EVALUATION OF HYBRID SNCR/SCR FOR NOx ABATEMENT ON A UTILITY BOILER

Authors:

Vincent Albanese
John Boyle
FUEL TECH, INC.
Alex Huhmann
Albert Wallace
PUBLIC SERVICE ELECTRIC & GAS

INTRODUCTION

The Clean Air Act Amendments of 1990 have given rise to a wave of technology development that anticipates meeting clean air challenges. Indeed, in the first half of this decade, the U.S. witnessed the retrofit of low NOx burners on coal, oil, and gas-fired boilers. Additionally, there were new developments in air staging technologies, gas reburn demonstrations under the Clean Coal Technology Program, in-field applications of SNCR retrofit on various types of utility boilers, and even a retrofit application of SCR on a cyclone coal-fired boiler. Industry observers predict large costs will be borne by major sources to meet the air quality goals in some Phase II provisions of the Act. In preparation for "life beyond Phase I," field development is now being focused on effective combinations of NOx controls. Potentially, two or more available means of NOx control can be compatibly combined to reduce NOx wherein the end result is more cost effective than the sum of its parts. Hybrid combinations of SNCR and SCR are a particularly flexible method for effecting moderate to deep reductions of NOx at cost ranges typically below those of a fully-engineered SCR retrofit.

The purpose of this paper is to discuss reductant utilization observed in recent field work, and ramifications of increased utilization on lifecycle costs of NOx reduction borne by owners and operators.

DESCRIPTION

Hybrid SNCR/SCR NOx reduction systems can be engineered in several forms. Clearly, it is possible to install a commercial SNCR system for furnace reductions of NOx, and install a commercial SCR system downstream of the economizer on the same unit for removal of the remaining NOx, and enjoy deep levels of NOx reduction with the combined system. For the purpose of semantic clarity, one might consider the foregoing system "combined SNCR/SCR" while reserving the "hybrid" description for units which utilize the ammonia slip from the SNCR process as the sole NOx reductant entering the downstream SCR.

Hybridized SNCR/SCR can assume several configurations depending upon the level of overall NOx reduction desired and unit configuration. Both factors combined lead to differences in catalyst dimensions and, therefore, catalyst contributions to the total capital requirement. Various configurations for consideration would be SNCR with:

- catalytic air heater
- "in-duct" SCR-existing duct dimensions
- "in-duct" SCR-expanded duct dimensions
- reactor-housed SCR
- combination of "in-duct" SCRs with catalytic air heater

Prior literature[1] surveyed the above combined technologies listing benefits and potential drawbacks of combining the technologies. It primarily reported from a technological feasibility viewpoint where a specific requirement for SCR is presumed. It is important to view the potential application of hybridized SNCR/SCR from an economic standpoint, particularly in the case where combustion modifications have already been employed.

Besides assuming several physical configurations, hybrid SNCR/SCR can be operated in different ways. Among the many considerations for the choice of designated hybrid operation are:

- What is the desired level of NOx reduction and NH_3 slip constraints?
- What volume catalyst can fit in the existing ductwork where face velocity will be within catalyst manufacturer specifications?
- What level of additional pressure drop is tolerable by the present fan?
- Are NOx reduction requirements incremental?
- What structural steel/ductwork changes must be made to support the catalyst?
- What is the expected/guaranteed life of the catalyst?
- What deviation from ideal reductant distribution is tolerable for the NOx limit?

It is obvious that total capital requirement for the catalyst retrofit will increase as the catalyst size and retrofit complexity increase. The key to minimizing lifecycle NOx reduction costs is to find the appropriate balance between annualized capital charges and operating costs for the remaining life of the system. The challenge for SCR retrofit is to minimize the capital requirement. The challenge for SNCR use is minimization of reagent required. Designing hybrid SNCR/SCR systems suggests optimization of these costs over the lifecycle for a specific level of NOx reduction.

