The Importance of an Integrated and Independent Approach to Catalyst Management

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ABSTRACT

Managing catalyst is an integral part of effective Selective Catalytic Reduction (SCR) operation. However, the catalyst is only one component of the SCR system as a whole. An integrated approach to catalyst management considers all factors affecting the SCR including fuel, NH_3/NOx distribution, flow and temperature distributions, fouling, etc. Thus, a better approach to optimal, less costly SCR operation is “SCR management” –rather than “catalyst management”— where all factors affecting the SCR are considered in an integrated manner.

Many catalyst management programs focus almost exclusively on reactor potential, making catalyst replacement or addition decisions based upon this parameter alone. This lack of integration results in a failure to properly consider other factors which influence SCR operation. In addition, catalyst management may be conducted by catalyst manufacturers or regeneration firms. In these cases, there may be no vested interest in developing solutions which do not involve catalyst sale or regeneration. Independent management firms can objectively address all factors affecting the SCR, and can develop integrated solutions which provide optimal economic and operational benefits.

It is clear that managing the SCR in both an integrated and independent fashion provides a more complete and objective approach. This allows for all solutions to be evaluated on an equal footing, potentially resulting in substantial cost savings, improved performance, and reduced balance-of-plant adverse impacts.

INTRODUCTION

Managing catalyst is an integral part of effective SCR operation. However, the catalyst is only one component of the SCR system as a whole. An integrated approach to catalyst management considers all factors affecting the SCR including fuel, NH_3/NOx distribution, flow and temperature distributions, fouling, etc. Thus, a better approach to optimal, less costly SCR operation is “SCR management”—rather than “catalyst management”—where all factors affecting the SCR are considered in an integrated manner.

Unfortunately, many catalyst management programs focus almost exclusively on reactor potential, making catalyst replacement or addition decisions based upon this parameter alone. This one-sided approach fails to consider other factors which influence SCR operation. In addition, catalyst management is often conducted by catalyst manufacturers or regeneration firms. In these cases, there may be no vested interest in developing solutions which do not involve catalyst sale or regeneration. Further, management firms which focus solely on catalyst performance may lack the expertise to address other SCR-related factors, unlike independent firms which may have much broader capabilities. Given the above concerns, it is clear that an independent and integrated approach to catalyst management, essentially an “SCR management” approach, can lead to more technically optimal and cost-effective SCR operation.

Some specific advantages of independent and integrated catalyst management include;

- Objective assessment of the rate of catalyst deactivation, and its performance as compared to guarantees.
- Consideration and correction of impacts from maldistributions in flow, NH_3/NOx ratio, and temperature.
- Assessment of fouling causes and all available corrective actions, including fuel effects, boiler operation, flow distribution, flow directionality, catalyst design, etc.
- Objective assessment of the general catalyst type most appropriate for the application (plate, honeycomb, hybrid).
- Objective assessment of new catalysts available for the application from a range of manufacturers, including advanced catalyst designs.
- Comparative analysis of new catalyst purchase versus regeneration.
- Integrated assessment of SCR impacts on downstream devices and emissions, including air preheater fouling, ESP/baghouse performance, ash ammonia contamination, SO_3 emissions, mercury emissions, etc.
- Preparation of bid specifications and objective evaluation of bids associated with catalyst purchase, regeneration, reactor and ductwork physical modifications, etc.

PRIMARY FACTORS AFFECTING SCR PERFORMANCE

Catalyst management focusing exclusively on catalyst activity/deactivation fails to take into account other factors influencing SCR operation, as discussed above. An integrated approach takes into account these other factors. In particular, the following performance parameters are of primary importance.

- NH_3/NOx Distribution
- Flow Distribution
- Fouling

The following discussions address in some detail the potential impacts of the above parameters, primarily as a function of the effects on ammonia slip or achievable deNOx. It should be noted that many other factors will have impacts, as well. These include fuel characteristics, boiler operation and load profile, shut-down/start-up frequency and procedures, etc.

