Experience With Twelve-Months-a-Year European Operation of SCR as Applied to System Design in U.S., High-Sulfur, Coal Service

William Ellison
Contributing Editor, Power Magazine,
McGraw-Hill, U.S.A.

Helmut Weiler
Director, Weiler Consultants, Germany

INTRODUCTION

Overseas coal-firing experience points to the beneficial role of a high coal-ash content in adequately sorbing SO_3-generation and attendant ammonia slip due to high-dust SCR operation. In near-future, year-round, operation of such U.S. SCR systems in typical high-sulfur, comparatively low-ash, bituminous coal service, significant tendency for air preheater fouling can be expected to challenge adequacy of the supplier's process system design.

JAPAN

In 1980, SCR technology was introduced into commercial service in Japan where it has been applied to more than 23,000 MW of its power stations firing coal in 61 plants. (See reference 1.) Indigenous Japanese coal with comparatively high sulfur has been replaced over the years by low-sulfur imported sources. Experience in use of high (~2%) sulfur coal has been gained at two plants…Shimonoseki (four Units: 5, 6, 7 and 9) of Chugoku Electric Power and Minato 1 (Units 5, 9 and 10) of Kyushu Electric Power Company. These units are 175 MW each (Shimonoseki) and 156 MW each (Minato). Shimonoseki was one of the world's first commercial coal-unit SCR retrofit installations. The design NO_x removal efficiency for these plants is only 55% and 53%, respectively, using high-dust SCR installations. Moreover, the catalyst design for these units was conservative in providing a generous 10 mm pitch. Provision was made to keep the SCR inlet gas temperature above 330^{0}C (625^{0}F) at all loads, thus maintaining it above the condensation temperature of ammonium bisulfate and ammonium sulfate. This was achieved with use of an economizer by-pass system. These plants have been operating for more than 20 years without any reported problems with respect to the critical issue of air preheater fouling…regular soot blowing as well as washing at a specified frequency have contributed to satisfactory performance. The use of enamel coated heat exchanger baskets has not been necessary…unlike most of the German installations. The ammonia slip has been maintained at a level of only 1 ppm or below. The deterioration of air heater performance due to corrosion and or deposition has thereby been successfully controlled. The balance of the Japanese SCR retrofits, as well as the new installations of SCR there, serve boilers firing low-sulfur coal, imported primarily from Australia and South Africa. Consequently, air preheater fouling has been minimal.

OVERVIEW

Europe

NO_x emission of coal-fired units in Germany, Austria, Denmark and Italy has been limited to 200 mg/Nm^3, (0.16 lb/MMBtu), for solid fuels, matching the recent/current, U.S., fleet average requirement, (150 mg/Nm^3 for liquid fuels and 100 mg/Nm^3 for gaseous fuels.)

In Europe, (see reference 2), more than 40,000 MW are fitted with secondary NO_x-reduction systems. The majority of the NO_x-reduction installations apply the selective catalytic reduction process (with only a few boilers using the SNCR process, i.e. in the case of special conditions, e.g. a more lenient emission limit or a low, raw-gas, NO_x concentration.) To reduce the amount of expenditure for secondary deNO_x operation, e.g. ammonia consumption, and analogous to U.S. practice, existing burner systems in dry bottom boiler service have been replaced by low-NO_x burner systems that limit furnace NO_x to 400-600 mg NO_x /Nm^3, (0.32-0.48 lb/MM Btu). With two principal types of firing systems installed in Germany – slag tap (wet bottom) and dry bottom boilers - and based on the results of extensive test runs and operating experience, the decision was made in the mid-eighties, (at the outset of the west German acid rain program), to preferably fit dry bottom boilers with high-dust SCR systems and slag tap boilers with SCR tail-end systems. The latter choice has avoided catalyst poisoning by heavy metals, e.g. arsenic, due to enrichment of such metals when, as is common, in Germany, up to 100% of captured fly ash is recirculated to the furnace. New burners, new coal classifiers, and additional combustion air nozzles were installed on slag tap boilers to achieve NO_x emission levels of 1200 to 1300 mg/Nm^3, (0.96 to 1.05 lb/MM Btu). Due to the high concentration of chemically-bound water in lignite, prevalent in Europe, (and resultant low combustion temperature), advantageous with respect to NO_x, lignite fired power stations (approximately 14,000 MW in North Rhine Westfalia and easternmost Germany) have needed no secondary deNO_x measures. The emission limit of 200 mg/Nm^3, (0.16 lb/MM Btu), is achieved by burner and furnace modification. The proportion of high-dust SCR systems is 68%, (23,800 MW) and of tail-end SCR system 30%, (17,600 MW). (The remainder comprise SNCR and activated coke systems.) 30% of the slag tap boilers are fitted with high-dust SCR and the remaining 70% with tail-end SCR but, on the other hand, 10% of the dry bottom boilers are fitted with a tail-end SCR. Over many years and through the nineties, approximately 80% of the bituminous coal burned in German power stations was indigenous. The composition, with domestic supply mainly from the Ruhr and Saar areas, is well defined…with sulfur content between 0.7-1.3% depending on the degree of physical coal cleaning carried out at the mine. However, coal supply in Germany began changing substantially in 2001. 55% or more of consumption is currently imported, principally from Poland, South Africa, Australia and U.S. The range of concentration of the critical constituents such as CaO, MgO and K_2O in the coal ash has thus increased substantially, in some instances to levels three times higher than that for Ruhr coal.

