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ABBREVIATIONS

GLOSSARY

INTRODUCTION

The NOx O&M Training Manual is a comprehensive collection of detailed technical information on Combustion NOx Control Equipment and Selective Catalytic Reduction (SCR) used on coal-fired units to reduce NOx emissions.

In an industry where the tribal knowledge is being lost at an alarming rate, this manual is a must for all companies with coal-fired units.

The benefits of this manual include:

- Enabling early detection of operating problems
- Decreasing susceptibility to incorrect problem resolutions
- Minimizing lost time in training due to job reclassification
- Reducing the dependency on third party consultants

0.1 Manual Objectives and Disclaimer

Manual Objectives

The NOx O&M Training Manual has been designed as both a training and reference manual, making it a necessary tool for the new operator as well as the experienced individual.

It is a modern, comprehensive training manual that combines theory, chemistry and design with a practical hands-on, day-to-day approach to Combustion NOx Control Equipment and SCR maintenance.

It has been formatted to be a state-of-the-art, interactive, on-line training tool filled with reference materials, tutorials, video clips and search capabilities which serve to enhance and clarify the comprehensive technical material included.

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0.2 NOx History

Engelhard Corporation, which determined that ammonia reacts with NOx over a catalyst, even in the presence of oxygen, originally investigated Selective Catalytic Reduction (SCR) technology in the U.S.A. in the 1950s. It was not until the late 1970's and early 1980's, that the first Selective Catalytic Reduction systems were actually installed on electric generating stations in Japan.

In 1984, new German national emission standards were issued restricting nitrogen oxides (NOx) emissions from coal-fired power plants larger than 300 MW to a maximum of 200 mg/dscm. As a result, over 30,000 MW of coal fueled generating capacity were retrofitted with SCRs. The German experience was based on the use of German coals and Japanese catalyst knowledge.

In the early 90's, ENEL, the Italian utility, began to research SCR technology in preparation for retrofitting existing power generating plants, both coal and oil fired. SCRs were eventually installed on several ENEL units, including novel designs such as in-duct systems.

Legislature in the U.S.A. has resulted in the retrofitting of NOx reduction technology in 22 states, setting the NOx emission limit at 0.15 lb/Mbtu designed to generally achieve a 70-85% reduction. Many of the retrofitted units already had installed low-NOx burners to meet Phase I of the Clean Air Amendment. Most of the U.S.A. SCRs were installed between 2000 and 2005 for operation on a seasonal basis during high NOx months.

Year-round operation of NOx reduction technology is required as of January 1, 2009 by the Clean Air Interstate Rule (CAIR), which ruling was previously vacated by the Supreme Court in July 2008 citing "more than several fatal flaws". In a decision applauded by environmentalists, the U.S. Court of Appeals for the D.C. Circuit issued an order on December 23, 2008 that leaves the Clean Air Interstate Rule in effect while the U.S. Environmental Protection Agency develops a new clean air program for power plants. The court essentially reversed its previous ruling made in July 2008, thereby sending CAIR back to the EPA for retooling.

0.3 NOx Formation

NOx is defined as the total of NO and NO_2 where:

- **NO = Nitric Oxide**
- **NO_2 = Nitrogen Dioxide**

Stack emissions are typically over 95% NO

The following three types of NOx productions can occur naturally during coal combustion:

- **Thermal NOx** - Produced from the nitrogen in the combustion air
- **Fuel NOx** - Produced from the nitrogen in the fuel
- **Prompt NOx** - Neither thermal or fuel NOx, requires carbon to be present to form

Typically coal contains approximately 20% thermal NOx and 80% fuel NOx.

The primary factors affecting NOx are:

- **Time** - The amount of time that the burning lasts
- **Temperature** - temperature to which fuel and air are subjected
- **Turbulence** - The mixing of the fuel and air
- **Stoichiometry** - the relative amounts of fuel and combustion air

Time

The time required for fuel burn out is a function of the particle size. To provide complete burnout, the particle size should be kept to a minimum. Fuel/air mixing rates regulate the burn rate and thus the resulting average combustion temperature.

Temperature

Most NOx is produced at temperatures above 2800 degrees Fahrenheit. To minimize NOx, the average combustion temperature should be kept as low as possible. The flame can be lengthened to provide more time for burnout and therefore lower combustion temperatures.

Heat rate affects the combustion temperature. As the heat release rate in the furnace increases, the resulting combustion temperature also increases. Older units were designed to have small furnaces and therefore have higher burner zone heat release rates. Newer NSPS units were designed with larger furnace with cooler burner zones.

Turbulence

Turbulence is required to completely mix the fuel and combustion air. Too much turbulence promotes rapid burning and high NOx production. Low-NOx combustion mixes fuel and combustion air more slowly and in more stages to reduce NOx production.

Stoichiometry

A stoichiometry of 100% or a stoichiometric ratio of 1.0 represents the exact amount of combustion air required to completely burn the fuel. Excess air is the amount of air supplied above 100% stoichiometry. The stoichiometry in the burner zone is less than 100% to minimize the mixing of air and fuel at the high temperatures present. The remaining combustion air and any excess air is mixed as overfire air. Fuel and air do not perfectly mix. If 100% air were supplied, not all fuel would combust. Excess air provides the amount of air required to compensate for the inefficiencies of mixing.

CHAPTER 1 - COMBUSTION NOx CONTROL EQUIPMENT

This chapter discusses the principles of combustion NOx control using low-NOx burners, low excess air, and overfire air and the unique issues relating to NOx control in cyclone boilers.

1.1 Low-NOx Burners

1.1.a Tangentially-Fired Boilers

In this type of boiler, the fuel and air nozzles are stacked into each corner of the furnace and aimed at an imaginary cylinder near the center. Fuel and air are admitted at several elevations and arranged so that each fuel nozzle has secondary air nozzles above and below it. Dampers that control the airflow to each compartment make it possible to vary the amount of air and the rate of mixing over the height of the wind box. These fuel and air nozzles can also be tilted in unison to control steam temperature and/or reduce NOx emissions.

Tangentially-fired combustion systems are inherently lower NOx producers than wall-fired combustion systems because a fuel-rich region exists from the fuel nozzle to the fireball. Over the last decade, burner suppliers have enhanced this reducing zone by modifying the coal buckets to better establish ignition close to the coal nozzles. The most common modification is the addition of "teeth" in the coal nozzle to create small areas of turbulence that assure flame attachment. These teeth need to be checked and replaced on a regular basis to assure optimum burner performance.

Also, it was found that NOx could be reduced by aiming the air nozzles 25 degrees outboard of the fuel nozzles to make the center of the fireball less fuel-lean. This modification is called "Low-NOx Concentric Firing" (LNCF). In this system, some of the secondary air (called fuel air) is injected parallel to the primary fuel-air stream while the balance (called auxiliary air) is injected toward the adjacent wall and away from the fuel.

1.1.b Wall-Fired Boilers

When existing boilers are retrofitted with low-NOx burners, the burners are usually selected to fit within the furnace configuration. For practical purposes, this requires that the new burners fit into the openings for the old burners, and that the flames fit within the confines of the furnace box. Straight pipe coal nozzles were replaced by new pipes containing internal and external flow distribution devices (venturis, kicker plates, teeth, et al). New burner registers were designed to provide multiple zones of secondary air, and to separately control the amount and swirl of the air in each zone. Finally, the shape of the burner quarl (conical-shaped entrance to the furnace) was changed to make the ignition zone more aerodynamically stable over a wide range of load conditions.

The B&W DRB-XCL and DRB-4Z burners are a good example of this burner type. Secondary air may enter the two annular regions that surround the central coal pipe. A smaller portion of air is admitted to the inner zone and highly swirled to enhance ignition and flame stability. The larger portion of air is admitted to the outer zone with moderate swirl to gradually mix on the outskirts of the flame. Total airflow to each burner can be regulated by a sliding disk and can be measured by a Pitot tube grid installed within the burner. Swirl to each air zone can also be controlled by adjusting vane angle (though most utilities maintain the original settings established during start-up). The 4Z burner adds a third inner air annulus controlled by a second sliding disk to fine-tune the mixing of the fuel-rich central flame with the surrounding combustion air.

One manufacturer has developed a split-flame burner that contains a single air annulus. However, this design is different in that the coal and primary air stream is mechanically split into four streams to increase the area within which the fuel-rich region mixes with secondary air. There are no clear cut advantages to any low-NOx burner type, but there are tradeoffs depending on furnace design constraints. There are no low-NOx burner designs for cyclone boilers and a few other specialized boiler types.

1.2 Low Excess Air

It should be obvious from the above discussion that operating with low excess air will minimize both thermal and fuel NOx by reducing the available oxygen in the flame. It is also well known that low excess air will improve boiler efficiency and reduce operating costs. Reducing average flue gas O_2 level from 3.6% to 2.2% will usually achieve a 20% reduction in NOx emissions and reduce heat rate by about 1.5 percent. So why are so many plants hesitant about cutting back on combustion airflow to the extent possible?

The answer is that bad things can happen when excess air goes too low. To compound the matter, many older boilers have inadequate instrumentation to measure flue gas O_2, and boiler casings may leak in "tramp air" so that the measured flue gas oxygen may be different from the furnace exit oxygen content. Therefore, operators may have inadequate warning when airflow is too low.

Air distribution is more of a concern when firing with low excess air, since only one or two burners starved for air can affect performance of the entire unit. If excess air is too low, you are likely to see darker fly ash that may not be salable due to excessive unburned carbon. High fly ash carbon can also lead to opacity spikes in more marginal precipitators. Flames also tend to get longer with low excess air, and can impinge on adjacent or opposite wall tubes. Flame impingement can shorten tube life by both removing the protective oxide layer from the tubes and depositing sulfur species that cause accelerated corrosion.

In general, low excess air operation (typically, but not always below an average flue gas oxygen content of three percent) is not recommended without advanced instrumentation to help keep burners operating at the desired air-fuel ratio. Such instrumentation could include air and fuel measurement for each burner, advanced flame quality monitors for each burner, or an array of O_2 and CO sensors that can be related to specific burners or groups of burners. Increased coal fineness (greater than 80% through 200-mesh) may also prove beneficial for reducing excess air levels. These technologies will be discussed later in this chapter of the NOx Manual.

1.3 Overfire Air

NOx is reduced by Overfire Air by diverting enough of the combustion air from the windbox so that all (or most) of the burners are running slightly fuel rich. The remaining combustion air is injected into the furnace through specially designed ports that are usually located above the burners (hence the name "Overfire Air Ports," or OFA for short). When operating fuel-rich, the burners cannot completely burn the coal, so the main purpose of the OFA ports is to mix in the air quickly enough to complete the combustion process within the furnace volume. The farther the OFA is from the main flames, the lower the NOx emission.

In operation, NOx emissions can be correlated to the burner zone stoichiometric ratio (SR). SR is defined as the air-fuel ratio in the burner zone divided by the theoretical air-fuel ratio derived from the fuel analysis. The design point is typically a SR of 0.90, although SR as low as 0.75 have been used with certain low-sulfur coals (especially PRB coals). At these design points, OFA is capable of reducing NOx emissions by 50 to 70 percent, but such high reductions are seldom sustainable in practice.

One limitation of deeper staging is less flame stability as burner throat velocity falls off when the secondary airflow is reduced (especially at reduced load). In some cases, manufacturers have replaced the old burners with new burners having smaller throats so that proper velocities can be maintained. The downside of this design strategy is higher NOx emissions if the OFA ports are closed.

OFA ports are designed and arranged to mix air with the fuel-rich gases quickly enough to achieve complete combustion, but slowly enough to minimize NOx emissions. This is no easy task! The air jets must have enough momentum to penetrate through the furnace gases to assure complete front-back coverage. This requires fewer, larger air ports. However, overfire air must also be dispersed evenly across the width of the boiler. This implies more, smaller air ports. Balancing these conflicting mixing requirements often involves advanced computer modeling of the flow fields, but even then OFA design is as much an art as a science.

One manufacturer offers a dual-zone OFA port design that allows the boiler operator to control mixing more closely. This port contains an inner air zone with a manually adjusted sliding disk to control axial airflow (air penetration deep into the furnace). There is also an outer zone equipped with swirl vanes that provide enhanced mixing near the port. In practice, this works well in conjunction with a CO sampling grid in the economizer outlet duct. When CO spikes are detected in a particular location, more axial air is added to the OFA port affecting that region until the spike goes away.

Most OFA ports are connected to the windbox and use hot combustion air. The amount of overfire air in these systems is limited by fan static pressure and the size of all the openings (burners and OFA ports) into the furnace. Booster fans can be used to raise static pressure (Nalco, formerly Mobotec) and achieve better mixing, but at some cost. If hot air is used, these booster fans tend to be massive and very expensive. If cold air is used, then boiler efficiency is reduced and combustion efficiency may also suffer. Therefore, tradeoffs must be made regarding higher operating cost and lower NOx.

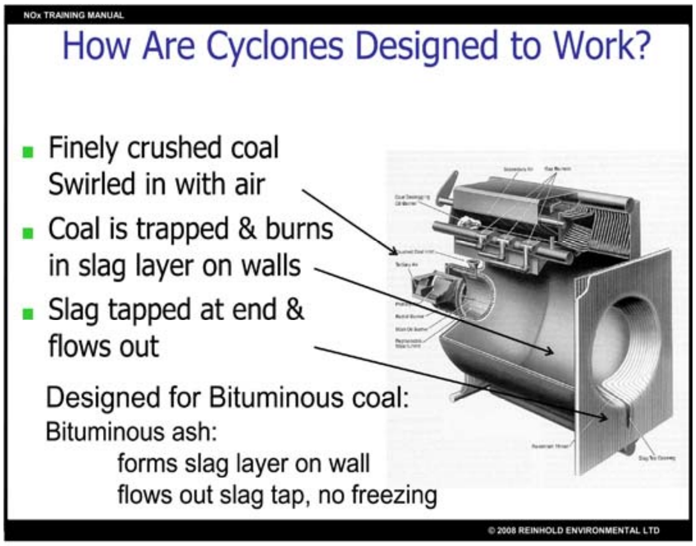
There are several ways operators can control SR to achieve lower NOx emissions or to minimize operating problems. Obviously, opening the OFA ports is one way to decrease NOx. However, in some cases, opening the OFA ports may reduce windbox pressure leading to poor air distribution among burners and OFA ports. This may cause high CO emissions, flames above the furnace arch, higher furnace exit temperatures, low steam temperatures, unburned carbon in the fly ash, high opacity spikes, and/or increased risk of tube corrosion. Often a better way to lower SR is to close off burner shrouds to force more airflow to the ports while maintaining or increasing windbox pressure. The same limitations listed above could still occur, but generally they allow slightly lower NOx emissions to be achieved first.

Maintaining proper airflow and fuel flow to each burner is critical to getting the lowest NOx emission out of your OFA system. Sensors are available to help operators measure and control primary, secondary, and overfire airflow to each burner/port. Your combustion system may already include Pitot grids located in the burners and OFA ports. Pitot grids are not very accurate (based on measuring and comparing very small numbers) and can be difficult to maintain. Other sensor types will be covered in a subsequent section.

1.4 Cyclone Boilers

NOx formation and control in cyclone boilers is different from other boiler types for the following reasons:

- Coal in cyclone boilers is not pulverized but crushed to a 4-mesh top size.
- Only a portion of the coal burns in flight (as it does in pulverized coal firing) while the rest of the coal is trapped in a slag layer and burned on the cyclone walls.
- Cyclones have high volumetric heat release rates and little heat transfer surface, so higher flame temperatures can be achieved.
- The higher flame temperatures are necessary for effective slag tapping operation.



NOx TRAINING MANUAL

How Are Cyclones Designed to Work?

- Finely crushed coal Swirled in with air
- Coal is trapped & burns in slag layer on walls
- Slag tapped at end & flows out

Designed for Bituminous coal:

Bituminous ash:

forms slag layer on wall

flows out slag tap, no freezing

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Cyclone Design

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Figure:

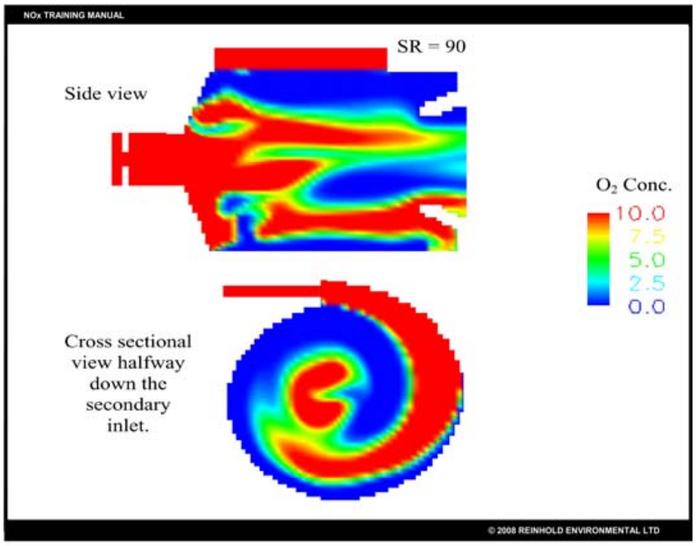
Cyclone Design

shows a schematic of a cyclone combustor and explains how it works.

Due to the high combustion temperatures necessary for cyclone operation, NOx emissions are higher than they would be for pulverized coal combustion. Furthermore, there are no low-NOx burner designs for cyclones. Without the use of overfire air ports, cyclone boiler NOx emissions ranged from about 0.8 to 2.0 lb/MBtu depending on the fuel, boiler size, and excess air. Powder River Basin sub bituminous coals produce the lowest NOx emissions in cyclones (less than 1 lb/MBtu).

Research work by EPRI and B&W that started in the 1970's has shown the potential for staged combustion with overfire air ports to greatly reduce NOx emissions from cyclone boilers. This technique was not used, however, until about a decade ago due to concerns over tube corrosion and refractory degradation due to reducing conditions in the lower furnace and cyclones. Better understanding of the cyclone combustion process has helped OFA system designers to minimize and operators to manage these concerns.

Normal cyclone combustion creates a fuel-rich (coal-laden) slag layer along the walls and an oxidizing flame core in each cyclone. With overfire air operation, about 20 to 30 percent of the secondary air is removed from the cyclones and routed to the air ports. The cyclone walls are still covered with a reducing slag as long as temperature stays above the slag melting point, but the flame core becomes less oxidizing.



Cyclone Firing Computer Simulation
(Used with permission)

Figure:

Cyclone Firing Computer Simulation

shows a computer simulation of the oxidizing and reducing zones within a cyclone firing at a stoichiometric ratio of 0.9, typical of current practice. The red and yellow colors are zones with high oxygen levels and the blue areas have no oxygen (reducing). There is very little difference in wall exposure to reducing conditions when firing with OFA ports, but NOx is much lower in the gas leaving the cyclones. Further NOx reduction takes place in the main furnace between the cyclones and the OFA ports. Main furnace water wall tubes and refractory is much more susceptible to corrosion during low-NOx firing.

NOx emissions can be reduced by about 60 percent in cyclone boilers by opening the OFA ports. Emissions have been reported as low as 0.2 lb/MBtu when burning PRB coal, and as low as 0.35 lb/MBtu with bituminous coals. The exact NOx emission that can be sustained at each boiler depends on how much overfire air can be added before operating problems crop up. These operating constraints could include:

- Slag tap freeze-up
- Low steam temperatures
- High convective tube temperatures
- Stack opacity violations
- High ash carbon content.

As OFA ports are opened, more combustion takes place outside of the cyclones. Therefore less heat is released in the cyclones and gas temperature is depressed. As a result, the slag layer may thicken or freeze up entirely.

One way to extend the operating range of a cyclone boiler is to add a fluxing agent to the coal to lower the melting temperature of the slag layer. For bituminous coals, limestone or lime kiln dust (or other inexpensive source of calcium) is often used for fluxing. For PRB coals, the ash already contains a significant amount of calcium so iron compounds can be added to lower the slag melting point. Care must be taken not to add too much iron to avoid a calcium-iron separation which can cause iron pooling in the slag. If iron precipitates out of the slag, it can plug the bottom ash drain and is very difficult to remove. An accurate blending and delivery system is needed for iron fluxing in a cyclone.

When more of the combustion takes place in the upper furnace (downstream of the OFA ports), the furnace exit gas temperature may increase to the point where there is too much heat available for reheating and superheating the steam. High attemperator spray flows will result, and steam temperatures may also increase. If this happens, operators may have the flexibility to adjust air port tilt or airflow distribution to alleviate the situation. However, more often relief is achieved by backing down the OFA dampers slightly until the temperatures return to normal.

In an extreme situation where flames extend above the furnace arch toward the entrance to the convective pass, secondary superheater tube metal temperatures may exceed recommended values. Adjustments to the overfire air must be made immediately if this occurs. Corrosion by decarburizing the steel surface can be rapid when tubes are overheated and exposed to CO and unburned carbon.

Low-NOx cyclone operation may lead to more coal carryover to the main furnace than the boiler designers had in mind. Typical cyclones firing bituminous coal collect 70 to 80 percent of the ash as bottom ash slag. Only 20 to 30 percent of the ash becomes fly ash. However, when the OFA ports are opened, the air vortex within the cyclones becomes less intense and less coal may impinge and burn on the walls. Therefore more coal is burned in the main furnace where its ash becomes fly ash. If the cyclone slag layer approaches its freezing point, even more coal will escape the cyclones and burn in the main furnace. The result will be more fly ash (perhaps 40-50% of the coal ash) and higher unburned carbon in the fly ash. B&W recommends crushing the coal finer (go from 95 to 99 percent passing a 4-mesh screen) to reduce the unburned carbon level, but finer coal will increase the total fly ash even further.

Many of the particulate control devices on cyclone boilers were designed for relatively low fly ash loadings. Low-NOx firing can cause a sharp increase in the fly ash loading to the precipitator or fabric filter. At this point, opacity spikes may result. The proper action if this happens is to make down the OFA dampers or increase excess air until the opacity settles back down.

CHAPTER 2 - COMBUSTION TUNING

This chapter discusses the art of combustion tuning on older coal-fired boilers.

2.1 Combustion Tuning

Maintaining low-NOx emissions in many of the older coal-fired boilers is like a person of that same age attempting to do the limbo. How low you can go may depend on how the boiler feels that particular day. However, operators can do a lot to keep their boilers in shape.

Tuning starts in the mills. Grinding surfaces and airflow gaps should be checked and adjusted at every opportunity. Daily fineness samples can give an indication of when a mill needs attention. Primary airflow should be reduced to levels as low as practical (while not going below a minimum velocity of about 3500 ft/m where coal particles could settle out in the lines). Airflow elements can be used to assure that each pipe is getting enough airflow and that all pipes are within 10% of each other.

In some cases, operators may find that biasing the coal flow to selected burners gives lower NOx emissions and lower unburned carbon in the ash. Usually the coal bias increases coal flow to lower and inner burners and decreases coal flow to the upper and wing burners. At the same time, secondary airflow is biased in the opposite direction (higher to upper and outer burners, lower to lower or inner burners). The theory is to make the lower flames more fuel rich because they have more time available to find air necessary for complete combustion, and to also concentrate the fuel-rich region in the middle of the furnace where it is hotter and less likely to interact with (corrode) tube surfaces. As discussed above, hot-rich, temperature-quenching, and cool-lean is the kinetic pathway to lowest NOx from a staged system.

Like an older person, each boiler has its own set of physical (design) and mental (operating) constraints that limit low-NOx performance. Furnace residence time can vary from less that a second to over three seconds. Furnace surface and convective pass surfaces are not normally changed to accommodate the different heat absorption profiles caused by longer flames or higher fireball position. Without getting into the gory details, operators must respond to each boiler differently and learn its quirks. This requires the following tools:

- Economizer Outlet Probe Grid with O_2 and CO Monitors

- Flame Quality Analyzers

- Air and fuel flow monitors

CHAPTER 3 - NOx CONTROL MAINTENANCE

This chapter discusses operation and maintenance issues and techniques for reducing NOx emissions.

3.1 NOx Control Maintenance

Operating any boiler for minimum combustion NOx emissions contains an element of risk that each plant must evaluate on a daily basis. The first issue is how much NOx reduction is needed for compliance? Soon, coal-fired plants in most states will have to maintain 0.15 lb/MBtu on a 24-hour rolling average throughout the year. Combustion NOx emissions will not necessarily be controlled to this level, as many units have been (or will be) equipped with Selective Catalytic Reduction (SCR) systems, but the ability to sell (or avoid buying) NOx Credits may be an incentive to find an economic minimum combustion NOx emission.

One risk of prolonged low-NOx firing is an increase in fireside tube corrosion. The reason for this observation is that low-NOx firing produces locally fuel-rich gas-phase conditions as well as longer flames. When these flames reach water wall tubes or pendent superheater surfaces, the gaseous and liquid sulfides and CO may deposit and remove the protective oxide layer. Alternating exposure to both oxidizing and reducing gases may be the most damaging situation since this oxide layer may rapidly form and strip in a repeating cycle. Deposition of other ash species, particularly alkali metal compounds (sodium), can also induce corrosion by forming sulfides that can dissolve or diffuse into the metal. This diffusion is also accelerated by high heat flux rates associated with flame impingement.

This issue can be managed by backing off on NOx reduction (less OFA, higher excess air) until the flames are observed to be tight and bright. If pendent tubes are instrumented with thermocouples, tube metal temperatures can be an accurate guide to excessive flame length. Superheat steam temperature also tends to spike upward when flames are too long. Some plants have tried to use heat flux sensors to detect and center the furnace fireball. Diligent observation using all available view ports in the furnace is also good practice.

Flame impingement can also be addressed by active combustion control technologies aimed at balancing burners (monitoring and controlling air-fuel ratio). Examples include Flame Doctor, Zolo, and numerous air and coal flow measurement devices.

Fuel-rich flames established at the burners during OFA operation tend to radiate with less intensity than fuel-lean flames, and the location of the ignition zone can fluctuate to a greater degree. These factors could hamper the operation of some commercial flame scanners if the flames elude the line of sight or if the scanner can no longer discriminate between its own flame and radiation from adjacent flames. Flicker-type scanners that rely more on frequency analysis than radiation intensity tend to be more reliable. Controls can be set to require that more than one scanner indicates a loss-of-flame episode before tripping a mill in order to avoid "nuisance trips".

Not only must a low-NOx combustion system be constantly tuned (see below), but also well maintained. Ash deposits called "burner eyebrows" can accumulate in burner throats and cause less stable combustion. Such deposits need to be poked loose before they harden into rocks. Below is a check list for operations personnel to use each shift to evaluate combustion quality.

- Are flames visible through view ports above the nose or in the lanes between secondary superheater tubes?
- Are flames bright when viewed from the burner front?
- Are wind burner flames tightly attached and flared outward when viewed from an adjacent side wall? A long, dark "skirt" could indicate trouble.
- Are flames hitting the opposite wall when viewed from a corner port?
- Are ash deposits building up in any of the burner throats?
- Are ash deposits visible in any area not accessible by soot blowers?
- Can you see "sparklers" in the flames (this could be sign of poor coal fineness)?
- When you open a view port, can you see a flame due to in-rushing air? This could indicate that a region is too fuel-rich.

In addition, pulverizers must be kept in good working order to attain good NOx reduction over a range of loads. In general, low-NOx systems perform better when the primary airflow is minimized. Better flame stability and higher coal fineness generally result from reducing the primary airflow. However, sometimes the coal flow capacity of the mill will drop down at the same time. This can affect the number of mills in service at low load, as well as the NOx reduction achieved at low load.

In general, NOx emissions decrease as the boiler drops from full load to about 70 percent load as long as excess air is held fairly constant. When burners are removed from service, the NOx emissions can either go up or down, depending on the mill selected for shut down. Usually removing an upper mill group of burners from service results in a NOx reduction because the upper burners serve as a second level of overfire air (the remaining burners are still fired fuel-rich or less lean). If a lower burner group is removed from service, the burner cooling air can mix with the other flames to increase excess air and thus raise NOx emissions. Often removing the lower burners from service is preferred at low load in order to maximize steam temperatures. Good low-NOx combustion practice involves developing low-load combustion strategies (mills in service, excess air level, and steam temperature control) that minimize NOx emissions but maintain desirable boiler heat rates.

CHAPTER 4 - SCR CHEMISTRY AND THEORY

This chapter will discuss SCR Chemistry and Theory.

4.1 SCR Chemistry and Theory

Selective Catalytic Reduction (SCR) is so termed because the process is selective in that it is designed specifically to destroy NOx and minimize other side reactions. It is catalytic because it utilizes a catalyst to promote the needed reactions. And, it is termed reduction because the primary chemical reaction is a reduction reaction, converting NOx to nitrogen and water.

SCR technology is based on the destruction of NOx by reacting NOx with ammonia to form water vapor and nitrogen. As nitrogen comprises roughly 80% of air, this reaction is highly desirable as a way to remove NOx in flue gases, since the products of the reaction are harmless.

The destruction of NOx, or deNOx, occurs via the reaction of ammonia (NH_3) with NOx, which is promoted by the catalyst. In absence of the catalyst, this reaction will proceed too slowly to be practical, unless the temperature is very high, as in the case of SNCR. NOx is a general term, denoting the combination of two nitrogen-oxygen species; NO and NO_2. In typical flue gases, the vast majority of NOx is present as NO (usually greater than 95%).

The primary chemical reactions related to the deNOx reaction can be expressed as follows:

- $4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O$
- $4NH_3 + 2NO_2 + O_2 \rightarrow 3N_2 + 6H_2O$

The first reaction above predominates, since this is the primary reduction for NO. This is termed a 1:1 reaction, since one mole of ammonia reacts with one mole of NO. In the second reaction, the NO_2 that is present requires 2 moles of ammonia for each mole of NO. Oxygen is required for both reactions, but there is typically sufficient oxygen in flue gas so as not to inhibit the reactions. Moisture in the flue gas may also have an effect on the reactions, although the effect is typically not substantial in the ranges common to most flue gases.

Many parameters such as temperature, flow rate, NH_3/NOx distribution, fuel, and catalyst volume, formulation and age will affect the deNOx capabilities of a given SCR system. All of these parameters are discussed in subsequent sections.

Side Reactions

It should be noted that although the SCR process is termed "selective," one particular unwanted side-reaction does occur with current SCR catalysts. This side reaction is termed "SO_2 conversion" or "SO_2 oxidation" and refers to the propensity of the catalyst to oxidize sulfur dioxide (SO_2) to sulfur trioxide (SO_3). "Side" reactions are so termed because they are secondary to the primary deNOx reactions of ammonia and NOx. SO_3 is a concern because of its adverse effect on downstream equipment. The ability of a catalyst manufacturer to minimize SO_2 conversion while maximizing NOx reduction is a major technical design issue.

SO_2 Conversion

The conversion, or oxidation, of SO_2 to SO_3 is an undesirable side reaction and is a major limiting factor in the design of catalysts when SO_3 is present in the flue gas. The reaction results in the formation of SO_3 across the catalyst, and therefore increases the total SO_3 levels downstream of the SCR. This increased level of SO_3 can be problematic, and will be discussed in subsequent sections. As with the deNOx reaction, many parameters affect the amount of SO_3 formed in an SCR system - these parameters are also discussed in subsequent sections. The oxidation of SO_2 can be expressed as follows:

- $SO_2 + 1/2\ O_2 \text{->} SO_3$

Ammonia - Sulfur Reactions

Another side reaction of concern, although not directly related to the catalyst, is the formation of ammonia-sulfur compounds. At relatively cool temperatures, within and downstream of the air preheater, ammonium bisulfate can form from the reaction of residual ammonia (ammonia slip) and SO_3. The chemical equation for this formation can be written as follows:

- $NH_3 + SO_3 + H_2O \text{->} NH_4HSO_4$ (ammonium bisulfate, ABS)

This is the most common reaction product for coal fired boilers, where there is typically an excess of SO_3 compared to ammonia.

In cases, where the SO_3 levels are low compared to the ammonia slip, then ammonium sulfate (AS) may be formed, according to the following equation:

- $2NH_3 + SO_3 + H_2O \text{->} (NH_4)2SO_4$ (ammonium sulfate, AS).

CHAPTER 5 - SCR APPLICATIONS

Essentially the same catalyst formulation (with minor adjustments as discussed in this chapter) is used in all SCR applications. What does change is the pitch of the catalyst, the length of the catalyst and the number of layers of catalyst depending on the type of fuel being used:

Catalyst Pitch used in various Applications

- 6.0 to 9.0 mm - High Dust Coal Fired
- 4.5 to 6.0 mm - Medium Dust Coal Fired, Diesel Engines
- 3.5 to 5.0 mm - Low Dust Oil and Gas Fired, Waste Incinerators
- 2.5 to 3.5 mm - Dust Free Gas Fired

5.1 Gas and Oil

The main difference when burning oil or gas is that there is little or no ash and the sulfur content of the fuel is usually very low. Since there is little ash with oil and no ash with gas, the catalyst pitch can be very small since there are no solids to plug the catalyst flow channels. The increased number of catalyst walls means that a given volume of catalyst has many times the catalyst surface area of the larger pitch catalyst used for coal. Therefore one layer of small pitch catalyst may contain the same catalyst surface area of two or more layers of large pitch catalyst. So often the SCR contains only one or two layers of catalyst total.

Since the fuel contains little sulfur, one can use a catalyst with higher activity since one doesn't have to worry about the higher activity oxidizing a large percentage of the SO_2 to SO_3 since there is very little SO_2 present. One also doesn't need to be as concerned about a minimum ammonia injection temperature since there is virtually no SO_3 present to react with the ammonia to form ammonium bisulfate or ammonium sulfate that could plug the catalyst pores.

One of the main active ingredients in an SCR catalyst is vanadium. The outlet flue gas from an oil fired boiler may contain vanadium depending on the type of oil being burned. If this vanadium attaches to the catalyst surface, it can enter into the NOx removal process and increase the activity of the catalyst layer. Because of this, the catalyst management plan for an oil fired unit may include removing some catalyst volume on a routine basis to keep the activity of the catalyst layer at its design value.

If an SCR is installed on a simple gas turbine or a combined cycle unit, the catalyst layer is typically installed in a horizontal duct location ahead of the exhaust stack or HRSG inlet. The SCR typically consists of one layer of catalyst modules which are lying on their sides in a vertical stack with the gas passing through the layer horizontally. The modules are usually installed through an opening that opens all the way across the top of the duct. The modules may be installed individually or welded together into larger assemblies that are lowered by crane into the duct opening. When it is time to change catalyst, the single layer is totally replaced with new catalyst.

Usually the distance between the ammonia injection grid and the catalyst face is very short in these gas turbine installations. The SCR cross section is typically larger than the normal duct cross section, so the challenge is to get the ammonia distributed evenly across the catalyst face in such a short distance. When measuring the gas profiles at the catalyst face, a three axis probe is often used to measure all the swirling gas profiles that are present.

5.2 Solid Fuels

When burning solid fuels, ash is created. Unless the SCR is installed after a hot side electrostatic precipitator, all of this ash must pass through the SCR catalyst. Some units have experienced catalyst flow channel pluggage due to Large Particulate Ash (LPA) that forms on some of the back pass components in a boiler and is released by temperature variations in the boiler. Special LPA removal screens have been installed in units to keep the LPA from leaving the economizer outlet area and traveling into the SCR catalyst beds. Not only is there the possibility of the ash plugging the catalyst flow channels, the ash contains various minerals that can poison or foul the catalyst surface.

A high ash loading can also erode away the catalyst material. The leading edge of the catalyst is often hardened to slow this process. Once this hardened zone is gone, the erosion will proceed more quickly. If catalyst flow channels become plugged, the gas velocity through the remaining open channels will increase which will also increase the rate of catalyst erosion. The metal support mesh retards the erosion rate in plate catalyst.

5.2.a Eastern Bituminous

One of the biggest concerns with Eastern coals is the varying amount of arsenic that is present in the coal. If the arsenic concentration is high enough, arsenic poisoning can shorten the life of the catalyst. Small amounts of limestone can be added with the coal in the furnace combustion zone. The limestone will react with the gaseous arsenic forming a compound that will lessen the possibility of catalyst poisoning.

Some of the Eastern coals contain high levels of sulfur. The higher the sulfur, the higher the minimum ammonia injection temperature is going to be. A high sulfur coal also generates high levels of SO_2 in the flue gas. To minimize the amount of SO_3 formation in the SCR, catalyst vendors have developed low oxidation catalysts that convert a smaller percentage of the SO_2 to SO_3.

5.2.b Powder River Basin

One of the biggest concerns with Powder River Basin (PRB) coal is the high concentrations of calcium oxide in the ash. This calcium oxide can react with the sulfur compounds in the flue gas and form a dense layer of calcium sulfate on the surface of the catalyst. This layer prevents the flue gas from contacting the active sites on the catalyst and NOx removal will be diminished. This phenomenon was an unpleasant surprise for some of the early SCR systems installed on units burning PRB coal. Changing the pore structure of the catalyst is one method used to combat the effects of this phenomenon.

The sulfur levels in PRB coal are low, so the minimum ammonia injection temperature will be lower than for Eastern coals. There is also less SO_2 present in the flue gas, so the oxidation potential of the catalyst is not as important since less SO_3 will be formed if a higher percentage of the SO_2 is oxidized.