CHEMICAL UTILIZATION

In post-combustion NOx control processes, NOx reduction is achieved at a given Normalized Stoichiometric Ratio, or NSR. Simply put, NSR refers to the ratio of chemical reductant applied to the amount of NOx existing in the flue gas. With SCR, ammonia is typically the reductant and is typically applied at an NSR of one for deep reductions. In other words, one mole of NH_3 is applied per mole of NOx. If only a 75% NOx reduction was required, the NH_3 NSR would be approximately 0.75. In non-catalytic systems, the reductant is applied in broader ranges of NSR because of relatively lower NOx reduction efficiency compared to catalytic systems. In commercial practice, NSRs range from 0.6-2.0. When urea is used for SNCR systems, an NSR of 1.0 means 0.5 mole urea is applied for 1.0 mole NOx because urea has two nitrogen moieties for reaction with NOx.

Chemical utilization is a quantification of NOx reduction efficiency expressed by:

$$\frac{\text{NOx Reduction \%}}{\text{NSR}}$$

In other words, if each lb-mole of injected urea or ammonia reduces NOx to the theoretical maximum amount[2], utilization is 100%. One hundred percent chemical utilization is approached in SCR systems, but in SNCR system values range from 30-60%. In commercial post-combustion NOx control systems, maximizing utilization, all other things being equal, minimizes lifecycle operating costs.

Figure 1 schematically depicts the enabling effect of downstream catalyst (downsized or otherwise) on SNCR performance in a hybrid system. SNCR NOx reduction occurs in a defined temperature window, roughly bell-shaped with maximum SNCR NOx reduction occurring at the top, or plateau of the bell. In a commercial "stand-alone" SNCR system, performance is optimized by operating at the "right side of the slope" in the temperature window curve[3] (in Area A). In this region, the hot side of the performance maximum, ammonia slip is very low or non-existent. This is often an operating constraint imposed by the source owner. In contrast, the SNCR component of the hybrid system operates best at the plateau which is lower temperature. In this region (Area B), SNCR NOx reduction is higher and some ammonia slip is produced. The ammonia slip is available to reduce NOx in a catalyst system downstream. When operated in this manner, SNCR NOx reduction is maximized (compared to its stand-alone performance) <u>and</u> additional NOx reduction occurs in the catalyst portion, fueled by the generated ammonia slip.