IMPACTS OF NH_3/NOX DISTRIBUTION

The distributions of NH_3 and NOx entering the SCR are extremely important to proper SCR operation. These two primary reactants must be present in a proportion that allows for sufficient NOx removal, but no so high as to produce excessive ammonia slip. As a result, the industry typically uses the ratio of NH_3 to NOx (i.e. NH_3/NOx ratio) as a convenient metric, with a certain maximum allowable maldistribution being specified according to the design requirements of the SCR. This maldistribution is usually quantified as %RMSD (% root-mean-squared deviation). This value is normally around 5% for SCRs operating at roughly 90% deNOx, but may be relaxed at lower rates of deNOx, or tightened at higher rates of deNOx.

Figure 1 shows the effect on ammonia slip for deviations in the NH_3/NOx %RMSD, with the assumption that the design value of NH_3/NOx distribution is 5% RMSD. This example is based on a nominal SCR design of 90% deNOx, with 2 ppm slip, and assumes 15% RMSD in the flow distribution (to be discussed later). *Note that this general design basis will be used in all further discussions.* Under this design scenario, the SCR will experience a sharp increase in slip as the NH_3/NOx %RMSD increases above 5%. For example, a broadening of the NH_3/NOx %RMSD to 9% will cause the slip to double, to 4 ppm. At 11% RMSD, the slip triples to 6 ppm. Thus it is clear that slip will be strongly affected by NH_3/NOx maldistributions. Notably, however, improving the NH_3/NOx distribution below 5% RMSD does not significantly impact ammonia slip, at least for this example. It is important to note that as the required NOx removal increases (especially above 90%), the NH_3/NOx %RMSD must be controlled with increasing stringency. This is because at high deNOx levels, the average NH_3/NOx ratio becomes near 1.0, which increases the likelihood that particular areas of the reactor will have NH_3/NOx ratios which actually exceed 1.0. In these cases, the excess ammonia will exit the reactor as slip, regardless of the reactor potential that is present. Thus, maldistribution in the NH_3/NOx ratio must be minimized to avoid the localized areas of excessive slip.

Figure 2 is complimentary to Figure 1 and shows the achievable NOx removal if ammonia slip is held to the design value of 2 ppm. The plot shows that the achievable deNOx is quite sensitive to the NH_3/NOx distribution, with achievable deNOx reduced to just 84% if the NH_3/NOx RMSD is relaxed to 9%, and a deNOx value of roughly 93% can be achieved if the NH_3/NOx ratio is reduced to 3%. Figure 3 offers an additional perspective, showing the required reactor potential (relative to the design basis) as a function of NH_3/NOx ratio %RMSD. At 7% RMSD (just slightly above the 5% RMSD of the design case) roughly 10% more reactor potential is required to meet 2 ppm slip if 90% deNOx is maintained. The required reactor potential increases to 140% of the design basis (roughly equivalent to a full layer of catalyst for most facilities) as the NH_3/ratio increases to 9% RMSD. As the NH_3/NOx maldistribution increases above 9% RMSD, it becomes impossible to meet 2 ppm slip and 90% deNOx regardless of the reactor potential.

Overall, it is quite clear that at high deNOx rates (90% and above) the NH_3/NOx distribution is critical to SCR operation. The adverse effects cannot be easily compensated for by increasing reactor potential (i.e. adding or replacing catalyst), and rather extreme performance reductions would be required in terms of deNOx if the specified slip is maintained. Alternately, very high levels of ammonia slip would be experienced if deNOx is maintained. The proper method for addressing NH_3/NOx maldistribution is to correct the maldistribution itself, rather than trying to compensate for the maldistribution by purchasing additional catalyst or reducing deNOx or slip performance. Various factors such as tuning, modification to the ammonia injection grid (AIG), correction of flow maldistribution at the AIG, etc. may all be employed to improve the NH_3/NOx distribution. These corrections will generally be far more economical than purchasing additional catalyst, de-rating the SCR, or dealing with maintenance issues related to high ammonia slip.