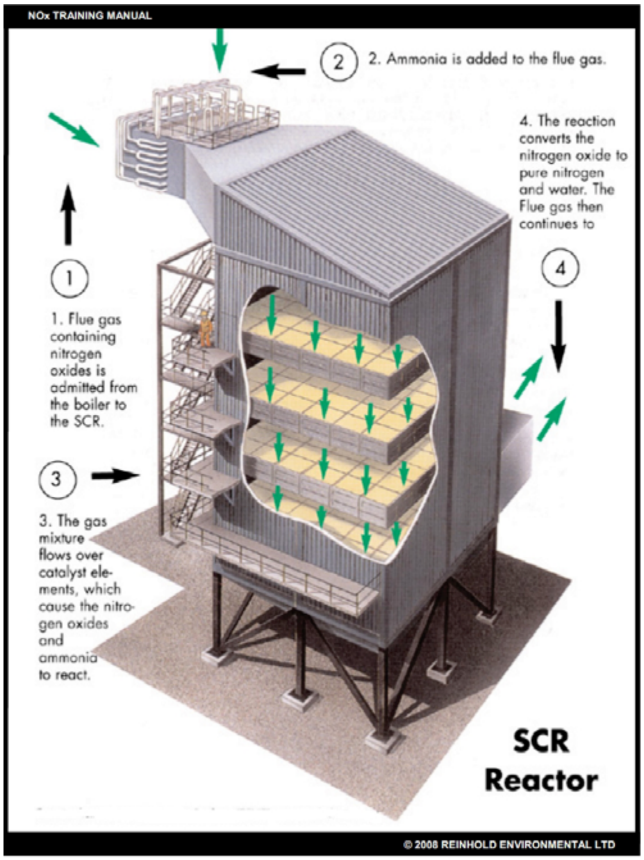
5.2.c Miscellaneous Solid Fuels

Many other types of solid fuel can be burned in boilers and incinerators. The ash characteristics of each fuel are unique. Units that burn a mixture of fuels can present even more challenges. Fortunately, many of these fuels have been burned in units with SCR systems in various worldwide locations, so the catalyst vendors may already have data on the effect a particular fuel will have on the catalyst. If not, catalyst coupons or small slip stream SCR test units will need to be installed on the unit to obtain data on the effect the fuel will have on the catalyst life before one can specify an SCR.

CHAPTER 6 - SCR SYSTEM DESIGN

This chapter will discuss the various aspects of SCR system design including:

- SCR Configuration and Ductwork
- SCR Reactor and Sootblower Design
- SCR Catalysts
- SCR Ammonia System Design
- SCR Control and Measurement Systems



SCR Reactor Schematic
(Used with permission)

6.1 SCR Configuration and Ductwork

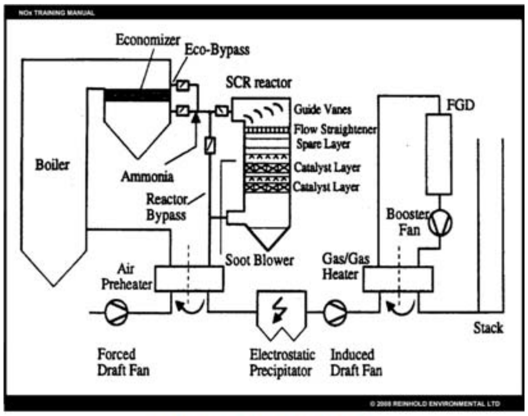
Separate Reactor SCR

There are three typical layout arrangements of separate reactor or "full" SCR systems applied to coal stations.

1. High Dust Position
2. Low Dust Position
3. Tailend Position

High Dust Position

The High dust position is the most widely used SCR configuration, especially with dry bottom boilers, because it does not require particulate emissions control prior to the deNOxification process. Although this location does not require flue gas reheating, the temperature may vary depending on the operating conditions, which can affect the removal efficiency to a certain extent. The SCR must be designed with the channels in the catalyst large enough to allow the dust to pass through without plugging the channels. See **Figure:**

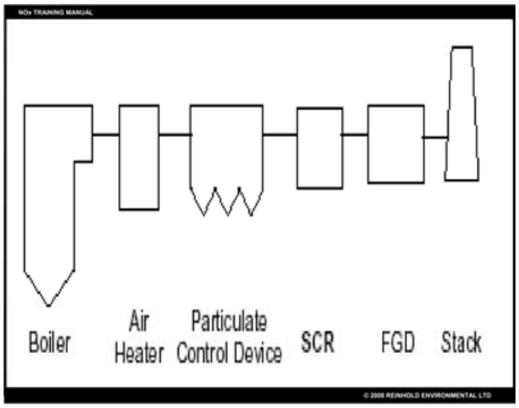


SCR High Dust Process
(Used with permission)

SCR High Dust Process

Low Dust Position

The Low Dust Position uses the exact same SCR as the High Dust Position. The Low Dust Configuration has the advantages that the pitch of the catalyst used may be lower due to the absence of fly ash which can cause pluggage and less catalyst degradation caused by fly ash erosion, but it requires either a costly hot-side ESP or reheat following the coldside ESP. See **Figure:**

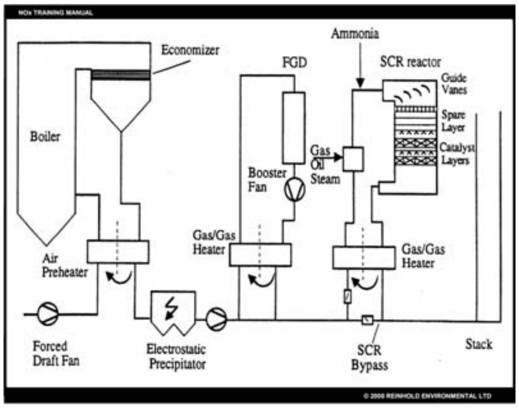


SCR Low Dust Configuration
(Used with permission)

SCR Low Dust Configuration.

Tailend Position

This SCR position has been used primarily with wet bottom boilers with ash recirculation to avoid catalyst degradation caused by arsenic poisoning. The configuration, with the SCR being located after the FGD, is also favored with retrofit installations (due to SCR space requirements) between the economizer outlet and ESP. The temperature of the flue gas is too low for the catalytic reaction and has to be raised to a higher temperature, normally around 482 degrees Fahrenheit. Although reheat causes an increase in capital cost, the catalyst will last longer, has a consistent reaction temperature, and is usually more compact. (See **Figure:**



SCR Tailend Process
(Used with permission)

SCR Tailend Process

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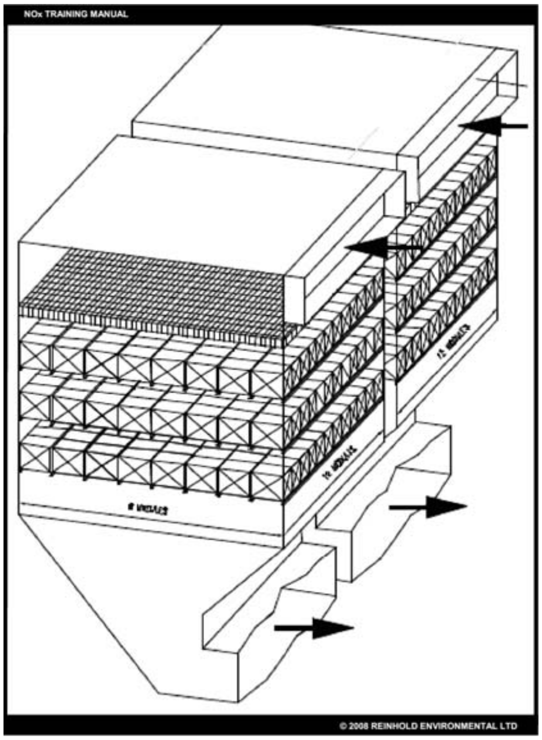
An ammonia grid is located upstream of the catalyst, which provides active sites where the ammonia and NOx reduction reaction takes place. Because of the temperature at which the SCR reaction occurs, the competing oxidation reaction, which is related to the SNCR process, is not significant. Thus a higher NOx removal efficiency and better utilization of the reagent is produced. The design of the delivery system for the ammonia is a critical factor in the SCR design. In a well-designed SCR, a mole of ammonia should reduce about a mole of NOx. If the NOx composition contains a mixture of NO and NO_2, the ammonia added equals the weighted average between one and two unit volumes of ammonia per unit volume of total NOx. The ammonia system will be discussed in a later section.

In-duct SCR

The advantage of the in-duct SCR is its lower capital cost and its ability to compliment SNCR technology. Yet there are several possible problems related to this technology, of which James Staudt itemized in a his report.

- The space limitations of the in-duct design limits the amount of catalyst that can be used and thus the performance.
- There is less retention time between the ammonia injection system and the catalyst to achieve good ammonia mixing of the gas, making mixing devices necessary. This is especially a concern for boilers that recirculate flue gas. Also it is very difficult to provide a uniform velocity at the ammonia injection grid.
- Catalyst face velocity and erosion is a concern for high dust applications because the frontal area will be limited and gas velocity high. For this application one would have to use a catalyst that incorporates a metal substrate or uses a hardened ceramic material on the catalyst leading edge.
- An SCR bypass may not be possible.
- Access to the catalyst for maintenance and replacement may be difficult.
- Installation of many layers of catalyst may be impossible.
- Draft losses across the catalyst may be higher than in a separate reactor.

In addition to in-duct SCRs, some suppliers have investigated catalyst-coated air heater baskets for Lungstrom type air heaters. Testing at Mercer Generating Station and in Europe has shown that is approach may offer additional NOx reduction and eliminate NH_3 slip. In the case of Mercer, a 20% reduction was achieved with the addition of air heater catalyst baskets, while maintaining the ammonia slip limit. However, catalytic air heater technology generally will not provide sufficient reduction of NOx to be a stand-alone technology.



SCR Reactor Diagram
(Used with permission)

Considering the limited experience concerning in-duct SCRs, the remainder of this training manual will discuss only separate reactor SCR technology.

6.2 SCR Reactor and Sootblower Design

6.2.a SCR Reactor Design

The SCR reactor is the large box that contains the SCR catalyst. The flue gas typically enters the top of the reactor and flows vertically downward. See **Figure:**

SCR Reactor Diagram

This is so the fly ash will be swept along with the gas flow and will all exit the bottom of the SCR reactor and continue toward the particulate collection devices. If the flow were upwards, it would be more difficult to keep ash particles from settling out on the catalyst forming large piles on top of the catalyst layers. Soot blowing devices are used in conjunction with the downward flow to keep the ash from accumulating in the SCR reactor. These devices will be discussed in a separate section.

The cross section of the reactor is rectangular. The dimensions of the reactor are determined by how many catalyst modules are required per layer to reduce the flue gas velocity to the range required for sufficient reaction time between the NOx in the flue gas and the reaction sites on the catalyst. Designers tend to keep the rectangle as square as possible instead of making it long in one dimension and narrow in the other dimension. This is to ease the task of obtaining a uniform low velocity across the entire reactor cross section as the gas flows from the smaller high velocity SCR inlet duct. This is why on large boilers it is typical to have two or three separate mostly square reactors side by side rather than having one large wide but shallow rectangular reactor. Velocity, ammonia concentration and temperature deviations across the width of a single large reactor have been a concern where they have been installed.

Depending on the catalyst volume requirements and the philosophy regarding equipment spares, a reactor will typically contain three, four or five layers of catalyst. Some designs also include a short "dummy layer" or flow straightening grid above the top catalyst layer to assure that the gas flow is completely vertical when it enters the first catalyst layer. Typically all of the layers are not filled with catalyst for the initial operation. The filling of the empty layer(s) is part of the catalyst management strategy.

Supporting the massive weight of the catalyst layers above the particulate control devices and the air heaters typically requires huge horizontal beams and strongly braced columns. See **Figure:**

Catalyst Support Beams

Catalyst Support Beams
(Used with permission)

)The SCR reactor is also subjected to large thermal stresses due to the high operating temperatures required by the SCR catalyst.

The catalyst vendors have standardized to a module cross section of approximately one meter by two meters. In this manner the catalyst modules from any vendor will fit into any SCR reactor. The catalyst support beams are spaced approximately on two meter centerlines. The catalyst modules are supported only by their ends that are setting on these beams. These beams need to be wide enough to support the weight of the catalyst modules but not so wide that they restrict the flow path of the gas through the catalyst modules.

The catalyst modules are hoisted from the ground up to the level of the catalyst layer. See **Figure:**

Loading Catalyst Transfer Cart

Loading Catalyst Transfer Cart
(Used with permission)

The modules typically enter the reactor through one or two openings at each catalyst layer. See **Figure:**

Catalyst Module Entering Reactor

These openings may be doors or bolted hatches. Some utilities choose to cut a hole in the reactor wall and then weld it closed once the catalyst is loaded. This saves the expense of engineering and fabricating a door or hatch.

Catalyst Module Entering Reactor
(Used with permission)

The catalyst module is moved inside the reactor using a trolley beam that runs along the reactor wall perpendicular to the catalyst support beams. Once the module is between the beams that will support it, it is typically moved by some sort of cart or trolley to its position on the beams. See **Figure:**

Catalyst Supports and Transfer Cart

Catalyst Supports and Transfer Cart
(Used with permission)

Thus the modules are moved to the furthest locations first and then stacked together back towards the entry location.

Each catalyst module has some sort of sealing arrangement that uses flat metal lips and flat fiber gaskets to prevent flue gas from passing through the gap that exists between the module walls. Some vendors design this seal at the bottom of the module and some vendors design this seal at the top of the module. There doesn't seem to be an advantage or disadvantage to either design. Of course all the catalyst modules on any one layer must have the same design to fit together properly.

Thin metal sealing strips must also be welded between the reactor walls and the peripheral catalyst modules to keep the flue gas from bypassing around the catalyst layer. These strips are usually placed at an angle like a tent wall to keep fly ash from building up on these seals.

The vertical distance between the catalyst module support beams must be sufficient to allow for the height of the catalyst modules as well as provide headroom for people to have access on top of the catalyst layer to pull catalyst samples, maintain seals, maintain soot blowing equipment, etc.

Each layer should also be provided with one or more personnel access doors located at the elevation of the top of the catalyst layer.

Below the lowest catalyst layer, there is typically a permanent sampling grid that is used to balance AIG ammonia feeds and sample outlet NOx and ammonia slip values across the cross section of the SCR reactor.

The SCR reactor, catalyst loading doors, and personnel access doors must be sufficiently insulated to keep the flue gas from losing temperature as it passes through the reactor.

6.2.b Sootblower Design

One must keep in mind that experience has shown SCR sootblowers are not very effective in removing large deposits of ash that have lodged in the catalyst beds. They are more effective in keeping ash deposits from building up on support frames and sealing strips. If large deposits of ash build-up in these areas, it can avalanche off and possibly plug sections of the catalyst. The frequency of sootblowing should be selected with that task in mind. Increasing the frequency of sootblowing after the differential pressure across a catalyst layer has increased will probably not make a lot of improvement in the differential pressure.

There are two styles of sootblowers that are most frequently used in SCR Reactors. They are the rake arm lance and the air horn.

Rake Arm Lance

This type of sootblower is almost identical to the retractable lance type sootblowers used on boilers. See **Figure:**

Rake Type Soot Blower

Rake Type Soot Blower
(Used with permission)

The drive mechanism (head) of the sootblower is virtually identical. The main difference is the lance itself. Instead of a straight lance that retracts when not in use, this lance is a straight lance with perpendicular horizontal branch arms coming off both sides. Each branch has numerous small nozzles to provide a uniform coverage of the area. Because of these branch arms, the lance cannot retract out of the SCR Reactor.

The spacing of the sootblowers is typically determined by the catalyst layout. The main sootblower lance is typically centered at the joint between two rows of catalyst modules. The branch arms are approximately two meters long so that the arm on each side of the main lance covers the width of one catalyst module. The lance moves some distance in and out, so the branches are spaced on the main lance the same distance apart as the amount of this movement. In this manner, one sootblower covers a swath of two rows of catalyst.

Sintered Ash Deposit
(Used with permission)

Thus there is typically one sootblower for every two rows of catalyst modules. Things get a little more interesting if there is an odd number of catalyst rows. The sootblower can use either steam or air. Due to thermal stress considerations, the catalyst vendors often place a limit on the temperature differential between the catalyst surface and the sootblower media. This often requires that the steam supply must be taken from a high pressure high temperature steam header on the boiler. This high temperature and pressure may lead to increased maintenance of the sootblower drive mechanism.

If air is used, there may be a danger that isn't recognized. The use of "low-NOx burners" can lead to deposits of unburned carbon lying on the surface of the catalyst. There has been at least one case where the unit had low-NOx burners and an SCR air sootblowing system. During maintenance, a hard sintered ash deposit was found fused onto areas at the top of the first catalyst layer. See **Figure:**

Sintered Ash Deposit

This deposit was extremely difficult to break off. It appeared that the hot carbon deposits may have smoldered or ignited. It is theorized that this happened during the periods of sootblowing when higher oxygen levels were present at the catalyst surface.

Air Horn

The air horn is a simple device that uses a small volume of low pressure air to vibrate a metal diaphragm creating a sound wave. A diverging horn bell guides this sound energy into the area to be covered. See **Figure:**

SCR Airhorns

The frequency and volume of this sound energy causes materials in the covered area to vibrate and move.

There is a limit on how far these sound waves can effectively move material, so air horns are more numerous on an SCR Reactor than rake arm lances. While the lance blower drive mechanisms are typically all located on one wall of the SCR Reactor, the air horns will be mounted on every wall of the SCR Reactor. The air horns will also be spaced more closely together. But since they are cheaper than a lance type blower, this is not cost prohibitive. See **Figure:**

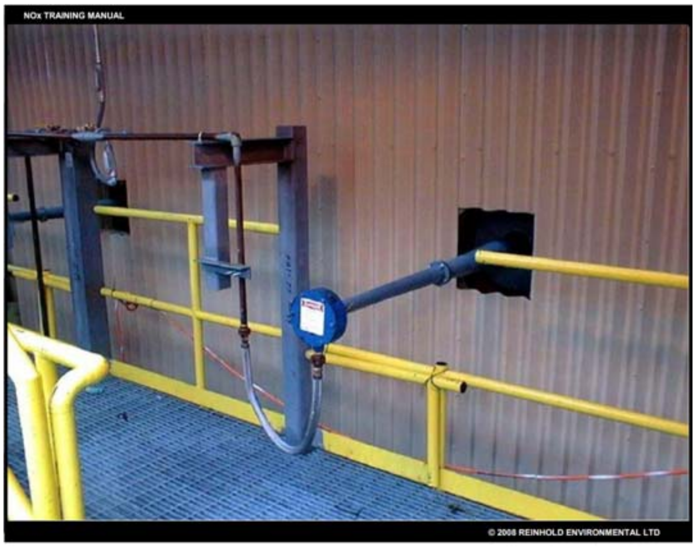
SCR Airhorns
(Used with permission)

Sonic Horn

One advantage of the air horn is there is only one moving part, the metal diaphragm, that is cheap and can be replaced easily. Another advantage is that there are no moving parts in the SCR Reactor to maintain or step over when working on top of the catalyst layer.

Experience has shown that it is critical to insulate all parts of the air horn that are on the exterior of the SCR Reactor. If the horn bell has any cold surfaces, moisture can condense and ash will build up in the horn throat. This will limit the sound output of the horn and make it less effective in its coverage.

Many units make it a practice to blow each of the air horns in a continuous rotating cycle to keep the SCR reactor as clean as possible at minimal cost. The operators should listen to the horns as they cycle to make sure they are all working. If a horn sounds different than the rest, there may be an ash deposit in the horn bell that needs to be removed at the first opportunity.



Sonic Horn
(Used with permission)

6.3 SCR Catalysts

6.3.a Introduction

The strict definition of a "catalyst" is a material that promotes a chemical reaction without itself being changed. In practice, catalysts are used to "speed up" the reaction of two or more chemicals to produce a useful product, or in the case of SCR technology, to destroy NOx. Catalysts differ widely from industry to industry and may be comprised of gases, solids, or liquids. SCR catalysts are of course solid. In SCR technology, the catalyst helps two species, ammonia (NH_3) and NOx (NO and NO_2), to react together, thereby destroying the NOx and producing nitrogen and water. These reactions are discussed in previous sections.

The general term used to denote a catalyst's ability to promote a reaction is termed its "activity." Thus, a highly active catalyst has a greater capacity to promote a reaction than does a catalyst of lower activity. High deNOx activity generally results in higher SO_2 conversion, but by manipulating the catalyst formulation, the SO_2 conversion can be minimized. This is the source of much of the proprietary knowledge among the various catalyst manufacturers. In practice, the limits placed on SO_2 conversion will limit the activity of the catalyst that can be installed and thereby affect catalyst volume - in this sense, SO_2 conversion "bounds" the maximum catalyst activity that can be realized.

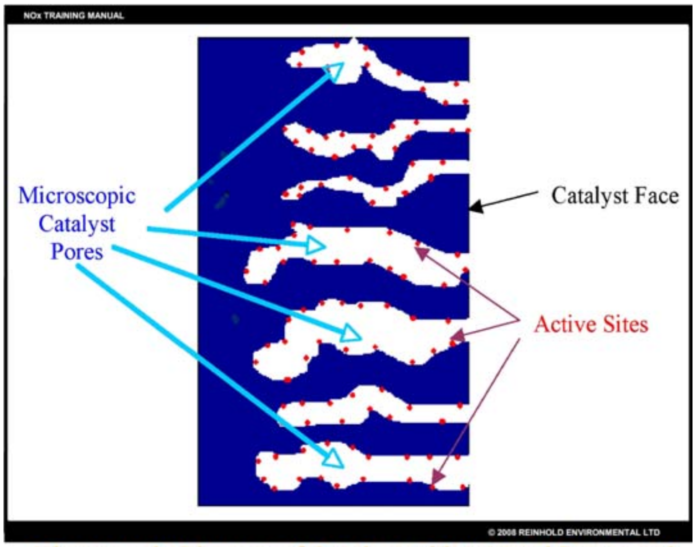
6.3.b SCR Catalyst Design and Composition

SCR catalysts are composed principally of a ceramic-like material which provides the necessary physical pore structure and chemical foundation for the active catalytic components of the catalysts. The ceramic-like material is made up primarily of titania (titanium dioxide, Ti_2O_5), but will include a number of additional components. In the catalyst industry, this ceramic-like material is typically called the catalyst "support." This term should not be confused, however, with gross support materials, such as metal screens and basket materials, which provide a global physical support structure to the catalyst. In addition to the screens, physical support materials such as glass fibers may be utilized.

All SCR catalysts operate on the same general principal. An active catalytic species (catalytically active components of the catalyst include vanadium, molybdenum, tungsten, and various other constituents based on the particular formulation and catalyst manufacturer) is dispersed on a substrate or carrier (titanium dioxide), which has a high surface area. This high surface area allows for an adequate number of active sites to accomplish the degree of reaction needed. When active sites are reduced in number, or are otherwise rendered incapable of performing their function, the term "deactivation" is used. **Figure:**

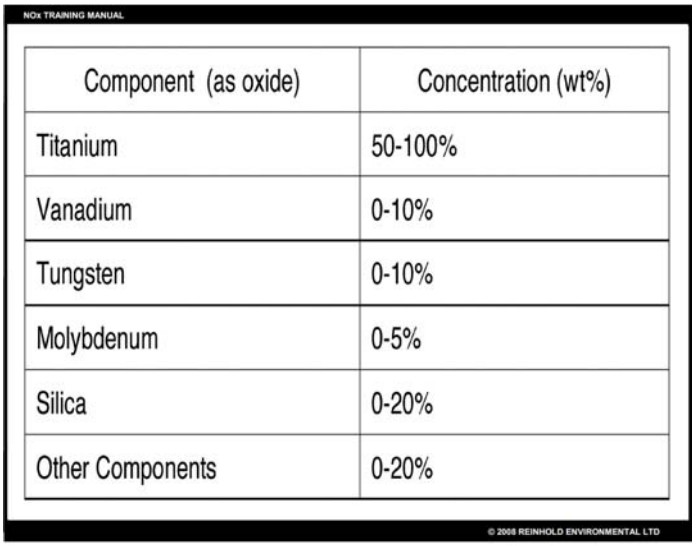
Microscopic Diagram of Catalyst with Internal Pores and Active Sites

shows a conceptual drawing of catalyst microscopic pores and the active chemical sites that promote the deNOx reaction. Note that the vast majority of the surface area available for reaction actually occurs on these internal pores, rather than on the external "geometric" surface area. The internal pore structure is what actually gives the catalyst its high surface area, making catalysis practical. Without these internal pores, there would not be enough surface area for the catalyst to adequately promote the deNOx reaction. The surface area actually available for the deNOx reaction is on the order of 100 m2/g of catalytic material, which is termed the total surface area or "BET surface area." This value includes all of the surface area due to the internal pores. This value should not be confused with the "geometric surface area," sometimes called the "specific catalyst surface area," which is expressed as m2/m3 and represents the apparent surface area of all the catalyst faces per cubic meter of catalyst. The geometric/specific surface area is on the order of 500



Microscopic Diagram of Catalyst with Internal Pores and Active Sites
(Used with permission)

m2/m3 for large pitch coal-fired catalysts, but will vary considerably depending on pitch and catalyst type (honeycomb, plate, etc.). Since a cubic meter of catalyst will contain many thousands of grams of material, it is easy to see that the BET surface area is actually many orders of magnitude greater than the geometric/specific surface area.



Component (as oxide)	Concentration (wt%)
Titanium	50-100%
Vanadium	0-10%
Tungsten	0-10%
Molybdenum	0-5%
Silica	0-20%
Other Components	0-20%

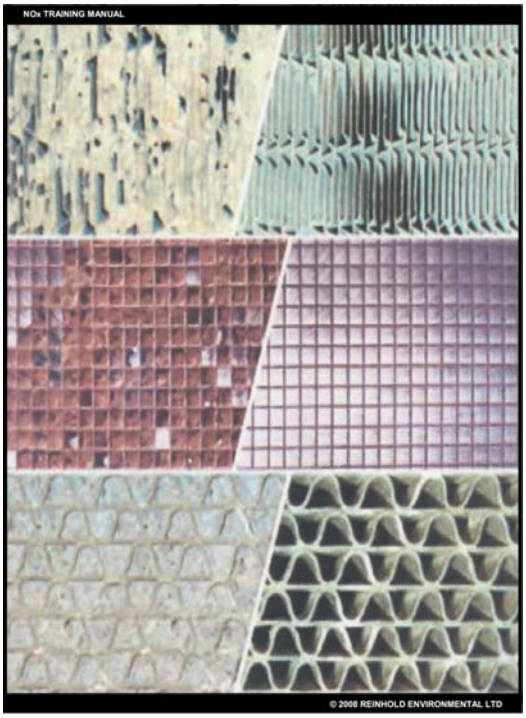
Typical SCR Catalyst Composition-Ceramic Portion

(Used with permission)

The specific design of any particular catalyst addresses many different factors. These include the total porosity, pore size distribution, internal surface area, geometrical surface area, vanadium content, promoter content (promoters are chemicals that may help increase activity or inhibit SO_2 oxidation, for instance), dispersion of the vanadium and promoters, physical strength, substrate design, etc. Thus, many technical factors must be addressed when designing a catalyst and the number of firms capable of providing SCR catalyst on a commercial basis is relatively small. When a particular catalyst design is offered for an application, all of these design factors must be considered to insure that an offering is being made which will meet the required guarantees. **Table:**

Typical SCR Catalyst Composition-Ceramic Portion

shows the typical ranges of components in the ceramic portion of SCR catalysts. As discussed, depending on the catalyst type, additional gross support material may also be present, such as metals from plate catalyst screen support. Each catalyst supplier will have a number of catalyst formulations designed for different flue gas applications, especially as related to the SO_2 conversion requirements for the particular application. Thus, the components present in any particular spent catalyst will vary greatly depending on application, catalyst manufacturer, and specific formulation. Spent catalyst will also contain a large number of trace constituents derived from contact with the flue gas, especially in coal-fired applications. In particular, low levels of arsenic, potassium, sodium, and other metals may be present on spent catalyst associated with coal firing. Fly ash particles will also adhere to the catalyst, adding to the large number of trace components present.



Typical Vanadium-Titanium SCR Catalysts, Various Types

(Used with permission)

As a result of the many technical issues related to SCR technology, catalyst design is extremely complicated and vendor offerings for any particular installation will represent a compromise between catalyst volume and cost, deNOx activity, SO_2 conversion, and pressure drop. Catalyst manufacturers typically address the many catalyst design issues by utilizing their technical expertise developed over many years of experience. Firms such as B&W must depend on catalyst manufacturers to design a catalyst offering to meet the system requirements, with parameters such as activity, volume, geometrical configuration, etc. all determined by the catalyst designer.

6.3.c Catalyst Types

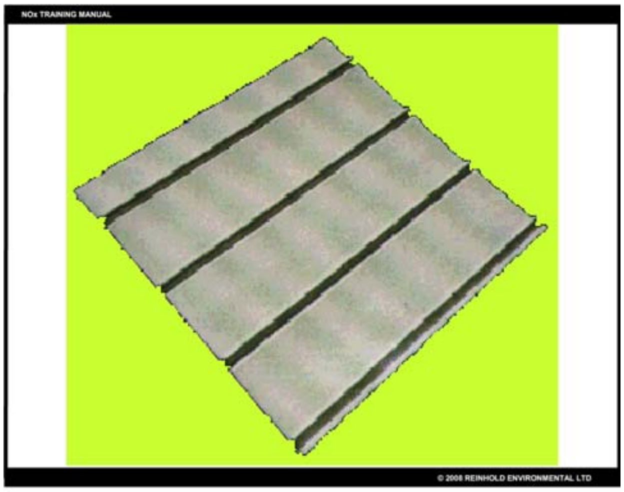
SCR catalyst is found in three general types; plate, honeycomb, and hybrid/corrugated. These terms refer to the general physical configuration of the catalyst geometry. Even though the catalysts appear to be quite different from a geometric standpoint, the underlying ceramic portions of the catalysts are quite similar from a bulk composition standpoint. **Figure:**

Typical Vanadium-Titanium SCR Catalysts, Various Types

shows fouled and clean versions of these three catalyst types from top to bottom, respectively.

Plate Catalysts

A number of SCR catalyst manufacturers produce plate-type catalyst. These include Hitachi Power Systems America, Ltd., and Argillon, LLC. For plate-type catalysts, the ceramic material is placed on a metal screen. This screen provides structural support to the plate, while the ceramic material provides the needed catalyst porosity and active catalytic component support. Due to the presence of the screen support, plate catalysts have a much larger proportion of recyclable bulk metals per unit catalyst mass than do honeycomb or corrugated catalysts. Plate catalyst will typically be heavier on a unit volume basis than their honeycomb and corrugated counterparts, as well. Plate catalysts are manufactured by pressing the malleable pre-fired clay-like ceramic onto the support screen, with subsequent firing/calcining processes used to harden the ceramic. Plate catalysts are characterized by having individual plates of catalyst which are assembled into catalyst modules. The plates are held together by compression and can be removed individually. Glass-like fibers may be added to the ceramic portion of the catalyst and used to help add strength and improve adherence to the screen materials. **Figure:**



Individual Catalyst Plate
(Used with permission)

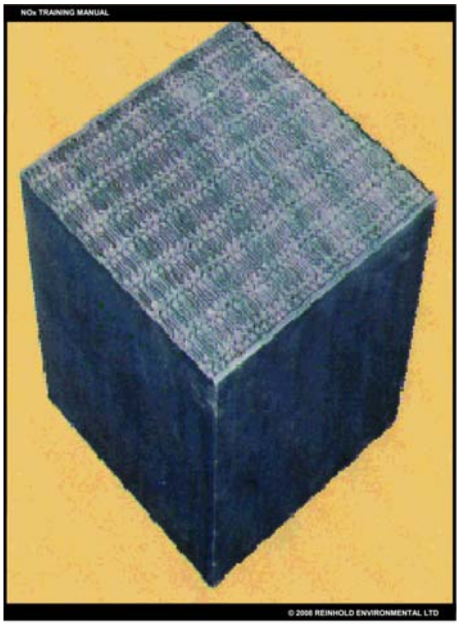
Individual Catalyst Plate

shows an individual catalyst plate. Typically these plates are on the order of 1.5 feet square and will have corrugations to create the needed channels for flue gas flow in the final assembly. Catalyst plates are not adhered to each other in the final assembly and can be removed as needed for testing, etc. simply by extracting plates with pliers. Note that the corrugations are such that when removing plates from their assembled blocks, plates should be removed in pairs to maintain the proper channel openings.

Figure:

Plates Loaded into Catalyst Block

shows plates loaded into a catalyst block or "can" which is a thin metal box or sheath open on two ends. These blocks are then loaded into a module which has support steel, ready for installation into the reactor, as shown in **Figure:**



Plates Loaded into Catalyst Block
(Used with permission)

Blocks Loaded into Final Catalyst Module-Ready for Installation
(Used with permission)

Blocks Loaded into Final Catalyst Module-Ready for Installation

.Typically a plate catalyst module will contain two layers of these blocks, with each layer containing 8 blocks for a total of 16 blocks per module (this assumes a module dimension of roughly 1 meter wide by 2 meters long, by 1 meter in height). Screens or grating may be installed on top of the catalyst module, as shown in **Figure:**

As-Installed Plate Catalyst with Grating

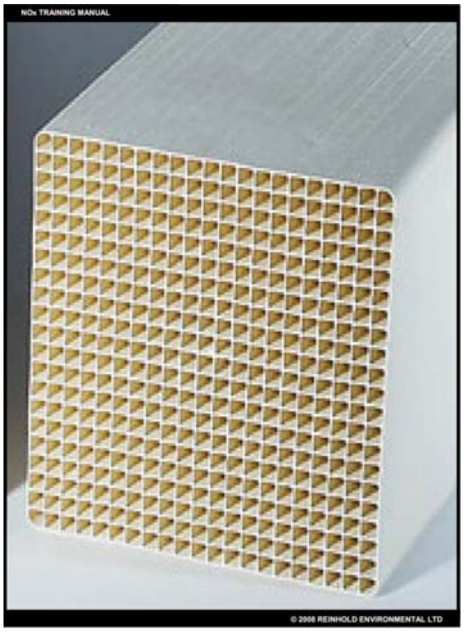
As-Installed Plate Catalyst with Grating
(Used with permission)

Catalyst screens and their benefits are discussed in subsequent sections.

Honeycomb Catalysts

Manufacturers of honeycomb catalysts include; Cormetech, Inc., KWH Catalysts, Inc., and Argillon, LLC. Most honeycomb catalysts are considered "homogeneous," since the ceramic material provides the gross physical support for the catalyst in addition to providing the needed pore structure and active catalytic component support. For most honeycomb catalysts, the chemical composition of the freshly manufactured material will be constant throughout the ceramic material. Honeycomb catalysts are typically manufactured by extruding the clay-like ceramic through a die, forming the honeycomb structure. The "logs" of catalyst are then heat-treated or "calcined," similar to other catalysts. **Figure:**

Individual Honeycomb Log



Individual Honeycomb Log
(Used with permission)

shows an individual honeycomb log. The pitch shown would be consistent with a coal fired application. These logs are on the order of 6" square by up to 1.1 meters in length and would be assembled on a single layer in the module. **Figure:**

Honeycomb Logs Being Loaded into Module

Honeycomb Logs Being Loaded into Module
(Used with permission)

shows individual logs being packed into a module. Note that the logs are typically not assembled into blocks or cans, as would be the case with plate catalysts.

Hybrid/Corrugated Catalysts

The primary manufacturer of hybrid/corrugated catalyst offered in the U.S.A. is Haldor Topsoe, Inc. Hybrid/corrugated catalyst is formed by using a mat-like fibrous material as physical support. The ceramic material is then applied on, and within, this mat. Monolithic blocks having a corrugated configuration are then produced, with their physical strength being provided by a combination of both the ceramic material and the fibrous support material. These catalysts are sometimes termed "hybrid" since they have characteristics of both plate and honeycomb catalysts. Unlike true plate catalysts, however, the final bulk catalyst is not composed of individual separate plates, since in the manufacturing process a monolith is formed which adheres the plates together. This monolithic structure, as well as the absence of a clearly distinguishable support screen, has similarities to honeycomb catalysts, but results in a physical appearance similar to plate. **Figure:**

Hybrid Type Catalyst

shows the undulated nature of the catalyst (inset) as well as a block/can ready for assembly into a module. These block/cans are similar to those found in plate catalysts.

6.3.d Catalyst Operation and Ammonia Slip

The SCR catalyst actually works by offering active vanadium sites upon which ammonia adsorbs. Once adsorbed, a chemical condition is set up whereby NOx can react easily with the adsorbed ammonia. Once the reaction occurs, the products of the reaction desorb and diffuse back into the bulk flue gas, leaving the active site available again for the reaction. This reaction mechanism fulfills the general function of a catalyst by promoting the deNOx reaction but ultimately not actually changing its form at the completion of the reaction. Via this reaction mechanism, as a mixture of ammonia and NOx passes through the SCR reactor and across the catalyst, NOx is destroyed, thus reducing the level of NOx in the outlet gas. In general, as flue gas passes through more and more catalyst, the levels of NH_3 and NOx become lower and lower. Invariably, however, not all of the ammonia or NOx will react as it passes through the catalyst. Theoretically, an infinite amount of catalyst would be necessary to react 100% of the ammonia present, but in practice the vast majority is reacted away by a reasonable amount of catalyst (two to four layers). The unreacted ammonia that passes through the reactor is termed "ammonia slip." Ammonia slip is a critical design parameter, comparable in importance to the required deNOx that defines the level of the NOx removal for the system - the principal purpose of the technology.

Hybrid Type Catalyst
(Used with permission)

6.3.e Ammonia Slip Relative to DeNOx

Ammonia slip is extremely important for several reasons:

- ammonia slip tends to react with SO_3 (another component of flue gas) downstream of the SCR reactor, which can form sticky, corrosive deposits that adversely affect downstream equipment
- ammonia slip byproducts can cause fine particulate emissions, contributing to opacity (stack clarity) issues and regulatory difficulties
- ammonia that is "slipped" through the reactor represents valuable reagent that is essentially discarded unused, thereby adding to the cost of the technology
- ammonia slip can cause contamination of the fly ash thereby preventing its sale
- ammonia itself is considered a pollutant, and thus releases of large amounts of ammonia release via slip could have regulatory impacts

When assessing the performance of an SCR system, ammonia slip level along with the particular deNOx level associated with that slip level are the primary parameters to be considered. DeNOx and slip are inter-related as well. For any particular system, as deNOx level is increased, the ammonia slip will increase as well, although the relationship is not linear. Thus, if faced with high ammonia slip, the operator must make the choice of reducing the level of deNOx to maintain the slip limit or accepting higher slip levels to maintain deNOx performance. In many cases, collateral issues related to high ammonia slip, such as air heater fouling, force the plant operator to reduce the level of deNOx.