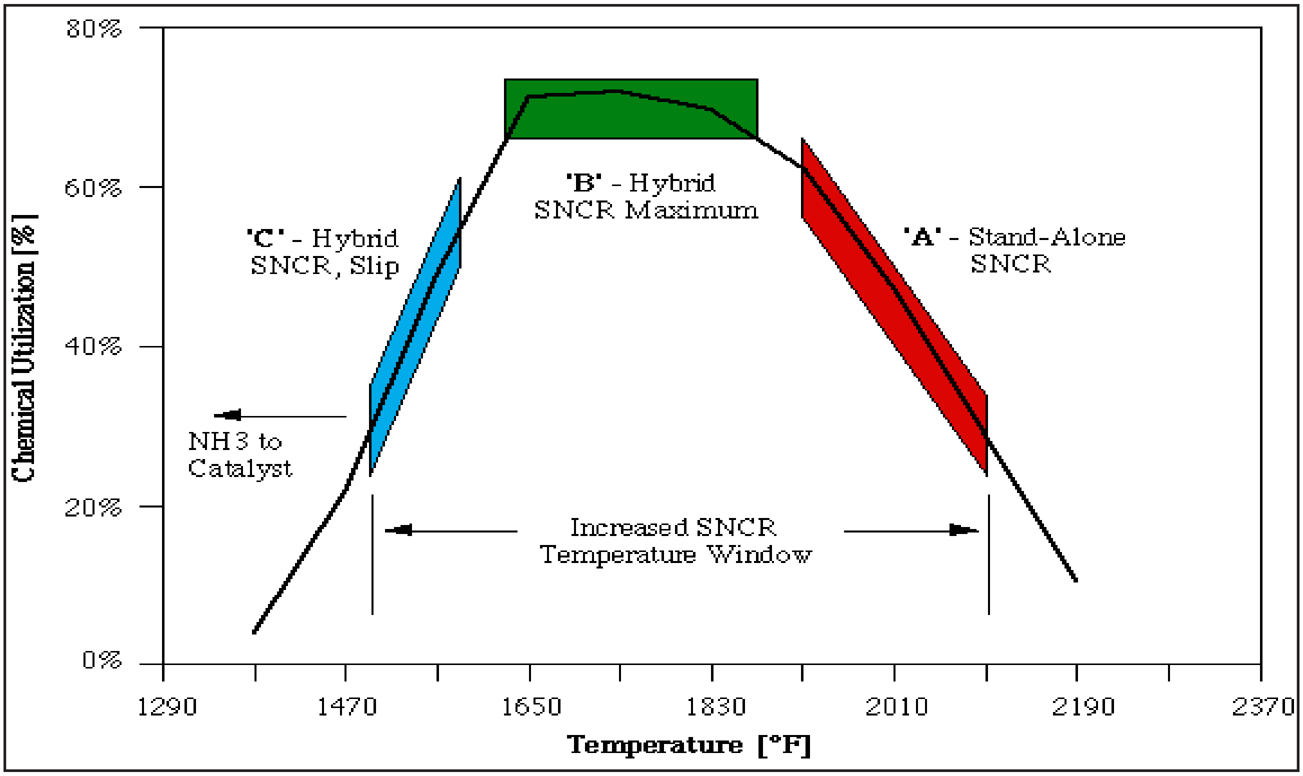

Figure 1. Hybrid SNCR/SCR Yields Improved SNCR Performance. Total Reagent Utilization Approaches 100%.

Hybrid systems can be designed to operate in the cooler zone (Area C - the "left side of the slope") which will produce more ammonia slip than the other regions. In this scenario, SNCR NOx reduction is less than maximal and SCR NOx reduction increases until limited by catalyst space velocity. Overall system NOx reductions beyond 75% would typically require this type of operation and require catalyst reactor dimensions that would not be possible to fit in existing duct space.

Hybrid systems can be designed to maximize SNCR performance while "existing duct" SCR controls the ammonia slip (Area B). Reagent utilization for NOx reduction can increase dramatically compared to stand-alone SNCR because of the reasons stated above. Therefore, reagent cost per unit of NOx reduced is lower with the hybrid system than with stand-alone SNCR. Current operators of SNCR systems consider these questions in the design stage for prospective hybrid systems:

- What is the expected additional reduction of NOx for a constant urea (reagent) flow?
- What is the expected reagent flow reduction for constant NOx reduction?

FIELD DEMONSTRATION

Seminal in-field work on hybrid SNCR/SCR was undertaken by Public Service Electric and Gas[4]. Among the many tests conducted during several months' work was the evaluation of commercial-scale, urea-based SNCR[*] in tandem with a full-scale (expanded duct) retrofit of plate-type catalyst installed between the economizer outlet and air heater inlet. In addition, hot-end air heater baskets were replaced with catalyst material similar to that installed in the economizer ductwork. There were two significant "firsts" associated with this demonstration. It was the first field-scale demonstration of urea-based SNCR "hybridized" with SCR. This paper addresses operations where managed levels of SNCR ammonia slip was the reductant feed for the catalyst on a pulverized coal-fired unit. That is to say, the catalytic NOx reduction system operated without an ammonia handling and injection system. Also, it was the first retrofit of catalyst in a horizontal duct.