SCR design and operation criteria:

The design of high-dust SCR installations in Europe has typically included the following features, (see reference 3):

- Standardized catalyst modules, readily replaced
- General criteria for design catalyst-volume based on a maximum ammonia slip as high as 5 ppm in typical low-sulfur service
- Provision for an economizer by-pass (where deemed necessary) to maintain the reactor temperature during low-load periods
- Routine use of flow model tests at 1:10 or 1:20 scale, strongly favored, (especially for boilers burning the low grade coal with high ash content), so as to avoid local deterioration of the catalyst by erosion
- Provision for addition of a spare layer of catalyst material to permit upgrading of deNO_x performance
- A three-dimensional, two-phase flow, computer program
- Fitting of the air preheater in the cold-end layer with enameled steel heating plates to avoid steel corrosion by condensed sulfuric acid. (A heating-plate surface-profile is chosen that is easy to clean, in situ, by soot blowers so as to avoid permanent plugging and fouling.)

OPERATING EXPERIENCE

SCR Overview

Extensive European activity (following extensive retrofitting of high-dust SCR in the 1980s), points to important, special, process design provisions that can be made, seeking to assure unit reliability in the U.S. upcoming challenging, yet-to-come, 24/7, secondary deNO_x service with high-sulfur coal:

- A catalyst with low SO_2-to-SO_3 conversion
- Ammonia injection upstream of the economizer to address boiler-formed SO_3
- Provision for alkali injection upstream of the air preheater to abate catalytic SO_3 formation
- Precisely uniform distribution of flow and flow characteristics within the SCR reactor
- Low ammonia slip.

Commercial SCR operations in U.S. high-sulfur service are at a comparatively early/ preliminary stage, lacking year-round high-load demonstration operation with specified deNO_x performance, often calling for 90% NO_x removal efficiency. (See references 4 and 5.) Cichanowicz and Smith have combed and assessed early real-time experience reflected by publicly available CEMS data, (routinely submitted to the EPA by each electric utility). Their late-2002 review indicates a significant deNO_x shortfall, i.e. in meeting the typical, 90% design SCR NO_x

removal efficiency. This was the case for all five (5) such large units, (of capacity 600 MW and above, firing high-sulfur coal), that began earliest commercial operation (and during the period, 1999 to early 2002.)

Removal efficiency shortfall at high load for these has ranged from 3 points, (wet bottom boiler operation), to 15 points, (dry bottom boiler operation), the latter performance spanning more than 5,000 overall hours of such high-load boiler operation. Moreover, as emphasized by Sanyal and Pircon, (see reference 6), the uniquely high, fuel sulfur levels in much of U.S. bituminous coal supply is accompanied by correspondingly high arsenic concentration (with the potential, without suitable coal treatment, for accelerated poisoning of SCR catalyst.) Thus even at this late date, and in consideration of a newly pending requirement for year-round operation, fullest recognition, understanding and use/application of specifically relevant (or "extrapolated") European experience, presented herein, could prove invaluable over time in managing the most challenging of U.S. high-sulfur applications. (Note that in light of the very wide scatter of the above reported, periodic, short-term readings, the performance implications are no doubt greater for SCR operation at newly built, U.S., high-sulfur coal units, this because of the comparatively short, emission-rate, averaging times that routinely apply in the new-plant construction/operating licensing process.) Unlike U.S. circumstances, relevant high-sulfur bituminous-coal fueling is very limited in Europe (and particularly in Japan.) Nonetheless, many valuable guidelines for reliable SCR performance are to be found from such long-term German experience beginning in the 1980s in applying SCR in this now common type of SCR service in the U.S. Principal insights are as follows:

- The most notable high-sulfur bituminous service in Europe, (see reference 7), entails firing, in part, of middlings from mine-mouth, physical coal cleaning operations in Germany. This fueling generates an SO_2 concentration equivalent to that of 2.7% sulfur, high-Btu, bituminous coal…this low-grade fuel containing ash content up to 40%, creating flue gas particulate loading in excess of 50 grams/m^3. Due to the scouring action of the ash extra effort has been necessary at such plants with high-dust SCR facilities, (e.g. VKR's Knepper Station C and Scholven Station, Steag's Herne Unit 4 and Walsum Unit 9, and Preussenelektra's Staudinger Units 1 and 2), to minimize catalyst plugging and erosion. (See references 8, 9, 10 and 11.) This is furthered by greater striving for nearly uniform, cross-sectional, gas-flow-velocity and dust-concentration profiles. But the uniquely high fly-ash loading desirably mitigates against air preheater fouling…as gas phase, ammonium bisulfate formed is largely sorbed by the gasborne particulate. Thus, uniquely, 70 to 80% of the ammonia salts is advantageously collected in the downstream electrostatic precipitator and only 10-20% in the air preheater.
- Means for tight control of SCR-reactor inlet temperature, (including provision for an adjustable, economizer gas by-pass), may be essential. SO_3 formation increases greatly when this temperature exceeds approximately 350^oC (660^oF).
- Nearly uniform flow distribution in the SCR reactor is essential. NO_x mass flow rate should not vary, cross-sectionally, more than + or – 20%, NH_3/NO_x ratio no more than + or – 5%, gas temperature no more than + or – 25^oC (45^oF) and particulate mass flow rate no more than + or – 30%.

- A good case can be made for limiting ammonia slip, i.e. measured at the air preheater inlet, to no more than approximately 1.5 to 3.0 ppm. This calls for close monitoring and sustaining of catalyst activity, increasing catalyst volume and/or activity in a timely manner by use of the spare/reserve layer or by periodic catalyst replacement.
- For up to 2/3 of the air preheater height, enamel plating is needed on the flue gas side for protection within the critical flue gas temperature region. Heating plate surface-profile and grooving is selected for ease/effectiveness of in situ soot blowing.
- Catalyst formulation should be modified as necessary to minimize catalytic oxidation of SO_2 to SO_3. Sanyal and Pircon urge, further, productive development of non-vanadium based catalyst for improved SCR performance and cost effectiveness.
- To limit SO_3 formation, catalyst charge, if any, known to be in excess, should be removed. This as contrasts with current typical U.S. SCR practice in designing for extra-low, outlet NO_x concentration, i.e. 0.055 to 0.12 lb/MM Btu, (even in high-sulfur service), rather than the present, nominal, regulatory target level of 0.15 lb/MM Btu, (e.g. to counter-balance economy-based planning for under-compliance at other, lesser, owned units). European operating conservatism on the other hand emphasizes the need to seek the most reliable, high-availability, SCR operation with no greater NO_x abatement (at any individual unit) than required.

If problems arise downstream of a high-dust SCR system, the resolution is often found by correcting any known malfunctioning of the SCR system:

- Poisoning of catalyst by arsenic, which can be avoided by addition to coal of limestone in the amount of 1-3%
- Optimization via flow model tests of the position and routing of the flue gas ductwork…leading to means of desired gas homogenization and to achievement of uniform gas velocity distribution
- Optimization of combustion, avoiding coarse ash/coke-particles; also by installation of catalyst elements with increased pitch, e.g. 10 mm instead of 7 mm