Ammonia slip and deNOx are typically measured during performance tests on the SCR system periodically throughout its operational life. NOx concentrations are relatively easily measured and are recorded continuously using monitoring equipment that measures flue gas concentrations at the inlet to the SCR and at the stack (the point of release to the environment). Other measurement locations are sometimes used as well. This allows for the continuous reporting of NOx removal for a plant equipped with SCR. Continuous reporting of NOx removal, total NOx emissions, or short-term averages of these parameters, is typically required by state and federal environmental regulators. Since NOx emissions are the focus of the applicable environmental regulations for SCR technology, most SCRs are operated to continuously achieve the required level of deNOx, irrespective of the ammonia slip, even if the particular ammonia slip level causes operational difficulties. Failure to meet the required deNOx level can result in several outcomes:

- the requirement to reduce electrical output from the plant (by lowering plant output, reduced flows through the SCR are created which allow a more favorable operating condition for the reactor, and thus lower ammonia slip)
- the forced purchase of NOx allowances, i.e., equivalent NOx reduction from other operating facilities, if these are available and regulatorily allowed
- the payment of regulatory fines for not meeting deNOx requirements

In some instances, NOx credits can be "traded" with other units within the same generating company system. In all events, the inability to achieve deNOx will typically result in adverse financial consequences for the utility.

The measurement of ammonia slip is much more difficult than for NOx, and is typically not done on a continuous basis. This is because the high levels of SO_2 in the flue gas interferes with an analyzer's ability to measure small concentrations of NH_3 present in the flue gas. There are one or two suppliers of continuous analyzers that claim to have overcome this problem. Ammonia concentrations in flue gas are usually measured manually, with technicians using special probes to extract known volumes of flue gas from the plant ducts that are subsequently analyzed for ammonia content in the laboratory. Since ammonia slip is rarely constant across the cross-section of any particular plant duct, numerous individual samples (or single samples of composites generated from several locations) are typically used to generate an "average" level of ammonia slip for the duct as a whole. Consequently, the ammonia slip is commonly measured only periodically (one to two times per year) to assess the system performance and to verify that the catalyst is meeting the performance guarantees offered by the catalyst designer/manufacturer. Ammonia slip testing may be performed more often if performance problems are encountered.

6.3.f Catalyst Activity, Deactivation/Life, and Testing

Catalyst activity varies in accordance with its particular design. The activity is affected by both the detailed chemical make-up of the catalyst (formulation) and its physical geometry. For these reasons, a given volume of catalyst of one formulation does not necessarily have the same total activity as the same volume of catalyst of another formulation. Thus it is important to note that different catalyst formulations (as well as manufacturers) will typically have different total catalyst volumes for the same application.

In practice, all SCR catalysts lose a portion of their activity over time, meaning that as the catalyst is continuously exposed to flue gas, its ability to reduce NOx is diminished. This loss of activity is termed "deactivation" and is the result of various phenomena and must be compensated for by the catalyst designer through the specification of extra catalyst installed at the beginning of the operational period. Catalyst "life" is used to denote this operational period, i.e., some period of time for which a particular operational guarantee will be in force. From a practical standpoint, it typically makes sense for a particular charge of catalyst to be designed in such a way that it would meet performance requirements for lives on the order of 16,000 to 36,000 hours, after which time catalyst would be added or replaced. Within any particular life period, there will be more catalyst present than necessary at the beginning of life to meet performance requirements. This is done to insure that as deactivation takes place, enough total activity will be present to accomplish the required deNOx at the end of the particular designated life.

Determining the exact amount of catalyst needed to meet a certain life requirement is a major design consideration that catalyst suppliers must address. This determination includes uncertainties, since the catalyst designer must accurately predict the rate of deactivation for the particular application. For instance, an initial catalyst life guaranteed for 24,000 hours may be obtained, with accompanying deNOx and ammonia slip requirements. This guarantee is based on a particular full-load flue gas flow rate and temperature. Thus, the catalyst is expected to maintain its ability to achieve the deNOx and ammonia slip requirements for 24,000 hours of operating time. At the end of this period of time, a catalyst addition or replacement would be expected. Thus, at the start up of the unit, additional catalyst would be present to compensate for deactivation during its life. Catalyst life should not be construed as a particular time limit after which the catalyst totally fails and ceases to be useful. The catalyst life is merely a terminology useful in offering guarantees or denoting time periods for which particular performance requirements can be met. Once catalyst is upgraded by adding an additional layer, or by replacing a layer, then the overall life guarantees will become more complicated. If catalyst is purchased from the same previous supplier, then an additional life guarantee may be offered reflecting the new/replaced catalyst. If catalyst is purchased from a different manufacturer, various guarantee methods may be utilized to reflect the presence of catalyst from multiple manufacturers.

Catalyst Deactivation

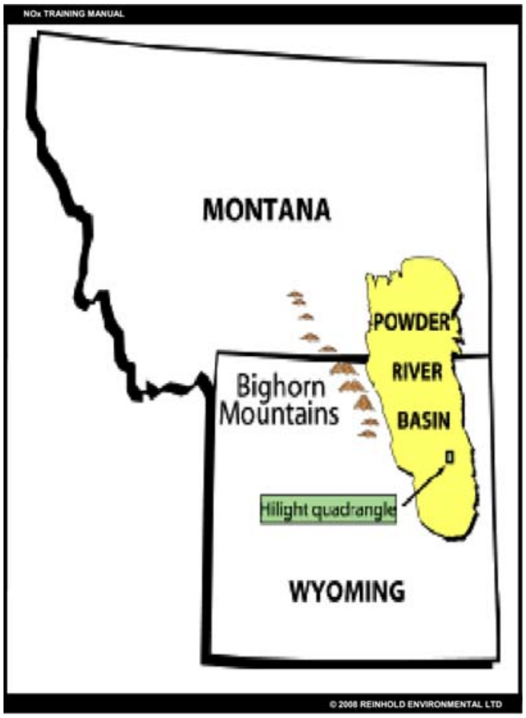
Catalyst deactivation is typically divided into two primary categories or mechanisms; physical and chemical. Chemical deactivation occurs from the direct attack of a chemical species on an active catalytic site rendering it unable to perform its primary function. Chemical deactivation mechanisms are often referred to as "poisoning," and include mechanisms such as arsenic poisoning and calcium poisoning. Physical deactivation occurs as a result of physical phenomenon unrelated to chemical attack on active sites Physical deactivation mechanisms are related to the loss of the physical integrity of the catalyst, and include such mechanisms as fouling, sintering, delamination, etc. The various mechanisms of catalyst deactivation are discussed in detail in the subsequent sections.

Chemical Deactivation

The two primary chemical deactivation mechanisms for SCR catalysts are arsenic poisoning and calcium sulfate poisoning (sometimes referred to as "PRB poisoning"). A key issue in the design of catalyst is the poisoning mechanism that will be prevalent for the particular application. For instance, an application where calcium poisoning will occur (such as with PRB applications) may require a catalyst design significantly different from that where arsenic poisoning will occur (as with Eastern Bituminous fuels). "Powder River Basin" (PRB) coal is mined from an area in Northeastern Wyoming and Southern Montana as shown in **Figure:**

Power River Basin Mining Area

. This fuel is characterized by high calcium levels and thus the predominant poisoning mechanism is by calcium poisoning.



Power River Basin Mining Area
(Used with permission)

Arsenic Poisoning

Arsenic poisoning prevails as the primary chemical deactivation mechanism for most coals mined east of the Mississippi River for use in commercial boilers, i.e. Eastern Bituminous coals. The mechanism of arsenic poisoning occurs via the chemical attack of arsenic on active vanadium sites, rendering these sites inactive for NOx reduction.

The amount of arsenic present in the process is determined by the boiler design and the coal composition. It is found in the form of As_2O_3, which volatilizes from the ash.

The arsenic has five points of deposit:

- 1. Bottom ash
- 2. Boiler
- 3. Clean gas downstream of the ESP
- 4. Fly ash in the ESP
- 5. SCR catalyst

Some fuels from western PA and West Virginia have insufficient CaO levels to neutralize the affects of arsenic. This problem is compounded by the fact that arsenic is very difficult to measure accurately since much of it is typically lost in sample preparation. In correct coal specifications can produce permanent affects, since arsenic deactivation in SCR catalysts is permanent. It cannot be reversed with cleaning.

There are a few options available to mitigate the impact of catalyst deactivation due to arsenic poisoning. These options include:

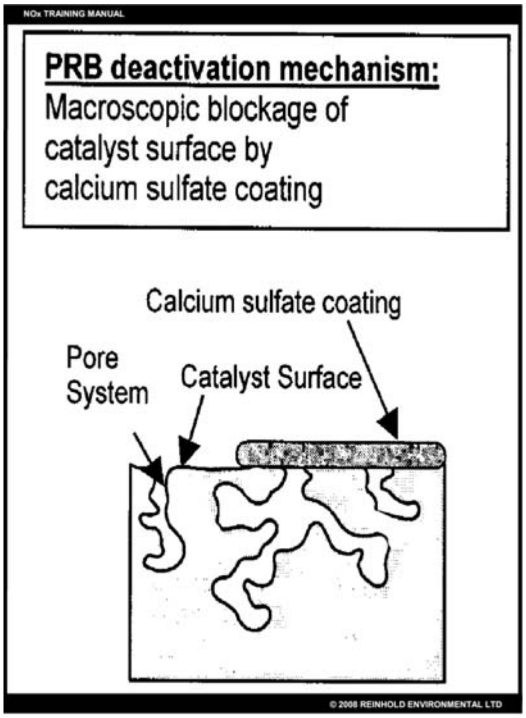
- Blending limestone with the fuels. In cyclone boilers, a typical limestone to fuel ratio is approximately 1:50. The free CaO in the limestone reacts with arsenic, forming a solid, $Ca_2(AsO_4)_2$, which will not poison the catalyst.
- Increasing the reactor catalyst volume
- Reducing the catalyst guarantee lifetime

Calcium Sulfate (PRB) Poisoning

"Calcium sulfate masking" is the more technically accurate term for calcium poisoning and will be discussed in more detail. In addition, sometimes the poisoning mechanism is termed "PRB poisoning" because of its close association with PRB coals. The subject Hawthorn unit fires PRB coal, and therefore subsequent discussions will be limited to poisoning associated with this type of coal.

PRB poisoning is a relatively new phenomenon to the industry. This is especially true since little PRB coal firing is present in Europe and Japan, where considerable SCR technology installation began much earlier (1980s) than in the United States. Arsenic poisoning was the predominant poisoning mechanisms in these overseas installations and is the predominant poisoning mechanism in the majority of U.S.A. SCR installations.

PRB poisoning was identified as a new mechanism of SCR catalyst poisoning in the mid to late 1990s. At the time that Hitachi America, Ltd. (HAL) was specifying the catalyst for Hawthorn (around 1999), no full-scale SCR installations had been completed on a unit firing 100% PRB coal. Nevertheless, calcium sulfate masking, or PRB poisoning, was a known potential problem, and was, in fact, the subject of pre-contract discussions between HAL and B&W. However, since long-term deactivation data on field installations takes several years to acquire, there was virtually no truly long-term (several years or more) deactivation data available from catalyst coupons placed at full-scale installations.


NOx TRAINING MANUAL

PRB deactivation mechanism:
Macroscopic blockage of catalyst surface by calcium sulfate coating

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Schematic of PRB Deactivation Mechanism
(Used with permission)

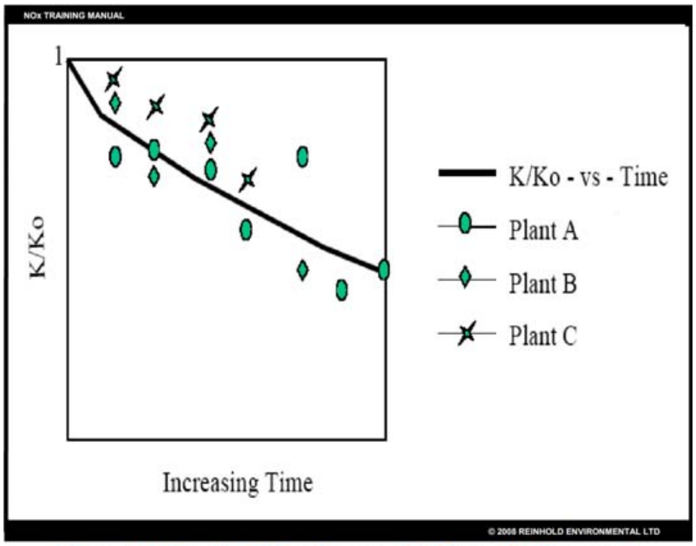
The first commercial SCR installation on a large utility boiler firing 100% PRB coal was at New Madrid, Unit #2, owned by Associated Electric Cooperative, Inc., which began operation in February 2000. Start-up of this facility began at roughly the same time that HAL was designing the Hawthorn catalyst. Limited data regarding catalyst operation in a PRB application was available, however, and will be discussed in detail in subsequent report sections. Other notable early PRB applications include Alabama Power's Plant Miller, and the subject Hawthorn unit. It appears from information available to the author, that the Hawthorn unit was the first dry-bottom pulverized coal unit firing PRB coal to be equipped with SCR. Although New Madrid began operations earlier, it is a "cyclone" boiler, indicating its firing configuration. Hawthorn is a "wall-fired" unit.

The detailed mechanism of PRB poisoning is somewhat unclear. It is known that high calcium levels are found on the catalyst exposed to PRB coal flue gases and that the calcium compounds chemically or physically deactivate the catalyst, either by attacking active sites as with arsenic poisoning, or by blocking catalyst pores and surfaces preventing diffusion of the reactant to the active sites, or both. The term used for heavy deposits that prevent diffusion is "masking." A schematic of this deactivation mechanism is shown below in **Figure:**

Schematic of PRB Deactivation Mechanism

Additional studies conducted by the author indicate that microscopic layers of calcium may be present which appear to deactivate the catalyst in absence of heavy masking layers.

Since PRB applications are relatively new to the industry (as compared to Eastern Bituminous applications), the exact rates of deactivation are more difficult for catalyst designers to predict due to limited field data. This was especially true at the time that the Hawthorn catalyst was being specified. This lack of field data increases the risk of the catalyst designer since the confidence in the predicted deactivation rate is limited. Catalyst designers/manufacturers must take care in specifying catalyst volumes and formulations so that sufficient catalyst volume is installed to meet guarantees. This is especially important for a long guaranteed life since as guaranteed life increases, the end-of-life activity becomes less certain, because it involves a longer-term prediction. The prediction of catalyst activity over time is the "deactivation curve," which will be discussed in detail in subsequent report sections. For facilities having severe deactivation rates, shorter guaranteed life is typically preferable to adding large amounts of extra catalyst at the beginning of life to compensate for the deactivation. The shorter life is preferred for several technical reasons, including a reduced average pressure drop over the life of the installation, and less "waste" of catalyst since extra catalyst needed to meet long life guarantees is in effect being placed in a deactivation environment unnecessarily. The drawback, however, to a short catalyst guarantee life is that outages must be taken more frequently for catalyst replacement.



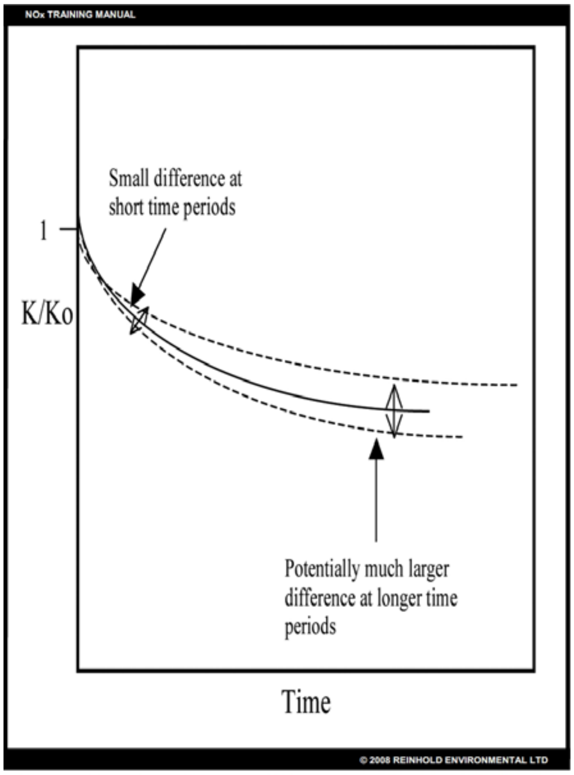
Example Deactivation Curve with Specific Example Data-Points
(Used with permission)

Deactivation Curves

Catalyst activity is typically expressed as the variable "K" in reactor design equations and offers a convenient way of expressing the "potential" of a catalyst for deNOx performance. This parameter is often used in the industry to describe catalyst activity, especially with respect to time. As previously mentioned, catalysts typically lose activity over time, and thus an activity curve will have a downward slope and may not be linear - this curve is often termed the "deactivation curve" since it describes catalyst deactivation. The following diagram, **Figure:**

Example Deactivation Curve with Specific Example Data-Points

, depicts an example of a deactivation curve, which utilizes a parameter (K/Ko) rather than simply K. Ko represents the activity of the catalyst as originally installed, without any deactivation, i.e., virgin catalyst material (catalyst as manufactured with no exposure to flue gas). K represents the activity of the catalyst at any given time, thus K/Ko reflects the ratio of catalyst activity at any particular time to that as originally installed. The parameter is presented as a decimal value or a percentage, thus for a K/Ko of 0.5 or 50%, the catalyst has an activity of one-half that of its original value. Note that at time zero, K/Ko is 1.0, or 100%.



Deactivation Curve Showing Uncertainty in Long-Term Activity vs. Short-Term
(Used with permission)

Activity (K) or K/Ko, often shows a relatively steep decline in activity for the first few thousand hours of operation, after which time the decline in activity levels out to some degree. Since deactivation rates are non-linear with respect to time, and differ substantially from one application to another, it is very difficult to determine the exact activity that will be present at the end of any particular guaranteed life. In addition, using catalyst activity data acquired over short exposure times to predict long-term deactivation, such as HAL apparently did for Hawthorn, involves a significant design risk, since a small change in curve shape potentially leads to a large change in remaining activity at the end of guaranteed life. This phenomenon is demonstrated in **Figure:**

Deactivation Curve Showing Uncertainty in Long-Term Activity vs. Short Term

.It should also be noted here that similar graphs may be produced showing deNOx efficiency versus time. These plots are similar to K/Ko versus time but contain information specific to an individual installation, since they reflect the achievable deNOx efficiency for an installation assuming that all other parameters are at design conditions.

6.3.g Catalyst Operating Parameters: Temperature, Pressure Drop and Ammonia Slip

Temperature

Operating temperature affects not only the production of ammonia bisulfate, but also the catalyst design and operating costs. A possible unit might find that if they increase their operating temperature by 6% the result is a 69% increase in SO2 oxidation, 15% increase in catalyst life, 6% increase in catalyst pressure loss, while maintaining the NOx reduction and ammonia slip.

Pressure Drop

As flue gas flows through ductwork or through equipment, its free flow is inhibited due to friction. This is typically represented by pressure drop, which is a measure of loss in pressure between two points in the system. High pressure drops require significant fan energy to overcome the loss in pressure, i.e. to maintain flow rate. Since the SCR catalyst represents a significant inhibitor to flow, limits will be placed on the allowable pressure drop that a catalyst can create. This allowable pressure drop plays a role in the catalyst design, dictating how much catalyst can be contained in a specific volume due to the geometrical requirements to minimize pressure drop, as well as the total volume of catalyst that can be accommodated in a reactor, given a specific geometrical configuration for the catalyst.

Ammonia Slip

If one is marketing fly ash, the ammonia slip that can be tolerated may be determined by the concentration of ammonia that can be present on the fly ash. A small amount of ammonia slip will be concentrated to a much higher concentration of ammonia on the surface of the fly ash. If the fly ash is being used in concrete, this ammonia can cause a noticeable odor as the concrete cures once the ammonia reaches a certain concentration on the fly ash.

6.3.h Catalyst Laboratory Testing and Performance Predictions

Some assessment of catalyst deactivation rate is obviously necessary for a catalyst designer/manufacturer to make a catalyst offering for any particular application. As previously noted, the prediction will depend on a designer's specific field experience and other data that may be generated from research projects, for example. This additional data may be obtained by using small amounts of catalyst exposed to flue gas at particular plants of interest - these small catalyst pieces are often termed "coupons." Also, pilot plants or "slip-stream" reactors may be used to collect applicable deactivation data. Obviously, when a catalyst designer/manufacturer has relatively few full-scale installations for a particular application type (such as PRB-fired plants) or the majority of its installations are relatively new, data available for predictive purposes will be limited. In these cases, the catalyst designer has a greater technical liability associated with its design offering for the particular application.

The predicted deactivation rate is utilized along with proprietary calculation methods - estimation procedures - to determine the catalyst volume that will be needed for a particular installation. These calculations also help to determine the specific catalyst formulation that would be most appropriate. These estimates must also be coupled with an appropriate design "margin" (i.e., additional catalyst) to help compensate for uncertainties such as the deactivation rate. This margin mitigates liability associated with failure to meet the guaranteed performance at the end of guaranteed life. Similar calculations are used to estimate field performance over the life of a facility using actual deactivation rates.

Actual deactivation rates are measured using catalyst samples removed periodically from the SCR reactor. These samples are measured for activity in laboratory. Additional measurements such as chemical composition, surface area, or pore distributions are typically obtained as well. If the measured deactivation rate is unexpected, the additional laboratory data might be used to help determine the source of the increased deactivation. Laboratory activity measurements are utilized, along with specifics of the installation (gas flow rate, catalyst volume, temperature, etc.) to predict the ammonia slip and other deNOx performance parameters that are expected in the field. The predictions can be performed for any operating parameter selected, but are typically performed for the design conditions for the particular installation. For example, the Hawthorn unit design specified a flow distribution of 10% RMS, and a temperature distribution of + or - 20 degrees F. Thus, the slip predictions utilizing the laboratory activity data would be performed using these values, unless otherwise specified. Such laboratory activity measurements and subsequent predictions were performed by HAL and play a major role in the opinions and conclusions developed in this report.

6.3.i Catalyst Management

About 50-60% of the capital cost of an SCR system is for the catalyst. Therefore, catalyst life and replacement schedules have a significant impact on the cost. Thus it is no wonder that a catalyst management plan that is designed to minimize the cost of catalyst replacement is an essential part of a SCR installation.

With time, the catalyst layer starts to deactivate resulting in an increasing ammonia slip down-stream of the SCR system. To determine the rate of this process, a test element must be pulled out of the reactor periodically during a shutdown and sent to a facility for testing of its reactivity. If the uncertainty of these measurements is more than 10%, the checks may not be reliable.

The deactivation of the catalyst is closely dependent on the installation of the SCR system.

- High dust system: The catalyst layers degrade nearly in the same way.
- Tail end system: In this case, the deactivation of the catalyst is dependent on the FGD rotating gas/gas heat exchanger. If there is no heat exchanger, only a low catalyst deactivation will be observed.

Catalyst Replacement

Catalyst layers are usually replaced in stages in a way to ensure the SCR's overall performance. Historically, catalyst was always replaced by the same catalyst from the same vendor to preserve the catalyst guarantee. However, recent trends are developing where the user is replacing catalyst layers with larger pitch catalyst to reduce LPA pluggage, different types of catalysts to facilitate removal or in-situ cleaning, and lower SO_2 conversion catalyst to reduce downstream problems caused by SO_3. The end result is that more SCR Reactor catalyst beds are becoming mixes of multi-type, multi-pitch and mult-vendor catalyst layers.

Catalyst Regeneration

Removal Regeneration Method

This process can remove most poisoning effects, even arsenic, by removing the deactivated catalyst sites and replacing them with new catalyst sites, as well as physical restrictions such as plugging and blinding. Obviously the mechanical destruction of the catalyst caused by erosion and/or abrasion cannot be reversed.

In-situ Regeneration Method

This process involves washing the catalyst layer within the SCR with water based regenerating solution sometimes containing minor amounts of non-toxic additives. The achievable improvement from this technique differs with the various mechanisms of catalyst degradation and depends on such factors as furnace type, ash composition, flue gas parameters, and SCR reactor operating practices.

6.4 SCR Ammonia System Design

For the catalyst to remove NOx there must be ammonia present at the active sites on the catalyst. It doesn't make any difference to the catalyst what the source of this ammonia is. The ammonia is chemically the same regardless of the source. In SCR systems the sources of ammonia typically used are anhydrous ammonia, aqueous ammonia and urea.

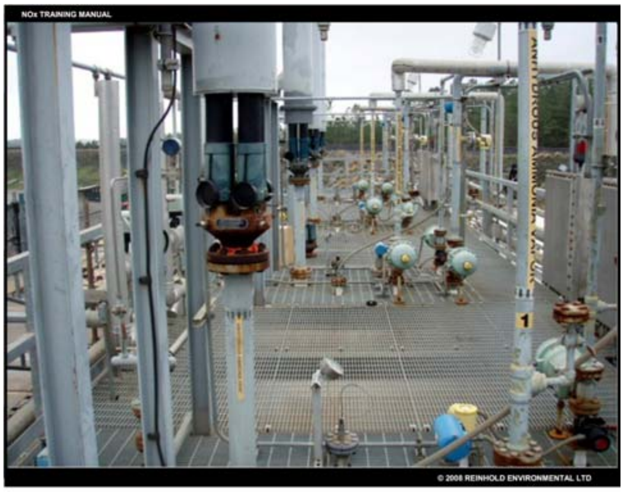
Anhydrous ammonia is the most cost effective since it is 100% ammonia in the delivered form. Ammonia gas will become a liquid at normal ambient temperatures if pressure is applied to it. At 79 degrees F this pressure is 150 psia. This liquid ammonia is shipped and stored in pressurized tanks. Because of the severe health hazards associated with ammonia exposure and because it is stored in pressurized tanks, there are numerous regulations involved in the handling and storage of anhydrous ammonia. EPA requires each site develop a "risk management program" and follow the developed procedures for maintenance and operation of the ammonia storage facility.

Ammonia Storage Area
(Used with permission)

Some utilities have decided not to use anhydrous ammonia due to the regulations and the safely reviews required to permit a storage site. Others in more populated regions have been prohibited from using anhydrous ammonia due to zoning laws or citizens' concerns.

Ammonia Storage Vessel
(Used with permission)

Aqueous ammonia is water that has had up to 30% ammonia by weight dissolved into it. At ambient temperatures, it has a vapor pressure very close to atmospheric pressure. This means that there are very low pressures in the delivery and storage tanks. Because of this, the rate at which ammonia is released into the atmosphere during a leak or spill is much less than it would be in the case of anhydrous ammonia. Some utilities have been forced to use aqueous ammonia containing less than 30% ammonia by local governments to reduce this rate of release even more. Because of this, the risks and regulations involved in handling and storing aqueous ammonia are not as great as they are with anhydrous ammonia.



Top of Ammonia Storage Vessels
(Used with permission)

The cost to use aqueous ammonia is greater because one must buy 4 - 6 tons of aqueous ammonia to get 1 ton of useable ammonia. The rest of the weight is water. So one ends up paying to haul and store large amounts of water to get the required ammonia needed for SCR operation.

Urea is a dry material sold as fertilizer in the agricultural market. It can be processed and broken down to release ammonia. The advantage to using urea is that there is no ammonia present during the transportation and storage of the material. The only ammonia present is the small amount in the SCR system between the conversion point and the SCR catalyst. The disadvantages of urea are the storage and handling issues of handling the dry urea prills, the additional cost for the material and the conversion process.

6.4.a Anhydrous Ammonia System Design

The typical anhydrous ammonia system consists of a storage area, forwarding pumps, vaporizers and a dilution air system which deliver warm ammonia gas to the ammonia injection grid (AIG).

Storage Area

Since anhydrous ammonia handling and storage are highly regulated, all ammonia storage areas are very similar in design. (See **Figure:**

Ammonia Storage Area

The number and size of the pressurized storage vessels will be dependent on the daily ammonia consumption of all the SCR systems at the site. A large multi-unit generating station can consume a rail car of ammonia per day. So the amount of storage capacity will be determined by how much can be delivered in a day and how many days per week the utility wants to have unloading personnel on site. Then there is the risk factor that one must include for delivery interruptions due to weather, equipment breakdowns, etc.

If there are multiple storage vessels, typically only one is discharging liquid ammonia at a time with the others valved out on standby. There are typically permissives that will not allow valves to open on a vessel if similar valves on another vessel are already open performing the same task. The pressure in a storage vessel is determined by the temperature of the vessel wall and how fast the ammonia is withdrawn from the vessel. Liquid ammonia is withdrawn from the bottom of the vessel. As the level decreases in the vessel, some of the ammonia will boil off to fill the gas space above the liquid. This boiling may cool the ammonia slightly. There are multiple pressure relief valves on each storage vessel to assure that the pressure does not exceed the design pressure of the vessel.

There are four main valved connections on each storage vessel.

1. Gas fill pipe
2. Liquid fill pipe
3. Liquid recirculation pipe
4. Liquid discharge pipe

There are typically two ammonia compressors in the storage area. The compressors are used to transfer liquid ammonia between storage vessels or delivery vehicles. To transfer ammonia, a compressor is connected to take suction from the gas fill pipe on the vessel that will receive the ammonia and pump it into the gas fill pipe on the vessel that will be delivering ammonia. The difference in pressure that this creates will cause the liquid ammonia to flow into the receiving vessel.

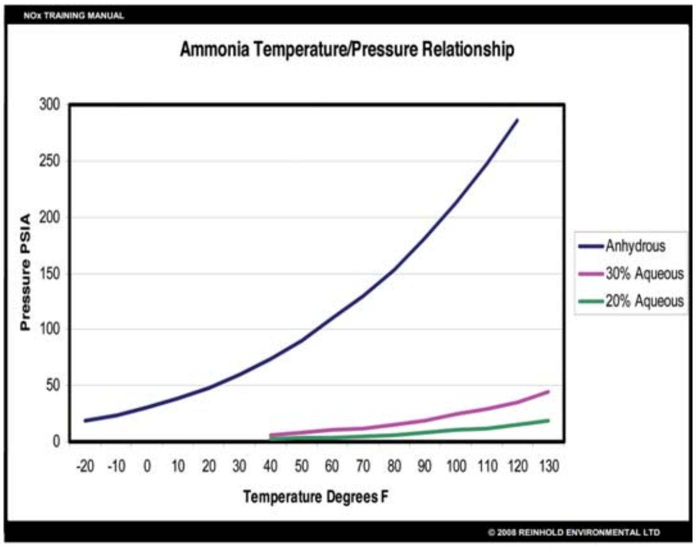
There is typically a rail unloading station and a truck unloading station for each storage area (See **Figure:**

Ammmonia Unloading Station

Ammonia Unloading Station
(Used with permission)

They are both designed the same, but the rail unloading station will have larger diameter liquid ammonia piping. There are swing arms with swivel couplings that allow piping to be connected to the gas and liquid connections on the delivery vehicle. The proper valves are opened to the receiving tank and a compressor is used to move the liquid ammonia from the delivery vehicle to the storage vessel. There are level detectors on the storage vessel that will automatically close the liquid fill valve if the vessel level reaches the maximum storage level. This is done to prevent the storage vessel from over pressurizing if the ambient temperature increases. (See **Figure:**

Ammonia Temperature-Pressure Relationship



Ammonia Temperature-Pressure Relationship
(Used with permission)

There is typically a nitrogen supply skid in the storage area. This nitrogen supplies the pressure needed to open some of the unloading valves at the rail and truck unloading stations. If the ambient ammonia sensors detect a leak or the person doing the unloading hits an "emergency stop" button, the nitrogen pressure is released and the unloading valves slam closed. The nitrogen is also used to purge and vent the unloading connections before they are disconnected. This prevents the person who is disconnecting the piping from getting a face full of ammonia when the connections are separated.

Forwarding Pumps

There are two or more specialized liquid ammonia pumps located in the storage area. (See **Figure:**

Liquid Ammonia Forwarding Pump Skid

Liquid Ammonia Forwarding Pump Skid
(Used with permission)

These forwarding pumps are used to provide the necessary pressure to move the liquid ammonia from the storage area (which is often in a remote area of the utility site) through the piping to the vaporizers which may be located at the upper elevations of the SCR reactor. During the warmer months, there may be sufficient pressure in the storage vessel to push the liquid ammonia to the vaporizers with the forwarding pumps bypassed and out of service.

There is an automatic recycle valve on the discharge of the forwarding pumps. As the demand for ammonia feed decreases at the SCR, this valve will sense the forwarding pump discharge pressure or flow rate and open to recycle liquid ammonia through the ammonia recycle pipe to the storage vessel in service and limit the pressure on the header to the vaporizers.

Some utilities have experienced a problem in the piping from the forwarding pumps to the vaporizers. If the routing of this pipe includes both underground or shaded areas as well as piping exposed to hot sunny conditions, it is possible to experience some flashing of the liquid ammonia to vapor in the hotter sections if there are pressure swings in the piping. This can cause a vapor lock in the piping especially if there are high spots in the piping run that can trap and hold the gas bubble. This can persist until the ammonia cools off or the pressure increases to return the ammonia gas to its liquid state.

Vaporizers

One or more vaporizers will be located near each SCR reactor. Sometimes they are at grade elevation, and sometimes they are located at an elevation near the SCR inlet duct. The purpose of a vaporizer is to convert all of the liquid ammonia to ammonia gas by heating the liquid ammonia to a temperature higher than its boiling point.

The source of heat may be electric, steam, or hot fluid depending on what is available at the most reasonable cost at that location. The heat source is on one side of the heat transfer surfaces and the liquid ammonia is on the other side. The vaporizer controls are designed to maintain a constant temperature in the vaporizer. As ammonia feed rate to the SCR increases, more liquid ammonia flows into the vaporizer lowering its temperature. The controls then increase the heat source to maintain the set point temperature. As ammonia feed rate to the SCR decreases, less liquid ammonia flows into the vaporizer allowing its temperature to rise. The controls then decrease the heat source to maintain the set point temperature.

It has been demonstrated that an SCR can operate without a vaporizer. The temperature at the AIG is sufficient to boil all the liquid ammonia to gas before it comes into contact with the catalyst. The problem is that a small volume of liquid ammonia makes a large volume of ammonia gas. It is more difficult to control a small flow of liquid ammonia passing through an ammonia feed control valve to maintain a constant ammonia feed rate than it is to control a larger volume of ammonia gas passing through an ammonia feed control valve.

Dilution Air System

The volume of ammonia gas needed in the SCR is relatively small in comparison to the total flue gas flow. This ammonia must be distributed as evenly as possible across the total cross section of the SCR inlet duct. This is the job of the AIG. Because the AIG may consist of numerous injection nozzles, it would be very difficult to divide this small ammonia flow evenly across these numerous nozzles.

The purpose of the dilution air system is to mix enough volume of air with the small volume of ammonia to make it more feasible to split the total flow evenly across all the AIG nozzles. The dilution air fans typically run at a constant flow so the total volume of gas through the system is virtually constant (since the varying ammonia volume is so small) and the split through the AIG nozzles will remain constant after it has been set during commissioning.

The dilution air is typically heated to prevent any condensation of moisture and reaction with the ammonia. The source of this heat may be electric, steam or hot fluid depending on what is available at the most reasonable cost at that location. There is a dilution air heat exchanger where this heat is added. Since the air flow is constant, the heat load on the dilution air heater doesn't change much except for ambient air temperature changes.

6.4.b Aqueous Ammonia System Design

An aqueous ammonia system is very similar to an anhydrous ammonia system. The differences are related to two main differences between aqueous ammonia and anhydrous ammonia. The aqueous ammonia is 70 - 90% water. This means that:

- A much greater volume of aqueous ammonia is going to be delivered, stored and vaporized at the utility site.
- The vapor pressure of the aqueous ammonia at typical ambient storage temperatures is low enough that safety concerns are much lower and vapor recovery is not a large issue when transferring the material.

Storage Area

Typically the aqueous ammonia will be stored in the same type of storage vessels as the anhydrous ammonia. It can, however, be stored in vertical tanks. The pressure in the vessels or tanks will be very low and does not change much with temperature changes, so there is not a need for as many pressure relief valves. The vessels will either be larger or more numerous since one needs 4 - 6 times the storage capacity than an equivalent sized anhydrous system. Utilities that have designed for anhydrous ammonia and then have been forced to convert to aqueous ammonia have had to retrofit the site with more storage vessels. The large multi unit plant that would have consumed one railcar of ammonia per day will be consuming 4 - 6 railcars per day of aqueous ammonia, so material delivery and unloading is a much greater issue and one of the factors that makes aqueous ammonia more expensive to use than anhydrous ammonia.

Since vapor recovery is not an issue compressors may not be needed. Compressors can be used to unload delivery vehicles, but pumps can be used instead. There may also be a nitrogen supply skid since some utilities prefer to keep a nitrogen cap in their storage vessels. Some sort of cap will be needed since the ammonia vapor pressure is so low that the pressure above the liquid could become quite low as one withdraws the liquid from storage.

Forwarding Pumps

The forwarding pumps and piping from the storage area to the vaporizers will need to be larger since one is pumping much higher volumes of liquid. Since there is very little vapor pressure in the storage vessels, the forwarding pumps will always be needed to move the aqueous ammonia to the vaporizers.

Vaporizers

The vaporizers will be much larger and so are most likely to be located at grade elevation. See **Figure:**

Aqueous Ammonia Vaporizer

They will also have to operate at a much higher temperature since they must boil all the water that is contained in the aqueous ammonia. This means they will typically be steam or electrically heated. This required heat consumption is the other factor that makes using aqueous ammonia more expensive than anhydrous ammonia.

The utilities that were forced to convert their design from anhydrous ammonia to aqueous ammonia had to scrap the original vaporizers and install new units. The size of the new units made it very difficult to place them in the same area as the original vaporizers.