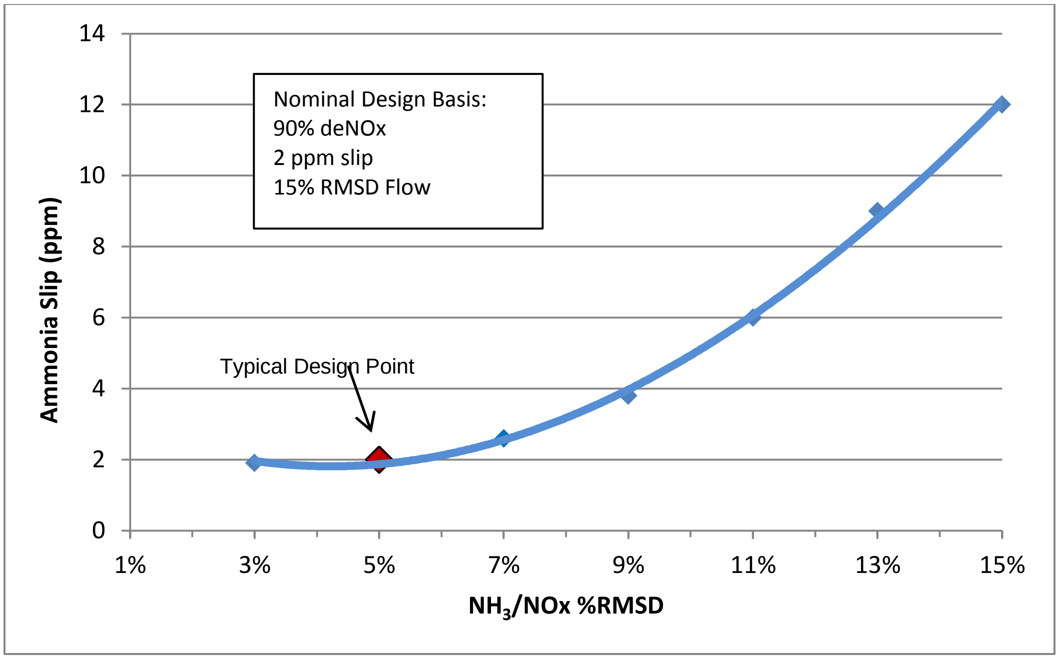

Figure 1. Effect of NH_3/NOx Distribution on Ammonia Slip

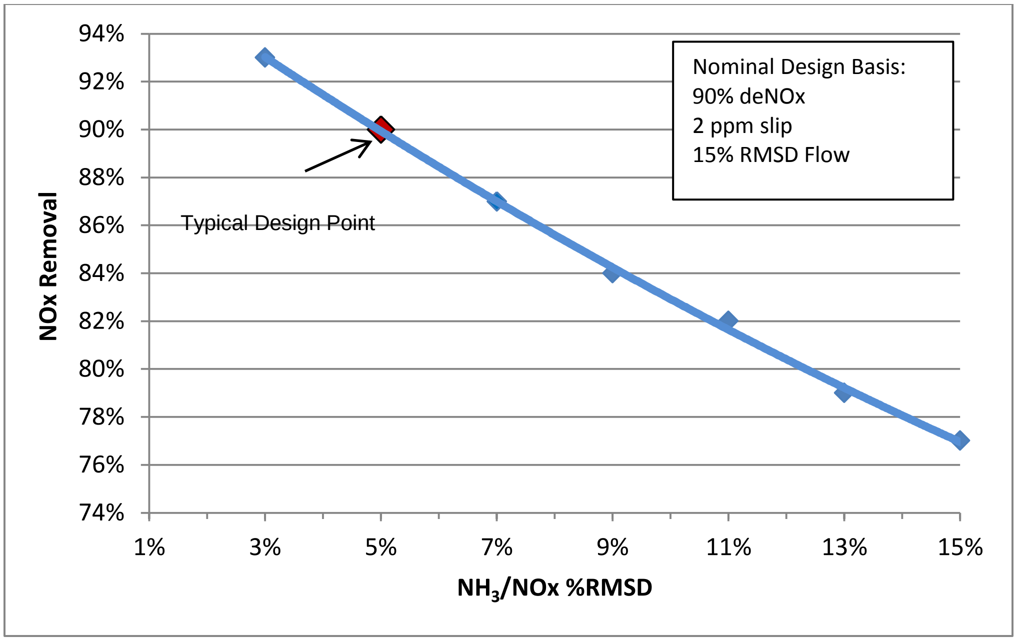

Figure 2. Effect of NH_3/NOx Distribution on Achievable deNOx

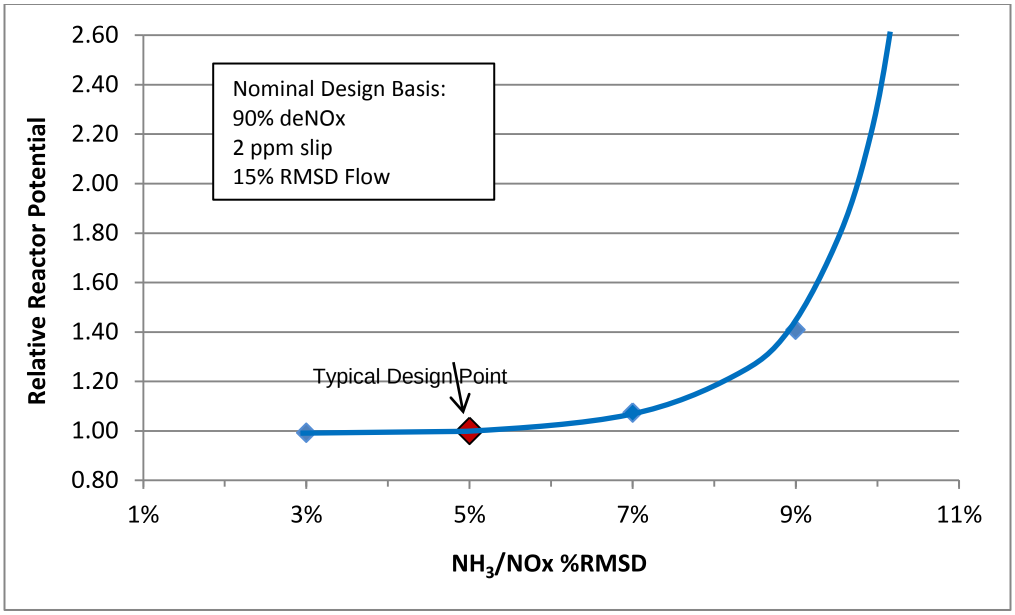

Figure 3. Effect of NH_3/NOx Distribution on Required Reactor Potential

IMPACTS OF FLOW DISTRIBUTION

Flow distribution is an important design parameter for SCRs. Catalyst specifications often limit the maximum flow maldistribution using the parameter of %RMSD, as described for the NH_3/NOx distribution. The specification is usually based on the flow distribution at the first (top) catalyst layer, but flow distributions are also a consideration in other areas of the ductwork, such as at the AIG, before and after turning vanes, flow straightening grids, and baffle plates, etc. The flow distribution, especially around the catalyst and AIG, is important for several reasons; 1) areas of high flow create localized regions of reduced reactor potential which can lead to excessive slip or a reduction in deNOx capability if slip limits are maintained, 2) flow maldistributions at the AIG can make it difficult to properly tune the AIG to maintain the proper NH_3/NOx ratio, 3) areas of high flow can contribute to catalyst erosion, and 4) areas of low flow or “dead zones” can contribute to catalyst fouling.