DEMONSTRATION RESULTS

Minor modifications to the existing urea-based SNCR system design were made to operate the SNCR appropriately for the hybrid SNCR/SCR. The changes consisted of installing reagent injectors to the slightly cooler furnace area which exist on the furnace rear wall, addition of one multi-nozzle lance (MNL) to the south furnace wall, and conversion of spray droplet size distribution on one level of injection that was common to both the stand-alone SNCR system and the SNCR system which existed as a component of the hybrid system. These modifications reflect design elements of the NOxOUT CASCADE^{Ò} hybrid system.

Data on overall NOx reduction, SNCR NOx reduction, SCR NOx reduction, SNCR NSR, overall NSR, SNCR reagent utilization, and overall reagent utilization for the re-engineered configuration are presented in Table 1. The data were taken at full load while firing 100% of the thermal input with pulverized coal or natural gas. The data represent injection rates (NSR) where NH_3 slip from the expanded duct catalyst was 10 ppm or less (as opposed to the air heater catalyst outlet).

The stand-alone SNCR data represent data at full load for the pre-hybrid SNCR design. Full load is the most challenging theoretical condition under which to measure reagent utilization.

One goal of these tests was to maximize SNCR performance and allow the incidental ammonia slip to reduce NOx through the catalyst. These data indicated slight <u>increases</u> in SNCR NOx reduction at <u>lower</u> feed rate than similar feed rate to SNCR alone. (That is, overall NSR of 1.15 and 0.79 compared to the stand-alone value of 1.19.) However, added to the SNCR NOx reduction in the hybrid was NOx reduction in the catalyst of an additional 16% at the lower feed rate (NSR = 0.79) and 54% SCR NOx reduction at the higher feed rate. The total hybrid system NOx reduction performance at the stand-alone SNCR feed rate was 71% compared to 37%. The resulting chemical utilization overall increased from the stand-alone SNCR value of 31% to 62%. In other words, double the NOx reduction occurred at the same reagent feed rate. At significantly lower urea reagent feed rate, the overall NOx reduction of 51% gave rise to 64% overall utilization.

Table 1. High Load (320MWe) Hybrid Results

Fuel	NOx Control System	NSR	SNCR Reduction	SNCR Utilization	SCR Reduction	Total Reduction	Overall Utilization
Coal	Standard SNCR	1.19	37.00%	31.10%	-	37.00%	31.10%
Coal	Hybrid	0.79	41.10%	59.20%	16.30%	50.70%	64.20%
Coal	Hybrid	1.15	36.90%	45.70%	54.20%	71.10%	61.80%
Coal	Hybrid	1.44	36.10%	38.60%	78.90%	86.50%	60.10%
Coal	Hybrid	1.56	39.00%	37.10%	83.60%	90.00%	57.70%

- Ammonia slip at 10ppm or less

Since these tests followed a demonstration of SCR capable of 90% NOx removal, more than enough catalyst was present to act as a "safety valve" for the SNCR. Subsequent testing pushed the SCR reduction by injection of SNCR reagent to produce an intentional level of NH_3 slip as catalyst feed. In this configuration, the SNCR NOx reduction was approximately maintained, while the furnace rear wall injectors applied urea reagent. Because of the low space velocity of the stationary catalyst (<6000 hr $^{-1}$), resulting SCR reduction varied from 78-83% at full load. Overall NOx reduction ranged from 86-90%. Overall reagent utilization ranged from 58-60%.

BEYOND PHASE I

Phase II of NOx controls in the United States currently refers to "beyond RACT" controls in ozone nonattainment areas or transport regions, as well as it refers to the statutory acid rain provisions. While the acid rain provisions require NOx limits be promulgated for remaining utility boilers (from Phase I) by January 1, 2000, other requirements are anticipated by May of 1999 for units which must reduce NOx for ozone-related reasons. The "Phase II" requirements will be moderate NOx reductions[5] beyond "RACT" (largely low NOx burners or other combustion modifications), and they will only be required during "ozone season" -- five months out of the year. According to the referenced Memorandum of Understanding[6], more controls may be required in Phase III in 2003.