Some utilities have learned the hard way that there can be differences between aqueous ammonia suppliers. Aqueous ammonia is made by adding anhydrous ammonia to water. If the supplier uses "city water" or "softened water" instead of "deionized water" when making their product, the utility will experience failure of their vaporizers as mineral deposits form on the heat exchanger surfaces. This will require an acid cleaning of the vaporizers to restore performance. It is imperative that a utility knows how the aqueous ammonia is manufactured.

Aqueous Ammonia Vaporizer
(Used with permission)

Dilution Air System

The volume of ammonia gas and water vapor going to the SCR is still relatively small in comparison to the total flue gas flow. This ammonia/water vapor mixture must be distributed as evenly as possible across the total cross section of the SCR inlet duct. This is the job of the AIG. Because the AIG may consist of numerous injection nozzles, it would be very difficult to divide this small ammonia/water vapor mixture flow evenly across these numerous nozzles.

The purpose of the dilution air system is to mix enough volume of air with the small volume of ammonia/water vapor mixture to make it more feasible to split the total flow evenly across all the AIG nozzles. The size of the dilution air system will be the same as it is for an anhydrous ammonia system. The dilution air fans typically run at a constant flow so the total volume of gas through the system is virtually constant (since the varying ammonia/water vapor mixture volume is so small) and the split through the AIG nozzles will remain constant after it has been set during commissioning.

The dilution air is typically heated to prevent any condensation of moisture and reaction with the ammonia. There is more moisture present since the water vapor from the aqueous ammonia is present. The source of this heat may be electric, steam or hot fluid depending on what is available at the most reasonable cost at that location. There is a dilution air heat exchanger where this heat is added. Since the air flow is constant, the heat load on the dilution air heater doesn't change much except for ambient air temperature changes.

6.4.c Urea System Design

Millions of tons of urea are produced every year. It is used mainly as an agricultural fertilizer. It is produced by reacting ammonia and carbon dioxide. Its chemical formula is $(NH_2)_2CO$. The resulting solution is sprayed into a drying tower where it forms small pellets called prills. These prills can be soft and fragile, so it is typically treated with formaldehyde to harden the prills.

It is a non hazardous material which has made it attractive to utilities as a source of ammonia. When it is heated, it will decompose and return to ammonia and carbon dioxide. In the utility SCR systems, the amount of ammonia present at any given time between where the urea decomposes and where the ammonia is used by the catalyst is very small. This has caused some utilities to choose (or be forced to use) this process as a way to minimize the potential for a hazardous ammonia release from their property. Of course this means they have chosen to use the most expensive way to deliver ammonia to the SCR system.

One vendor is offering a system that consists of:

- An air blower
- A decomposition chamber complete with fuel burner to generate hot combustion gas
- A urea solution pumping/metering system
- A urea storage system
- A process control system

The air is blown through the decomposition chamber along with the hot combustion gasses. The urea solution is metered into the decomposition chamber where it decomposes into ammonia and isocyanic acid. This stream is then fed directly into the AIG.

The systems that have been installed by several utilities consist of:

- A urea storage system
- A urea dissolution system
- A urea solution storage system
- Hydrolyzer feed pumps
- Hydrolyzers

The following description will be based on this system.

Urea Storage

At the earliest installations, urea was delivered in pneumatic tank railcars or truck trailers. The material was pneumatically transferred into storage silos. (See **Figure:**

Urea Storage Silos

Urea Storage Silos
(Used with permission)

The problem that was experienced arose because urea prills are hygroscopic. This means they will absorb moisture from the air. When this happens, the prills can cake and stick to each other. This led to bridging of the material in the storage silos preventing it from flowing out of the silos. This was especially a problem if material was left in the silos during the seasonal shutdowns.

Various schemes such as heated fluidizing air, bin vibrators, etc. can be employed to overcome this problem. Others resorted to "just in time" deliveries to minimize the amount of time the material remained in the storage silo.

Some of the newer installations have changed philosophies by dissolving the urea prills as soon as they are delivered and then storing the resulting hot urea solution in large insulated storage tanks.

Urea Dissolution and Solution Storage

The urea prills are mixed with heated deionized water. Most systems make a solution that contains 40 - 50% urea. The size of the solution storage tanks and the number of solution transfer pumps will depend on whether the solution is made as needed or is made at the time the urea prills are delivered. See **Figure:**

Urea Small Solution Storage Tank

Urea Small Solution Storage Tank
(Used with permission)

A solution of this concentration must remain heated during its storage and movement through pumps and piping. This can be accomplished through the use of heat tracing and insulation. The maintenance of all heat tracing and insulation is a critical part of system O&M if one doesn't want to experience pluggage of pumps and piping systems.

Hydrolyzer Feed Pumps

Hydrolyzer feed pumps take suction from the urea solution storage tanks. See **Figure:**

Urea Hydrolyzer Feed Pump

Urea Hydrolyzer Feed Pump
(Used with permission)

They are used to overcome the hydrolyzer pressure and to maintain a fairly constant level of urea solution in the hydrolyzer. Again, the maintenance of all heat tracing and insulation is a critical part of system O&M if one doesn't want to experience pluggage of these pumps.

Hydrolyzer

The hydrolyzer is a kettle reboiler style heat exchanger that is heated by steam and typically operates around 80 psig and 280 - 310 degrees Fahrenheit. (See **Figure:**

Urea Hydrolyzer

As the urea solution is heated, it decomposes into ammonia, carbon dioxide and water vapor. The higher the temperature, the faster the decomposition proceeds.

In controlling the hydrolyzer, the urea solution is controlled at a constant level by controlling the discharge of the hydrolyzer feed pumps. If the demand for ammonia increases, the gas pressure in the hydrolyzer decreases and the steam valve opens raising the temperature of the hydrolyzer. If the demand for ammonia decreases, the gas pressure in the hydrolyzer increases and the steam valve closes lowering the temperature of the hydrolyzer. The volume of the hydrolyzer and the piping creates a surge capacity for ammonia volume, so the hydrolyzers have been operated successfully while following rapid wide load or NOx swings.

The number of hydrolyzers is determined by the total ammonia flow required and the utility's equipment sparing policy. The discharge gasses from the hydrolyzers are fed directly to the AIG through heat traced piping. The formaldehyde on the urea prills is also driven off into this gas stream. The SCR catalyst will oxidize most of this formaldehyde vapor.

Urea Hydrolyzer
(Used with permission)

Potential Problems

Trace amounts of impurities in the dissolution water or the urea prills will show up as mineral deposits in the hydrolyzers. Impurity levels should be maintained as low as possible. This will maximize the time between hydrolyzer inspections and cleanings. A buildup of these minerals can foul the hydrolyzer heat exchange surfaces.

Failure to maintain heat tracing and insulation on the urea solution storage tanks, solution pumps, hydrolyzer pumps and piping can lead to urea crystal deposits that may cause flow interruptions. See **Figure:**

Urea Solution Pump

Ammonium carbamate is an intermediate reaction product in the formation and decomposition of urea. If the gas mixture leaving the hydrolyzer is not kept at a high enough pressure and temperature, solid deposits of ammonium carbamate can form on surfaces. Some utilities have found this is a problem with piping stubs and nipples used to connect instruments and controls to the hydrolyzer and hydrolyzer discharge piping. If the heat tracing and insulation are not sufficient on these stubs or nipples, ammonium carbamate will form and completely block the connection. This leads to a loss of signal to the instrument or control.

Urea Solution Pump
(Used with permission)

6.5 SCR Control and Measurement Systems

The automated control of the SCR dampers during start-up and shut down is discussed in the SCR System Normal Operation section of this manual.

This chapter will focus on the various types of measurements that are continuously made and discuss how this data is used to control the SCR system operations.

TEMPERATURE

SCR Inlet Temperature Grid

The average temperature across the entire upper face of the top catalyst layer is of great concern to the catalyst vendors. They are also concerned about any isolated cold or hot regions. Since this area is so large, one usually installs a rather extensive grid of thermocouples to give readings across the entire area. One then calculates the average temperature.

If the SCR has been out of service for enough time for the catalyst to cool, there are usually temperature ramp rates established for reheating the catalyst to operating temperature. These ramp rates are designed to prevent thermal shock to the thin catalyst walls that could cause cracking of the catalyst walls. There may be multiple ramp rates with the slowest one occurring while the catalyst is cold, and then the slope of the ramp rates increasing as the catalyst warms.

In units with bypass dampers, it is easy to control this heating process by moving the SCR Bypass and SCR Inlet dampers in coordination to maintain the temperature ramp. In units without bypass dampers, the firing rate of the boiler will have to be varied to follow the ramps or else the ramps will have to be ignored at the risk of some catalyst damage.

There is typically a minimum temperature that must be reached before ammonia feed can begin. This is usually determined by looking at the coldest thermocouple. The concern here is that at low temperatures, the ammonia can react with SO_3 in the flue gas to form ammonium bisulfate. If this happens, the material formed can temporarily block the pores of the catalyst rendering it ineffective. Once the coldest thermocouple is above this minimum temperature, the permissive will be met to open the ammonia feed valve. If the temperature of any thermocouple drops below this minimum temperature, the ammonia feed valve may be programmed to automatically close. If the Dilution Air flow rate drops below a certain level, the ammonia feed valve may be programmed to automatically close.

Some units have an Economizer Bypass Damper that can open to bring hotter flue gas into the SCR inlet. If the SCR Inlet Damper is completely open and the SCR Bypass Damper (if there is one) is completely closed, whenever the coldest thermocouple reaches some minimum temperature (typically slightly higher than the ammonia feed cut off temperature), the Economizer Bypass Damper will be opened to maintain the temperature above this minimum temperature. This typically happens during periods of low boiler load. When the temperature returns to some higher set point, the Economizer Bypass Damper will close.

If any thermocouple reaches a certain high set point, a SCR High Temperature Alarm may be sounded. If the temperature reaches an even higher set point a SCR High High Temperature Alarm may sound indicating that a catalyst fire may be occurring. Refer to the SCR Abnormal Operation Section 7.2 of this manual for the proper response to this alarm.

SCR Outlet Temperature Grid

Since the SCR Outlet temperature is less critical, there are less thermocouples installed beneath the last catalyst layer. They give the operator indication when all the catalyst layers have attained the normal operating temperature. They may also be included into some of the logic functions along with the inlet thermocouples.

When the SCR system is out of service, the catalyst vendors usually specify some minimum catalyst temperature to prevent the dew point being reached in the SCR Reactor. If this happens, moisture can form on the catalyst surface which may lead to various types of catalyst poisoning. The thermocouple grids are used to monitor the temperature in the SCR Reactor during system shutdown.

PRESSURE

At the minimum one should have indication of the differential pressure across the total catalyst bed. This will give the operator indication if the flow channels in the catalyst layers are beginning to plug. If this is happening, the operator should check the operation of the SCR Sootblowers and may want to increase blowing cycles.

The catalyst vendor or SCR system vendor may have established some maximum allowable pressure drop across the catalyst bed. If this value is reached, it is an indication that there is a problem inside the SCR that should be addressed.

It is helpful if there is a differential pressure indicator across each individual layer. This can help the operators determine which layer is having a problem.

O_2

For some of the calculations that the controls will make using the NOx values, they also need to know the O_2 content of the flue gas in the SCR Inlet. A separate analyzer could be installed at the SCR inlet to measure this value. But since the SCR is before the air heater (where air may leak in around the shaft seals), it is just as easy to use the value that is already being measured in the boiler economizer outlet duct.

NOx

The SCR controls need a SCR Inlet NOx reading and a SCR Outlet NOx reading. Some utilities tried saving money by using the Stack CEM NOx reading for the SCR Outlet NOx reading. But experience has shown that there is too much time delay in this reading to properly control SCR ammonia feed. So an analyzer needs to be installed in each location.

The NOx values are used to control the ammonia feed valves. The difference between the two values is used to calculate the percentage of NOx removal which indicates if the SCR is performing properly.

AMMONIA FEED CONTROL

The ammonia feed system is typically a "feed forward/feed back" type of control logic. The system needs a flue gas flow signal either from the boiler control system or a flow meter. It combines this signal with the SCR Inlet NOx reading (which has been converted to a constant O_2 basis). In this way it can anticipate the need to change ammonia feed rate based on either changes in flue gas flow or NOx content.

The logic then looks at the SCR Outlet NOx reading (which has been converted to a constant O_2 basis) to trim the ammonia feed signal to obtain the desired set point value for NOx at the SCR Outlet.

AMMONIA SLIP

Since all the catalyst guarantees are based on the amount of ammonia completely passing through the catalyst layers (ammonia slip), it makes sense to install an ammonia monitor at the catalyst outlet. However, it has been demonstrated that it is extremely difficult to accurately measure trace amount of ammonia in the high ash and high SO_2 environment present in the flue gas. Both of these factors interfere with the ammonia measurement.

The instrument vendors have been working hard to develop an instrument that will perform satisfactorily. Before specifying or installing an ammonia monitor in this location, one needs to research the demonstrated performance of the instrument being considered in the environment that it will be operating.

In practice, most utilities have been periodically measuring the ammonia that has adsorbed onto the fly ash that is present in the precipitator hoppers. Some relationships have been developed that predict the concentration of ammonia at the SCR Outlet based upon the concentration of ammonia on the fly ash. While not as accurate as a duct mounted analyzer, this does give the utility a rough trend of how the ammonia slip is increasing over time.

CHAPTER 7 - SCR OPERATION

This chapter covers the procedures originally written for seasonal operation of SCRs, which after January 1, 2009 can also be used for outage related startup, operation and shutdown of SCRs being operated year-round.

7.1 SCR Normal Operation

This section is written to cover a typical set of procedures for a typical SCR system that was designed for seasonal operation. One must refer to the operating manuals for one's actual system to determine the actual sequence of steps and values of various start-up parameters. This section is written to illustrate why certain things are done in starting and stopping the SCR system.

The typical seasonal operation design includes a bypass duct around the SCR catalyst beds and also a way to introduce warm air into the catalyst box to keep the catalyst above ambient temperature when the SCR is out of service.

The start-up and shut-down sequences are designed to protect the catalyst from:

- Rapid temperature changes which could cause the ceramic catalyst material to crack and loose mechanical strength.
- The build-up of materials that could foul the catalyst surface or poison the catalyst.

There are typically thermocouples above the upper catalyst layer and below the lower catalyst layer to indicate the temperature profile across the SCR catalyst box. The following sequences are typically programmed into the DCS control system and will occur automatically once the operator presses the SCR Start or Stop buttons. The steps are listed here to illustrate what the operator should see happening and why they are happening.

7.1.a Start-up

The boiler is typically operating normally if this is a start-up related to the beginning of the NOx season. If the boiler is not operating, it would be best (if the operating permits and regulations allow) to bring the boiler up to a load where coal is being burned to minimize the amount of oil film that enters the catalyst beds. The flue gas is flowing around the SCR catalyst box through the bypass duct into the air heater.

The SCR catalyst is typically at some reduced temperature that has been maintained by heated air.

Once the operator initiates a SCR Start signal: (Some vendors may specify a minimum economizer outlet gas temperature before the control system will have a permissive to start this sequence.)

1. The SCR Outlet Damper(s) open in a rapid continuous motion to open a gas flow path out of the SCR catalyst box. Once the limit switches indicate that the damper(s) is(are) fully open, the permissive is given to proceed to the next step.

2. The SCR Inlet Damper(s) start(s) to pulse open in gradual steps. The control system is monitoring the rate of temperature increase at the SCR catalyst box inlet thermocouples to maintain a gradual temperature ramp. This ramp rate may be something around 25-30 degrees Fahrenheit per minute if the inlet temperature is below the 300-350 degrees Fahrenheit range. Once the inlet temperature is above this 300-350 degrees Fahrenheit range, the ramp rate may increase to something in the 80-100 degrees Fahrenheit per minute range. The idea is to heat the catalyst slowly to minimize the mechanical stress on the catalyst material due to temperature changes. (These numbers may vary depending on whether it is plate or honeycomb catalyst, wall thickness, catalyst formulation, etc.) Once the limit switches indicate that the damper(s) is(are) fully open, the permissive is given to proceed to the next step.

3. The SCR Bypass Damper(s) will now begin to pulse closed in gradual steps maintaining the appropriate temperature ramp described in the preceding step. Once the SCR Bypass Damper(s) is(are) fully closed, the flue gas flow through the SCR catalyst box is in its normal NOx removal configuration.

4. The catalyst vendor may have specified a minimum temperature below which ammonia is not to be introduced to the catalyst. This is to prevent the formation of ammonia bisulfite on the catalyst surface which can foul the catalyst pores. (A complete explanation of this can be found in the section on catalyst fouling and poisoning.) If the SCR catalyst box inlet temperature is still below this minimum temperature (and if the system is so equipped), the Economizer Bypass Damper(s) will open. The control system will modulate the dampers to allow the proper amount of warmer flue gas to enter the SCR catalyst box to obtain the desired ammonia injection temperature. (Once the economizer outlet gas temperature reaches the required temperature, the control system will close the Economizer Bypass Damper(s).)

5. Once the SCR catalyst box inlet temperature has reached the catalyst vendor's specified minimum temperature, the Ammonia Shut Off Valve(s) will be opened and the control system will maintain the proper ammonia flow to reach the desired NOx outlet value. The SCR system is now in normal service.

7.1.b In Service

Once the SCR is in service, it requires very little attention. The control system will vary the ammonia feed rate to match the inlet NOx, the flue gas flow, and the desired outlet NOx value.

The catalyst cleaning system should be in operation. If one is using steam or air with rake type soot blowers, they may operate once per (shift or day) per layer. This frequency may need to increase if there is any indication of increasing pressure drop across the catalyst beds. If sonic horns are being used, it is not unusual to operate one horn at a time in a continuous cycle, although some utilities program a rest period between cycles. It is important that the operation of the cleaning devices be confirmed on a daily basis.

If the load is reduced on the boiler, it is possible for the SCR catalyst box inlet temperature to approach the vendor specified minimum temperature for injecting ammonia. If the SCR system is equipped with (an) Economizer Bypass Damper(s), the control system will open this(these) damper(s) to maintain an acceptable temperature for ammonia injection. If the SCR system is not equipped with (an) Economizer Bypass Damper(s) or if this(these) damper(s) cannot maintain the required minimum temperature, the control system will close the Ammonia Shut Off Valve(s) and NOx removal will cease until the boiler load and the SCR catalyst box inlet temperatures increase.

7.1.c Shutdown

If one plans a shutdown, it is a good practice to operate the catalyst cleaning devices at an increased frequency to minimize the amount of ash remaining on top of the catalyst layers.

Once the operator initiates a SCR Stop signal:

1. The Ammonia Shut Off Valve(s) is(are) closed.

2. If any Economizer Bypass Damper(s) is(are) open, they will be closed.

3. The sequence will now pause while the control system compares the SCR inlet and outlet NOx values. Once the two values are reasonably identical (which indicates all the ammonia has been consumed) the sequence will resume.

4. The SCR Bypass Damper(s) will open. Once the limit switches indicate that the damper(s) is(are) fully open, the permissive is given to proceed to the next step.

5. The SCR Inlet Damper(s) will close.

6. The SCR Outlet Dampers will close.

7. The heated air system should be placed into service to maintain the SCR catalyst at a temperature above ambient during a prolonged out of service period. (If the SCR will only be out of service for a short period, it is better not to

place the heated air system in service. The ceramic catalyst will hold a large amount of heat. The SCR catalyst inlet temperature will be higher and the temperature ramp durations shorter if the catalyst hasn't been cooled down to the heated air system temperature.)

7.2 SCR Abnormal Operation

This section will describe what actions should be taken if one of these rare occurrences should happen.

7.2.a SCR Catalyst Box High Temperature

The SCR catalyst box should operate at the temperature of the flue gas passing through it. If a higher temperature is indicated, it could be caused by several occurrences.

Faulty Thermocouple

There are typically multiple thermocouples in an area. If only one thermocouple is reading high, it is likely a sensor problem. The faulty sensor should be checked and/or replaced in a reasonable time period.

Boiler Upset

If a group of thermocouples in one area are reading high and there has been a large load swing or a burner problem in the boiler, there may be a temporary gas flow imbalance at the SCR inlet that is showing on these thermocouples.

Fire On The Catalyst Surface

This is a very serious condition that can turn out badly if not handled properly.

Unburned carbon can collect on top of a catalyst layer. This is most prevalent on the top catalyst layer. One source can be soot from oil fired in the boiler. A more likely source is unburned coal particles that are typical with many of the "low-NOx burner" designs being used in current boilers.

As these carbon deposits sit, they can begin to smolder. If a group of thermocouples shows a steadily increasing temperature that is approaching the 780-800 degrees Fahrenheit range, it is very possible that there is smoldering carbon in the SCR catalyst box.

If the temperature of the carbon mass reaches a high enough temperature, it can melt its way down into the catalyst layer. There have been reports of the metal mesh in plate catalyst melting.

It is very important that one:

1. Stops the feed of ammonia to that SCR catalyst box.

2. Stops the flow of dilution air to that SCR catalyst box. One wants to keep a low oxygen level in the area to slow the combustion process.

3. Continues the flow of flue gas through that SCR box. One wants to continuously remove the heat from the area to cool the smoldering carbon.

It is equally important that one:

1. Does not operate any steam or air soot blowers in the area. One does not want to stir up the smoldering carbon or supply air to the combustion process.

2. Does not close the SCR catalyst box inlet and/or outlet dampers to isolate the SCR catalyst box. The loss of flue gas flow will allow heat to build up in the SCR catalyst box which will increase the severity of the event.

3. Does not open any inspection doors or access doors to look inside the SCR catalyst box. An open door will allow oxygen to enter and may cause a flash of fire that could severely injure anyone standing at the door.

Once the temperature returns to normal, the dilution air flow and ammonia feed can be resumed.

The SCR catalyst box can also be taken out of service and an inspection of the damage be made if desired. There is no compelling reason to do such an inspection of the catalyst layer unless there has been a large change in the pressure drop across the catalyst layer.

7.2.b SCR Catalyst Box High Differential Pressure

If the high differential pressure reading is confirmed, then plugging of the catalyst beds with ash has occurred. The top layer of catalyst is the most susceptible to plugging since Large Particulate Ash (LPA) will collect on the top layer since it is too large to pass through the catalyst channels.

If there are pressure taps between the catalyst layers, measure the differential pressure across each layer. Increase the frequency of soot blowing on the plugged layer(s). It should be noted that soot blowing will have a minimal effect on LPA plugging or severe ash deposits. Soot blowing may prolong opening the SCR catalyst box(es) for inspection, but opening the SCR catalyst box(es) is probably inevitable.

If the SCR is taken out of service and the unit is remaining on line, it can take a long time to get all the heat out of the SCR catalyst box(es). If the unit is coming off line also, leave the flue gas path open through the SCR catalyst box(es) and use the FD and ID Fans to cool off the SCR catalyst box(es) with cool air once the fires are out of the boiler.

Vacuum the ash deposits from the top of the catalyst layers and inspect the catalyst modules for plugging. Some utilities have had success in vacuuming the top of the plugged areas while blowing air through from the bottom of the catalyst (it is easier to blow the LPA back out the way it came in rather than trying to force it on through the catalyst channel). If it is honeycomb catalyst, care must be taken not to damage the surfaces of the catalyst with the vacuum nozzle or the air nozzle. The walls of the honeycomb elements are fairly fragile in respect to mechanical damage. If it is plate catalyst, getting the plates to flex and move slightly can help loosen the plugging.

Some utilities have done "in situ" washing with various degrees of success. There has been more experience and success using "ex situ" washing either on site or off site. Either "ex situ" method is lengthy and is usually accomplished by replacing the plugged catalyst with clean catalyst, returning the SCR to service, washing the plugged catalyst, and warehousing the cleaned catalyst for future use.

If possible, the source of the plugging should be determined and the appropriate flow adjustments made or LPA screens installed to prevent reoccurrences.

CHAPTER 8 - SCR PERFORMANCE TESTING

The chapter discusses procedures for optimizing NOx reduction in an SCR by tuning the Ammonia Injection Grid (AIG)

8.1 AIG Tuning

For optimum NOx reduction, one unit of NH_3 must be present at the same location as one unit of NOx . When this is the case, the NH_3 / NOx distribution ratio is 1.0. If there is more NH_3 than NOx the distribution ratio will be greater than 1.0. In this area there will be NH_3 slip due to the excess NH_3 . If there is less NH_3 than NOx, the distribution ratio will be less than 1.0. In this area, there will be NOx emissions due to the lack of NH_3 to complete the removal.

Even though the ideal situation would be to have a distribution ratio of 1.0 across the entire cross section of the SCR box, this is impossible in real life due to NOx profile and flue gas flow distribution variations in the boiler and the ducts. Most units have been able to achieve distribution ratios that are within a maximum of 5% standard deviation from each other across the entire cross section of the SCR box.

The AIG design will have some effect on one's ability to achieve a low standard deviation. If the unit has less than 10 ammonia feed pipes and adjusting valves, the tuning will not be as accurate as on a unit that has more than 20 ammonia feed pipes and adjusting valves.

Many of the SCR vendors and catalyst suppliers suggest that the AIG/SCR tuning should be done at least annually. This decision is solely at the discretion of the utility unless there is a stipulation in the environmental operating permits that mandate a tuning frequency. If one is going to perform tuning annually and the SCR is operating in a seasonal mode, it makes sense to perform the tuning at the beginning of the annual operating season.

8.1.a Sample Grid

To do the tuning, one must sample discreet points across the cross section of the SCR box instead of analyzing an average sample of the gas from the SCR box. To do this, the SCR designers have typically installed a sampling grid below the lowest catalyst layer. The grid will consist of 20 - 50 sample lines that terminate at discreet locations across the cross section of the SCR box.

Before tuning can be accomplished, one needs to blow out each sample line to assure that it is open. One must also make sure that each sample line is clearly identified with a name or number that is unique from every other sample line.

There have been reports of sample line corrosion and perforation near the wall of the SCR catalyst box. This will cause the sample being measured to be different from what is shown on the sample grid diagram. Some companies hook up each line to a NOx analyzer. They blow air back through the sample line and then time how long it takes for NOx to register as they pull a sample. These times should vary in relation to the length of the line. Shorter times are an indication of a hole in the line. Others have slid a thermocouple into each line with a purge air stream. They are looking for the temperature spike where the air leaves the line and the thermocouple measures hot flue gas. They check the length of the thermocouple insertion versus the designed length of the sample line.

For the testing company to make any sense from the data collected, one must give them a drawing that shows the identification of each sample line and the physical location in the SCR cross section where that sample line terminates.

One must also have a drawing that indicates for each ammonia feed adjustment valve where the ammonia concentration will be affected on the cross section of the SCR box. When one is doing the tuning, one must know which valves will affect the ammonia feed at the sample locations that tested high or low.

8.1.b Sampling Theory

The basic chemical equation for the SCR operation at any given sample point (p) is:

- $NH_3feed(p) = \{NOxin(p) - NOxout(p)\} + NH_3slip(p)$

If one were to feed a significantly lower than theoretical amount of ammonia (like 50%), there is no chance of having any ammonia slip. In this case, the equation becomes:

- $NH_3feed(p) = \{NOxin(p) - NOxout(p)\}$

It is easier to measure NOx with an electronic analyzer in an SCR than it is to measure NH_3. This is due to interferences by other gases such as SO_2 that interfere with low ammonia readings in an ammonia analyzer. But one can see from the preceding equation that one can determine the NH_3 feed that was present at a given sample point by testing two separate NOx values and then calculating the ammonia value.

There is no sampling grid to test the NOxin values above the catalyst layers. It is easy to overcome this shortcoming. If no ammonia is being fed to the SCR, no NOx will be removed from the gas stream. So if one analyses the sampling grid points when no ammonia is being fed, one is reading the NOxin values.

While keeping all the boiler and fuel conditions as stable as possible, one then feeds an intermediate amount of ammonia (50 - 60 % normal feed) to the SCR. The analysis of the sampling grid points will now give one the NOxout values.

Since one knows the NOxin and NOxout values, one also knows the NH_3feed values from the preceding equation. One can then calculate the NH_3/NOx distribution ratio for each sample point using the equation:

- $\{NH_3/NOx\}(p) = 1 - \{NOxout(p)/NOxin(p)\}$

8.1.c Sampling Equipment

The primary analysis to accomplish a SCR tuning will be done using NOx analyzers. For each data point, it takes the analyzer several minutes to settle down when it starts reading a new sample point. Thus it could take 5 - 10 minutes to record an accurate value for each sample point. There are numerous sample points. One is trying to keep the boiler and fuel parameters as stable as possible over the entire test so that the SCR operating conditions are the same for each point sampled.

For this reason, it is best to have 10 - 15 identical analyzers that can sample different points simultaneously. It is reasonable to sample a quarter or a third of the sampling points at a time. In that way, the data collection period for each set of NOxin and NOxout values is in the range of 15 - 40 minutes and the entire tuning test run can be finished in less than two hours.

Some testing companies have a bank of analyzers built into a trailer. Temporary sample lines must be run from each permanent sample line down to the trailer. Other companies place the individual analyzers at the sampling point locations with wiring for the data running to a central data collection device.

The results of the individual distribution ratios can be entered onto a chart or into a spreadsheet in their relative location to each other. This type of data can be difficult to visualize. Many of the testing companies have software that takes the tabular data and generates a plot showing similar ranges of normalized distribution ratios surrounded by boundary lines. The plot looks like a topographical map. It is much easier to visualize this presentation of the data. They also have statistical software to calculate the standard deviation of the data.

8.1.d Performing The Test

Once all the equipment is in place and ready for the test, the boiler should be operated at a steady load while burning its typical fuel for the duration of each test. Since the tuning is attempting to optimize the NOx removal that one will achieve on a daily basis, it is prudent to perform the test at the boiler load that will occur for the majority of the time.

1. If ammonia is being fed to the SCR, discontinue the ammonia feed. Once the NOx values stabilize for the sampling points being monitored, cycle through all the sampling points recording the NOxin values.

2. Then restart the ammonia feed at an intermediate feed rate (typically 50 - 60% of the normal feed rate for the given boiler load and inlet NOx value). Once the NOx values stabilize for the sampling points being monitored, cycle through all the sampling points recording the NOxout values.

3. Calculate all the distribution ratios, plot the data points, and calculate the standard deviation of the distribution ratios. If it is decided the standard deviation of the distribution ratios is acceptable, the testing and tuning are complete and one should jump to step 6. If it is decided to try to narrow the standard deviation, proceed to step 4.

4. Using the plot of the distribution ratios and the map showing which area is affected by each ammonia feed valve, make adjustments to the proper ammonia feed valves. It is prudent to mark the original location of each valve before moving it so it will be possible to return it to that location if an adjustment makes things worse. In the areas where the distribution ratios are the greatest, the valves should be closed slightly. In the areas where the distribution ratios are the least, the valves should be opened slightly.

5. After the appropriate ammonia feed valves have been adjusted, return to step 1 and repeat the testing cycle.

6. Return the ammonia feed to its normal condition allowing the SCR controls to adjust the ammonia feed. Once the NOx values stabilize for the sampling points being monitored, cycle through all the sampling points recording the NOxout values to document the optimum NOx emission levels that were obtained after the tuning.

Once the tuning is complete, make sure the locking device is fully engaged on each ammonia feed valve. It is also prudent to permanently mark the position of each valve so that if something should occur and the valve is inadvertently moved, it can be returned to the proper location without having to run another tuning test.

8.1.e Possible Additional Data

At least one testing company claims gas flow distribution data can be collected using the exact same equipment and set up that was used for the AIG/SCR tuning tests.

The theory is that if there is a sufficiently large excess of ammonia present in the catalyst layers, the effect of any maldistribution of the ammonia feed becomes nonexistent. Therefore, any differences in the NOxout values are a function of local space velocity (or flue gas velocity effects if one assumes that the catalyst activity is uniform). If one wants to generate a velocity profile while the AIG/SCR tuning equipment is in place:

1. Increase the ammonia feed to somewhere near 50% above the normal feed rate. (Caution: High ammonia slip can have a detrimental effect on air heater fouling. Make sure you don't exceed any chimney outlet ammonia slip values that may be specified in environmental operating permits. Keep the test duration as short as possible.)

2. Once the NOx values stabilize for the sampling points being monitored, cycle through all the sampling points recording the NOxout values.

3. Return the ammonia feed to normal operation.

4. Plot the NOxout data on the sample point location diagram. The areas with lower NOxout values are where the flue gas velocity is relatively low. The areas with higher NOxout values are where the flue gas velocity is relatively high.

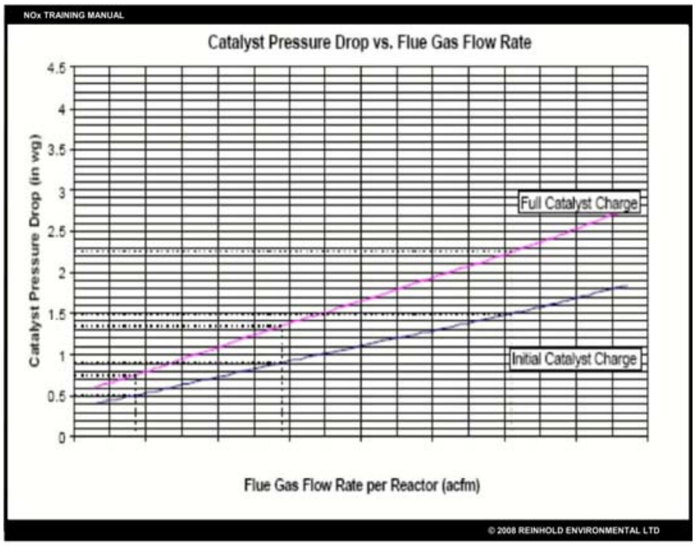
There are no adjustments that can be made to change these velocity values with the unit in service. Adjustments to turning vanes or other flow devices would have to be made during subsequent unit outages.

CHAPTER 9 - SCR GUARANTEES

The guarantees on a SCR system will be somewhat dependant on the project specifications. This chapter demonstrates the types of guarantees that have typically been given to U.S.A. utilities.

9.1 SCR Guarantees

The guarantees are typically prefaced with all the fuel and boiler operating conditions that were given in the design specification. Any deviations from these design conditions can trigger changes to the guarantee values. Catalyst vendors will often supply correction curves to calculate the corrected guarantee values based on the measured process conditions at the time.



Pressure Drop Curve
(Used with permission)

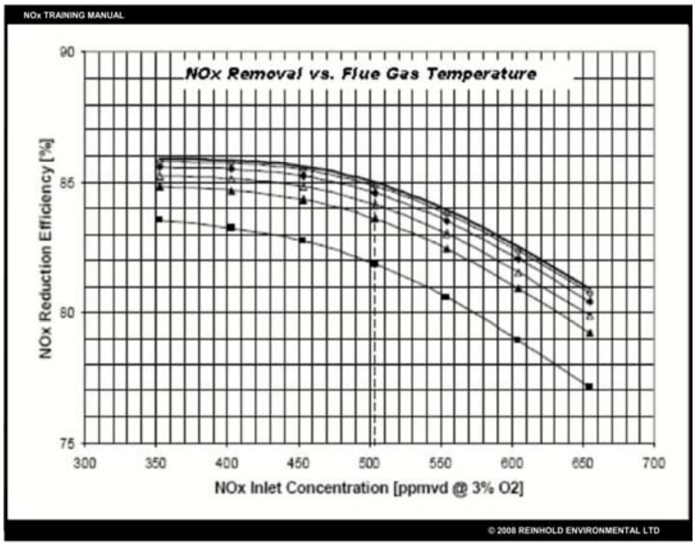
Normal Catalyst Vendor Guarantees

- Ammonia Slip - the maximum average ammonia value that will be present at the SCR outlet when the catalyst has reached the end of its design life
- Catalyst Life - the number of hours that the catalyst will remain in service while meeting all of its guaranteed operating parameters, after this point the catalyst will still remove NOx and can remain in service in the SCR, but an additional or replacement catalyst layer will have to be added to the SCR to obtain the guaranteed operating parameters
- Pressure Drop - the maximum average pressure drop across all the installed catalyst layers in the SCR. See **Figure:**

Pressure Drop Curve

- NOx Removal - the minimum percentage of NOx removal comparing the SCR inlet and SCR outlet NOx values. See **Figure:**

NOx Removal Curve



NOx Removal Curve
(Used with permission)

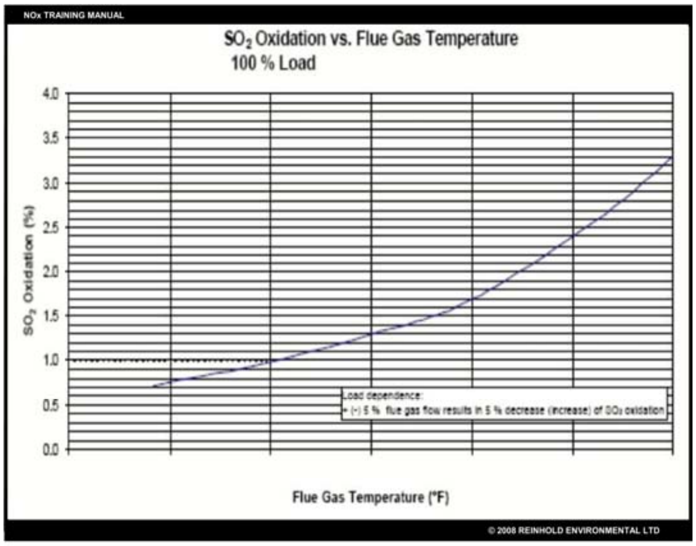
- SO_2 Oxidation - the maximum percentage of flue gas SO_2 that is oxidized to SO_3 as it passes through the SCR based on a specific flue gas temperature. See **Figure:**

SO_2 Oxidation Curve

Possible Catalyst Vendor Guarantees

- Ammonia Consumption - the maximum ammonia consumption at the design conditions and NOx removal

- Power Consumption - The total electrical power consumption for the SCR system including the ammonia feed system
- NOx Emission Rate - the maximum NOx emission rate from the SCR system given in one or more of the following units: 1) lb/hr, 2) lb/mmBtu or 3) ppmvd @ (specified value) O_2
- End of Life Activity - percentage of the original catalyst activity left in the catalyst when it reaches its guaranteed "end of life".