Figure 4 shows the kinetic effect of flow maldistribution (as measured at the first layer catalyst face) on ammonia slip for the previously detailed basic design case. An increased flow maldistribution from a typical value of 15% RMSD to 25% RMSD will lead to an increase in slip to roughly 3 ppmv. This does not seem particularly large, but as shown in Figure 5, if 2 ppmv slip is maintained, the achievable deNOx is reduced to approximately 70%. Note that these figures focus only on the reaction effect of localized lower reactor potential, and assume that the NH_3/NOx distribution can be maintained even with the increased flow maldistribution. As may often be the case, a large flow maldistribution may lead to a larger NH_3/NOx maldistribution, depending on specific location of the flow upset. These maldistribution effects may then combine to produce a rather marked increase in slip or reduction in deNOx capability.

In addition to kinetic effects, flow maldistributions may create the potential for erosion in areas of high flow, and the potential for fouling in areas of low flow, as mentioned previously. Improper flow distributions are a leading cause of fouling, which is a pervasive problem in the coal-fired SCR fleet. The effects of fouling will be discussed in detail, below, but it is clear that the combined adverse effects of flow maldistribution make this a critical parameter for SCR performance. Further, the adverse effects of flow maldistribution cannot easily be compensated for by increasing reactor potential (i.e. catalyst replacement or addition) – adverse effects can only be properly addressed by investigating and correcting the root cause of the maldistribution.