Fly Ash, Ammonia Slip and SO_3

Fly ash contamination by ammonia, a result of SCR use, can be a significant hindrance in byproduct management in coal-fired operation. In the typical case in Germany of firing of coal of low-sulfur with modest ash concentration, the early, 5 ppm, ammonia-slip criterion has been commonly found to be unsatisfactory for limiting ash ammonia content to the 80 mg/kg, (80 ppm), odor threshold. Ammonia-slip levels as low as 1 to 1.5 ppm are necessary to ensure marketability of fly ash. Ammonia slip in combination with elevated flue-gas SO_3 concentration may, more significantly, lead to gas-phase reaction products and air preheater fouling that impairs plant availability. The degree of such impact is, at the same time, a function of a great many factors in Ljungstrom air preheater site-specific design, (as detailed in reference 12). The NH_3 concentration in the collected fly ash depends on several parameters. Moreover, the most suitable (practical) means to routinely measure changes in the ammonia slip is to analyze the collected fly ash. It is a well-used and preferably applied method to track ammonia slip level over the course of time. Adequate quality of fly ash is of essential importance in Germany due to the fact that nearly all fly ash has to be commercially used. Only limited land space is available for discarding fly ash and, thus, throwaway disposal is very expensive. To avoid problems with ammonia contamination of fly ash and to avoid significant ammonia odor from it in its commercial use, the ammonia content of fly ash supply should not be higher than 100 ppm. Laboratory and field tests have verified that the structural properties of concrete containing fly ash contaminated with up to 2,000 ppm of ammonia are not affected by the ammonia…but that there is an oppressive odor of ammonia in use of such highly contaminated fly ash. Several German investigations and studies have clearly shown that thermal or chemical treatment of contaminated fly ash to mitigate carbon content is not sufficiently cost effective. With ash content in coal generally above 5%, experience has clearly shown that, instead, an improvement of the $deNO_x$ system operation is always the best technical/ commercial solution. Thus, no fly ash treatment plants have been erected and operated in Germany.

Due to complex cyclical influences, including boiler soot blowing, a resulting continuous variation in the SO_3 concentration of the boiler gas is ominous and costly in and of itself in some high-sulfur applications of SCR. (Retrofitting of SCR can increase SO_3 generation and exacerbate any preexisting SO_3 problem.) To begin with, SO_3 is generated both in the furnace, i.e. homogeneous/gas-phase interaction of SO_2 with atomic oxygen, and in the downstream, convective pass, i.e. temperature and tube-surface-area dependent, heterogeneous/ catalytic oxidation of SO_2 by molecular oxygen. Below 600^{o}F (316^{o}C), SO_3 combines with H_2O (v) to form H_2SO_4 (v). Some of this acid condenses onto cold surfaces (T <280^{o}F, i.e. 138^{o}C) and is adsorbed onto gas-entrained fly ash. A simplistic, EPA-based, proportionality constant indicates that a nominal 0.7% of flue-gas SO_2 becomes oxidized to SO_3 by the boiler. But, due to an array of factors, including the cyclically varying catalytic-oxidation influence of iron, i.e. iron oxide, (present in both the boiler tube material and in ash), a broad range of SO_3 concentration may be experienced daily. This is because:

- The rate of oxidation of SO_2 to SO_3 by iron oxides peaks at 1300^{o}F, (704^{o}C).
- Periodic, low-temperature, soot blowing boiler gas at 1100 to 1600^{o}F, i.e. 593 to 871^{o}C, brings SO_3 formation to a peak by causing exposure and enhancing the significant catalytic oxidation brought about by boiler tube metal.

Power company NYSEG, (Binghamton, NY), has reported that continuous variation in the degree of tube fouling in its boilers has, at times, through influence on rate of catalyzed SO_3 generation, created significant cyclical episodes impacting the air preheater. A focused, Penn State/NYSEG model study has emphasized the complex catalytic influence on SO_2 oxidation of the iron oxide coated surface of the exposed superheater metal: operation with a clean superheater was shown to result in 20 ppm flue-gas SO_3 concentration, and a heavily fouled superheater yielded 32 ppm while with a moderately fouled superheater the amount was the highest: 70 ppm!! Moreover, even in the absence of high-dust SCR facilities, (and attendant ammonia slip and boost in SO_3), some high-sulfur plants have a significant history of air preheater fouling associated with such high levels of boiler generation of SO_3. TVA's large, high-sulfur, Cumberland Station, with a comparatively high rate of SO_3 formation, has experienced 60% capture of resulting raw-gas SO_3 content in the air preheater, resulting in severe air preheater plugging that required periodic unit derating. (The situation was somewhat alleviated, substantially improving unit reliability, by increasing the pressure of the air preheater soot- blowing steam supply). The complexity of this issue is evidenced by the fact that, transversely/horizontally, across the width of the air preheater exit duct, gas SO_3/H_2SO_4 concentration transitions from 10 to 25 ppm due to the cyclical mechanical functioning of commonly applied, Ljungstrom air preheaters. Additional preheater-related aspects include the adverse effects of:

- Prevailing internal leakage from air side to gas side
- Physical displacement of flue gas into the air stream and visa versa
- Pronounced acid formation (within the flue gas stream and on contacted internal metal surfaces) in the localized regions of low air/gas and metal temperature (causing significant corrosion including that brought about by acid-wetted, sticky ash and salty deposits.)