Such a part-time control requirement, on units already employing primary controls which reduce NOx to 0.38-0.50 lb/MMBtu, complicates the consideration of minimizing lifecycle control costs.

LIFECYCLE COSTS

The use of hybrid SNCR/SCR systems permits "tailoring" NOx reduction and lifecycle cost to the potentially complex future requirements of NOx reduction for ozone mitigation. The total lifecycle cost of the modified SNCR/SCR NOx reduction process is a function of chemical utilization and catalyst size and capital requirement. Very high NOx reductions, of perhaps 90%, require a substantial catalyst volume. This system cannot be placed in existing duct dimensions and will always require, at the very least, major modifications. A modified SNCR/SCR system, providing between 50-60% precatalytic reduction, would require between 75-80% further NOx reduction to achieve 90% overall. This would still demand 88% of the original catalyst volume. Similarly, for an overall NOx reduction of 75%, a stand-alone SCR system requires approximately 88% of the original high reduction catalytic volume. (These design computations are graphed in Figure 2.)

A modified SNCR/SCR process would conceptually be effective for approximately 75% overall NOx reduction. Precatalytic SNCR reduction of 50-60% requires only 38-50% SCR reduction, and no more than half of the original catalyst volume as designed for 90% reduction. This is also only 57% of the catalyst volume required for stand-alone SCR targeted at 75% overall reduction. An "in-duct" catalyst may be used on a site-specific basis to fulfill this half-sized volume requirement.

Prior work at the plant site in development of the commercial-scale SNCR system which exists there indicated that 38% NOx reduction was achieved on a long-term basis within

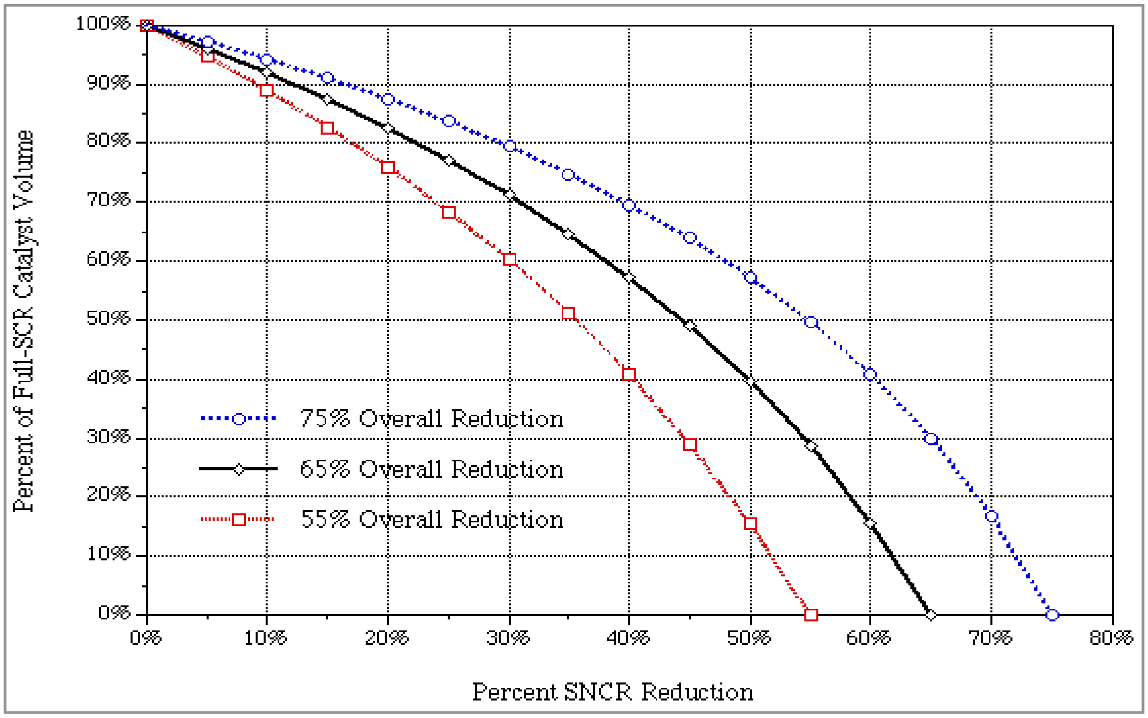

Figure 2. CASCADE Fraction of Full-Scale SCR Catalyst Volume Needed to Achieve the Specified NOx Reduction.