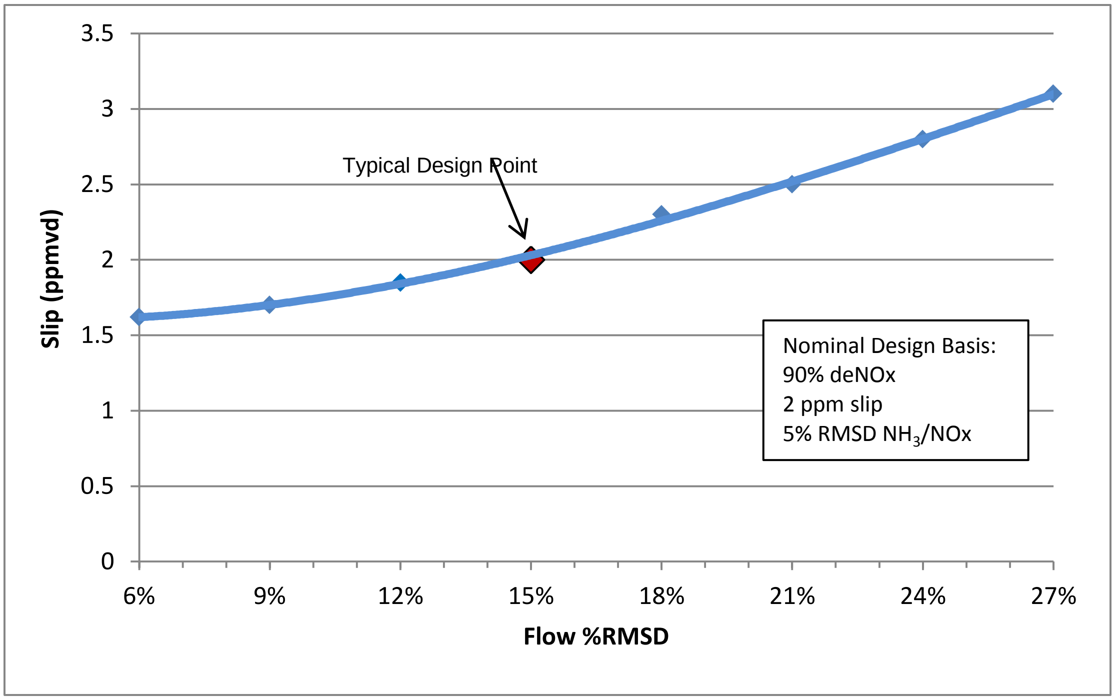

Figure 4. Effect of Flow Distribution on Ammonia Slip

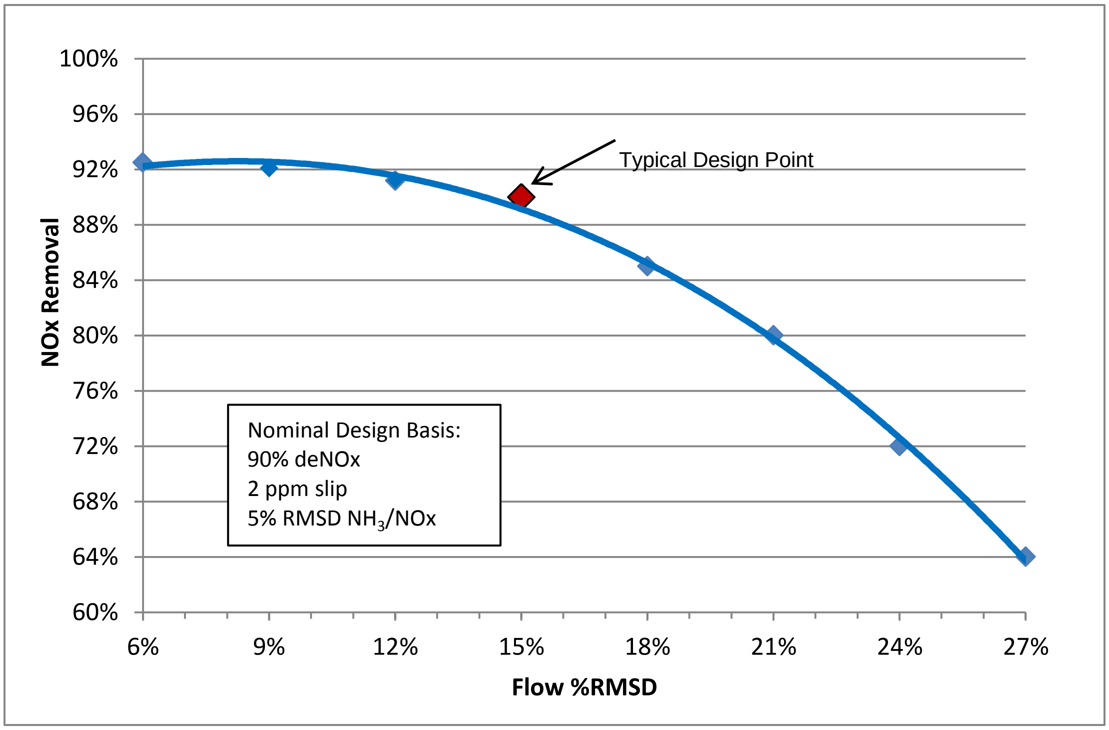

Figure 5. Effect of Flow Distribution on Achievable deNOx

IMPACTS OF FOULING

As mentioned above, fouling is a pervasive problem within the coal-fired utility fleet. Fouling can be simply summarized as fly ash accumulation in the catalyst flow channels (plugging) or over significant areas of the SCR reactor cross-section blocking portions of the catalyst from flue gas exposure. The fouling characteristics of individual SCRs vary greatly on a case-by-case basis, with some reactors operating without significant fouling-related impacts, while others experience acute or chronic fouling problems. The specific coal characteristics control the amount, and to a large degree the nature, of the ash produced by any particular boiler. These factors are considered in the original SCR design, with reactor gas velocity and catalyst pitch being two primary parameters that are adjusted according to coal specifications. The industry has become experienced in designing SCRs according to fuel characteristics, and currently basic SCR designs vary primarily according to general coal type (i.e. eastern bituminous, PRB, or lignite), with fine-tuning of the design made according to the specific fuel characteristics.