SO_2 Oxidation Curve

(Used with permission)

Possible Flow Modeling Provider or System Designer Guarantees

- Velocity Deviation - the maximum plus/minus percentage velocity deviation about the arithmetic mean gas velocity across some specified percentage of the duct or the catalyst bed
- NOx Concentration Deviation - the maximum plus/minus percentage NOx concentration deviation about the arithmetic mean concentration across some specified percentage of the duct, upstream of the catalyst bed or downstream of the catalyst bed
- Ammonia Concentration Deviation - the maximum plus/minus percentage ammonia concentration deviation about the arithmetic mean concentration across some specified percentage of the duct, upstream of the catalyst bed or downstream of the catalyst bed
- Temperature Deviation - the maximum plus/minus percentage temperature deviation about the arithmetic mean temperature across some specified percentage of the duct or upstream of the catalyst bed
- NH_3/NOx Ratio Deviation - the maximum plus/minus percentage NH_3/NOx ratio deviation about the arithmetic mean ratio across some specified percentage of the duct or upstream of the catalyst bed after the AIG has been tuned
- Pressure Drop - the maximum average pressure loss across the entire SCR system with either initial catalyst layers or all the catalyst layers installed.

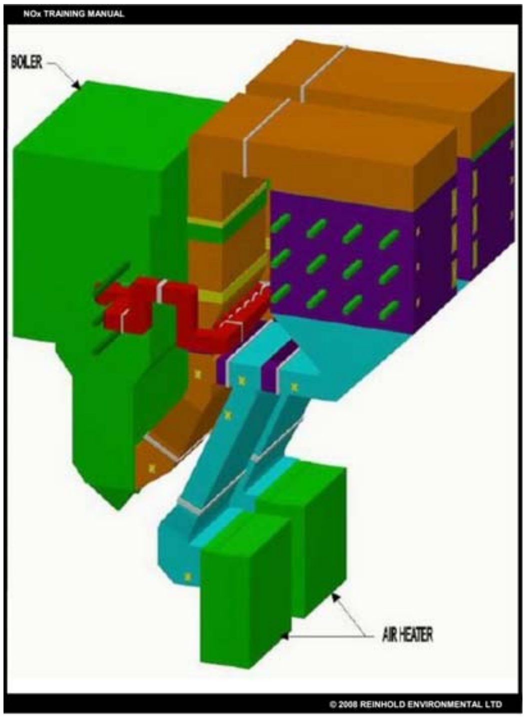
CHAPTER 10 - SCR MAINTENANCE

This chapter discusses maintenance inspections of the various components of the SCR (Economizer Outlet, Dampers, Ducts, Turning Vanes, Ammonia Injection Grid, etc.) as well as inspection and maintenance of an anhydrous ammonia tank farm.

10.1 SCR System Inspection

The SCR system is much simpler than an FGD system since there are fewer moving parts and control systems. It is more like an electrostatic precipitator. And like an electrostatic precipitator, uneven gas flows and failures of stationary components can severely degrade the performance of the SCR system. See **Figure:**

Typical SCR Layout



Typical SCR Layout
(Used with permission)

Doing a thorough inspection of the system during unit outages is critical to identify:

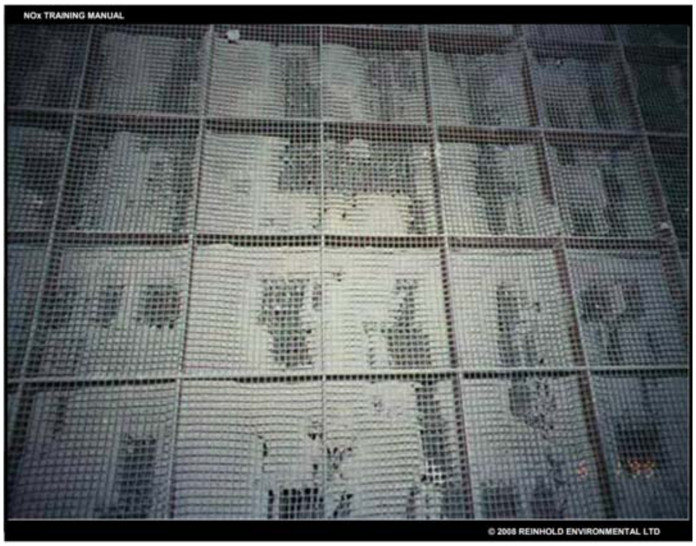
- Signs of uneven gas flow through the system
- Damage to dampers and turning vanes
- The ability of the ammonia feed system to properly feed ammonia across the entire cross section of the ducts
- The physical condition of the catalyst, i.e. ash pluggage, erosion, burnt areas
- The effectiveness of the catalyst soot blowing systems

At the same time, catalyst sampling must be done to assess the ability of the catalyst to remove NOx. This information is needed to compare the actual performance of the catalyst against its predicted performance to:

- Assess if any catalyst poisoning is taking place
- Predict when layers of catalyst will need to be added, removed, cleaned or regenerated

As long as the SCR systems operate on a seasonal basis, and assuming that dampers will seal properly (this is not a good assumption on many units), some of the inspections and catalyst sampling can be done while the boiler is still in operation. There are important parts of the system, however, that can only be inspected during a complete unit outage.

The arrangement of this section will start at the economizer outlet area of the boiler, proceed through the duct work and ammonia feed area, and then move into the SCR box and the catalyst.



Economizer Leak Aftermath
(Used with permission)

10.1.a Economizer Outlet

What happens in the economizer outlet area has a large impact on the physical plugging of the catalyst. Any large particles of ash that leave this area and are larger than the openings in the SCR catalyst will collect on top of the catalyst, or worse yet, become lodged in the flow channels of the catalyst. Since these large ash particles are heavy, they tend to move along the floors of the ducts. This means they are found on the catalyst modules that are closest to the gas inlet side of the SCR box since they travel along the duct floor and drop quickly as the gas flow slows entering the larger SCR box.

The first utilities that experienced this catalyst plugging referred to it as a "popcorn ash" problem. Once more research was done on the problem, it was noticed that the problem ash was not the dense round "popcorn ash" that is formed in the combustion zone of the furnace. It was a porous irregular shaped particle. Further research indicated that this ash formed on tubes in the back passes of the boiler and then broke off during temperature cycles. So, the utilities began referring to this ash as "large particulate ash" or LPA. See **Figure:**

LPA

LPA
(Courtesy of Evonik Energy Services)

Most economizer outlet areas have some sort of perforated plate where the boiler gasses exit the boiler and enter the ducts. The orientation of these plates and the size of the holes do not allow these plates to significantly stop the flow of LPA into the ducts. In reality, these plates are only gas flow distribution devices.

Several companies now offer screens designed specifically to remove LPA and reject it to the economizer ash hopper. If one finds much plugging of the catalyst with LPA, serious consideration should be given to installing LPA screens. If one already has LPA screens, the screens should be inspected carefully. The high erosion potential of all the ash that normally passes through these screens will wear away the screens in several years allowing the LPA to once again plug the catalyst. It is much cheaper to repair or replace screens than it is to clean or replace catalyst. See **Figure:**

LPA Screens

LPA Screens
(Courtesy of Evonik Energy Services)

The other area of concern in the economizer outlet is the economizer ash hopper. First, one must make sure that the hopper is not plugged since a high ash level in the hopper will spill directly over into the ducts and then into the SCR box. Secondly, one must make sure that the large ash particles dropped into the hopper aren't being swept back out by swirling gas passing through the hopper. If there are signs of high gas flow across the top of the ash in the hopper, one must consider installing baffles or grating to break up this gas flow so it can't carry ash back out of the hopper.

10.1.b Ducts

The biggest thing one is looking for in the ducts is a build-up of ash which would indicate low flow zones in the duct. One is especially looking for uneven ash distribution which would indicate a lower flow of gas on the side of the duct with the most ash deposits. This could indicate the need for more turning vanes or other devices to even out the gas flow across the entire cross section of the duct. Flow modeling would probably be required to determine the best solution to any problems seen.

Of course, with all the ash flowing through the duct at high velocity, one is also looking for erosion damage to the duct walls that may indicate the need for repair before a perforation of the duct wall occurs.

10.1.c Dampers

When the damper vendors looked at the SCR designs, some of them said "these are the same size as the dampers we supplied for FGD," and so they supplied the same dampers that they had built for FGD. What they didn't take into consideration was that FGD dampers operate at precipitator outlet temperatures while SCR dampers operate at economizer outlet temperatures.

What some utilities have experienced is that the damper blades in the hot gas flow have expanded while the stiffer damper frames which are at a cooler temperature do not move. This causes the damper blades to severely warp. These warped blades have bound up and/or will not seal properly. When inspecting dampers, they will be at ambient temperature and the blades will have contracted back to their original dimensions. Look for any signs of warping of the blades or seals. Look for any damage along the sealing surfaces of the damper and the duct. Look for any signs on the duct walls of scraping of the damper blades against the wall during operation.

On the exterior of the damper, look for any bending or other damage to the actuators and linkages that may have occurred if the damper has been binding as it operates.

10.1.d Turning Vanes

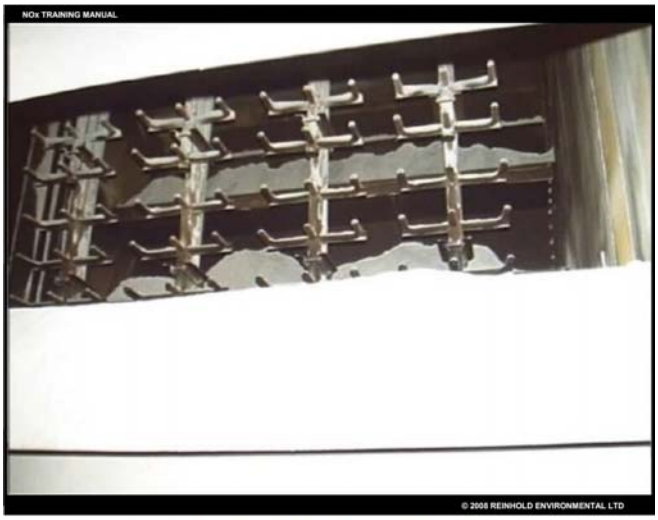
Turning vanes are located in the moving ash laden gas stream. The first thing one should look at is any ash build-up on the back side of turning vanes. If the gas flow is evenly spread across the duct, the ash build-up should be minimal and fairly uniform on all the turning vanes. Some utilities have seen patterns where there is little ash on the vanes on one side of the ducts and 3 - 4 feet of ash on the vanes on the opposite side of the duct. This is a good indication that there are some serious gas distribution issues in the duct that should be addressed.

Any large deposits of ash should be removed from the turning vanes. The vanes should be visually inspected to determine if there are any broken structural welds. They should also be inspected for any erosion damage that would affect their structural integrity or their ability to smoothly turn the gas.

Some designs use a series of smaller delta wings to spread the flue gas evenly across the duct or the inlet of the SCR catalyst box. These delta wings should receive the same inspection for structural integrity and erosion damage as a turning vane. See **Figures:**

Turning Vane Deposits 1 & 2

Turning Vane Deposits - 1
(Used with permission)



Turning Vane Deposits - 2
(Used with permission)

10.1.e Ammonia Injection Grid (AIG)

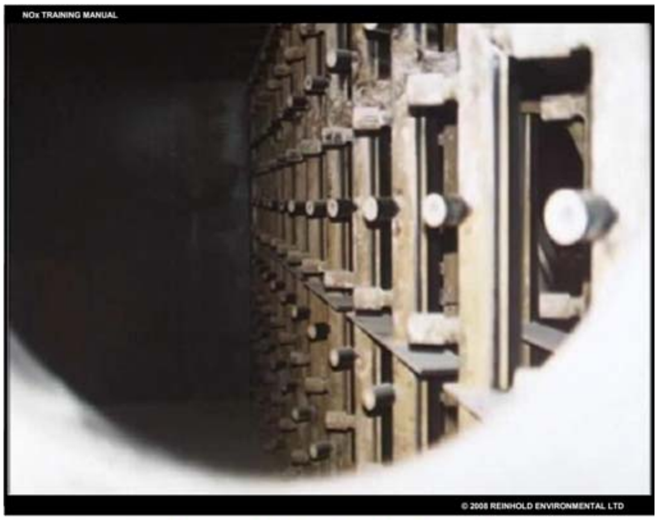
There are three types of ammonia injection grids that are commonly used to obtain a uniform ammonia concentration across the large ducts leading to the SCR box:

- Multiple Nozzles
- Delta Wings
- Static Mixers

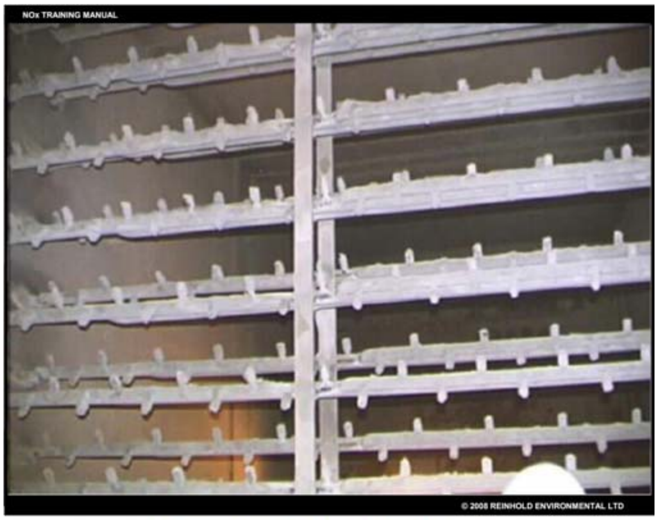
Multiple Nozzles

In this design, there are numerous small diameter nozzles located across the cross section of the duct. There are various nozzle styles in use. The main thing one is looking for is that all the small nozzle holes are open and not clogged with ash or other debris. One can also look at the small bore piping leading to the nozzles to make sure it is all connected and doesn't contain holes from ash erosion. (See **Figures:**

Ammonia Injection Nozzles 1 & 2



Ammonia Injection Nozzles - 1
(Used with permission)



Ammonia Injection Nozzles - 2
(Used with permission)

Delta Wings

Delta wings are large flat pieces of metal (usually circular) that are mounted at an angle across the duct. Large bore open pipes terminate at the center of each plate. The turbulence of the gas around the plates mixes the ammonia with the gas.

Since the ammonia pipes are large bore, there is typically no plugging of these pipes with ash. One is mainly looking at the structural integrity of the metal plates and their attachments to the duct wall. One is also looking for any erosion damage to the metal plates, the attachment structures, and the ammonia piping. (See **Figures:**

Delta Wing Mixer Layout & Delta Wing Mixer

Delta Wing Mixer Layout
(Used with permission)

Delta Wing Mixer
(Used with permission)

Static Mixers

Static mixers are a series of smaller plates of various shapes welded together at various angles to each other. A series of medium bore open pipes terminating at evenly spaced intervals across the static mixer inject the ammonia into the turbulent gas stream passing through the static mixer.

Since the ammonia pipes are medium bore, there is typically no plugging of these pipes with ash. One is mainly looking at the structural integrity of the metal plates and their attachments to the duct wall. One is also looking for any erosion damage to the metal plates, the attachment structures, and the ammonia piping. See **Figures:**

Typical Static Mixers & Static Mixers 1 &2

Static Mixer - 1
(Used with permission)

Static Mixer - 2
(Used with permission)

10.1.f Ammonia Injection Feed Piping

External to the ducts will be a group of ammonia feed pipes entering the duct to the AIG. Each pipe will have a valve (typically a butterfly style valve) with a mechanism to lock the valve in position. These valves are used to adjust the ammonia feed profile across the duct to match the gas flow and NOx profile to obtain the optimum NOx removal. It is not unusual for these valves to be in slightly different positions from each other.

If these valves are going to be stroked or otherwise worked on during the inspection, it is critical that each valve be returned to the original position that it was in before the inspection. All of the valves and valve locking mechanisms must be able to operate properly so that performance testing and ammonia feed tuning can be done to the SCR system. See **Figure:**

Ammonia Injection Piping

Ammonia Injection Piping
(Used with permission)

10.1.g Balance Of The Ammonia Feed System

Ammonia can be supplied by an anhydrous ammonia system, an aqueous ammonia system, or a urea based system. There are variations in the equipment that may have been supplied with each system. Rather than trying to guide you in how to deal with these systems, we call these items to your attention.

- Various Federal, State, and Local regulations have determined the design and operation of each ammonia feed system.

- It is quite likely that an OSHA Process Safety Management (PSM) review was done on the system which included writing various operating and maintenance procedures that are to be followed during the operation and maintenance of the system. Failure to follow these procedures could subject the facility to OSHA penalties.
- Certain parts of the system (i.e. pressure relief valves, isolation valves, gauges, etc.) may have certain inspection/repair/replacement criteria established by some of the regulations covering the ammonia feed system.
- Only persons familiar with the above items and the safety hazards of ammonia should inspect and repair these systems.
- It is critical that all insulation and heat trace systems be maintained in a urea based system since the chemicals involved will crystallize and plug the system at normal ambient temperatures.

10.1.h Soot Blowers

There are two types of soot blowers: rake arms and sonic horns. Both have been used successfully.

Rake Arms

On the inside of the SCR box, one should inspect each rake arm to assure that all the blow holes are open in each arm. One should inspect the hanger rollers and the surrounding area to assure that the rake assembly can move freely back and forth over the top of the catalyst modules.

On the outside of the SCR box, one should inspect the gear box and the valves on each rake arm assembly to assure that they are functioning properly. See **Figure:**

Rake Type Soot Blower

Rake Type Soot Blower
(Used with permission)

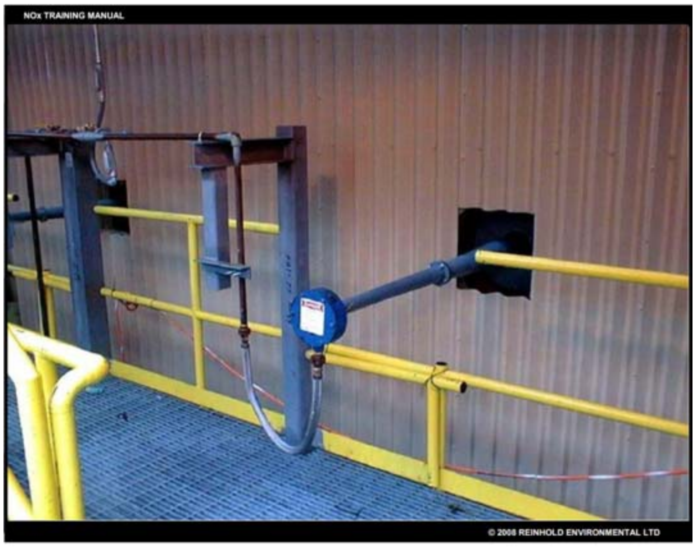
Sonic Horn

All of the components of a sonic horn are located on the exterior of the SCR box. The only moving and replaceable parts are the thin metal diaphragm located in the throat of the horn and the solenoid valve that allows air to enter the horn.

To inspect the sonic horns, one should stand beside each horn as it is activated. If one doesn't hear a noise from the horn, either the solenoid valve isn't opening allowing air to enter the horn or the metal diaphragm needs to be replaced.

If one hears a higher pitched squeal from the horn, ash deposits may be restricting the inner throat of the horns. The horn body sections will need to be disassembled from each other and the ash deposits removed.

Utility experience has been that if the entire sonic horn body isn't insulated, condensation of the hot flue gas will occur in the horn body which can aggravate the ash deposit problem and also corrode the horn body to the point of perforation. See **Figure:**



Sonic Horn
(Used with permission)

Sonic Horn

10.1.i Catalyst Layers

The first thing one is looking at when entering a catalyst layer is the location of any ash deposits on top of the catalyst layer. The height and area covered (both location in respect to the SCR inlet and the magnitude of how many catalyst modules are covered) by the ash should be documented by diagrams and photographs. This information will be valuable in determining whether there is a soot blowing issue or a LPA problem. See **Figures:**

Dirty Honeycomb Catalyst 1 & Dirty Charred Honeycomb Catalyst 2

Dirty Charred Honeycomb Catalyst - 2
(Used with permission)

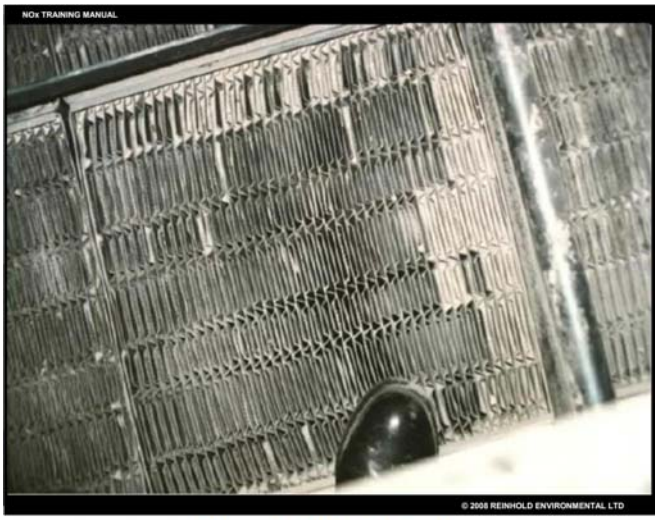
Dirty Honeycomb Catalyst - 1
(Used with permission)

Next one should look at the sealing devices between the catalyst modules and also between the catalyst modules and the walls of the SCR box. Some of these seals may be in the form of metal tents or plates over the gaps. Other designs use gaskets compressed between metal lips on the catalyst modules. There should be no open areas where gas can bypass the catalyst modules.

Finally one should do a detailed inspection of the catalyst modules to see how much pluggage of the catalyst channels has occurred. This usually works best if someone with a bright spotlight or large fluorescent lamp is below the catalyst layer shining the light up through the catalyst. The person on top of the catalyst layer can then look down through the catalyst layer to determine if the channels are open or plugged. This will take some coordination between the two people as they move across the layer. See **Figures:**

Plugged Honeycomb Catalyst 1 & Plugged Plate Catalyst

Plugged Honeycomb Catalyst - 1
(Used with permission)



Plugged Plate Catalyst
(Used with permission)

Whether all the catalyst modules or just a representative number in a layer are inspected will be dependent upon how clean the catalyst appears and how much detail the utility feels it needs to make a determination on the layer's condition. It is important that some modules across the entire cross section of the layer be inspected since LPA pluggage tends to be worse near the SCR box inlet and less away from the inlet.

The results from each module inspected should be plotted on a diagram of the catalyst layer to see if any patterns emerge as to catalyst pluggage. There is no magic number as to how much of the catalyst can be plugged and the SCR still operate. There are two things that need to be considered:

- Will the plugged catalyst lead to gas flow distribution issues, high gas flow rates through the remaining open channels, and high pressure drop across the catalyst layer?
- Is there enough open catalyst surface area remaining at the higher gas flow velocities through the layer to provide adequate NOx removal until the next SCR outage?

It is easier to obtain quantitative inspection results with honeycomb catalyst because the channels are arranged in discrete squares that are arranged in rows and columns. In a plate catalyst the channels are of varying cross section separated by corrugations in an alternating configuration.

Honeycomb Catalyst

Typically one would not inspect and count every channel in an entire catalyst module. The number of channels makes this impractical. One typically selects a pattern of catalyst elements (some call them logs) that will be inspected to give a representation of the entire module. One can inspect and count each channel in these elements, but the number involved can be mind numbing. Some catalyst suppliers suggest inspecting one row and one column in each element. In field testing where results were compared counting every channel versus counting one row and one column of the same elements, the results were not statistically different.

If one chooses to inspect using the one row and one column method, it is important that the same row and column is inspected on each catalyst element. It is also important that the row or column chosen does not align with one of the steel support bars that hold the bottom of the module together. The shadow of the bar in the inspection light will make it look like the catalyst channels are plugged when they may actually be open.

If one sees a channel that is partially plugged with an object, it is best to count it as a plugged channel. Typically a channel becomes partially plugged, and then over time ash will build up on top of the object completely closing the channel (often filling the channel to the top surface of the catalyst element).

By determining the number of channels plugged versus the number of channels inspected, one can get a fairly accurate number that represents the percent pluggage of the catalyst module.

Plate Catalyst

The arrangement of the catalyst channels does not lend itself to the orderly travel of one's eye across the catalyst element. The size of the catalyst element is also significantly larger than the honeycomb element. This makes counting individual channels and moving in rows and columns virtually impossible.

Most people who have inspected plate catalyst have adopted a fairly subjective system. They move their head around getting a view of all the channels in the catalyst element. They will then assign a percent plugged number based on their perception of how much of the cross section was plugged.

This system is not as accurate as with the honeycomb catalyst, but with some practice and the same persons doing the entire inspection, it is probably accurate enough to give a utility the information they will need to determine what action should be taken with the catalyst layer.

10.1.j Catalyst Sampling

The only way to monitor the chemical properties of the catalyst is to remove samples for analysis on a periodic basis. Whether these samples are sent to the catalyst supplier, an independent test lab, or both is entirely the choice of the utility.

The catalyst modules have a removable screen covering the top that is used to keep large objects from contacting the catalyst and for use as a walkway as one is moving around the catalyst layer. This screen will have to be removed to gain access to remove the catalyst sample.

Honeycomb Catalyst

Honeycomb catalyst can only be removed from those modules that have removable test elements built into them. The test elements can be identified because they reside in a metal sleeve that completely surrounds them. There are two types of test elements:

- The metal sleeve is the same size as the surrounding catalyst elements and the test catalyst element has a smaller cross section than the other catalyst elements.
- The metal sleeve is larger than the surrounding catalyst elements (which means some of the surrounding catalyst elements have had one side shaved off to make room for the sleeve) and the test catalyst element is the same size as the other catalyst elements.

It is important to assure that one has additional replacement catalyst elements of the proper size before removing a test catalyst element. (See **Figure:**

Honeycomb Test Element

Honeycomb Test Element
(Used with permission)

To remove a test catalyst element, one gets below the layer and presses up on the element. As it slides up, a person on top of the layer can extract the element. Some designs have a metal handle that snaps into the metal sleeve to pull the test catalyst element out of the assembly from on top of the layer. Once the test catalyst element is extracted, the replacement element should be installed in the hole.

The locations and removal dates for all test catalyst elements removed should be recorded in the unit's records. This is also important so that in the future, the number of "in service" hours of the replacement test catalyst elements can be determined.

It is important to remove samples from the entire cross section of a layer since operating conditions can vary depending on whether the catalyst module was located near or far away from the SCR box inlet. There may also be some gas flow differences from one side of the SCR box to the other.

The value of the laboratory results can be compromised unless all of the following information is recorded on one side of the test catalyst element using a permanent marker.

- Station name and unit number
- SCR box designation if there are more than one per unit (i.e. A, B, 1, 2)
- Catalyst layer (i.e. top, middle, bottom)
- The location of the catalyst module in the layer
- The direction of gas flow through the element
- The date the test catalyst element was removed
- The number of hours the test catalyst element was in service

The ceramic honeycomb catalyst elements are very fragile. It is best to obtain padded shipping boxes from the catalyst vendor or the testing lab to ship the samples to the testing locations.

Plate Catalyst

Catalyst samples can be removed from any catalyst module with plate catalyst. The sample is most easily removed with two pairs of flat nosed pliers. With a pair of pliers in each hand, grab hold near each side of a pair of catalyst plates. Pull the plates straight up out of the catalyst element. You may have to jiggle the plates to get them to slide out freely. If any adjacent plates move up with the removed plates, push them back down into place.

The reason you must remove a pair of plates is because of the corrugations in the plate. All the plates are exactly the same. When the plates are put in the catalyst element, the plates are alternately rotated 90 degrees. This staggers the corrugations which causes the spacing between the plates. If one removes only one plate, the plates on either side of it will nest together and there will be no spacing between these plates.

The locations and removal dates for all test catalyst plates removed should be recorded in the unit's records. The catalyst plates are compressed slightly into the catalyst element. It is prudent not to remove more than two plates from a catalyst element so that the remaining plates do not become loose and move around under flow conditions. These records can prevent repeated sampling from the same catalyst element. (See **Figure:**

Sampling Plate Catalyst

)It is important to remove samples from the entire cross section of a layer since operating conditions can vary depending on whether the catalyst module was located near or far away from the SCR box inlet. There may also be some gas flow differences from one side of the SCR box to the other.

The value of the laboratory results can be compromised unless all of the following information is recorded on one side of each test catalyst plate using a permanent marker. Write the information in a small area near one of the edges of the plate.

- Station name and unit number
- SCR box designation if there are more than one per unit (i.e. A, B, 1, 2)
- Catalyst layer (i.e. top, middle, bottom)
- The location of the catalyst module in the layer
- The direction of gas flow past the plate
- The date the test catalyst plate was removed
- The number of hours the test catalyst plate was in service

Sampling Plate Catalyst
(Courtesy of Argillon)

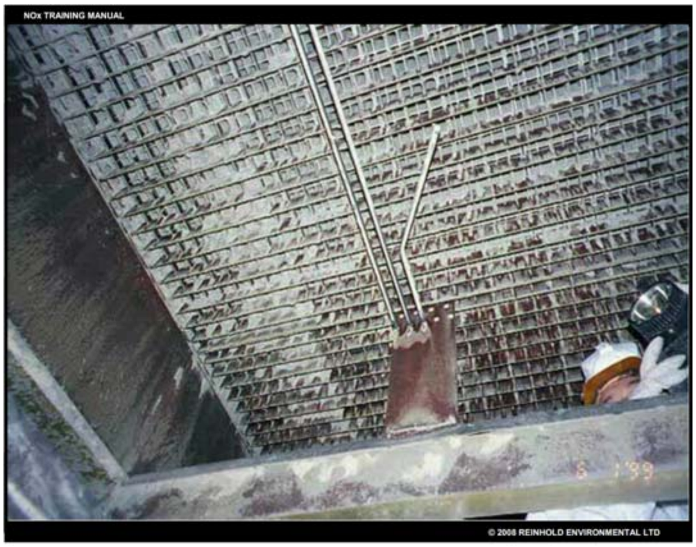
For shipping purposes, all of the test catalyst plates can be oriented in the same direction and nested together to save space in shipping. The stack of plates should be wrapped in plastic. The plastic wrapped stack can then be placed in a box or wrapped in several layers of kraft paper for shipping. The plates are fairly indestructible and don't require any special handling.

10.1.k Performance Testing Grid

Below the bottom catalyst layer, there is typically a grid of sampling lines that are used in performance testing of the SCR catalyst. These are typically small bore stainless steel tubing of various lengths that are routed to sampling clusters located on the exterior of the SCR box.

These sample lines should be inspected to assure that the ends of the lines are open and not plugged with ash. One should also check that all the lines are firmly mounted to their support structures and that there are no holes eroded into the length of the lines.

At least once during the life of the SCR system, it should be verified that the open end of each sampling line is located in the physical location in the SCR box that matches the identification name or number that is assigned to that line versus the drawing of where that sample line is supposed to be located.



Test Grid Sample Lines
(Used with permission)

If these sample lines are plugged or not mounted where they are thought to be located, it will make tuning the ammonia feed to obtain optimum NOx removal very difficult. See **Figure:**

Test Grid Sample Lines

10.2 Anhydrous Ammonia Tank Farm Maintenance

The regulations covering anhydrous ammonia systems require internal inspections of the ammonia storage tanks at some regular interval. The regulations also require the replacement of some emergency shut-off valves and pressure relief valves at certain intervals.

In order to perform this work, certain parts of the anhydrous ammonia system must be emptied of ammonia and purged with nitrogen (and air if entry to a storage tank is required) to allow for safe personnel access to the equipment.

If the unit is still operating in a "seasonal mode," the SCR can be put in service and all the ammonia drains and nitrogen purges can be routed to the SCR. This allows the SCR to consume any ammonia so there will be no environmental release. The entire ammonia storage system can be emptied and purged if desired to allow maintenance on all parts of the system.

If the unit is operating "year round," individual tanks will have to be emptied and purged. Individual sections of piping will have to be sectionalized and purged to work on valves. This will require using vents on individual equipment. To prevent environmental releases, this venting will have to be done through water to absorb the ammonia. While a tank of water may work in some cases, for larger equipment some sort of spray tower or packed bed absorber may be preferable to handle the gas flow rates. The water will need to be continually freshened, and the overflow ammoniated water will need to be disposed of properly.

System Description

Most anhydrous ammonia systems typically consist of:

- A rail car unloading station
- A truck unloading station
- Two compressor skids
- Several large ammonia storage tanks
- A forwarding pump skid with two pumps

These procedures were written for such a typical system to serve as a template for performing the work. Adjustments may have to be made for one's specific system design.

Ammonia Safety

Liquid anhydrous ammonia has a very low boiling point (-28 degrees Fahrenheit) at atmospheric pressure. It can only remain a liquid at higher temperatures if it is under pressure. The pressure in a closed tank containing liquid anhydrous ammonia will be approximately 75 psig if the tank is at 50 degrees Fahrenheit and will be approximately 200 psig if the tank is at 100 degrees Fahrenheit. So if the pressure in one of the ammonia storage tanks is near 0 psig, one can be assured that no liquid anhydrous ammonia remains in the tank.

Ammonia gas is lighter than air. Ammonia gas will dissolve readily in water, so a spray of water can remove ammonia from the air. Because the ammonia gas is attracted to moisture, the primary concern for an individual is their eyes, nose, throat and lungs. The ammonia gas will be absorbed by the moisture in these mucous membranes which will cause irritation of the tissue. This can cause a burning sensation as well as coughing and bronchial spasms.

OSHA has determined that it is permissible for an individual to be exposed to 50 ppm or less of ammonia for an 8 hour work period. If the ammonia concentration reaches 300 ppm, workers are required to immediately evacuate the area. Ammonia has a very pungent odor that the nose can detect at levels as low as 5 ppm. So it is possible that one could smell an ammonia odor and it still be safe to work in the area without wearing respiratory protection equipment.

The concentration levels of ammonia can be measured using electronic meters that have been calibrated for ammonia or by using handheld sampling pumps equipped with ammonia detection tubes that indicate the ammonia concentration through a color change of the material in the glass sample tube.

Respiratory Protection Equipment

If the concentration of ammonia gas is unknown, one can wear a full face respirator that is equipped with ammonia removal cartridges. This will protect the eyes, nose, throat and lungs.

A half face respirator equipped with ammonia removal cartridges will protect the nose, throat and lungs. A face shield will provide some eye protection, however at higher ammonia concentrations, one may feel some irritation of the eyes as the ammonia gas is attracted to the moisture of the eyes.

If the eyes become irritated from ammonia, they should be flushed with a large amount of water.

The skin is typically not affected by exposure to ammonia gas.

10.2.a For a Unit Operating on a Seasonal Basis

Purging the Entire Anhydrous Ammonia System for Inspection and Maintenance

Purpose of Procedure

Before any valve maintenance or tank inspections can be done, the anhydrous ammonia that is present in the system must be relocated or removed in a safe and environmentally correct manner.

- This procedure describes the steps one can take to empty each ammonia storage tank. This can be done by consuming the ammonia in an operating SCR system or by transferring the ammonia from one storage tank to another.
- After a storage tank is emptied of liquid anhydrous ammonia, the remaining ammonia gas in the tank must be purged with nitrogen until it is at a safe level to open the manways and vent the remaining gas out of the tank with forced air ventilation. All of the associated piping, compressors and pumps must also be purged to this level.
- Experience has shown that 8 to 10 purges are required to get the tanks to a level where it is safe to open the manways. At this point, the ammonia meter will read "over range" (greater than 200 ppm) if one places the probe directly into the gas sample stream, but will read less than 50 ppm if the probe is held a few inches on either side of the sample stream. Anyone standing near the sample stream will not notice much ammonia odor.

Once the manways are open, ventilation through the tank should be started to remove the remaining ammonia gas.

Once the purge is complete for each section of the system, that section can be isolated and made available for the maintenance and inspection work that is scheduled to be performed.

Removing All Liquid Ammonia From Ammonia Storage Tank

Before any purging of the system with nitrogen can begin, all the liquid anhydrous ammonia must be removed from the parts of the system that need to be purged. To empty the liquid from the piping going to the SCR, it must not be allowed to "boil off" in the piping since this will cause the liquid to cool and possibly freeze and block the piping.

The easiest way to keep the ammonia in the liquid state is to pressurize the Ammonia Storage Tank with nitrogen. This does two things:

- It keeps the pressure in the system above the boiling pressure of the ammonia which will keep it liquid.
- It provides the force needed to push the liquid ammonia to the SCR since the Forwarding Pumps will not be usable due to little or no liquid level in the Ammonia Storage Tank.

If the Ammonia Storage Tank is pressurized to 100 psig, this should be sufficient pressure to move the ammonia and keep it liquid unless the ambient temperature is above 60 degrees Fahrenheit. If the temperature is above this, one will have to pressurize the tank to a level above the vapor pressure of the anhydrous ammonia. The Ammonia Storage Tank can be filled with nitrogen using any of the following procedures. Once the tank is pressurized, follow the procedure to depressurize the tank through the vaporizer and the SCR.

The vaporizers should remain in service as long as liquid anhydrous ammonia is flowing to them. Once the line is almost empty and slugs of gas and liquid flow through the vaporizer, the vaporizer will trip. The flow path should remain open so the remaining gas/liquid mixture can continue to flow into the SCR. The process should continue until the pressure in the Ammonia Storage Tank and the piping reaches a low level and all the liquid anhydrous ammonia has boiled off. The system is now ready to purge with nitrogen flushes.

Nitrogen Supply

Either gaseous or liquid nitrogen can be delivered for the purges. The advantage of gaseous nitrogen is that the Ammonia Storage Tanks can be filled more quickly. The disadvantage is that a truckload of gaseous nitrogen doesn't supply as much volume so numerous truckloads of gaseous nitrogen will need to be delivered to the job.

The advantage of liquid nitrogen is that a truckload will supply a very large volume of nitrogen, so one truckload will fill an Ammonia Storage Tank numerous times. The disadvantage is that one must rent a liquid nitrogen skid that has a storage tank and a vaporizer. The discharge hose connections from the skid are smaller, so the fill rate of the Ammonia Storage Tank will be slower than from a gaseous supply truck.