Environex, (Wayne, PA), in the face of such adversity, has indicated that unless the amount of vanadium in the SCR catalyst is greatly restricted, inlet-gas SO_3 concentration may be further increased by as much as 20 ppm by the operation of a high-dust system. In conjunction with its urging to wisely limit SCR design NO_x removal efficiency to 70%, (a significant retreat from 80 to 90% levels achieved for SCR in low-sulfur coal service in western Germany's massive retrofit deNO_x program in the 1980s), it proposes that ammonia slip at the SCR exit can/should (in the interest of air preheater operational reliability) be limited to 5 ppm. This includes the critical period of many weeks of operation toward the end of a typically long, boiler operating campaign. In conjunction with regularly scheduled, off-line washing of the air preheater, this ammonia management is intended to provide adequate means for management of air preheater fouling otherwise resulting from condensation of SO_3/ammonia, gas-phase, reaction products.

Depending on the boiler type, slag tap or dry bottom boiler, coal composition and boiler operating conditions, the average SO_2-to-SO_3 conversion rate in the boiler can range as high as 1.5%. Significant, additional, SO_3-concentration increase is caused by high-dust SCR systems. Measured overall SO_3-conversion rates are 1.0 to 4.5%, depending mainly on catalyst type and operating temperature. (See reference 13.) In several power plants in Germany, H_2SO_4 concentration of 140 mg/Nm³ (32 ppm) is measured downstream of SCR. There are results from 3.3% sulfur, residual oil fired power stations wherein H_2SO_4 concentrations of 200 mg/Nm³ (45 ppm) are measured upstream of high-dust SCR and 330 mg/Nm³ (74 ppm) downstream. (See reference 14.) To eliminate or minimize the aerosol plume opacity, several reagents have been applied on a trial basis but without great success. Only ammonia injection in the economizer delivers adequate results, but acid aerosol is substituted by a visible ammonium salt plume since, to achieve a high SO_3 removal efficiency, excess ammonia has to be injected. By contrast with the extremes of SO_3 generation in oil fired stations, related problems (e.g. aerosol plume generation) have not been encountered in coal fired stations because the latter stations, i.e. in Germany, forming high flue-gas SO_2 concentration, are normally burning middlings from coal cleaning operations, i.e. low grade coal, (as noted earlier), with very high ash content that effectively sorbs SO_3.

Addressing Operational Problems

There are unique challenges to generating-unit availability for U.S. plants applying high-dust SCR in fuel use of our common high-sulfur/low-ash coal. But related overseas SCR operations and experience can offer good system engineering and operational guidance. Based on German experience since the late 1980s the unimpaired function of components downstream of high-dust SCR installations depends on suitably tailored design and guarded operation of such facilities. If the functioning of SCR is adversely affected by (a) design inadequacies or (b) changing operating conditions, leading to either fouling, poisoning or plugging of the catalyst, …air preheater fouling and fly ash quality problems will be soon magnified! Moreover, limiting of design ammonia-slip to no more that 2 ppm, measured at the air preheater inlet, may be crucial for U.S. applications, particularly where SO_3 has already been a significant concern prior to retrofit addition of SCR. This calls for close monitoring of catalyst activity, increasing catalyst volume and/or activity in a timely manner by use of a spare/reserve layer or by periodic catalyst replacement. Also, to enable the sustaining of catalyst performance, the ammonia content of the collected fly ash should be measured daily in an attentive manner. Means for tight control of SCR-reactor inlet temperature may be essential, (including provision for an adjustable, economizer gas by-pass to maintain an adequately high reactor temperature at low load). Recognize, conversely, that SO_3 formation by SCR increases greatly when this temperature exceeds approximately 350^{o}C (660^{o}F). The back end flue-gas temperature should be stabilized, in part, by tempering of inlet combustion air, e.g. in cold weather operation.