Regardless of coal characteristics, all SCR systems must be properly flow modeled to insure that the flow distribution entering the reactor is adequate in terms of the velocity distribution and localized ash loadings (in addition to insuring proper NH_3/NOx distribution). Various methods are employed to correct flow maldistributions, such as turning vanes, perforated plates, baffles, and flow straightening grids. Despite these efforts, many reactors still experience significant fouling issues.

Generalized chronic fouling encompassing the entire catalyst face may be the result of poor sootblowing or sonic horn design or operation. This may also be caused by catalyst selection where the pitch is too narrow for the particular fuel. This may occur in particular when fuel is switched from the original design basis. Examples of this type of fouling are shown in Figure 6, where the fouling is spread somewhat randomly across the catalyst face. In these examples, roughly 10-20% of the catalyst channels are blocked.

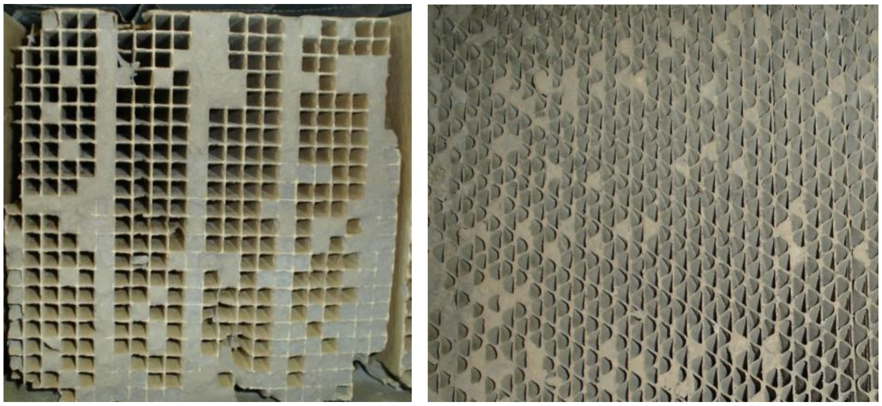

Figure 6. Random Fouling on Honeycomb and Corrugated Catalysts

Acute fouling involves relatively large areas of catalyst which are totally blocked, often with large amounts of ash, forming deep “mounds”. This most often occurs near reactor walls, and is most often found on the boiler-side of the reactor, where it is especially difficult to smooth the flows due to tight reactor hood designs. Figure 7 shows a photograph of this type of fouling, where several modules are virtually completely blocked. Simply removing the ash does not address the underlying causes of the fouling, and often the underlying catalyst is irreparably blocked, unless removed and rejuvenation/regenerated.

