCR operation or SCR-equipped units without SCR bypass. The removed catalyst is sent off-site to be regenerated. When total SCR catalyst activity drops to a minimum acceptable

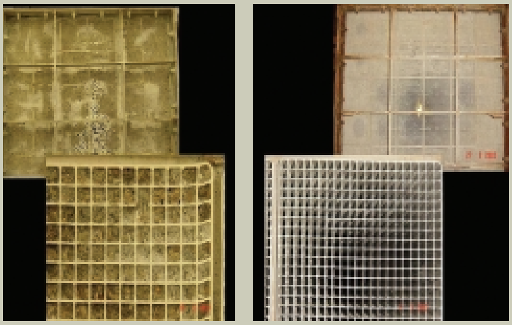
Movie not included

Atlanta-based Southern Company was challenged with popcorn ash pluggage at two of its coal-fired units—Unit 10 of Alabama Power Co.'s Plant Gorgas in Parrish and Units 1 and 2 of Georgia Power Co.'s Plant Bowen in Cartersville. Each of the three units fires bituminous coal and is equipped with two SCR reactors. The SCR reactors can accommodate four catalyst layers, although three layers were initially installed. The 196 catalyst modules per layer are arranged as a 7 x 14 row grid. The SCR systems at Plant Bowen Units 1 and 2 were commissioned in 2001; the one at Plant Gorgas Unit 10 followed in spring 2002.

In the case of Plant Bowen Unit 1, the level of catalyst plugging was 30% in the best locations and 100% in the worst (Figure 5) after fewer than 2,800 operating hours. The first two layers of Unit 1 were replaced with new catalyst after the 2001 ozone season. After the catalyst was removed, some modules were sent for cleaning to Charlotte-based SCR-Tech (now part of Gilbert, Ariz.–based Catalytica Energy Systems). Others were cleaned on-site by personnel from a joint venture of Cincinnati-based Enerfab Inc. and Vienna, Austria–based Envirgy Inc.

In the case of Plant Gorgas Unit 10, most of the catalyst from the first layer was removed and sent to SCR-Tech for cleaning off-site. But some of it had to be replaced because it had been severely eroded during operation.

SCR-Tech has a dedicated catalyst regeneration facility in Charlotte. The multi-step cleaning process begins with the vacuuming of loose flyash and eroded catalyst from the modules before they are soaked in a chemical solution. After washing and rinsing, the units get another deep, ultrasonic cleaning in a chemical solution. After that, yet another rinse removes any chemicals, flyash, and loose popcorn ash particles. The next two steps involve high-temperature air drying to remove residual moisture from the catalyst and blowing with compressed air to remove any remaining stubborn particles. The final steps are replacing any damaged catalyst elements and conducting a thorough inspection of all the modules.

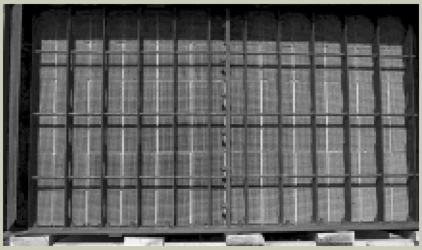


7. Before and after. If there are any doubts that SCR catalyst cleaning is effective, these before and after photos of Plant Bowen Unit 1 should dispel them. *Courtesy: Southern Company*

The modules cleaned on-site by the Enerfab/Envirgy alliance went through a different process. It uses a patented low-energy oscillating motion—much like a washing machine—and an air bubbling step to remove popcorn ash particles and other flyash. Chemical additives are also used to optimize the cleaning process. According to the two firms, their processes allow a catalyst to be restored to greater than 95% open channels (Figures 6 and 7).

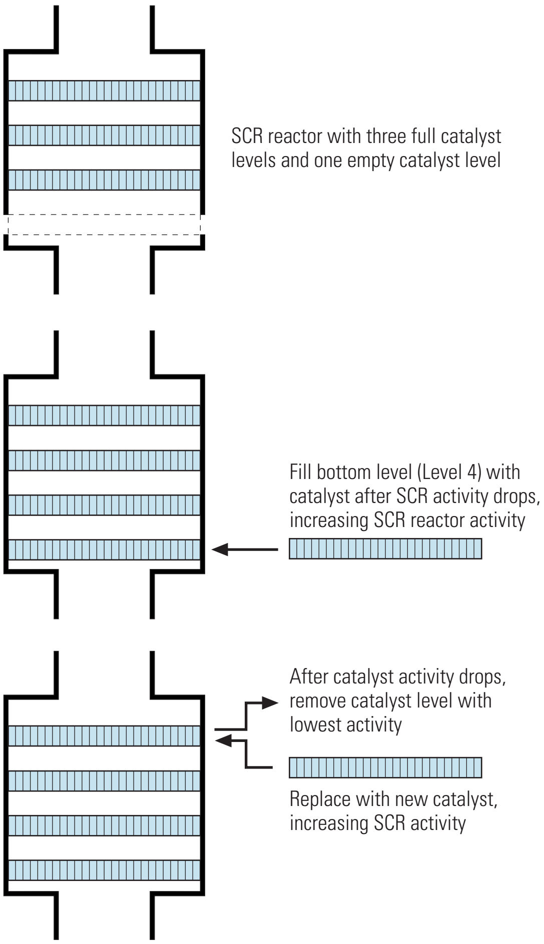
According to Ed Healy, consulting engineer at Southern Company, "Both Enerfab/Envirgy efforts and SCR-Tech's methods addressed our popcorn ash pluggage problems within established budgets and schedules."