Table 2. Cascade Process Design

Case:		SNCR to 0.3 30% SCR 100% GHI	SNCR to 0.3 30% SCR 75% GHI	SNCR to 0.3 30% SCR 50% GHI	SNCR to 0.3 40% SCR 100% GHI	SNCR to 0.3 40% SCR 75% GHI	SNCR to 0.3 40% SCR 50% GHI	SNCR to 0.3 50% SCR 100% GHI	SNCR to 0.3 50% SCR 75% GHI	SNCR to 0.3 50% SCR 50% GHI
Unit Description										
Unit GHI	[10^6Btu/hr]	746	560	373	746	560	373	746	560	373
Fuel Factor		2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Fw	[SCFw/10^6Btu]	11186	11186	11186	11186	11186	11186	11186	11186	11186
Operating O2	[% w]	2.8	4.0	6.0	2.8	4.0	6.0	2.8	4.0	6.0
Flue Gas Flow	[SCFH - wet]	9635657	7739885	5852530	9635657	7739885	5852530	9635657	7739885	5852530
NOx Before NOxOUT®	[ppmvdc]	584	545	481	584	545	481	584	545	481
	[lb/10^6Btu]	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900
	[lb/hr]	671.4	503.6	335.7	671.4	503.6	335.7	671.4	503.6	335.7
NOxOUT® System										
NOx After NOxOUT®	[ppmvdc]	195	182	160	195	182	160	195	182	160
	[lb/10^6Btu]	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
NOxOUT® Reduction	[%]	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%
NOxOUT® NSR		1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
NOxOUT® Utilization		50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
SCR System										
Inlet NOx	[ppmvdc]	195	182	160	195	182	160	195	182	160
Reduced NOx	[ppmvdc]	136	127	112	117	109	96	97	91	80
	[lb/10^6Btu]	0.21	0.21	0.21	0.18	0.18	0.18	0.15	0.15	0.15
SCR Reduction	[%]	30.0%	30.0%	30.0%	40.0%	40.0%	40.0%	50.0%	50.0%	50.0%
Overall Reduction	[%]	76.7%	76.7%	76.7%	80.0%	80.0%	80.0%	83.3%	83.3%	83.3%
Ammonia at Catalyst Entrance	[ppmvdc]	68	65	58	88	83	74	107	101	90
Ammonia Slip at Exit	5 or 10 ppm	10	10	10	10	10	10	10	10	10
Space Velocity	[1/hr]	50969	50969	50969	44561	44561	44561	34188	34188	34188
Catalyst Volume	[ft3]	453.7	364.5	275.6	519.0	416.9	315.2	676.4	543.3	410.9
Actual Cascade Duct Area	[ft2]	504.0	504.0	504.0	504.0	504.0	504.0	504.0	504.0	504.0
Resulting Cascade Depth	[ft]	0.90	0.72	0.55	1.03	0.83	0.63	1.34	1.08	0.82
Face Velocity (at 360°C)	[ft/s]	11.5	9.2	7.0	11.5	9.2	7.0	11.5	9.2	7.0
CASCADE Summary										
SNCR NOx Reduction		66.7%	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%
Average SCR Reduction		30.0%	30.0%	30.0%	40.0%	40.0%	40.0%	50.0%	50.0%	50.0%
Total Reduction		76.7%	76.7%	76.7%	80.0%	80.0%	80.0%	83.3%	83.3%	83.3%
Overall Utilization		57.5%	57.5%	57.5%	60.0%	60.0%	60.0%	62.5%	62.5%	62.5%

the plant-imposed 5 ppm NH_3 slip constraint[7]. To achieve this level of reduction with a permanent, commercial system required approximately $14/kw capital. Design NSR for urea reagent is approximately 1.0 for the 38% reduction. Equivalently, this is 38% utilization averaged across the load range.