The most notable high-sulfur bituminous service in Germany entails firing of discarded middlings, called "ballast coal", from mine-mouth, physical coal cleaning operations of parent coal companies that own IPPs such as Steag. This fueling generates an SO_2 concentration equal to that formed in firing of a 2.7% sulfur, high-Btu, bituminous coal…with the fuel containing ash content up to 40%, creating gross flue-gas particulate loading in excess of 50 grams/Nm^3. Due to the scouring action of the gasborne ash extra effort has been necessary at such plants equipped with high-dust SCR facilities, (e.g. VKR's Knepper Station C and Scholven Station, Steag's Herne Unit 4 and Walsum Unit 9, and Preussenelektra's Staudinger Units 1 and 2), this to minimize catalyst plugging and erosion…this by the further striving for nearly uniform, cross-sectional, gas-flow-velocity and dust-concentration profiles. However, the uniquely high fly-ash loading desirably mitigates against air preheater fouling…as gas-phase, ammonium bisulfate formed is largely taken up (sorbed) by the uniquely large amount of gasborne particulate. Thus, 70-80% of the ammonia salts is collected (as sorbed particulate) in the downstream electrostatic precipitator and only 10-20% in the air preheater.

- In a few cases, ignition of fly ash deposits containing a great amount of unburned carbon has occurred on the catalyst surface. This problem is now avoided by expanding the soot blowing program to provide for intensive blower operation immediately before boiler shutdown.
- Blocking of catalyst by coarse fly ash particles in high-dust SCR applications is avoided by:

  - Optimization of the combustion system, coal blending, etc.
  - Optimization of the soot blowing system and its cyclical operation

- Use of catalyst with increased pitch
- Employing wire netting upstream of the SCR reactor.

German power station operators indicate that during normal operation and when design conditions, conservatively selected, are fulfilled there have been no serious deficiencies observed with the air preheater, ESP or FGD. Only when the catalyst performance fails to meet design conditions do problems arise downstream of SCR. Malfunctioning, blockage in or incorrect adjustment of the ammonia injection system can lead to an increase of ammonia content in fly ash and the FGD-wastewater discharge. In these circumstances, fly ash blending is used to meet fly ash standards, and, before discharge, the wastewater is diluted with an amount of ammonia-free, water supply. When washing of the air preheater is carried out, the exit wash water contains a major amount of ammonia salts and heavy metals, which are not allowed to be discharged to the municipal sewer or to receiving streams. After chemical treatment the wash water can be added to the recirculating cooling tower water system and the ammonia stripped to the atmosphere in the cooling tower, or a steam-heated, stripping column is used. The ammonia content of the discharged wastewater has to meet a 10 mg/l limit.

Catalyst Management

With current strict cost control practice in Germany, expense for maintenance and repairs is curtailed so far as possible without affecting safety and availability. Depleted catalyst elements are preferably cleaned up and reused instead of being replaced. The disposal of a great amount of catalyst material has thereby been avoided. The regeneration of the catalyst material uses 3 steps:

- Washing
- Ultrasonic (mechanical) cleaning
- Chemical reactivation.

Approximately 10,000 cubic meters of catalyst material has thereby been reactivated in Germany. (It is believed that approximately 2,500 cubic meters of catalyst has been regenerated in the U.S.) Successful regeneration has been accomplished with diverse catalyst types: plates and honeycombs, these with large and small pitch, from different suppliers, used either in coal and oil fired power plants or in waste incineration plants. Depending on site constraints the regeneration time for a 200 m^3 quantity of $deNO_x$ catalyst is between 7 and 10 days. The reactivated catalyst has been meeting originally specified reaction coefficients and SO_2/SO_3 conversion coefficients, thus avoiding ongoing operational and corrosion problems with the air preheater and ducts. Plugging of catalyst elements by popcorn ash in some services results in increased pressure loss, reduced catalyst efficiency and increased ammonia slip and can cause abrasion of unplugged catalyst portions due to higher local flow velocity. This can be avoided by installation of a popcorn separator, which screens out the coarse particles upstream of the catalyst bed. The system is newly installed in 2 power plants and results will be available for publication within the next year.

DESIGN EMPHASIS

A Most Crucial Factor, Homogeneity Within the Reactor Gas Flow Space

Nearly uniform, transverse, distribution of flow characteristics within the SCR reactor is essential. NO_x mass flow rate should not vary, cross-sectionally, more than + or – 20%, NH_3/NO_x concentration ratio no more than + or – 5%, gas temperature no more than + or – 30%. Comparable stringency throughout several ozone seasons in some U.S. retrofitting has, we believe, gained sustained, high availability.