5. Plugged catalyst. A severely plugged catalyst module from the first layer of Plant Bowen's Unit 1 SCR, after vacuuming to remove surface pluggage. *Courtesy: Southern Company*

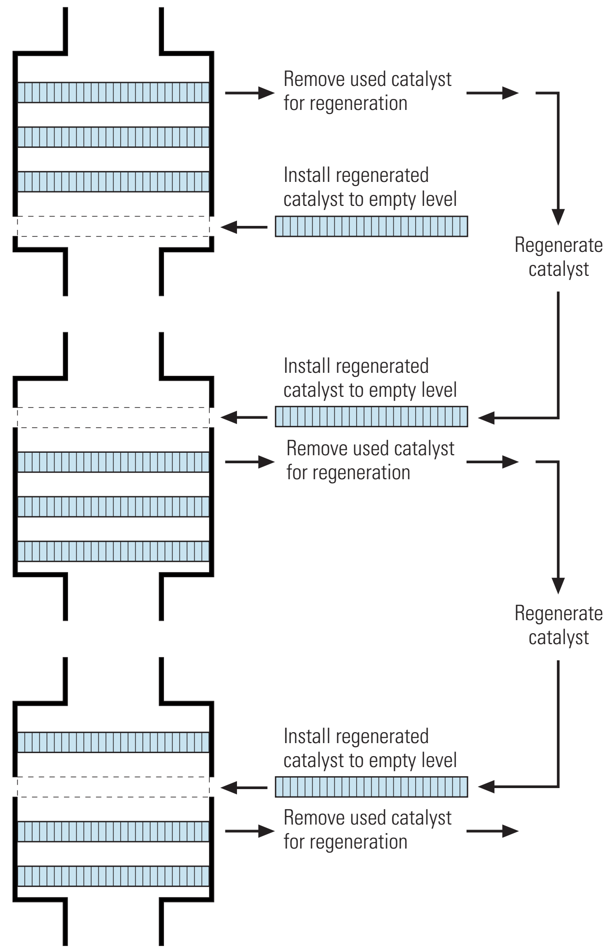


6. Cleaned catalyst. The cleaned catalyst modules from Plant Gorgas were returned to the SCR system for reinstallation and operation. Meanwhile, a full layer of catalyst from Plant Bowen's Unit 1 was cleaned and stored for future use. *Courtesy: Southern Company*

8. Normal add and replace sequence. When the SCR catalyst activity drops to a point where ammonia slip increases to an unacceptable point, then new catalyst must be added to Level 4. 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. *Source: Andover Technology Partners*



9. Regeneration sequence. Regeneration normally requires that one level of catalyst always be empty so the removed catalyst can be sent off-site. 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. *Source: Andover Technology Partners*



point, the regenerated catalyst is then added to the empty catalyst level, and the catalyst level with the lowest activity is then removed for regeneration.

The advantages of a regeneration approach such as this are:

- If the catalyst is physically intact, regenerating it is less costly than buying a new catalyst.
- The resulting pressure drop across the SCR reactor is lower than that from add-and-replace approaches, which fill the SCR reactor.
- A lower catalyst loading will result in lower SO_2-to-SO_3 oxidation.
- Depending upon SCR reactor access and available staffing, shutdowns for catalyst regeneration may be shorter than for a catalyst-level replacement. As one layer is removed for regeneration, it may be possible to simultaneously install regenerated catalyst on another level.
- Regeneration eliminates concerns regarding the cost and liability of used catalyst disposal.

However, catalyst regeneration does have some downsides, including:

- Shutdowns for catalyst changes will typically be more frequent because of the lower catalyst loading.
- A catalyst that is reactivated with new active material may not behave in the same way as the original catalyst with respect to either SO_2-to-SO_3 oxidation or deactivation.
- If the catalyst is badly eroded or physically damaged, regeneration may not be possible. Normally, after two or three cycles of exposure and regeneration the catalyst is so eroded from flyash abrasion that it lacks enough remaining active surface area or mechanical strength to be regenerated.

Whether the decision is to replace or regenerate the catalyst, it is important to identify the layer with the lowest activity and replace or regenerate that layer. 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 because it tends to be exposed to the highest concentration of impurities. That's another reason why annual catalyst activity testing by a qualified laboratory should be an important part of any catalyst management program. ■

Dr. Jim Staudt is president of Andover Technology Partners and can be reached at staudt@AndoverTechnology.com.