Filling an Ammonia Storage Tank With Nitrogen

Most of the fills can be done through the truck unloading area vapor unloading arm. At least one of the fills per tank should be done through the liquid unloading arm to purge the rest of the piping going to the Ammonia Storage Tank. Depending on the nitrogen supply, the fills can be done through both arms to speed the process.

1. Filling Through the Vapor Unloading Arm.

a. Connect the nitrogen truck to the fitting at the vapor unloading arm.
b. Open Emergency Ammonia Block Valve
c. Open Cross Over Valve Between Unloading Stations
d. Either Open Compressor #1 Bypass Valve or Open Compressor #2 Bypass Valve
e. Check Closed Tank Manual Liquid Inlet Valve
f. Check Closed Tank Manual Outlet Valve
g. Check Closed Tank Manual Recirculation Inlet Valve
h. Open Tank Manual Vapor Inlet Valve
i. Open Tank Automatic Vapor Inlet Valve
j. Open Manual Valve at Unloading Station
k. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves. Pressurize the ammonia storage tank to 20-25 psig.
l. Once the tank is pressurized, Close the valve on the nitrogen truck.
m. Close Manual Valve at Unloading Station
n. Close Tank Manual Vapor Inlet Valve

2. Filling Through the Liquid Unloading Arm.

a. Connect the nitrogen truck to the fitting at the liquid unloading arm.
b. Open Emergency Ammonia Block Valve
c. Open Liquid Line Tie Valve
d. Check Closed Tank Manual Vapor Inlet Valve
e. Check Closed Tank Manual Outlet Valve
f. Check Closed Tank Manual Recirculation Inlet Valve
g. Open Tank Manual Liquid Inlet Valve
h. Open Tank Automatic Liquid Inlet Valve

i. Open Manual Valve at Unloading Station
j. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves. Pressurize the ammonia storage tank to 20-25 psig. (If there are any 3-way valves to isolate relief valves on this equipment, rotate the 3-way valve handle so any liquid ammonia is released from both arms of the 3-way valve)
k. Once the tank is pressurized, close the valve on the nitrogen truck.
l. Close Manual Valve at Unloading Station
m. Close Tank Manual Liquid Inlet Valve

Depressurizing an Ammonia Storage Tank

Before starting this step, at least one SCR catalyst bed must be at normal operating temperature with flue gas flowing through it. One may not see much NOx reduction since the amount of ammonia entering the SCR will be much less than normal.

Since there is only a nitrogen/ammonia gas mixture, it doesn't matter whether the vaporizer is at operating temperature or not.

On the Forwarding Pump Skid, check closed vent valve on the Forwarding Pump Bypass Line. If there is a blank or plug on the open end of the valve, remove the blank or plug. This is the location that will be used to measure the ammonia concentration in the Ammonia Storage Tank.

3. Depressurizing an Ammonia Storage Tank

a. Check Closed Tank Manual Vapor Inlet Valve
b. Check Closed Tank Manual Liquid Inlet Valve
c. Check Closed Tank Manual Outlet Valve
d. Check Closed Tank Manual Recirculation Inlet Valve
e. Open Tank Automatic Outlet Valve (This may require a temporary Management of Change as the valve may need to be forced open from the DCS System in the Control Room)
f. Check Closed Forwarding Pump #1 Suction Manual Valve
g. Check Closed Forwarding Pump #2 Suction Manual Valve
h. Check Closed Forwarding Pump #1 Discharge Manual Valve
i. Check Closed Forwarding Pump #2 Discharge Manual Valve
j. Open Bypass Around Ammonia Forwarding Pumps
k. Open Inlet Valves to Ammonia Vaporizers
l. Open the Bypass on the Pressure Control Valves
m. Open the Bypass on the Flow Control Valves
n. Open Vaporizer Outlet Valves
o. Slowly Open Tank Manual Outlet Valve so you don't trip closed the excess flow valve.
p. (Don't do this step until at least the fifth purge or one will severely "over range" the ammonia detector and it may take hours for it to recover.) As the gas is flowing from the Ammonia Storage Tank, put on the proper respiratory protective equipment and take the ammonia test equipment to pump bypass vent valve. Open the valve slightly to obtain a gas flow which can be tested for ammonia concentration. At the end of the test, close the vent valve.
q. When the Ammonia Storage Tank pressure reaches 5 psig, Close Tank Manual Outlet Valve. (One can go to 0 psig, but the time required to get there is probably not worth the benefit.) The Vaporizer and SCR System can remain in service or be removed from service depending upon the time lag until it will be needed again.

4. Purging the Ammonia Storage Tank Recycle Line (This will need to be done in conjunction with the preceding Procedure #3 once the ammonia concentration in the tank is at a low value)

As the Ammonia Storage Tank is being depressurized using the preceding procedure #3

a. Open Tank Automatic Recirculation Inlet Valve
b. Open Tank Manual Recirculation Inlet Valve

c. Either route flow through the #1 Ammonia Forwarding Pump line by:
i. Opening Forwarding Pump #1 Recirculation Line Manual Valve
ii. Opening Forwarding Pump #1 Recirculation Line Control Valve
iii. Opening Forwarding Pump #1 Discharge Manual Valve
d. Or route flow through the #2 Ammonia Forwarding Pump line by:
i. Opening Forwarding Pump #2 Recirculation Line Manual Valve
ii. Opening Forwarding Pump #2 Recirculation Line Control Valve
iii. Opening Forwarding Pump #2 Discharge Manual Valve
e. Slowly Close Tank Manual Outlet Valve so you don't trip closed any excess flow valves
f. Let the gas flow through the Recirculation Line for at least 5 minutes
g. Slowly Open Tank Manual Outlet Valve so you don't trip closed any excess flow valves
h. If you routed flow through the #1 Ammonia Forwarding Pump line then:
i. Slowly Close Forwarding Pump #1 Recirculation Line Manual Valve
ii. Close Forwarding Pump #1 Recirculation Line Control Valve
iii. Close Forwarding Pump #1 Discharge Manual Valve
i. Or if you routed flow through the #2 Ammonia Forwarding Pump line then:
i. Slowly Close Forwarding Pump #2 Recirculation Line Manual Valve
ii. Close Forwarding Pump #2 Recirculation Line Control Valve
iii. Close Forwarding Pump #2 Discharge Manual Valve
j. Close Tank Automatic Recirculation Inlet Valve
k. Close Tank Manual Recirculation Inlet Valve

5. Purging the #1 Ammonia Forwarding Pump (This will need to be done in conjunction with the preceding Procedure #3 once the ammonia concentration in the tank is at a low value)

As the Ammonia Storage Tank is being depressurized using the preceding procedure #3

a. Open Forwarding Pump #1 Suction Manual Valve
b. Open Forwarding Pump #1 Discharge Manual Valve
c. Close Bypass Around Ammonia Forwarding Pumps
d. Let the gas flow through the #1 Ammonia Forwarding Pump for at least 5 minutes (If there are any 3-way valves to isolate relief valves on this equipment, rotate the 3-way valve handle so any liquid ammonia is released from both arms of the 3-way valve)
e. Open Bypass Around Ammonia Forwarding Pumps
f. Close Forwarding Pump #1 Discharge Manual Valve
g. Close Forwarding Pump #1 Suction Manual Valve

6. Purging the #2 Ammonia Forwarding Pump (This will need to be done in conjunction with the preceding Procedure #3 once the ammonia concentration in the tank is at a low value)

As the Ammonia Storage Tank is being depressurized using the preceding procedure #3

a. Open Forwarding Pump #2 Suction Manual Valve
b. Open Forwarding Pump #2 Discharge Manual Valve
c. Close Bypass Around Ammonia Forwarding Pumps
d. Let the gas flow through the #2 Ammonia Forwarding Pump for at least 5 minutes (If there are any 3-way valves to isolate relief valves on this equipment, rotate the 3-way valve handle so any liquid ammonia is released from both arms of the 3-way valve)
e. Open Bypass Around Ammonia Forwarding Pumps
f. Close Forwarding Pump #2 Discharge Manual Valve
g. Close Forwarding Pump #2 Suction Manual Valve

7. Purging the #1 Compressor Skid (This will need to be done in conjunction with the preceding Procedure #1)

a. Connect the nitrogen truck to the fitting at the vapor unloading arm.
b. Open Emergency Ammonia Block Valve
c. Open Cross Over Valve Between Unloading Stations
d. Close Compressor #1 Bypass Valve
e. Position Compressor 4-way Valve in the "B" position
f. Open Upper Compressor Manual Valve at 4-way Valve
g. Open Lower Compressor Manual Valve at 4-way Valve
h. Open Ammonia Vapor Tie Valve if needed to purge to the desired Ammonia Storage Tank
i. Check Closed Tank Manual Liquid Inlet Valve
j. Check Closed Tank Manual Outlet Valve
k. Check Closed Tank Manual Recirculation Inlet Valve
l. Open Tank Manual Vapor Inlet Valve
m. Open Tank Automatic Vapor Inlet Valve
n. Open Manual Valve at Unloading Station
o. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves.
p. Let the gas flow through the #1 Compressor for at least 5 minutes
q. Open Compressor #1 Bypass Valve for 1 minute
r. Close Compressor #1 Bypass Valve
s. Close the valve on the nitrogen truck.
t. Close Manual Valve at Unloading Station
u. Close Tank Manual Vapor Inlet Valve
v. Close Ammonia Vapor Tie Valve (if it was opened)
w. Close Upper Compressor Manual Valve at 4-way Valve
x. Close Lower Compressor Manual Valve at 4-way Valve
y. Position Compressor 4-way Valve in the "A" position
z. Close Cross Over Valve Between Unloading Stations

8. Purging the #2 Compressor Skid (This will need to be done in conjunction with the preceding Procedure #1)

a. Connect the nitrogen truck to the fitting at the vapor unloading arm.
b. Open Emergency Ammonia Block Valve
c. Open Cross Over Valve Between Unloading Stations
d. Close Compressor #2 Bypass Valve
e. Position Compressor 4-way Valve in the "B" position
f. Open Upper Compressor Manual Valve at 4-way Valve
g. Open Lower Compressor Manual Valve at 4-way Valve
h. Open Ammonia Vapor Tie Valve if needed to purge to the desired Ammonia Storage Tank
i. Check Closed Tank Manual Liquid Inlet Valve
j. Check Closed Tank Manual Outlet Valve
k. Check Closed Tank Manual Recirculation Inlet Valve
l. Open Tank Manual Vapor Inlet Valve
m. Open Tank Automatic Vapor Inlet Valve
n. Open Manual Valve at Unloading Station
o. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves.
p. Let the gas flow through the #2 Compressor for at least 5 minutes
q. Open Compressor #2 Bypass Valve for 1 minute
r. Close Compressor #2 Bypass Valve
s. Close the valve on the nitrogen truck.
t. Close Manual Valve at Unloading Station
u. Close Tank Manual Vapor Inlet Valve
v. Close Ammonia Vapor Tie Valve (if it was opened)

w. Close Upper Compressor Manual Valve at 4-way Valve
x. Close Lower Compressor Manual Valve at 4-way Valve
y. Position Compressor 4-way Valve in the "A" position
z. Close Cross Over Valve Between Unloading Stations

Purging the Rail Unloading Skid

If just the lines are going to be purged, use Procedures #9 and #10. It would be best to route this purge to an Ammonia Storage Tank that has not been purged to a low ammonia concentration since ammonia will be purged to the tank. Any of the tanks that are at 0 psig can be used.

If one of the Ammonia Storage Tanks is going to be filled from the Rail Unloading Skid, use Procedures #11 and #12.

9. Purging the Rail Unloading Skid Liquid Piping (Blanks or plugs will have to be installed to block the normal openings at the Rail Unloading Liquid Arm and Vapor Arm)

a. Check Open the valve on the nitrogen supply system.
b. Open Manual Liquid Valve at Unloading Station
c. Open Emergency Ammonia Block Valve on Liquid Line
d. Open Tie Valve on Liquid Line if needed to route to desired tank
e. Open Tank Automatic Liquid Inlet Valve
f. Open Tank Manual Liquid Inlet Valve
g. Slowly Open Manual Nitrogen Valve at Unloading Station so you don't trip closed any excess flow valves
h. Let the nitrogen flow for * minutes. (If there are any 3-way valves to isolate relief valves on this equipment, rotate the 3-way valve handle so any liquid ammonia is released from both arms of the 3-way valve. *Number of minutes depends on vapor piping length)
i. Then Close Manual Nitrogen Valve at Unloading Station
j. Close Tank Automatic Liquid Inlet Valve
k. Close Tank Manual Liquid Inlet Valve
l. (If opened) Close Tie Valve on Liquid Line
m. Close Manual Liquid Valve at Unloading Station
n. Close Emergency Ammonia Block Valve on Liquid Line

10. Purging the Rail Unloading Skid Vapor Piping (Blanks or plugs will have to be installed to block the normal openings at the Rail Unloading Liquid Arm and Vapor Arm)

a. Check Open the valve on the nitrogen supply system
b. Open Manual Vapor Valve at Unloading Station
c. Open Emergency Ammonia Block Valve on Vapor Line
d. Open Compressor Bypass Valve
e. Open Tie Valve on Vapor Line if needed to route to the desired tank
f. Open Tank Automatic Vapor Inlet Valve
g. Open Tank Manual Vapor Inlet Valve
h. Slowly Open Manual Nitrogen Valve at Unloading Station so you don't trip closed any excess flow valves
i. Let the nitrogen flow for * minutes. (*Number of minutes depends on vapor piping length)
j. Then Close Manual Nitrogen Valve at Unloading Station
k. Close Tank Automatic Vapor Inlet Valve
l. Close Tank Manual Vapor Inlet Valve
m. (If opened) Close Tie Valve on Vapor Line
n. Close Manual Vapor Valve at Unloading Station
o. Close Emergency Ammonia Block Valve on Vapor Line

11. Filling Through The Rail Unloading Skid Liquid Piping

a. Connect the nitrogen truck to the Rail Unloading Skid Liquid Arm
b. Open Manual Liquid Valve at Unloading Station
c. Open Emergency Ammonia Block Valve on Liquid Line
d. Open Tie Valve on Liquid Line if needed to route to the desired tank
e. Open Tank Automatic Liquid Inlet Valve
f. Open Tank Manual Liquid Inlet Valve
g. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves. Pressurize the ammonia storage tank to 20-25 psig. (If there are any 3-way valves to isolate relief valves on this equipment, rotate the 3-way valve handle so any liquid ammonia is released from both arms of the 3-way valve)
h. Once the tank is pressurized, Close the valve on the nitrogen truck.
i. Close Tank Automatic Liquid Inlet Valve
j. Close Tank Manual Liquid Inlet Valve
k. (If opened) Tie Valve on Liquid Line
l. Close Manual Liquid Valve at Unloading Station
m. Close Emergency Ammonia Block Valve on Liquid Line

12. Filling Through The Rail Unloading Skid Vapor Piping

a. Connect the nitrogen truck to the Rail Unloading Skid Vapor Arm
b. Open Manual Vapor Valve at Unloading Station
c. Open Emergency Ammonia Block Valve on Vapor Line
d. Open Compressor #1 Bypass Valve
e. Open Tie Valve on Vapor Line if needed to route to the desired tank
f. Open Tank Automatic Vapor Inlet Valve
g. Open Tank Manual Vapor Inlet Valve
h. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves. Pressurize the ammonia storage tank to 20-25 psig.
i. Once the tank is pressurized, Close the valve on the nitrogen truck.
j. Close Tank Automatic Vapor Inlet Valve
k. Close Tank Manual Vapor Inlet Valve
l. (If opened) Close Tie Valve on Vapor Line
m. Close Manual Vapor Valve at Unloading Station
n. Close Emergency Ammonia Block Valve on Vapor Line

Proceeding With The Outage Work

The maintenance crew can begin the outage work on the section of piping or the Ammonia Storage Tank once the section of piping or the Ammonia Storage Tank

- has been purged to an ammonia concentration of 50 ppm or less
- has been properly isolated and tagged
- and maintenance personnel have completed the proper paperwork to accept the tagged equipment.

Whenever the first fitting or connection is going to be opened on a section of pipe or a tank, a full face respirator with ammonia cartridges or a half face respirator with ammonia cartridges and a face shield should be worn in case there is some residual pressure or ammonia in the equipment. If exposure to ammonia causes burning of the eyes, the eyes should be flushed out with a large amount of water.

Once the connection has been opened and the area tested as having an ammonia concentration of 50 ppm or less, respiratory protection for ammonia will no longer be required.

The Ammonia Storage Tanks are confined spaces and cannot be entered until all applicable confined space entry protocols have been followed. The nitrogen in the Ammonia Storage Tanks has the same density as air. It will not move out of the tanks without forced ventilation of air through the tank.

After a tank has been inspected and closed, pressurize the tank to the desired pressure with nitrogen and then check all manway gaskets and any other fitting that were disconnected for leaks. The nitrogen can then be vented from the tank. This also displaces any air that entered the tank when it was ventilated.

13. Reintroduction of Ammonia Into an Ammonia Storage Tank

a. Check Closed Tank Manual Outlet Valve
b. Check Closed Tank Manual Recirculation Inlet Valve
c. Check Closed Tank Manual Liquid Inlet Valve
d. Check Closed Tank Vent Valve
e. Check Closed Manual Vapor Valve at Rail Unloading Station
f. Check Closed Emergency Ammonia Block Valve on Vapor Line at Rail Unloading Station
g. Check Closed Manual Vapor Valve at Truck Unloading Station
h. Check Closed Emergency Ammonia Block Valve on Vapor Line at Truck Unloading Station
i. Open Tank Manual Vapor Inlet Valve
j. Open Tank Automatic Vapor Inlet Valve
k. (If transferring between the #3 or #4 Ammonia Storage Tank and the #1 or #2 Ammonia Storage Tank) Open Tie Valve on Vapor Line.
l. Open Tank Automatic Vapor Inlet Valve on the tank that ammonia will be transferred out of.
m. Slowly Open Tank Manual Vapor Inlet Valve on the tank that ammonia will be transferred out of. There is an excess flow valve on each tank involved, so too rapid a transfer will slam closed one or both of these valves. The pressure in the ammonia filled tank will force ammonia vapor into the empty tank.
n. Once the pressure has equalized between the two tanks, Close Tank Manual Vapor Inlet Valve on the tank that ammonia was transferred out of.
o. Close Tank Automatic Vapor Inlet Valve on the tank that ammonia was transferred out of.
p. Close Tank Manual Vapor Inlet Valve
q. Close Tank Automatic Vapor Inlet Valve
r. The tank can now be vented to remove any nitrogen remaining in the tank. To do this, use the Depressurization Procedure #3. Vent the tank a sufficient time to displace any nitrogen in the tank.

The tank is now ready for all the valves to be returned to their normal positions. The tank can be refilled in the normal manner from a truck or rail car. Once refilled, the tank can return to normal service.

10.2.b For a Unit Operating on a Year Round Basis
Purging a Single Anhydrous Ammonia Tank for Inspection and Maintenance

Purpose of Procedure

Before a tank inspection can be done, the anhydrous ammonia that is present in the tank must be relocated or removed in a safe and environmentally correct manner.

This procedure describes the steps that one can take to empty an ammonia storage tank. This can be done by consuming the ammonia in an operating SCR system or by transferring the ammonia from one storage tank to another.

After a storage tank is emptied of liquid anhydrous ammonia, the remaining ammonia gas in the tank must be purged with nitrogen until the remaining ammonia gas is at a safe level to open the manways and vent the remaining gas out of the tank with forced air ventilation.

Experience has shown that 8 to 10 purges are required to get a tank to an ammonia level where it is safe to open the manways. At this point, the ammonia meter will read "over range" (greater than 200 ppm) if one places the probe directly into the gas sample stream, but will read less than 50 ppm if the probe is held a few inches on either side of the sample stream. Anyone standing near the sample stream will not notice much ammonia odor.

Once the manways are open, ventilation through the tank should be started to remove the remaining ammonia gas.

Blanks (pancakes) will need to be installed at four locations to isolate the tank before anyone enters the tank to perform inspections or repairs. The blanks should be installed on the tank side of these valves.

1. Tank Manual Vapor Inlet Valve
2. Tank Manual Liquid Inlet Valve
3. Tank Manual Outlet Valve
4. Tank Manual Recirculation Inlet Valve

Placing the blanks in these locations gives the protection of two closed valves between the liquid ammonia in the headers and the flanges that will be separated to install the blanks. Proper PPE must be worn while installing these blanks.

Removing All Liquid Ammonia From Ammonia Storage Tank

Before any purging of the system with nitrogen can begin, all the liquid anhydrous ammonia must be removed from the parts of the system that need to be purged. Any liquid that has not been transferred out of the tank will need to be boiled off through a vent. The only vent that can be used is located on the top of the tank. A blind flange will have to be removed to allow flow from this vent.

A large hose will have to be run between this vent and whatever device will be used to absorb the ammonia gas. This may be a large tank of water. A better choice might be a small spray tower with recirculating water. Fresh water will need to be continuously added to either device. The overflow, which will be ammoniated water, will need to be routed to a location where it can be treated in such a manner so as not to cause any NPDES issues.

This same venting arrangement will also be used for the subsequent nitrogen purges of the tank to remove any ammonia in the purge streams.

Nitrogen Supply

Either gaseous or liquid nitrogen can be delivered for the purges. The advantage of gaseous nitrogen is that the Ammonia Storage Tanks can be filled more quickly. The disadvantage is that a truckload of gaseous nitrogen doesn't supply as much volume so numerous truckloads of gaseous nitrogen will need to be delivered to the job.

The advantage of liquid nitrogen is that a truckload will supply a very large volume of nitrogen, so one truckload will fill an Ammonia Storage Tank numerous times. The disadvantage is that one must rent a liquid nitrogen skid that has a storage tank and a vaporizer. The discharge hose connections from the skid are smaller, so the fill rate of the Ammonia Storage Tank will be slower than from a gaseous supply truck.

Filling an Ammonia Storage Tank With Nitrogen

The fills can be done through the truck unloading area vapor unloading arm and the liquid unloading arm to purge the rest of the piping going to the Ammonia Storage Tank.

1. Filling Through the Truck Unloading Skid Vapor Unloading Arm.

a. Connect the nitrogen truck to the fitting at the vapor unloading arm.
b. Open Emergency Ammonia Block Valve
c. Open Cross Over Valve Between Unloading Stations
d. Either Open Compressor #1 Bypass Valve Or Open Compressor #2 Bypass Valve

e. Check Closed Tank Manual Outlet Valve
f. Check Closed Tank Manual Recirculation Inlet Valve
g. Open Tank Manual Vapor Inlet Valve
h. Open Tank Automatic Vapor Inlet Valve
i. Open Manual Valve at Unloading Station
j. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves. Pressurize the ammonia storage tank to 25 psig.
k. Once the tank is pressurized, Close the valve on the nitrogen truck.
l. Close Manual Valve at Unloading Station
m. Close Tank Manual Vapor Inlet Valve

2. Filling Through the Truck Unloading Skid Liquid Unloading Arm.

a. Connect the nitrogen truck to the fitting at the liquid unloading arm. Make sure any liquid ammonia in the unloading piping has been purged or boiled off.
b. Open Emergency Ammonia Block Valve
c. Open Liquid Line Tie Valve
d. Check Tank Manual Outlet Valve
e. Check Closed Tank Manual Recirculation Inlet Valve
f. Open Tank Manual Liquid Inlet Valve
g. Open Tank Automatic Liquid Inlet Valve
h. Open Manual Valve at Unloading Station
i. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves. Pressurize the ammonia storage tank to 25 psig.
j. Once the tank is pressurized, Close the valve on the nitrogen truck.
k. Close Manual Valve at Unloading Station
l. Close Tank Manual Liquid Inlet Valve

3. Filling Through the Rail Unloading Skid Liquid Piping

a. Connect the nitrogen truck to the Rail Unloading Skid Liquid Arm. Make sure any liquid ammonia in the unloading piping has been purged or boiled off.
b. Open Manual Liquid Valve at Unloading Station
c. Open Emergency Ammonia Block Valve on Liquid Line
d. (If filling the #3 or #4 Ammonia Storage Tank) Open Tie Valve on Liquid Line
e. Open Tank Automatic Liquid Inlet Valve
f. Open Tank Manual Liquid Inlet Valve
g. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves. Pressurize the ammonia storage tank to 25 psig.
h. Once the tank is pressurized, Close the valve on the nitrogen truck.
i. Close Tank Automatic Liquid Inlet Valve
j. Close Tank Manual Liquid Inlet Valve
k. (If purging to the #3 or #4 Ammonia Storage Tank) Close Tie Valve on Liquid Line
l. Close Manual Liquid Valve at Unloading Station
m. Close Emergency Ammonia Block Valve on Liquid Line

4. Filling Through the Rail Unloading Skid Vapor Piping

a. Connect the nitrogen truck to the Rail Unloading Skid Vapor Arm
b. Open Manual Vapor Valve at Unloading Station
c. Open Emergency Ammonia Block Valve on Vapor Line
d. Open Compressor #1 Bypass Valve
e. (If purging to the #3 or #4 Ammonia Storage Tank) Open Tie Valve on Vapor Line
f. Open Tank Automatic Vapor Inlet Valve

g. Open Tank Manual Vapor Inlet Valve
h. Slowly Open the valve on the nitrogen truck so you don't trip closed any excess flow valves. Pressurize the ammonia storage tank to 25 psig.
i. Once the tank is pressurized, Close the valve on the nitrogen truck.
j. Close Tank Automatic Vapor Inlet Valve
k. Close Tank Manual Vapor Inlet Valve
l. (If purging to the #3 or #4 Ammonia Storage Tank) Close Tie Valve on Vapor Line
m. Close Manual Vapor Valve at Unloading Station
n. Close Emergency Ammonia Block Valve on Vapor Line

Depressurizing an Ammonia Storage Tank

Before starting this step, make sure the vent hose and the ammonia removal system are ready for service.

5. Depressurizing an Ammonia Storage Tank

a. Check Closed Tank Manual Vapor Inlet Valve
b. Check Closed Tank Manual Liquid Inlet Valve
c. Check Closed Tank Manual Outlet Valve
d. Check Closed Tank Manual Recirculation Inlet Valve
e. Check Open Valve to Tank Pressure Gauge and Transmitter
f. Slowly Open Tank Vent Valve
g. After the sixth purge of the tank and as the gas is flowing from the Ammonia Storage Tank, put on the proper PPE and take the ammonia test equipment to start getting readings of the ammonia concentration. This is done by removing the plug in the one side of the 3-way valve at the tank pressure gauge and then rotating the 3-way valve to the position that will give a sample flow. (Sampling any sooner than this will severely "over range" the meter to the point that it may take several hours for the sensor to recover.)
h. When the Ammonia Storage Tank pressure reaches 0 psig, close Tank Vent Valve.

Proceeding With The Outage Work

Once the Ammonia Storage Tank

- has been purged to an acceptable ammonia concentration
- has been properly isolated and tagged
- and maintenance personnel have completed the proper paperwork to accept the tagged equipment

The maintenance crew can install the blanks (pancakes) in the flanges on the tank side of the following valves:

- Tank Manual Vapor Inlet Valve
- Tank Manual Liquid Inlet Valve
- Tank Manual Outlet Valve
- Tank Manual Recirculation Inlet Valve

Whenever these flanges are going to be opened, a full face respirator with ammonia cartridges or a half face respirator with ammonia cartridges and a face shield should be worn in case there is some residual pressure or ammonia in the equipment. If exposure to ammonia causes burning of the eyes, the eyes should be flushed out with a large amount of water.

Once the connection has been opened and the area tested as having an ammonia concentration of 50 ppm or less, respiratory protection for ammonia will no longer be required.

The Ammonia Storage Tanks are confined spaces and cannot be entered until all applicable confined space entry protocols have been followed. The nitrogen in the Ammonia Storage Tanks has the same density as air. It will not move out of the tanks without forced ventilation of air through the tank.

Putting the Ammonia Storage Tank Back Into Service

The first step of this process is to remove the blanks that were installed at these valves.

- Tank Manual Vapor Inlet Valve
- Tank Manual Liquid Inlet Valve
- Tank Manual Outlet Valve
- Tank Manual Recirculation Inlet Valve

The next step is to pressurize the tank to the desired pressure with nitrogen to check for leaks at the manway gaskets and piping gaskets that were replaced. This is done in the same manner as the previous nitrogen fills of the tank. This fill will also start to displace the oxygen that entered the tank during the inspections and repairs. Oxygen can lead to stress corrosion cracking of the tank wall steel.

After the leak checking is complete, depressurize the tank in the same manner as before.

The tank is now ready for the reintroduction of ammonia into the tank. This is done in the following manner.

6. Reintroduction of Ammonia Into an Ammonia Storage Tank

a. Check Closed Tank Manual Outlet Valve
b. Check Closed Tank Manual Recirculation Inlet Valve
c. Check Closed Tank Manual Liquid Inlet Valve
d. Check Closed Tank Vent Valve
e. Check Closed Manual Vapor Valve at Rail Unloading Station
f. Check Closed Emergency Ammonia Block Valve on Vapor Line at Rail Unloading Station
g. Check Closed Manual Vapor Valve at Truck Unloading Station
h. Check Closed Emergency Ammonia Block Valve on Vapor Line at Truck Unloading Station
i. Open Tank Manual Vapor Inlet Valve
j. Open Tank Automatic Vapor Inlet Valve
k. (If transferring between the #3 or #4 Ammonia Storage Tank and the #1 or #2 Ammonia Storage Tank) Open Tie Valve on Vapor Line
l. Open Tank Automatic Vapor Inlet Valve on the tank that ammonia will be transferred out of
m. Slowly Open Tank Manual Vapor Inlet Valve on the tank that ammonia will be transferred out of. There is an excess flow valve on each tank involved, so too rapid a transfer will slam closed one or both of these valves. The pressure in the ammonia filled tank will force ammonia vapor into the empty tank.
n. Once the pressure has equalized between the two tanks, Close Tank Manual Vapor Inlet Valve on the tank that ammonia was transferred out of.
o. Close Tank Automatic Vapor Inlet Valve on the tank out of which the ammonia was transferred
p. Close Tank Manual Vapor Inlet Valve
q. Close Tank Automatic Vapor Inlet Valve
r. The tank can now be vented to remove any nitrogen remaining in the tank. To do this, use the Depressurization Procedure #5. Vent the tank a sufficient time to displace any nitrogen in the tank.

The tank is now ready for all the valves to be returned to their normal positions. The tank can be refilled in the normal manner from a truck or rail car. Once refilled, the tank can return to normal service.

CHAPTER 11 - SCR YEAR-ROUND OPERATION

Year-round operation of NOx reduction technology is required as of January 1, 2009 by the Clean Air Interstate Rule (CAIR), which ruling was previously vacated by the Supreme Court in July 2008 citing "more than several fatal flaws". In a decision applauded by environmentalists, the U.S. Court of Appeals for the D.C. Circuit issued an order on December 23, 2008 that leaves the Clean Air Interstate Rule in effect while the U.S. Environmental Protection Agency develops a new clean air program for power plants. The court essentially reversed its previous ruling made in July 2008, thereby sending CAIR back to the EPA for retooling.

This chapter will discuss some of the issues related to converting from seasonal to year-round operation.

11.1 SCR Year-Round Operation Issues

The most obvious change if SCR operations change from seasonal to year round is that the SCR will be in service 2.4 times as many hours in a year. This means that the SCR will consume 2.4 times more ammonia per year which will make chemical costs 2.4 times more. It also means that catalyst "end of life" will be reached 2.4 times faster on the calendar.

The less obvious impact will be felt in catalyst management plans and maintenance planning. Currently catalyst inspection, sampling, cleaning and replacement are carried out during the seasonal SCR outage. Now inspection and sampling will have to be done during short planned outages or any unplanned outages that may occur. Catalyst cleaning or replacement will have to be scheduled during longer planned unit outages that may occur only every few years. This makes the job of predicting catalyst "end of life" much more critical. If the catalyst should plug or deactivate more quickly than predicted, an undesirable longer forced outage will be needed to correct the situation.

Inspection and repair of ammonia feed system equipment will be more difficult. At a single unit site, these activities will have to occur during unit outages. At a multi unit site, parts of the ammonia feed system will need to remain in service for the operating units even though one unit may be having an outage. Changes to current ammonia storage area designs may need to be done to address these situations.

And of course in the northern states, SCR system components will have to operate during the coldest months of the year. Additional heat tracing and insulation may be required at certain locations within the SCR system.

One thing that will improve is that one won't need to worry about keeping the SCR reactors and catalyst beds warmed above the dew point during the seven month idle period to prevent catalyst poisoning.

11.2 SCR-AIG Tuning During Year-Round Operation

Tuning of the ammonia injection grid still needs to be done at least annually. Many utilities choose to do it more frequently.

One complication occurs because now one doesn't have the luxury of inspecting the sampling grid during the off season. One should use the methods described in Chapter 8.1.a. to prepare and test the sampling grid before tuning.

The other complication is that due to emission limits, one will not be able to turn off the ammonia feed to get the inlet NOx baseline data or run the ammonia feed at 50% during the tuning runs. So one won't be able to map the inlet NOx distribution deviation across the catalyst bed or calculate the NH_3/NOx distribution ratio for each point.

Most utilities have adopted the strategy of just measuring the outlet NOx at each sampling grid point, and then adjusting the ammonia feed valves to obtain the most uniform outlet NOx profile possible.

CHAPTER 12 - SCR BALANCE-OF-PLANT EFFECTS

The addition of a SCR system to a unit can have several effects on the existing equipment. The biggest effects occur in the air heater. But other smaller effects can occur also.

12.1 SCR Balance-of-Plant Effects

Air Heater

A SCR will convert some of the SO_2 in the flue gas to SO_3. These increased levels of SO_3 increase the amount of sulfuric acid that can form on cooler air heater surfaces. There is also the potential for "ammonia slip" from the SCR catalyst. The ammonia slip gradually increases as the catalyst ages. This ammonia can react with the sulfuric acid to form ammonium bisulfate (ABS) and ammonium sulfate.

The sulfuric acid can be very corrosive and dissolve air heater baskets and structures. The ABS forms sticky deposits on the air heater surfaces. These sticky deposits can then attract fly ash particles. This results in air heater basket pluggage and high differential pressure drop across the air heater.

Typical plates in air heater baskets are bare carbon steel. Because of the higher sulfuric acid levels, some utilities have chosen to use coated steel plates that are resistant to the acid. They typically use enameled plates. These plates are heavier and thicker than normal plates. So, they create both physical design and heat exchange property issues in the basket design. If the enamel coating becomes cracked or broken off, the plates are still exposed to the effects of the corrosive acid.

A typical air heater design has three layers of baskets (cold end layer, intermediate layer and hot end layer). There is a gap between each layer. If one is sootblowing the baskets from either the hot end side or the cold end side, the blowing media is dispersed and loses some of its energy as it crosses the gap into the intermediate layer. Because of this, the intermediate layer isn't cleaned as thoroughly. Any material that is dislodged from the intermediate layer can also accumulate in these gaps.

The temperature profile in an air heater is such that ABS deposits will form on both the intermediate and cold end layers. Because of the sootblowing issue, many utilities have chosen to redesign the air heaters with the intermediate and cold end layers being combined into a single deep layer so there is no gap where the ABS deposits form. This provides full sootblowing energy across the entire ABS deposit.

Many utilities have also converted to "multi-media sootblowers" that can blow with several different media such as air, steam, or water. As the ammonia slip increases from the catalyst, one needs to keep a close eye on the air heater differential pressure drop and use the sootblowing system more often to prevent the deposits from becoming too large and plugging the air heater basket flow channels.

Ammonia on Ash

Any ammonia slip from the SCR catalyst will adsorb onto the fly ash particles. This normally doesn't cause any problems with the ash handling characteristics. It can be a problem, however, if one is selling the fly ash. Depending on what the ash is being used for, the buyer may place a limit on how much ammonia can be present on the ash.

The potential loss of ash sales may influence the decisions on how often one balances the AIG to optimize the NH_3/NOx ratio across the catalyst bed, how often catalyst samples are removed for activity testing, and how high the ammonia slip can be allowed to go before catalyst is added or replaced.

Ammonia in Water

If the fly ash is disposed of in ash ponds, the ammonia adsorbed on the ash will dissolve in the pond water. This dissolved ammonia concentration can lead to NPDES discharge limit concerns if the concentration is high enough. The nitrogen from the ammonia in the water can also fertilize any algae growing in the pond.

Low Load Restrictions

At lower boiler loads, the SCR inlet temperature may drop below the minimum ammonia feed temperature limit. If an economizer bypass system is designed into the SCR system, the dampers can open to maintain the temperature. If the utility decides not to spend the money to install an economizer bypass system, there may be limits placed on how low the boiler load can go for extended periods of time. This will effect how the unit can be dispatched in the utility system.

Precipitator Structural Upgrades

There is a pressure drop across the SCR system. Since the SCR is ahead of the precipitator, the normal operating pressure in the precipitator will now be more negative. If the precipitator box was not designed for this lower pressure, or if corrosion issues have weakened the precipitator box, structural upgrades will be required to the precipitator to withstand these greater negative pressures when the SCR system is added to the system.

Induced Draft Fan Upgrades

There is a pressure drop across the SCR system. If the ID Fans are not capable of providing the negative draft to overcome this additional pressure drop, the ID Fans will need to be upgraded.

CHAPTER 13 - SCR TROUBLESHOOTING

This chapter discusses techniques for troubleshooting SCR problems including using the Data Acquistion Systems for performance monitoring and troubleshooting.

13.1 SCR Troubleshooting

If a problem develops, one of the first places to look is the data acquisition system for the DCS control system. (Refer to the Using Data Acquisition Systems for Performance Monitoring and Troubleshooting section of this chapter) One needs to determine whether the trouble is a result of a sudden event or a long term trend.

The sudden events are typically caused by a control system or other equipment malfunction or failure. These are much easier to find and correct in a short period of time.