Moderation of SCR Duty

Moreover, to limit SO_3 formation, catalyst charge, when known to be in excess, should be removed. Typical U.S. SCR practice to date includes designing for extra-low, outlet NO_x concentration, i.e. 0.05 to 0.1 lb/MM Btu, even in high-sulfur service, rather than the present, regulatory, fleet-average, target level of 0.15 lb/MM Btu. (This strategy seeks to provide counter-balance in economy-based planning for acceptable under-compliance at other, less significant units of the Owner). European design and operating conservatism on the other hand emphasizes (in challenging applications) the need to seek the most reliable, high-availability, high-dust SCR operation with no greater NO_x abatement (at any individual unit) than absolutely necessary.

Proposed Design Criteria for the U.S. Bituminous Coal Service

With familiarity with high-sulfur experience of European electric utility owners of high-dust SCR systems retrofitted in the 1980s the following special provisions for the substantially more challenging, U.S. applications in typical low-ash, high-sulfur, coal-fired service (uncommon in Europe and elsewhere) are recommended:

- A catalyst with a low SO_2-to-SO_3 conversion rate, i.e. less than 0.4%
- Ammonia injection upstream of the economizer when necessary to adequately moderate air preheater acid corrosion and stack emission of sulfuric acid aerosol…this accomplished with sacrifice in the quality of collected fly ash
- Alkali injection upstream of the air preheater
- Enameled heating plates on the flue gas side of the air preheater extending to up to 2/3 of the plate height
- Protection against corrosion of the casing and rotor structure on the cold side of the air preheater
- Optimal means for adequate, in situ, soot blowing action within the air preheater.

SUMMARY

General

Despite uniquely greater challenges in SCR application for U.S. plants in their extensive use of high-sulfur/low-ash coal fueling, the somewhat comparable, European SCR operations and experience provides good design and operational guidance. Generally, the proper functioning of components downstream of high-dust SCR installations depends on the suitably tailored design and proper operation of the SCR system. If the functioning of SCR is adversely affected by design inadequacies or changing operating conditions that lead to fouling, poisoning or plugging of the catalyst, resulting problems with air preheater operation and fly ash quality can be significant. Moreover, limiting of design ammonia-slip to no more than 2 ppm may be crucial for the most challenging of such U.S. applications, particularly where SO_3 generation and impact were already a significant operating problem prior to retrofitting of SCR facilities. In a rigorous manner that enables means of sustaining catalyst performance, the ammonia content of the collected fly ash should be measured daily. Conversely, when operations indicate that catalyst charge is excessive, it should be reduced so as to limit SO_3 generation. Back end flue-gas temperature should be stabilized (maintained), in part, particularly in cold weather operation, by tempering of inlet combustion air. Mitigation of boiler SO_3 generation and minimization of the impact of SCR, (in its generation of SO_3 and release of ammonia slip), will clearly be important in the generally more difficult, high-sulfur, SCR applications in the U.S. Adequacy of such design/operating provisions will, in turn, be highly dependent on sustained, unfettered performance of the in-place, SCR catalyst charge.

Additional Pointers

To cognizant European SCR system Owners (familiar especially with high-sulfur experience with high-dust SCR systems retrofitted there in the 1980s) the following special provisions are believed warranted for the unique and more challenging, U.S. applications that face operation in pending, year-round, day-in/day-out, low-ash, high-sulfur, coal-fired service, (the latter uncommon in Europe and elsewhere):

- A catalyst with a low, SO_2 to SO_3 conversion rate, i.e. less than 0.4%
- Ammonia injection upstream of the economizer when necessary to adequately moderate air preheater acid corrosion and stack sulfuric acid aerosol emission
- Alkali, e.g. $Mg(OH)_2$, injection upstream of the air preheater to further suppress SO_3
- Protection against corrosion of the casing and rotor structure on the cold side of the air preheater
- Optimized on-line soot blowing action within the air preheater.

Proof of the Pudding

The extensive, relevant, long-term, European field experience referenced herein will be useful in providing guides and insights as to appropriate, conservative, design and operating measures…to be justified by resulting sustained deNO_x system performance and high generating-unit availability.

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