The full-scale SCR installed for the PSE&G demonstration of that technology was capable of achieving 90% NOx reduction and more for the several-month investigation. Installed capital cost for the retrofit was reported to be $90/kw.[8]

The field demonstration of the hybrid SNCR/SCR system verified that on a coal-fired unit, the SNCR-related cost performance can be improved substantially.

The next step for field development of the hybrid concept is design of in-duct (existing duct) catalyst on a pulverized coal-fired unit, with assessment of broad applicability to the various types of boilers within that population. The proof-of-concept field work at PSE&G had the advantage of high-quality coal (~5% ash) being burned in a wet-bottom slagging unit. The bulk of the coal-fired boiler population requiring NOx control will have fly ash concentrations that may be significantly higher than that of the first demonstration boiler.

NFT has designed and commercially proposed a hybrid SNCR/SCR system for field use in such a system[9] located in the Ozone Transport Region. The intent is to reduce lifecycle operating cost by increasing reagent utilization at modest catalyst capital requirement.

In Table 2, design data are given for NOx reduction levels of 30%, 40% and 50% beyond the SNCR emission level of 0.3 lb/MMBtu. The data are provided relative to performance, NSR, and reagent utilization over three load points in the unit operation. The catalyst composition was selected in accordance with the NOx reduction requirements, tolerance of flue gas SO_3 level, and face velocity encountered above the air heater at the insertion point for the catalyst modules. Catalyst weight inserted during the retrofit is 30 tons. Installed, delivered catalyst retrofit cost is $9/kw.

For the 50% reduction case (which in this case reaches the MOU[10] NOx limit for the year 2003 of 0.15 lb/MMBtu) through the load range average NSR is 1.03, with overall chemical utilization of 64%.

CONCLUSIONS

1. The technological feasibility of urea-based SNCR intentionally providing ammonia slip as the sole reductant feed to an SCR was field proven.
2. Large NOx reductions, 90% and greater, are possible with hybrid SNCR/SCR.
3. Overall reagent utilization in a hybrid system can be twice that of commercial SNCR systems, hence lowering lifecycle costs.
4. The next developmental step is field retrofit of SCR within existing duct dimensions of a pulverized coal-fired boiler for operation downstream of commercial SNCR.

REFERENCES

1. Jantzen and K. Zammit, "Hybrid SCR," presented at EPRI/EPA NOx Symposium, Kansas City, 1995.
2. For NH_3, this is lb-mole NOx; for urea the value is two moles of NOx.
3. U.S. Patent 4,780,289, issued 1988.
4. Wallace, A. J., F. X. Gibbons, R. Roy, J. H. O'Leary, E. Knell, "Demonstration of Post-Combustion NOx Control Technology on a Pulverized Coal, Wet-Bottom Boiler," A&WMA, San Antonio, TX, June 1995.
5. Ozone Transport Commission Memorandum of Understanding, Newport, RI, September 27, 1994.
6. Ibid.
7. Wallace, A. J., F. X. Gibbons, J. M. Boyle, J. H. O'Leary, D. Hubbard, "Evaluation of Hybrid and Combined SNCR/SCR for NOx Abatement on a Utility Boiler", EPA Acid Rain Conference, Tempe, AZ, January 1995.
8. Presentation to Ozone Transport Assessment Group, Strategy and Controls Subgroup, Washington, DC, August 24, 1995.
9. Nalco Fuel Tech internal communication from R. A. Johnson, September 13, 1995.
10. Supra, at 5.