Figure 7. Acute Fouling of Large Areas of Catalyst

Fouling has an adverse impact on the SCR operation, because it reduces the available reactor potential in direct proportion to the level of fouling. For instance, if 20% of the catalyst’s channels are blocked, then the available potential is reduced by 20%. Some level of fouling is always assumed when the catalyst volume is specified for a specific installation, often in the range of 10-15%. However, when fouling levels exceed the assumed value, a dramatic effect on SCR performance may occur, especially toward the catalyst's end of life. This typically results in high slip levels, or reduced deNOx capability. In addition to reducing the available catalyst potential, fouling increases the flue gas velocity in the open areas of catalyst, potentially leading to erosion. Further, flow disturbances are created by the fouled areas of catalyst, especially when rather large areas are completely blocked. This leads to additional fouling due to non-uniform flow, creating a cascading effect.

Two plots have been prepared to demonstrate the effect of fouling on SCR performance. Note that these focus solely on reduced catalyst potential as a function of fouling. Additional adverse effects will also occur, as discussed above. Figure 8 shows the effect of fouling on ammonia slip for the basic SCR design previously utilized. For this example, 10% fouling has been assumed for the design basis. The effect on slip is quite dramatic. An increase in fouling to just 20% leads to a slip value of nearly 4 ppm, while an increase in fouling to 30% leads to slip of 6 ppm. Figure 9 offers an alternate perspective, showing the achievable deNOx if the ammonia slip is held to the original design value of 2 ppm. For this example, fouling of 20% reduces the achievable deNOx to just 55%, and at 30% fouling the achievable deNOx is reduced to just above 30%. Given the sensitivity of SCR performance to fouling, and the prevalence of fouling problems within the industry, fouling perhaps has the greatest adverse effect on SCRs, in general, of all potential factors adversely affecting SCRs.