The long term trends can be caused by:

- Catalyst plugging
- Catalyst fouling or poisoning
- Temperature or flow imbalances in the ducts or the SCR reactors
- NH_3/NOx ratio imbalance

These types of problems will require a longer term investigation to determine the cause and the solution. Unit outages may be required to inspect SCR internals and obtain catalyst samples. Sampling traverses may need to be made across ducts or SCR Reactors. The AIG may need to be balanced.

Low NOx Removal

Low ammonia feed rate or a NOx analyzer drifting out of calibration can cause the calculated NOx removal value on the control indication to read low. Some items that should be checked include:

1) Are the ammonia feed valves opened to their normal position for the unit load and the inlet NOx value?

2) Are the ammonia vaporizers' temperatures and pressures normal?

3) Has the inlet or outlet NOx analyzer values changed significantly from where they normally run?

- If the inlet NOx value is different, has something changed in how the boiler is being fired or is the analyzer out of calibration or not receiving proper sample flow?
- If the outlet NOx value is different, is the analyzer out of calibration or not receiving proper sample flow?

4) Has the unit outlet NOx value measured by the CEM increased over time?

5) Are all of the ammonia feed adjusting valves on the AIGs still in the positions they were set at during the last AIG tuning?

6) Has there been a sudden increase in catalyst bed pressure differential that would indicate ash pluggage of the catalyst flow channels?

- Are the SCR sootblowing systems working properly?
- Does increased sootblowing improve the differential pressure?

If the loss of removal has occurred gradually over a longer period of time, some items that should be checked include:

1) Has the SCR inlet temperatures been low for a significant time which could have lead to ammonium bisulfate fouling of the catalyst surface?

- If the temperatures have been low, run with the SCR inlet temperatures as high as possible for 3 - 4 times the number of hours that they have been low. This may break down the fouling layer.

2) Has there been a gradual increase in catalyst bed differential pressure that would indicate ash pluggage of the catalyst flow channels?

- Are the SCR sootblowing systems working properly?
- Does increased sootblowing improve the differential pressure?
- Do an inspection of the catalyst layers as described in the SCR Inspection chapter to determine the percentage of plugged flow channels?
- If the unit is equipped with LPA screens, inspect them for erosion damage?

3) Inspect the AIG looking for nozzle pluggage or other abnormalities.

- One may want to perform an AIG tuning to confirm that the NH_3/NOx ratios across the catalyst cross section have not changed.

4) Remove catalyst samples from several locations in each layer

- Have them analyzed for catalyst activity.
- Have them analyzed for any signs of catalyst poisoning.

5) Inspect the catalyst layer baffles and seals to assure that no flue gas is passing around instead of through the catalyst modules

Catalyst Pluggage

If one finds the catalyst flow channels plugged with ash, one needs to investigate the cause:

1) Was the soot blowing system functioning properly?

2) Was the soot blowing system used as often as necessary?

3) Has large particulate ash (LPA) plugged the catalyst?

- One sign of this is that most of the pluggage occurs in the first several rows of catalyst directly under the flue gas inlet to the SCR reactor.

4) Does the unit have LPA screens installed?

- If yes, are the screens in good repair?
- If no, are there signs of large heavy ash particles on the floors of the ducts?

5) Have the SCR inlet temperatures been low which may have caused the formation of ammonium bisulfate on the catalyst surface?

- This deposit can be sticky and will attract ash deposits on top of it.

6) Are there large piles of ash on the back side of turning vanes or in corners of the ducts that could have moved into the SCR reactor all at once?

- If yes, a review of flow modeling design and actual measured gas flows may be needed to determine the cause of these deposits.

7) Has there been a boiler economizer leak that allowed large amounts of water to enter the SCR inlet ducts?

- In cases where this has happened, the resulting wet ash has contacted the hot catalyst which bakes the moisture out of the ash and a crusty hard ash deposit has been left in the catalyst flow channels.

The ash deposits will have to be removed. This is not a simple or an inexpensive task.

1) In Europe, some utilities have cleaned out the flow channels in honeycomb catalyst by pushing stiff wires through the flow channels.

- This is very slow and labor intensive
- It is easy for the wire to be deflected by a heavy ash deposit and poke through the flow channel wall destroying it
- This will be very expensive at U.S.A. labor rates.

2) Pressurized air, vacuum, or a combination of both can be used to dislodge the ash.

- It is most effective if the pressurized air is applied to one face of the catalyst while the vacuum is applied to the other face of the catalyst
- The challenge is for the persons on both sides of the catalyst to move together so they are both working on the same section of the catalyst at the same time
- This work will create a very dusty dirty environment for the workers, proper respiratory protection will be required
- It is very easy to mechanically damage the catalyst faces if the cleaning equipment makes direct contact with the catalyst surface.

3) Plate catalyst is less susceptible to mechanical damage than honeycomb catalyst.

4) There are providers who can wash the catalyst layer "in-situ":

- Collection trays are located beneath the catalyst layer
- Hoses, pumps, and nozzles recirculate the wash solution from the collection trays to the top of the catalyst layer and down through the catalyst flow channels
- This method has had various success depending on the type of pluggage encountered.

5) The are providers who can wash the catalyst layer "ex-situ" (removed from the SCR reactor).

- There is a large amount of labor required to remove and reinstall the catalyst modules
- Some providers can wash the catalyst "on site"
- Some providers require that the catalyst be shipped to their washing location
- Both methods have shown that they can remove the majority of the deposits, even if they are caused by LPA
- Due to the time for the washing process, some utilities have purchased a spare catalyst layer so the catalyst can be immediately replaced and the SCR placed back in service, then the dirty catalyst can be washed at a more leisurely (less overtime cost) pace and placed back into storage as the next spare layer

Ash Build-up or Temperature Differentials in Ducts

One needs to obtain the original flow model design information and compare the actual gas flows and boiler exit temperatures with the design conditions. If there are significant variations, one needs to investigate the cause for the differences. If the conditions are per design, one should:

1) Inspect turning vanes or delta wings for structural integrity and proper placement per the flow model design.

2) Run flow traverses across ducts and the SCR reactor to identify where the differences are from the flow model design.

3) Use the new data to remodel the flow and design the changes needed to turning vanes or delta wings.

Liquid Ammonia Flow Problems

Vapor Lock

Some utilities have experienced temporary flow restrictions in liquid ammonia headers going to ammonia vaporizers. These flow restrictions can limit the amount of ammonia that is available to feed the AIG.

The problem has typically occurred in systems where:

1) The ammonia storage location is a long distance from the vaporizer skids.

2) The ammonia storage vessels are shaded with a roof.

3) The liquid ammonia header has a tortuous routing with several changes in elevation which causes one or more high points (inverted U shaped loops) in the header.

4) Some or all of the header is not insulated.

5) Some of the header may be in direct sunlight while other sections are in shade.

Because much of the ammonia system is insulated or in the shade, the header pressure is lower due to the liquid ammonia's temperature. When the liquid ammonia flows through a section of sunlight heated piping, the temperature may be high enough to cause some of the ammonia to boil off into gas at the header pressure. This ammonia gas can collect in any high spots causing the ammonia header to "vapor lock". This condition can continue until the ammonia gas cools and condenses or the header pressure is raised above the gas's boiling pressure.

The utilities that have experienced this have:

1) Insulated or shaded all of the liquid ammonia header.

2) Rerouted the piping to eliminate or minimize high spots in the piping.

Frozen Plug

Another problem can occur if there is a sudden large flow increase and a resulting sudden large pressure drop in the liquid ammonia header. If the pressure drops low enough, the liquid ammonia can boil off in the header. As it boils, it removes heat from the header. If the header is insulated, heat from the surroundings cannot enter the header. There have been cases where a frozen plug has formed in the header blocking flow. Once this happens, one must wait for the header to warm up and melt the plug. This can be a slow process with an insulated header.

The best way to avoid this problem is:

1) Use the ammonia forwarding pumps so there is a higher pressure maintained in the liquid ammonia feed header

2) Limit the speed at which one opens the ammonia feed valves when starting the SCR system.

13.2 Using Data Acquisition Systems for Performance Monitoring and Troubleshooting

The modern DCS control systems look at thousands of data points every several seconds. All the data is stored in the system or archived off line. The nice thing is that all these data points are available electronically. There are software vendors that have systems to access these points and present the data in graphical format.

One can use this data for both performance monitoring and problem troubleshooting. The problem with the control board screens is that they show an instantaneous "snapshot" of what is happening at that instant. With the graphical programs, one can look back into time to see what happened over any time range desired. This allows one to see trends over long time periods or to "zoom" in on a specific time when many things were happening so quickly that one couldn't see everything. One can determine what happened first, second, etc. that led to the final outcome.

Most software allows one to build screens and then save them. Each time the screen is opened, it repopulates the graphs with the latest specified values in the specified time period. This can be extremely helpful to a SCR operator. Screens such as these can be developed for a 24 hour time period:

- SCR Reactor ammonia feed rate, inlet NOx, outlet NOx and boiler load
- Catalyst bed differential pressure and catalyst layer differential pressure
- SCR Reactor inlet temperatures and outlet temperatures
- Ammonia vaporizer temperature, pressure and dilution air temperature
- Ammonia storage tank levels
- Hydrolyzer temperatures and pressures (if it is a urea based system)
- Air heater differential pressures and boiler load
- Ammonia slip (if one has an ammonia slip monitor)

If an operator looks at this type of data at the beginning of the shift, he/she has a better idea of how the process has been running for the last 24 hours and what can be expected on his/her shift.

NOx TRAINING MANUAL

START VIDEO

RE Consulting

SCR O&M

Ronald L Richard
Senior Consultant
RE Consulting

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Using Data Acquistion Systems for Performance Monitoring and Troubleshooting

(Narrated by Ron Richard, RE Consulting)

Such information can also be helpful if things start changing on the control board screens. A quick check of the graphical screens can help identify what is changing in the process that is causing the controls to respond.

If a problem occurs, these systems greatly aid the problem solving process. On the long range basis, one can look back days, weeks, or months to see what was happening that led up to the problem. Different data points can be placed on the same graph to see if there was any interaction or correlation that led to the problem. Different theories can be explored by plotting different data on the same graph.

Once the probable solution is determined, graphs can be developed that alow one to track the progress of the solution as it occurs (or doesn't occur if the right solution wasn't chosen). These graphs may be plotted on a one hour or a 15 minute time scale so any changes will be apparent more quickly.

The other helpful tool is to "zoom" in on a problem. If several things happened at about the same time, one can plot the data on a 10 minute or one minute time scale. By placing all the data points in question on the same graph, it is easier to resolve which event happened first and follow the chain of events as it unfolds.

The actual use of such systems will be dependant on the software package and the control system data points available in each particular SCR system. The usefulness of these systems is limited mostly by the imagination and the understanding of the person selecting which points to display over which time scale to determine what is actually happening that is causing the problem. There can be a lot of trial and error to find the right combination of data points that shows what is really happening.

CHAPTER 14 - SNCR CHEMISTRY, THEORY AND APPLICABILITY

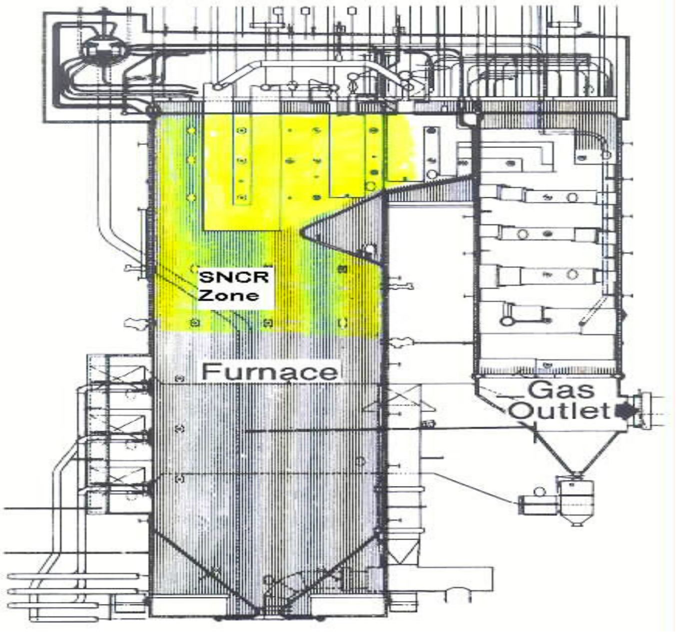
SNCR stands for Selective Non Catalytic Reduction. This chapter discusses the basic chemistry and theory for SNCR's as well as a brief description of the SNCR/SCR hybrid technology.

14.1 SNCR Chemistry, Theory and Applicability

SNCR stands for Selective Non Catalytic Reduction of NOx to nitrogen (N_2) and water vapor (H_2O) through the selective reaction of NOx with ammonia (NH_3) and oxygen (O_2) at the proper temperature. NOx is mostly nitric oxide (NO) along with a small amount of nitrogen dioxide (NO_2). The reaction is:

- $4NO + 4NH_3 + O_2 \Rightarrow 4N_2 + 6H_2O$

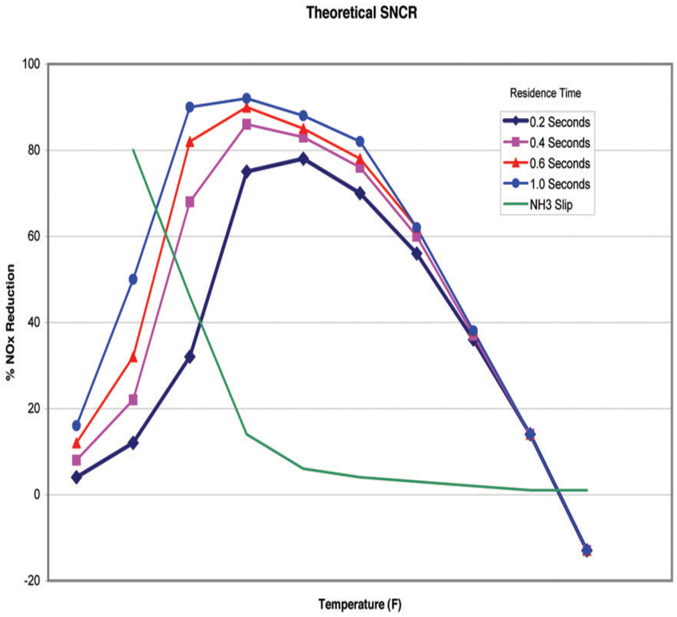
This is done in the radiant heat zone above the burners in the boiler. See **Figure:**



SNCR Zone

Since there is no additional ductwork, reactor vessels or catalyst, an SNCR is significantly less expensive than an SCR. Its main weakness is that it cannot obtain as high a percentage of NOx removal as an SCR can achieve.

The theory of operation is very simple. At a temperature in the range of 1600 degrees F - 2200 degrees F, any ammonia present will selectively react with the NOx in the presence of oxygen (O_2) converting it to nitrogen and water. See **Figure:**



Temperature Removal Relationship

Of course, nothing in real life is as simple as the theory. The area in a boiler that falls within this temperature window is fairly narrow in its vertical dimension and tends to move up and down in the boiler as the boiler load changes.

It is difficult to inject the ammonia evenly and completely across the cross section of the boiler. In areas where the ammonia concentration is low or the temperature is incorrect, some NOx will remain. In areas where the ammonia concentration is high, the NOx will be removed but residual ammonia will "slip" with the gas exiting the boiler causing problems in the downstream equipment. As the boilers become larger in cross section, this difficulty in uniformly injecting the ammonia causes the percentage of NOx removal possible to become less. This is why SNCRs are found mostly on small to medium sized boilers.

Due to the safety concerns storing and handling ammonia, many SNCR systems use a solution of urea ($(NH_2)_2CO$) as the chemical injected. The urea decomposes as it enters the boiler producing the ammonia needed for NOx removal. The decomposition reaction is:

- $(NH_2)_2CO \Rightarrow NH_3 + NHCO$

Several reactions then take place simultaneously that result in the NOx removal.

- $NH_3 + OH \Rightarrow NH_2 + H_2O$
- $NHCO + H \Rightarrow NH_2 + CO$
- $NHCO + OH \Rightarrow NCO + H_2O$
- $NH_2 + NO \Rightarrow N_2 + H_2O$
- $NCO + NO \Rightarrow N_2O + CO$

Notice that the last reaction forms nitrous oxide (N_2O) which will be released from the chimney. Notice also that carbon monoxide (CO) emissions (or CO_2 if it reacts with oxygen) will be increased if urea is used as the source of ammonia. Ammonia "slip" is still a concern when using the urea solution.

At the higher end of the temperature range, some of the NH_3 can react with O_2 to form NO which reduces the overall NOx removal percentage. The rate of this unwanted reaction increases as the concentration of CO increases.

In practice, an SNCR can achieve a 30 to 60% reduction of NOx depending on all the above variables and how they interact in any given boiler. The critical process parameters that determine SNCR performance are:

- Residence Time
- Temperature
- Baseline NOx
- CO concentration in the injection region
- Fuel Sulfur
- Reagent Distribution

SNCR/SCR HYBRID

Some vendors are offering a hybrid system where an SNCR is installed in the boiler followed by a traditional SCR system after the boiler. They are claiming cost savings and operational benefits because:

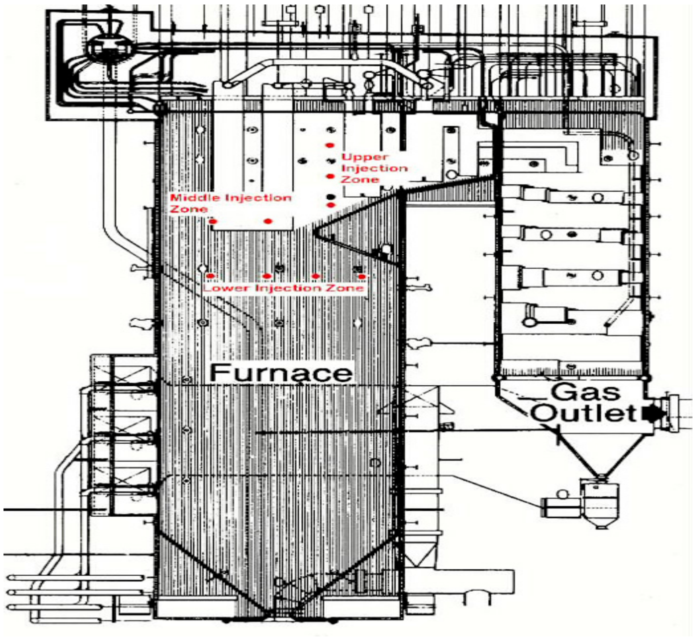
- The SNCR can be operated in the lower temperature range making the urea utilization more effective since the higher temperature doesn't oxidize some of the urea to NO. This results in a higher NOx removal percentage but tends to cause more ammonia "slip". This "slip" is not a problem, however, since the ammonia will be consumed in the SCR and will not cause problems with downstream equipment.
- A smaller SCR can be added to the system since the NOx inlet loading is less. This reduces the SCR capital cost while still providing the high NOx removal capabilities of an SCR.
- The smaller amount of SCR catalyst reduces the amount of SO2 that is converted to SO3 by the SCR.
- The hybrid system can provide low NOx emission levels even at low boiler loads.
- The hybrid system provides greater operational flexibility in meeting seasonal NOx emission limits.

CHAPTER 15 - SNCR SYSTEM DESIGN

15.1 SNCR Injection Grid

Undoubtedly the most important item in designing a SNCR system that will obtain good NOx removal is the placement of the injectors and lances.

- If the chemicals are injected in an area that has a low temperature, the NOx removal will be low and the ammonia slip will be high.
- If the chemicals are injected in an area that has a high temperature, the NOx removal will be lower or may be nonexistent as much of the ammonia will be oxidized creating NOx.
- If the chemicals are injected in an area with the proper temperature, the NOx removal will be high and the ammonia slip will be low.



Even if the temperatures are correct, if the chemicals are not injected uniformly across the entire cross section of the boiler:

- The areas with low chemical concentration will have low NOx removal.
- The areas with high chemical concentrations will have high NOx removal, but there will also be high ammonia slip due to the excess unreacted ammonia.

The starting point of any SNCR design is to get an accurate set of temperature maps of the boiler interior. This can be done using any combination of existing boiler thermocouples, optical pyrometers, and thermocouple traverses. The complication arises because one wants as many data points as possible across the entire boiler cross section in both horizontal dimensions as well as in the vertical dimension. And of course there are only so many access doors through which one can obtain data.

Then there is the complication that this temperature mapping needs to be repeated for each of the load settings that the boiler typically operates at. One finds that as the boiler load increases, the narrow 1600 degrees F - 2200 degrees F operating zone shifts upwards into the boiler nose and slope area.

The next step is to collect some boiler gas flow information such as gas velocity and direction at numerous points across the boiler cross section similar to the temperature mapping effort. This data will be needed to calibrate the CFD boiler model that will be created to determine the location of the injection nozzles and lances.

One would like the chemicals to be in the proper temperature zone for at least 0.5 second to obtain higher NOx removal. This is more important at the lower end of the temperature zone. At the higher end of the temperature zone, the contact time is not as important. The turbulence and gas path in the boiler determines this contact time. The flow pattern in a single wall or opposed wall fired boiler will be different than in a tangentially fired boiler. Some experience in units with Rotating Opposed Fire Air (ROFA) has shown an improvement in SNCR performance due to the mixing of the chemicals and the longer reaction time due to the rotating pattern imparted on the boiler gas flow.

The next phase of the design becomes an iterative process where the injection grid designers place the injectors and lances where they think they will be the most effective at the various boiler loads and then the CFD modelers run the model to see how it looks. Then the designers look at the results and make placement adjustments and the modelers test the new design. This continues until the optimum solution is achieved. Of course this optimum solution is only as good as the temperature and gas flow data that was used to build and calibrate the CFD model.

The final design may be a compromise between the optimum CFD modeled solution and the physical reality of where injectors can be placed due to external boiler stiffeners, existing boiler penetrations, sootblower locations, and the location of pendant tube panels above the boiler slope.

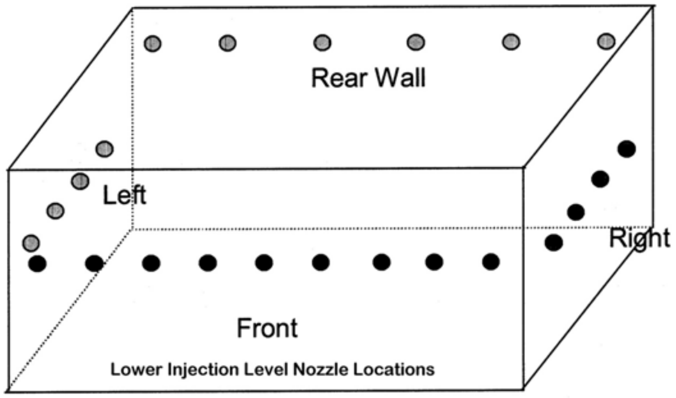
There are typically at least three levels of injectors or lances. See **Figure:**

SNCR Injection Zones

At low boiler loads, the temperature zone is at the lower two injection levels. At high boiler loads, the temperature zone is at the upper two injection levels. There may be some intermediate boiler loads where some injectors or lances in all three injection levels are in service as the temperature zone is moving upwards. These are the types of details that the CFD model will show.

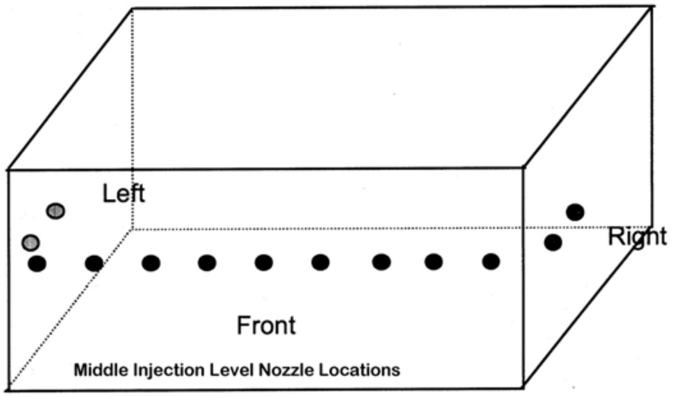
In the lower regions of the boiler, the injectors can be located on all four sides of the boiler. See **Figure:**

Lower Injection Level Nozzle Locations



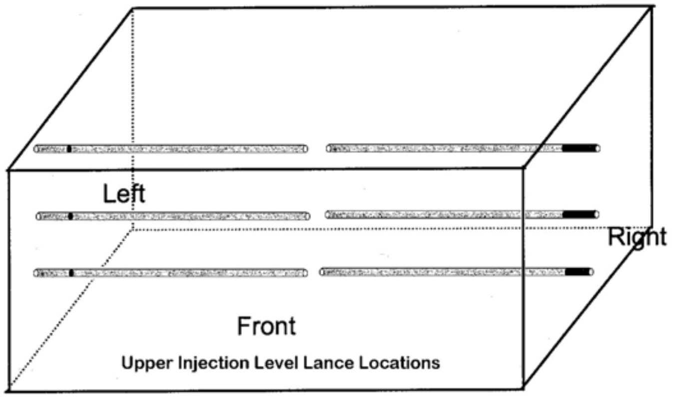
This helps in getting the chemicals injected evenly across the entire cross section. As the injection zone approaches the nose of the boiler, there is typically no access for injectors across the back wall of the boiler and sometimes not even across the entire side walls. See **Figure:**

Middle Injection Level Nozzle Locations



Above the nose where the flue gas is traveling in a more horizontal direction, multi-nozzle injection lances are sometimes used to obtain a more uniform injection pattern. See **Figure:**

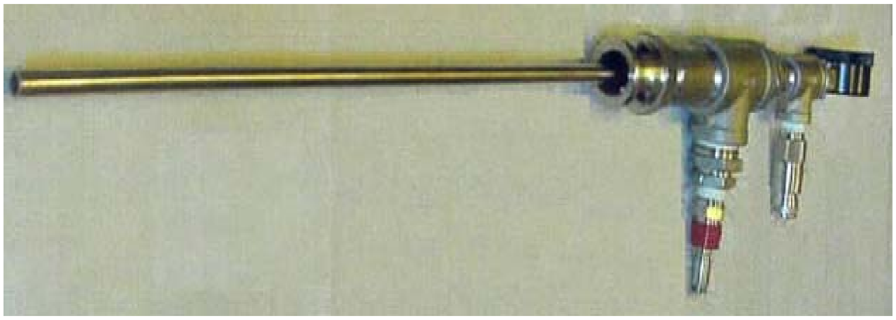
Upper Injection Level Nozzle Locations



The chemical being injected can be either gaseous ammonia or a liquid solution of ammonia or urea. The gaseous ammonia will react more quickly but it can be difficult to spray this chemical all the way into the center of the boiler. The droplets of the liquid solutions can be given more momentum to reach all the way into the center of the boiler. The disadvantage of the liquid solutions is that there is a slight delay before the water evaporates and the ammonia is released to react with the NOx. One needs to known which chemical is going to be used since it will affect injector placement and spray pattern.

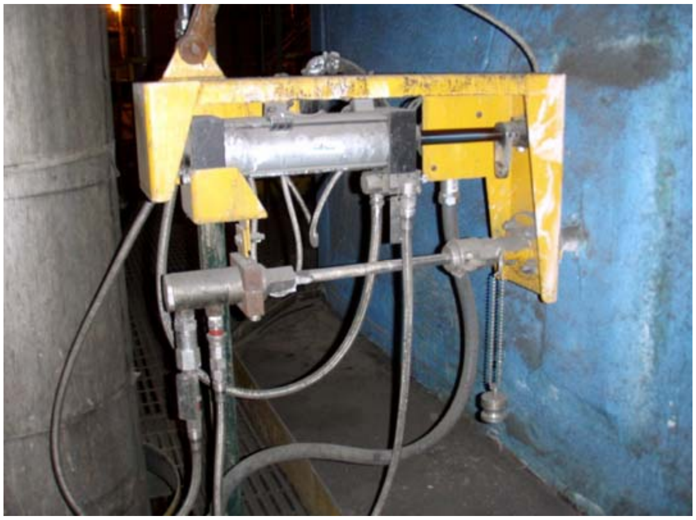
Wall Injectors

The injectors have a dual fluid nozzle. They are typically made of stainless steel to withstand the high boiler temperatures. They typically are mounted with a system to automatically withdraw the injector from the boiler when they are out of service. See **Figure:**



SNCR Retractable Injector

Air or steam is one of the fluids and is injected through the outer ring of the nozzle. The air or steam helps cool the injector as well as atomizing the chemical which is fed through the inner tube of the nozzle. See **Figure:**

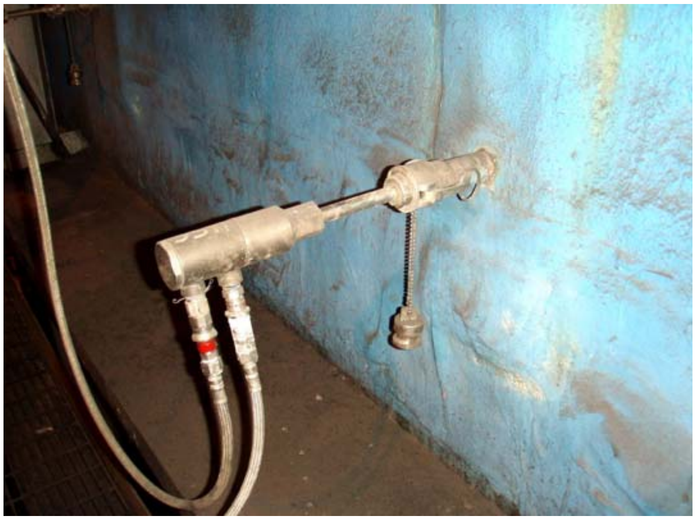


SNCR Fixed Injector

The spray pattern of the nozzle is relatively narrow since one is attempting to distribute the chemical a significant distance from the wall to provide ammonia from the wall to near the center of the boiler cavity.

Changes in the air or steam atomizing pressure will affect the chemical droplet size and how far they penetrate into the boiler.

Each injector typically can be shut off individually and each injector typically has a rotameter so the chemical flow can be adjusted to each nozzle to match the NOx profile present in the boiler.



Multi Nozzle Lances (MNL)

The multi nozzle lances are designed very similar to the retractable lance style soot blowers used on boilers. Since the lances will remain in the boiler for significant periods of time, they must be made of stainless steel and have some sort of fluid moving through the interior of the lance for cooling whenever it is inserted into the boiler. See **Figures:**

Multi Nozzle Lances

Some designs use steam to atomize the chemical and cool the lance. Other designs use a once through or recirculating flow of water or other cooling liquid through an interior jacket to cool the lance. There have been reports that over time, some lances have sagged making them more difficult (or impossible) to insert and remove from the boiler.

The lances have a series of chemical injection nozzles along their length to spread the chemical across the width of the boiler. These nozzles may be piped individually or in clusters to give one the ability to adjust the chemical feed to match the NOx profile across the left/right horizontal dimension of the boiler. Some lances can also be rotated to further adjust the spray pattern across the vertical dimension. In practice, most lance nozzles are piped together as a single cluster and the lance is not rotated.

15.2 SNCR Piping System

Pumping Area

If one is using anhydrous or aqueous ammonia, there will be ammonia forwarding pumps at the storage site that will pump the liquid ammonia directly to the SNCR area. This piping does not need to be insulated, but sometimes it is.

If one is using a urea solution, the concentration of the solution that is typically delivered causes it to require insulation, heat tracing and tank heaters to keep the solution from crystallizing. There is concern about liquid sitting in an idle pipe cooling and solidifying. Because of this there is typically a piping loop that goes from the urea solution circulating pumps, to the SNCR area, and then returns to the urea storage tank. See **Figure:**

Urea Solution Circulating Pump Skid

This piping is heat traced and insulated, and the urea solution is constantly circulated.

Chemical Preparation Area

Near the boiler there will be an area where the chemical is prepared for injection and routed through headers to the various injection locations on the boiler. There will likely be isolation valves and flow meters on the various headers to isolate and monitor the injection levels.

If one is using anhydrous ammonia, there will be a vaporizer to convert the liquid stream into ammonia gas. Depending on the design, there may be a small blower to mix heated dilution air with the ammonia gas to more evenly divide the volume among the various headers. Or, the ammonia gas may be routed directly to the headers.

If one is using aqueous ammonia, it can be split and routed directly to the various headers.

If one is using urea, the concentrated solution is typically diluted with water at this point to lower the concentration to a point where the piping no longer needs to be heat traced and insulated. See **Figure:**

Urea Solution Dilution Skid

There will be dilution water pumps, urea metering pumps, flow meters, control valves, and probably in-line mixers to produce the desired concentration of the solution and route it to the headers. See **Figure:**

Urea Metering and Dilution Water Pumps

Chemical Distribution Area

At each injection level, there will be one or more distribution areas where the chemical from the header is routed to each individual wall injector or MNL. There is typically a rotameter or some other device to adjust and meter the chemical flow to each individual wall injector or MNL. In this way the chemical injection can be tuned to match the NOX profile in the boiler.

There will be a small diameter chemical pipe from each metering device to its injection location. There will typically be a manual shut off valve at the injection end of the pipe. From this valve a flexible line will connect to the injector or lance. (For a lance with multiple independently adjustable nozzles, there may be several individual chemical pipes and flexible lines attached to one lance.) The flexible line is needed to allow the injector or lance to be inserted into and retracted from the boiler. See **Figure:**

Retractable Injector Piping

Air or Steam Piping

Since the injectors use dual fluid nozzles, there will be air or steam headers and smaller diameter air or steam pipes routed to each injection location. The small air or steam piping will also have a manual shut off valve on the injection end of it. From the valve a flexible line will attach to the injector or lance just like the chemical line.

Multi Nozzle Lance Cooling System

To keep the lances from overheating and sagging, they must be equipped with cooling systems.

If steam is being used as the atomizing fluid, the steam flow may be sufficient to cool the lance.

If air is being used as the atomizing fluid, some sort of liquid cooling through an internal jacket in the lance must be provided. This system may use water or a glycol solution. The details of this system will be site specific based on what is available at the location of the lances. It may be a once through system or a recirculating system with its own pumps and heat exchangers. The connections from this system to each lance must also be made with flexible lines since the lances are inserted and retracted.

15.3 SNCR Control and Measurement System

There are two primary items that are controlled when operating a SNCR system.

- Which levels of injectors or lances are in service
- How much chemical is being fed to reduce NOx

Levels in Service

During the original data collection and design, it is typically determined at what boiler load or boiler steam flow the furnace temperature window reaches the point where one should switch from the bottom and middle level of injectors being in service to the middle level injectors and the upper level injectors or lances being in service.

During the initial testing and tuning, the actual best point to make this transition will be determined. This boiler load or boiler steam flow is then entered into the control system. The controls will then activate the lower levels and deactivate the higher level below this point and activate the higher levels and deactivate the lower level above this point.

Most systems activate and deactivate an entire level of injectors or lances at a time instead of trying to remove individual injectors or lances in a level in smaller incremental boiler load or steam flow changes. Most systems have retractable injectors on the lowest level and retractable injectors or lances on the highest level since they will be out of service for long periods of time. Many systems have fixed injectors on the middle level since they will remain in service anytime the SNCR is in service.

If the boiler has an optical pyrometer or some other device installed to monitor the furnace temperature at a certain elevation, this data may be used to trim the control point so the transition is based on boiler load or steam flow and the temperature being in a specific range at that elevation. See **Figure:**

Optical Pyrometer

This can account for variations in fuel characteristics or burners in service which might change the temperature window at that elevation of the boiler at a certain load or steam flow.

Chemical Feed

The chemical feed must change in relation to how much NOx is present at the SNCR inlet and the amount of removal desired. What is typically done is to specify a "pounds per million BTU" NOx value that one wants to obtain at the outlet of the SNCR (if there is an analyzer installed there) or at the CEMS monitor on the chimney.

The chemical feed is increased if the outlet NOx is above the set point and is decreased if the outlet NOx is below the set point.

If one is using anhydrous or aqueous ammonia, the controls will typically send a signal to a chemical feed valve which will open/close to increase/decrease the chemical flow into the dual fluid injectors/lances where it will mix with the atomizing air or steam.

If one is using urea in a system which has dilution skids, the dilution water flow to the injectors/lances is typically kept constant. The controls will send a signal to the urea solution metering pumps to increase/decrease the amount of concentrated urea solution being blended with the dilution water. See **Figure:**

Urea Flow and Air Pressure Control Panel

Ammonia Slip

While the ammonia slip in the SNCR system is an important parameter determining the "balance of plant" effects, most units do not have any sort on ammonia slip monitor installed. SNCR operators have typically relied on the effects of the ammonia slip to determine if it is a problem. The typical indicators used are:

- The amount and severity of air heater pluggage
- The amount of ammonia that is present on the ash in the precipitator hoppers

If ammonia slip becomes a problem, one may have to settle for a slightly higher outlet NOx value to obtain a lower ammonia slip. The alternative is to perform a SNCR tuning to balance the ammonia profile across the boiler cross section in such a way as to obtain a uniform NOx outlet profile at the economizer outlet duct test ports. This will minimize the ammonia slip to the lowest value obtainable at that outlet NOx value.

15.4 SNCR Ammonia Systems

15.4.a. Urea Systems

Millions of tons of urea are produced every year. It is used mainly as an agricultural fertilizer. It is produced by reacting ammonia and carbon dioxide. Its chemical formula is (NH2)2CO. The resulting solution is sprayed into a drying tower where it forms small pellets called prills. These prills can be soft and fragile, so it is typically treated with formaldehyde to harden the prills.

It is a non hazardous material which has made it attractive to utilities as a source of ammonia. When it is heated, it will decompose and return to ammonia and carbon dioxide. In the utility SNCR systems, the amount of ammonia present at any given time is the small amount where the urea decomposes in the boiler. This has caused some utilities to choose (or be forced to use) this process as a way to minimize the potential for a hazardous ammonia release from their property.
The urea is typically delivered to the site as a solution of 50% or more by weight urea dissolved in water. See **Figure:**

Urea Solution Storage Tank

It is in a utilities best interest to assure that the urea solution supplier has a strainer on the line used to fill delivery trucks. There have been occasions where debris in the urea solution delivered has entered the utilities urea storage tank and caused continual pluggage of the urea circulating pump suction strainers taking the SNCR out of service until the suction strainers could be cleaned. See **Figure:**

Urea Solution Unloading Connection

This solution must be kept heated in storage and during pumping to the boiler to prevent urea crystal formation. Most facilities have a recirculating piping loop from the storage tank to the boiler area and then back to the storage tank. This prevents the solution from "dead heading" in the supply header and cooling off. The urea solution for injection is then drawn from the recirculating loop near the boiler injection location. See **Figure**:

Urea Solution Circulating Pump Skid

The heating of the solution is normally done with heat tracing of insulated tanks, pumps and piping.