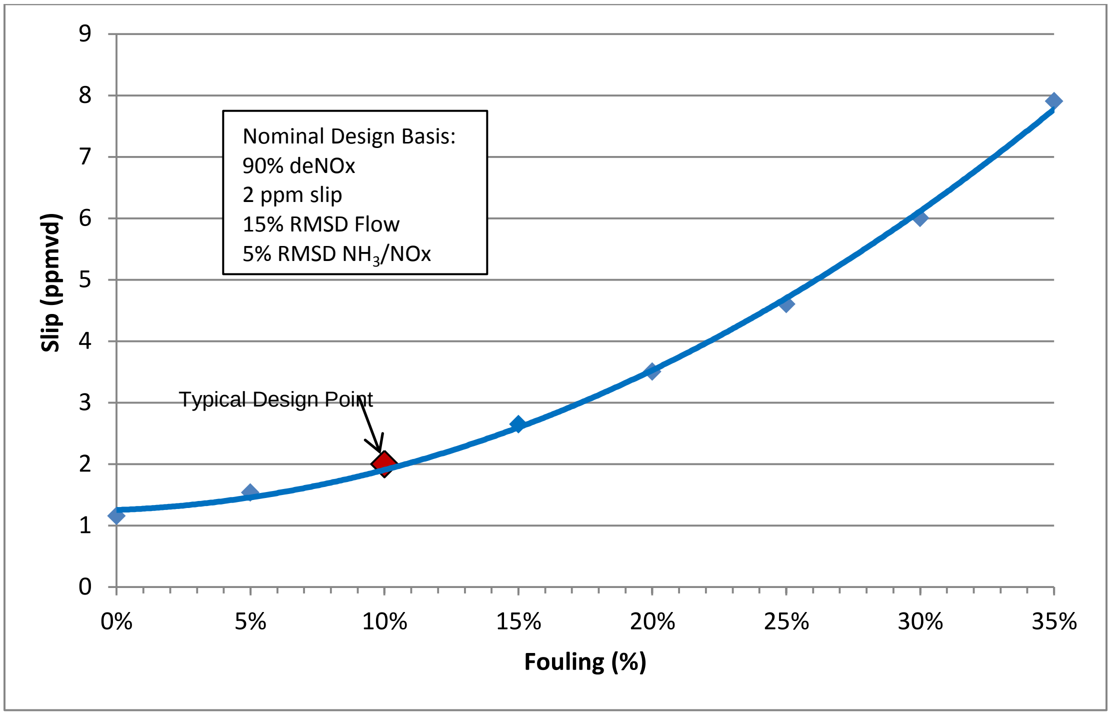

Figure 8. Effect of Fouling on Ammonia Slip

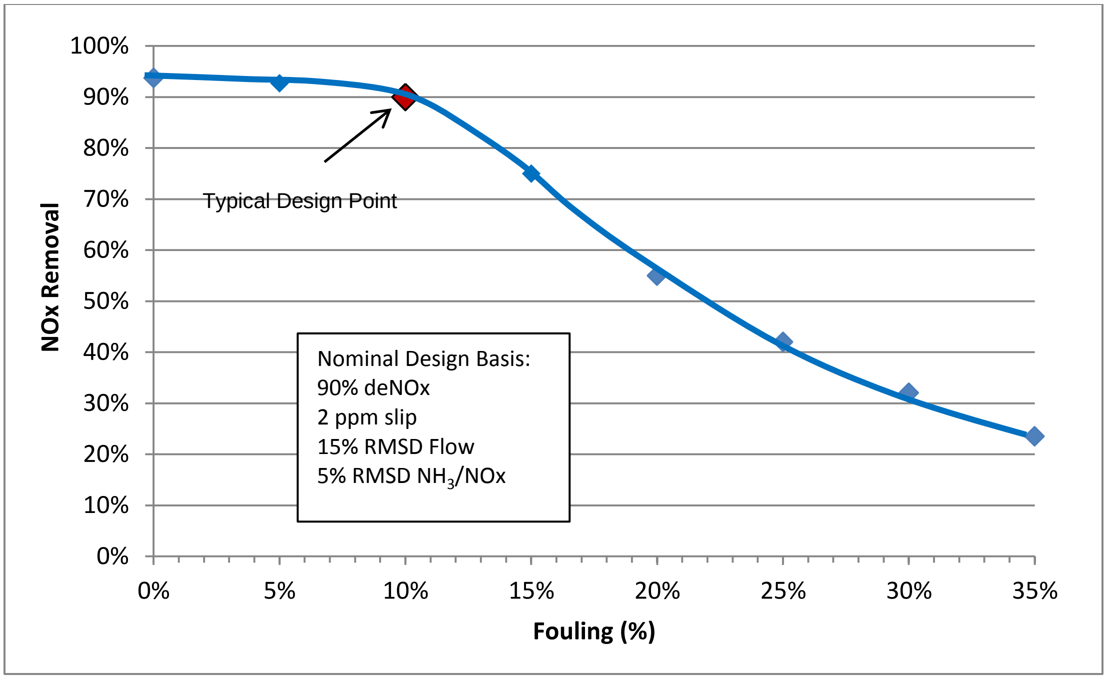

Figure 9. Effect of Fouling on Achievable deNOx

CONCLUSIONS

There are clear economic and operational benefits to managing an SCR in an integrated fashion. The timing of catalyst purchase or replacement is only one factor in properly managing an SCR, although it is often the primary focus area. Other SCR parameters have as much or more potential to affect SCR operations. In particular, these other parameters include the NH_3/NOx distribution, flow distribution, and fouling. Independent management firms can effectively take this needed integrated approach, focusing solely on solutions that provide the best economic and operational solutions regardless of whether or not catalyst purchase or replacement is part of that solution. This allows for all solutions to be evaluated on an equal footing, resulting in optimal solutions from both an economic and operational standpoint. Independent and integrated SCR management potentially results in substantial cost savings, improved performance, and reduced balance-of-plant adverse effects.

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