If one is planning to prepare urea solution on site from urea prills, read the urea section in the SCR portion of this manual.

15.4.b. Anhydrous Ammonia Systems

The typical anhydrous ammonia system consists of a storage area, forwarding pumps, and vaporizers which deliver ammonia gas to the SNCR injectors or lances.

Storage Area

Since anhydrous ammonia handling and storage are highly regulated, all ammonia storage areas are very similar in design. The number and size of the pressurized storage vessels will be dependent on the daily ammonia consumption of all the SNCR systems at the site. The amount of storage capacity will be determined by how much can be delivered in a day and how many days per week the utility wants to have unloading personnel on site. Then there is the risk factor that one must include for delivery interruptions due to weather, equipment breakdowns, etc.

If there are multiple storage vessels, typically only one is discharging liquid ammonia at a time with the others valved out on standby. There are typically permissives that will not allow valves to open on a vessel if similar valves on another vessel are already open performing the same task. The pressure in a storage vessel is determined by the temperature of the vessel wall and how fast the ammonia is withdrawn from the vessel. Liquid ammonia is withdrawn from the bottom of the vessel. As the level decreases in the vessel, some of the ammonia will boil off to fill the gas space above the liquid. This boiling may cool the ammonia slightly. There are multiple pressure relief valves on each storage vessel to assure that the pressure does not exceed the design pressure of the vessel.

There are four main valved connections on each storage vessel.

- Gas fill pipe
- Liquid fill pipe
- Liquid recirculation pipe
- Liquid discharge pipe

There are typically two ammonia compressors in the storage area. The compressors are used to transfer liquid ammonia between storage vessels or delivery vehicles. To transfer ammonia, a compressor is connected to take suction from the gas fill pipe on the vessel that will receive the ammonia and pump it into the gas fill pipe on the vessel that will be delivering ammonia. The difference in pressure that this creates will cause the liquid ammonia to flow into the receiving vessel.

There may be a rail unloading station and a truck unloading station for each storage area. They are both designed the same, but the rail unloading station will have larger diameter liquid ammonia piping. There are swing arms with swivel couplings that allow piping to be connected to the gas and liquid connections on the delivery vehicle. The proper valves are opened to the receiving tank and a compressor is used to move the liquid ammonia from the delivery vehicle to the storage vessel. There are level detectors on the storage vessel that will automatically close the liquid fill valve if the vessel level reaches the maximum storage level. This is done to prevent the storage vessel from over pressurizing if the ambient temperature increases.

There is typically a nitrogen supply skid in the storage area. This nitrogen supplies the pressure needed to open some of the unloading valves at the rail and truck unloading stations. If the ambient ammonia sensors detect a leak or the person doing the unloading hits an "emergency stop" button, the nitrogen pressure is released and the unloading valves slam closed. The nitrogen is also used to purge and vent the unloading connections before they are disconnected. This prevents the person who is disconnecting the piping from getting a face full of ammonia when the connections are separated.

Forwarding Pumps

There are two or more specialized liquid ammonia pumps located in the storage area. These forwarding pumps are used to provide the necessary pressure to move the liquid ammonia from the storage area (which is often in a remote area of the utility site) through the piping to the vaporizers. During the warmer months, there may be sufficient pressure in the storage vessel to push the liquid ammonia to the vaporizers with the forwarding pumps bypassed and out of service.

There is an automatic recycle valve on the discharge of the forwarding pumps. As the demand for ammonia feed decreases at the SNCR, this valve will sense the forwarding pump discharge pressure or flow rate and open to recycle liquid ammonia through the ammonia recycle pipe to the storage vessel in service and limit the pressure on the header to the vaporizers.

Some utilities have experienced a problem in the piping from the forwarding pumps to the vaporizers. If the routing of this pipe includes both underground or shaded areas as well as piping exposed to hot sunny conditions, it is possible to experience some flashing of the liquid ammonia to vapor in the hotter sections if there are pressure swings in the piping. This can cause a vapor lock in the piping especially if there are high spots in the piping run that can trap and hold the gas bubble. This can persist until the ammonia cools off or the pressure increases to return the ammonia gas to its liquid state.

Vaporizers

One or more vaporizers will be located near each SNCR system. The purpose of a vaporizer is to convert all of the liquid ammonia to ammonia gas by heating the liquid ammonia to a temperature higher than its boiling point.

The source of heat may be electric, steam, or hot fluid depending on what is available at the most reasonable cost at that location. The heat source is on one side of the heat transfer surfaces and the liquid ammonia is on the other side. The vaporizer controls are designed to maintain a constant temperature in the vaporizer. As ammonia feed rate to the SNCR increases, more liquid ammonia flows into the vaporizer lowering its temperature. The controls then increase the heat source to maintain the set point temperature. As ammonia feed rate to the SNCR decreases, less liquid ammonia flows into the vaporizer allowing its temperature to rise. The controls then decrease the heat source to maintain the set point temperature.

15.4.c. Aqueous Ammonia Systems

An aqueous ammonia system is very similar to an anhydrous ammonia system. The differences are related to two main differences between aqueous ammonia and anhydrous ammonia. The aqueous ammonia is 70 - 90% water. This means that:

- A much greater volume of aqueous ammonia is going to be delivered, stored and vaporized at the utility site.
- The vapor pressure of the aqueous ammonia at typical ambient storage temperatures is low enough that safety concerns are much lower and vapor recovery is not a large issue when transferring the material.

Storage Area

Typically the aqueous ammonia will be stored in the same type of storage vessels as the anhydrous ammonia. It can, however, be stored in vertical tanks. The pressure in the vessels or tanks will be very low and does not change much with temperature changes, so there is not a need for as many pressure relief valves. The vessels will either be larger or more numerous since one needs 4 - 6 times the storage capacity than an equivalent sized anhydrous system. Utilities that have designed for anhydrous ammonia and then have been forced to convert to aqueous ammonia have had to retrofit the site with more storage vessels. Material delivery and unloading is a much greater issue and one of the factors that make aqueous ammonia more expensive to use than anhydrous ammonia.

Since vapor recovery is not an issue compressors may not be needed. Compressors can be used to unload delivery vehicles, but pumps can be used instead. There may also be a nitrogen supply skid since some utilities prefer to keep a nitrogen cap in their storage vessels. Some sort of cap will be needed since the ammonia vapor pressure is so low that the pressure above the liquid could become quite low as one withdraws the liquid from storage.

Forwarding Pumps

The forwarding pumps and piping from the storage area to the vaporizers (or directly to the SNCR injectors and lances) will need to be larger since one is pumping much higher volumes of liquid. Since there is very little vapor pressure in the storage vessels, the forwarding pumps will always be needed to move the aqueous ammonia to the vaporizers or SNCR.

Liquid Aqueous Ammonia Injection

Most SNCR installations have been designed to directly inject the aqueous ammonia liquid directly into the boiler. The advantage is that the vaporizers are no longer needed. The disadvantage is that there is a slight time delay at the injection points as the liquid stream evaporates and the ammonia is released. Some utilities have found this time delay to be an advantage because it makes it easier to project the ammonia towards the center of the boiler before it is released and consumed.

Vaporizers

If one is using ammonia gas, the vaporizers will be installed ahead of the SNCR injectors and lances.

The vaporizers will be much larger. They will also have to operate at a much higher temperature since they must boil all the water that is contained in the aqueous ammonia. This means they will typically be steam or electrically heated. This required heat consumption is the other factor that makes using aqueous ammonia more expensive than anhydrous ammonia.

The utilities that were forced to convert their design from anhydrous ammonia to aqueous ammonia had to scrap the original vaporizers and install new units. The size of the new units made it very difficult to place them in the same area as the original vaporizers.

Some utilities have learned the hard way that there can be differences between aqueous ammonia suppliers. Aqueous ammonia is made by adding anhydrous ammonia to water. If the supplier uses "city water" or "softened water" instead of "deionized water" when making their product, the utility will experience failure of their vaporizers as mineral deposits form on the heat exchanger surfaces. This will require an acid cleaning of the vaporizers to restore performance. It is imperative that a utility knows how the aqueous ammonia in manufactured.

15.5 SNCR Ammonia System Design

For the SNCR system to remove NOx, ammonia must be injected into the boiler in a specific temperature region. The ammonia is chemically the same irregardless of the source. In SNCR systems the sources of ammonia typically used are anhydrous ammonia, aqueous ammonia and urea.

Anhydrous ammonia is the most cost effective since it is 100% ammonia in the delivered form. Ammonia gas will become a liquid at normal ambient temperatures if pressure is applied to it. At 79 degrees F this pressure is 150 psia. This liquid ammonia is shipped and stored in pressurized tanks. Because of the severe health hazards associated with ammonia exposure and because it is stored in pressurized tanks, there are numerous regulations involved in the handling and storage of anhydrous ammonia. EPA requires each site develop a "risk management program" and follow the developed procedures for maintenance and operation of the ammonia storage facility.

Some utilities have decided not to use anhydrous ammonia due to the regulations and the safely reviews required to permit a storage site. Others in more populated regions have been prohibited from using anhydrous ammonia due to zoning laws or citizens' concerns.

Aqueous ammonia is water that has had up to 30% ammonia by weight dissolved into it. At ambient temperatures, it has a vapor pressure very close to atmospheric pressure. This means that there are very low pressures in the delivery and storage tanks. Because of this, the rate at which ammonia is released into the atmosphere during a leak or spill is much less than it would be in the case of anhydrous ammonia. Some utilities have been forced to use aqueous ammonia containing less than 30% ammonia by local governments to reduce this rate of release even more. Because of this, the risks and regulations involved in handling and storing aqueous ammonia are not as great as they are with anhydrous ammonia.

The cost to use aqueous ammonia is greater because one must buy 4 - 6 tons of aqueous ammonia to get 1 ton of useable ammonia. The rest of the weight is water. So one ends up paying to haul and store large amounts of water to get the required ammonia needed for SNCR operation.

Urea is a dry material sold as fertilizer in the agricultural market. It can be processed and broken down to release ammonia. The advantage to using urea is that there is no ammonia present during the transportation and storage of the material. The only ammonia present is the small amount in the boiler as the urea solution decomposes.

The urea/water solution delivered to the site will need to be kept heated so that urea crystals do not form in the solution.

CHAPTER 16 - SNCR OPERATION

16.1 SNCR Normal Operation

Most SNCR systems are fully automated and go into service from the control system.

System Set-up

- The ammonia system or the urea circulating loop should be in service and available to the chemical feed control valves or metering pumps on the SNCR system.
- The dilution water skids (if there are any) should be ready for service with all pump and valve control selectors on "auto".
- The injection air or steam should be valved in and ready for service.
- If there are any MNLs, their cooling systems should be valved in and ready for service.
- The injector and MNL control switches should be in the "auto" position (See **Figure:**

SNCR Injector Control Panel

- The injector and MNL air or steam pressure control regulators and chemical feed rotameters should be set to their normal settings.

Start-up

- When the SNCR controls are given a "start" signal, the appropriate injectors and MNLs will be placed in service depending on the boiler load or steam flow.
- The air or steam valves will open on the injectors or MNLs placed in service.
- The chemical feed valves will open on the injectors or MNLs placed in service.
- The ammonia feed valves or the urea dilution skids will be placed in service and chemical will begin to flow through the rotameters at the proper rate to the injectors or MNLs.
- If there is a trim signal in the controls, the ammonia feed rate or urea dilution will be controlled by outlet NOX or boiler temperature depending on the design.
- It is a good practice for an operator to walk the system down to make sure that all the components are functioning properly.

Shut Down

- When the SNCR controls are given a "stop" signal, the ammonia feed valves or the urea dilution skids will be removed from service and chemical will stop flowing through the rotameters to the injectors or MNLs.
- The chemical feed valves will close on the injectors or MNLs in service.
- The air or steam valves will close on the injectors or MNLs in service.
- The injectors and MNLs will be removed from service.

- The urea circulating loop should remain in service to keep the piping warm and free from crystallized urea.

16.2 SNCR Abnormal Operation

If the SNCR system is in service, the outlet NOx is higher than it typically runs, and the outlet NOx monitor has been checked and is functioning properly, there are two things that might be happening.

- The urea/ammonia feed rate is low or is not being fed into the correct areas.
- The urea/ammonia feed is going into a higher temperature zone and is actually being converted in NOx.

The following outlines a logical progression of things to check to find where the problem is at.

Low Feed Rate

If anhydrous or aqueous ammonia is being fed, check that the ammonia pressure and flow is normal at the ammonia feed control valve. If urea is being used, make sure the urea circulating pump suction strainer isn't plugged and there is normal pressure and flow in the urea circulating loop. If urea is being fed, check the dilution skid. Make sure the urea metering pumps and dilution water pumps are operating properly. Make sure any strainers or mixing valves on the skid aren't plugged. Check the concentration of the diluted urea to assure that the mixing is happening properly. At the injector control skids, make sure that the air or steam pressure regulators are set for the proper pressures. A change in the atomizing pressure will change the spray pattern of the injector or MNL. If the chemical isn't getting to the center of the boiler, there will be areas of low NOx removal. Make sure the chemical flow through each rotameter is at the proper rate.

Injectors and Lances

Check that all the fixed injectors, retractable injectors or MNLs that are supposed to be in service are actually in service. Look through boiler inspection doors where possible to see if the injector spray patterns are correct. If in doubt, the injector may need to be removed from the boiler and the spray pattern checked where it can be seen.

Control System

Check that the "feed forward" signal based on boiler load or steam flow is proper for the boiler operating conditions. If there is a "trim" signal based on outlet NOx or boiler temperature, check that the value of this signal is correct for the current conditions. Verify the boiler temperature monitor if one is being used to obtain a control signal.

Boiler Temperature

Use an optical pyrometer or similar device to measure the boiler fire box temperature at the elevation of the lowest level of injectors or lances in service. If changes in the fuel being burnt or the combustion air feed have caused this temperature to be above 2200 degrees F, you may need to take this level of injectors out of service. The ammonia being fed will react with oxygen at these temperatures and create NOx. Blowing soot in the radiant sections of the boiler can also reduce the temperature by removing the soot buildup on the tubes which will allow more heat to be absorbed by the boiler. This may lower the temperature and may also reduce the outlet NOx value.

Now What?

If all of the above items are proper, the NOx profile in the boiler may have shifted. One will have to set up the test equipment and balance the injector and lance chemicals flows as described in Chapter 17 to obtain the most uniform NOx profile possible at the economizer outlet duct.

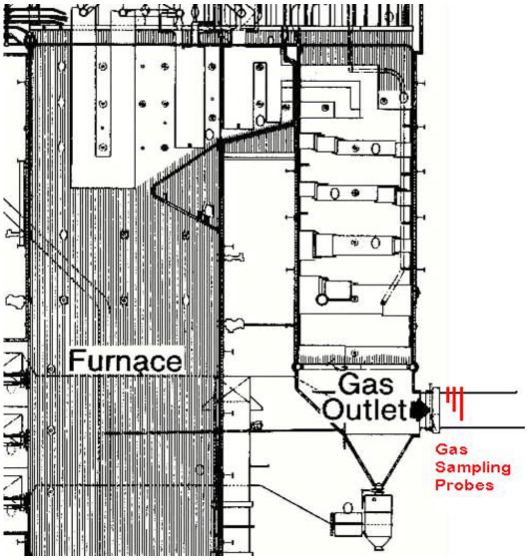
CHAPTER 17 - SNCR PERFORMANCE MEASUREMENTS AND TUNING

17.1 SNCR Performance Measurements and Tuning

The unit's CEM can tell one whether the SNCR is reducing the NOx emission value to the desired number, but it cannot tell one about ammonia slip since most of the ammonia slip will be removed in the air heater or the ESP. It also cannot tell one if the various SNCR wall injectors and MNLs are adjusted to obtain the optimum SNCR performance.

Test Preparation

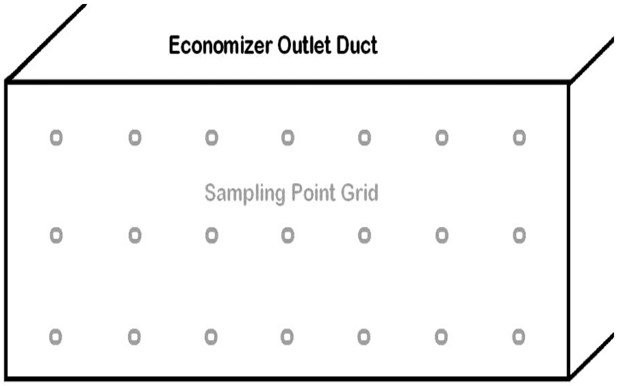
To measure the true SNCR performance and tune the injectors and lances, one needs to take numerous samples at the boiler outlet. This is typically done in the economizer outlet duct. See **Figure:**



Gas Sampling Probes

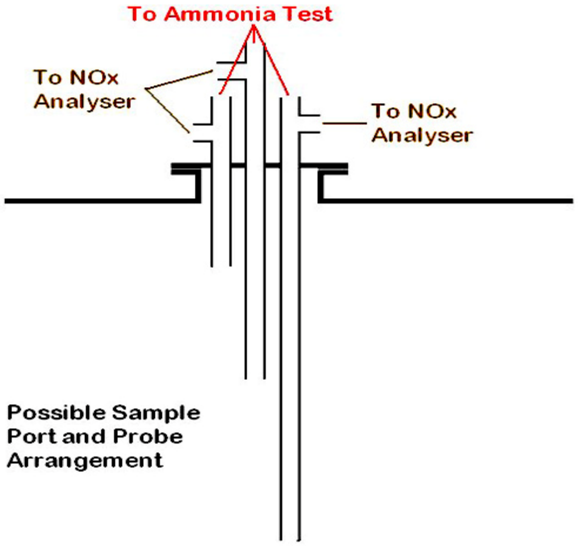
On most boilers, one has access to the top of this duct before it connects to the air heater. There are usually some boiler outlet gas thermocouples and oxygen probes already installed in this area.

Depending on the vertical dimension of the duct, one will want to sample at 3 or 4 elevations in the duct to obtain representative samples across the vertical cross section. The horizontal dimension will determine how many sample probes need to be installed to obtain representative samples across the horizontal cross section. See **Figure:**



Sampling Point Grid

The more probes that are installed, the more accurate the results will be. But, more probes mean longer test run times, more samples to analyze, and higher testing costs. So, there will be some compromise in the number of probe locations to get the accuracy needed at the lowest cost possible. See **Figure:**



Possible Sample Port and Probe Arrangement

Sample ports will most likely have to be installed in the roof of the economizer outlet duct. One can run all the vertical sample probes for one location through the same sample port. A tee at the top of each sample probe will allow one line from each probe to be run to the gas analyzers for that point while the other leg of the tee can be connected to the sampling device that will be collecting the ammonia sample for each point.

Just like SCR testing, the large number of sampling points can lead to very long test runs. To shorten the test runs, multiple analyzer trains are typically used to run numerous sample points simultaneously. Some testing companies have trucks with 10 - 15 sampling trains installed. Sample tubing must be run from each sample point down to the sample truck. Multiport valves on top of the duct can be used to connect several sample points to each sample line running down to the truck. Then the valves can be moved in sequence to sample each of the test points during a test run. Other testing companies place multiple analyzer trains on top of the duct to shorten the sample line lengths. The multiport valves can be used in this arrangement also. NOx is the primary measurement one is interested in. Since NOx formation and reduction is influenced by the O2 and the CO present in the boiler, these values are typically measured so the NOx values can be corrected to the same basis as "baseline" NOx values in respect to O2 and CO during the duration of each test run. The CO values will be higher if one is using urea as the source of the ammonia present in the SNCR.

The ammonia slip is measured for two reasons:

- Ammonia slip is chemical that was wasted since it didn't react with NOx.
- Ammonia slip will cause detrimental "balance of plant" problems.

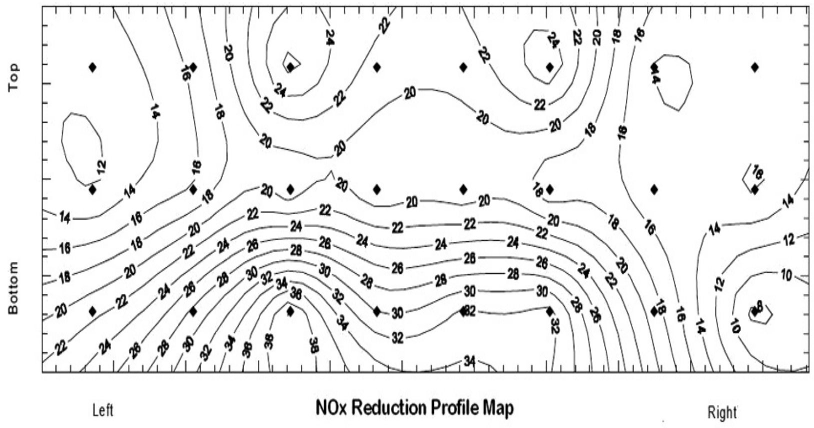
The higher the slip, the worse the problems. There is typically a maximum allowable ammonia slip specified in the design of the SNCR. The tuning process is to obtain the best NOx reduction possible while having the lowest ammonia slip possible.

Since different levels of burners and different levels of SNCR injectors and lances are placed in service at different loads, the testing program must collect a complete set of data for each of the typical loads that the boiler will be operating at for significant periods of time. Some shorter test runs at various loads between these complete data sets can also be helpful in smoothing the performance curves generated to determine at which load points the SNCR injection setting will need to be changed to optimize SNCR performance.

Test Methodology

The testing begins by selecting the boiler load that will be used for the test and getting the boiler stabilized at that load. The gas sampling system is then used to measure the NO, CO and O2 at each of the sample points. Most testing companies have software to graphically plot a map of the NO, CO and O2 profiles across the duct. See **Figure:**

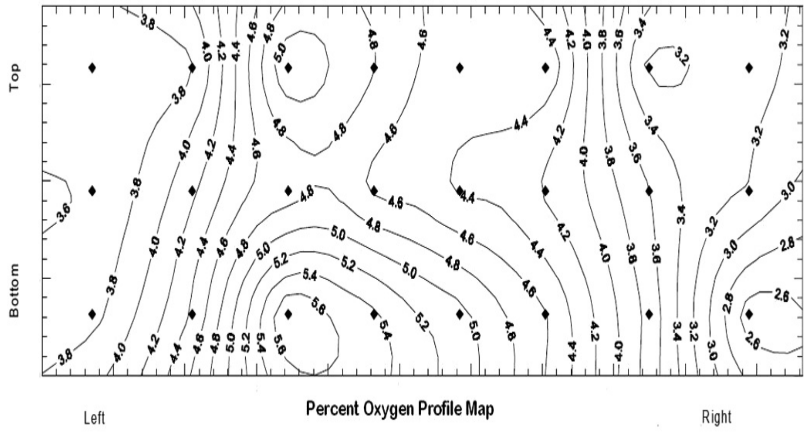
NOx Reduction Profile Map



NOx Reduction Profile Map

The NO readings should all be corrected to some CO and O2 value which will be used throughout the test to standardize all the data to the same reference conditions. These are the baseline values for the test series. See **Figure:**

Percent Oxygen Profile Map



Percent Oxygen Profile Map

The SNCR system should be placed in service with the injectors needed for the boiler load based on the CFD modeling work. The chemical feed should be based on a desired normalized stoichiometric ratio (NSR). The NSR is defined as:

- NSR = (moles N injected) / (moles initial NOx)

If one is feeding urea, this can also be calculated as:

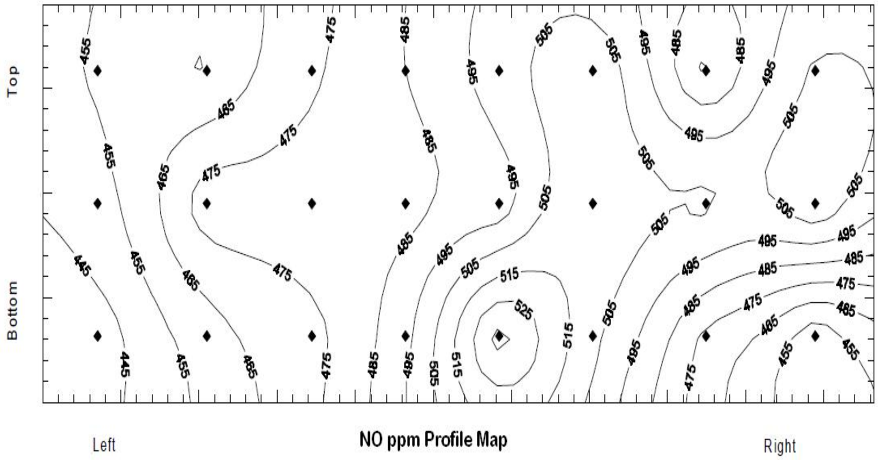
- NSR = 2 x (moles urea injected) / (moles initial NOx)

The gas sampling system is then used again to measure the NO, CO and O2 at each of the sample points. The NO values are again corrected to the baseline CO and O2 values. A calculation can then be performed for each sample point comparing the sampled NO with the baseline NO to determine the percent of NOx reduction. This data can then be plotted on a profile map showing percent NOx reduction.

Tuning

With the baseline NOx profile map and the percent NOx reduction profile map in hand, one is ready to tune the injectors and lances to see if any improvement to NOx reduction can be made. See **Figure:**

NO Profile Map



NO ppm Profile Map

Unfortunately tuning a SNCR is not as straightforward as tuning an SCR.

In an SCR the various turning vanes and mixing devices are designed such that a specific area of the ammonia injection grid (AIG) influences a specific area of the catalyst layer. So one can look at which area of the catalyst layer where one wants to make a change and predict which ammonia injection valve will need to be adjusted to make that change.

In the SNCR case, there is significant turbulence in the boiler burner zone which can be affected by any overfire air, so the relationship between a section of the economizer outlet duct and a particular injector or lance is not as clear. In general the injectors on the right wall of the boiler will affect the right side of the duct and those on the left wall of the boiler will affect the left side of the duct. The injectors on the front wall of the boiler will affect the top of the duct and those on the back wall will affect the bottom of the duct. However if one is working with a tangentially fired boiler or one with ROFA installed, even this might not be true since there will be an overall spin imparted on the gas as it travels upwards through the boiler.

Any CFD modeling reports for the given load will be the most valuable guide in determining which injectors or lances to adjust to obtain the desired change. The tuning process will be a "trial and error" exercise that may take several iterations to obtain the desired result.

During the tuning, the total chemical flow will remain the same but how it is divided between the various injectors or lances will be changed using the rotameter or other flow device installed on the chemical feed line to each injector or lance.

In general, the areas with low NOx reduction probably need more chemical while the areas with high NOx removal may be able to have a little less chemical. The only problem with this generality is when one is adjusting chemical flow on a level where the temperatures are higher. If the NOx removal is low because of a lack of chemical, then increasing the chemical feed will improve the situation. If the NOx removal is low because the high temperature is converting some of the NH3 into NOx, then increasing the chemical feed will aggravate the situation.

At the lowest loads, the lowest levels of injectors will be in service. At the highest loads, the highest levels of injectors and lances will be in service. But there is a load range in the middle where some injectors and lances in each of the levels may need to be in service. So in these ranges one is trying to decide which injectors and lances need to be in service as well as balancing the chemical flows between the injectors and lances that are in service. (Note: Many utilities have decided to only insert and retract entire levels of injectors and lances and not try to operate with partial levels in service. This simplifies the tuning and the control system.)

After any adjustments are made, another set of sampling data will need to be taken. If the boiler is operating fairly stable, a new baseline set of data may not be needed before each test. The new data can be compared with the original baseline data. The cycle of taking data, looking at the profile maps, and making injector adjustments continues until one is satisfied with the chemical balance.

One then needs to sample some or all of the sample points to measure the ammonia slip present. One may have to lower the chemical feed to any injectors or lances that are producing unacceptable ammonia slip at any one area. If the ammonia slip is fairly uniform, one can tune the system to get the highest NOx removal possible with an acceptable ammonia slip. This can be done by increasing the total chemical feed rate while watching the NOx values on the CEM and taking ammonia slip values from some of the sample points. The final NSR obtained will determine the desired chemical flow for that boiler load.

This entire sequence of events must then be repeated at each boiler load that is going to be tested. It will work best if one can find chemical feed rotameter settings for each injector or lance that don't have to be changed during changes in boiler loads. One would prefer that for each load setting the only thing that changes is the total chemical feed rate (NSR) and which injectors or lances are in service.

This information can be programmed into the SNCR control system to automatically vary the configuration of the injectors or lances in service and vary the total chemical feed rate based solely on boiler load.

Operational Tuning

Once the system has been placed in service, the unit's emission limits may prevent running the unit without feeding chemicals to the SNCR. Thus it is impossible to determine the baseline NOx values to tune as described above. This also makes it impossible to calculate the percent NOx reduction for each point.

Some utilities have used the NOx values in a sister unit running at the same load without an SNCR as a substitute for the baseline NOx values. Most have simply forgotten about baseline NOx values and calculating NOx reduction. They balance the outlet NOx values across the outlet duct as evenly as possible and consider the tuning successfully completed.

CHAPTER 18 - SNCR GUARANTEES

18.1 SNCR Guarantees

Typically the only guarantee that one can expect to receive from the SNCR system supplier is an outlet NOx value at some ammonia slip value. An example would be:

- 0.24 lb/mmbtu outlet NOx with no more than 2 ppm ammonia slip

This will probably be predicated on some maximum uncontrolled boiler NOx value.

A percent removal guarantee isn't worth that much since one is typically limited by permit to some maximum outlet NOx value. The other problem is that once the system is in service, one would have to shut it off for enough time to establish the uncontrolled NOx baseline value to calculate the percent removal. Most locations cannot afford to have a period of uncontrolled emissions under their permit requirements and averaging times.

CHAPTER 19 - SNCR MAINTENANCE

19.1 SNCR Maintenance

The experience with SNCR operation seems to indicate that the dilution water quality may have the biggest impact on the number of manhours required for maintenance. Those using higher calcium content dilution water report needing several persons full time just to deal with all the plugging issues. They report spending time dealing with issues such as:

- Injector and lance nozzle pluggage
- Rotameter glass cloudiness which prevents seeing the float level
- Mixing valve pluggage
- Strainer pluggage
- Pluggage in hoses and piping

Those who are using water that is calcium free report that they are not experiencing these kinds of issues.

Even if one is not having issues caused by dilution water quality, there are still areas that must be addressed.

Insulation and Heat Tracing

If one is using urea, all the tanks, pumps, and piping that contain urea solution at a concentration higher than the mid-30% range need to be heated to prevent crystals from forming and blocking the flow. Systems are designed with heat tracing and insulation to keep the solution warm.

During normal operations and maintenance activities, this insulation and heat tracing may be damaged or removed. It is important that all the insulation and heat tracing is maintained in its original working condition.

Ammonia Storage Equipment

If aqueous or anhydrous ammonia is being stored and used in the SNCR, there are certain regulatory requirements that must be met in the maintenance of the storage vessels and their appurtenances. There are variations in the equipment that may have been supplied with each system. Rather than trying to guide one in how to deal with these systems, we call these items to one's attention.

- Various Federal, State, and Local regulations have determined the design and operation of each ammonia feed system.
- It is quite likely that an OSHA Process Safety Management (PSM) review was done on the system which included writing various operating and maintenance procedures that are to be followed during the operation and maintenance of the system. Failure to follow these procedures could subject the facility to OSHA penalties.
- Certain parts of the system (i.e. pressure relief valves, isolation valves, gauges, etc.) may have certain inspection/repair/replacement criteria established by some of the regulations covering the ammonia feed system.

Only persons familiar with the above items and the safety hazards of ammonia should inspect and repair these systems.

There is further information about preparing an anhydrous ammonia storage system for maintenance in Chapter 10.2 of the training manual.

Wall Injectors

There are fixed and retractable wall injectors. The retractable injectors will need some preventive maintenance on the retraction mechanisms to keep them operating freely in a hot and sometimes dusty environment. If the injector sags or has build up around the tip, it may lodge and not fully retract or retract but then not go back into the hole. The injector will have to be cleaned or replaced if that happens.

The atomizing air or steam acts as a cooling medium for the injector. If the atomizing flow is lost, the injector may overheat and sag. If this happens the injector will have to be replaced.

In some instances, the injector nozzle may plug with debris which will create an improper spray pattern. In some cases the nozzle will fall off which creates a solid stream of chemical running down the boiler wall. If either case is suspected, the injector will have to be removed and tested. The nozzle can then be cleaned or replaced and the injector reinstalled.

Multi Nozzle Lances

The retraction mechanism is identical to that used on lance type soot blowers. The mechanism will need the same type of preventive maintenance as that given to the soot blower retraction mechanism.

The nozzle may use atomizing steam as the cooling medium or have a once though or recirculating type cooling system. Whichever type of system is used, the reliability of the cooling system is very critical. A loss of cooling flow will cause the lance to sag very quickly. It may sag to the point where it is difficult or impossible to retract it from the boiler. The lance will have to be replaced.

If one is using a once through or recirculating cooling system and any leaks develop in the lance internal jacket between the chemical injection lines and the cooling media, one may find a buildup of ammonia in the cooling media which will raise its pH and may cause problems in the cooling system.

Even if the cooling system is working properly, the lance may sag over time. This can make it difficult to insert or remove the lance. In some instances, the sagged lance will impact some boiler internal component which can prevent the lance from being fully inserted into the boiler. The lance will have to be replaced.

In some instances, one of the nozzles on the lance may plug with debris which will create an improper spray pattern. In some cases a nozzle will fall off which creates a solid stream of chemical running into the boiler. If either case is suspected, the lance will have to be removed and tested. The nozzle can then be cleaned or replaced and the lance reinstalled.

Pumps and Valves

Unless one is experiencing dilution water quality problems, the pumps and valves will not require a lot of maintenance. They will however require the manufacturer's recommended preventive maintenance. The suction strainers ahead of the pumps should be checked on a regular basis and the strainer baskets cleaned when the differential pressure begins to increase.

The suction strainer for the urea solution circulating pumps is the most likely to plug. This will happen if any debris is in the concentrated urea solution that is delivered into the urea storage tank. Make sure the delivery connection is covered when not in use. Check that there is a strainer being used at the urea supplier's truck loading station to catch any foreign material before it enters the delivery truck.

Certain parts of a urea based system must be kept warm to keep the urea from crystallizing as it cools. If one does work on any pumps or valves that are heat traced and/or insulated, it is imperative that the heat tracing and/or insulation be returned to its designed condition at the end of the maintenance job.

CHAPTER 20 - SNCR BALANCE-OF-PLANT EFFECTS

20.1 SNCR Balance-of-Plant Effects

The "balance of plant" effects from the SNCR arise because it is very easy to have a high ammonia slip from the SNCR if the system isn't working properly. The ammonia slip can be fairly substantial even when the SNCR is working properly.

Some utilities have been forced to lower the NOx removal they were trying to obtain from the SNCR just to lower the ammonia slip and mitigate some of the "balance of plant" effects they were experiencing.

Air Heater Fouling

The ammonia slip will react with any sulfuric acid (SO_3 + H_2O at the dew point) to form ammonium bisulfate (ABS) or ammonium sulfate (AS). The higher the sulfur in the coal or the higher the ammonia slip, the worse this problem can become.

The sulfuric acid can be very corrosive and dissolve air heater baskets and structures. The ABS forms sticky deposits on the air heater surfaces. These sticky deposits can then attract fly ash particles. This results in air heater basket pluggage and high differential pressure drop across the air heater.

A typical air heater design has three layers of baskets (cold end layer, intermediate layer and hot end layer). There is a gap between each layer. If one is sootblowing the baskets from either the hot end side or the cold end side, the blowing media is dispersed and loses some of its energy as it crosses the gap into the intermediate layer. Because of this, the intermediate layer isn't cleaned as thoroughly. Any material that is dislodged from the intermediate layer can also accumulate in these gaps.

The temperature profile in an air heater is such that ABS deposits will form on both the intermediate and cold end layers. Because of the sootblowing issue, many utilities have chosen to redesign the air heaters with the intermediate and cold end layers being combined into a single deep layer so there is no gap where the ABS deposits form. This provides full sootblowing energy across the entire ABS deposit.

Many utilities have also converted to "multi-media sootblowers" that can blow with several different media such as air, steam, or water. As the ammonia slip increases from the SNCR, one needs to keep a close eye on the air heater differential pressure drop and use the sootblowing system more often to prevent the deposits from becoming too large and plugging the air heater basket flow channels.

Some utilities have installed a Breen Energy Solutions AbSensor - AFP Condensables Anti-fouling Probe to give them a real time indication of the fouling potential due to the dew point and the ABS and AS rates of formation. This allows them to be proactive in keeping the air heater clean rather than being reactive in trying to clean it up after the fouling has occurred.

Ammonia on Ash

Any ammonia slip from the SNCR will adsorb onto the fly ash particles. This normally doesn't cause any problems with the ash handling characteristics. It can be a problem, however, if one is selling the fly ash. Depending on what the ash is being used for, the buyer may place a limit on how much ammonia can be present on the ash.

The potential loss of ash sales may influence the decisions on how high the ammonia slip can be allowed to be from the SNCR.

Ammonia in Water

If the fly ash is disposed of in ash ponds, the ammonia adsorbed on the ash will dissolve in the pond water. This dissolved ammonia concentration can lead to NPDES discharge limit concerns if the concentration is high enough. The nitrogen from the ammonia in the water can also fertilize any algae growing in the pond.

CHAPTER 21 - SNCR TROUBLESHOOTING

21.1 SNCR Troubleshooting

Plugged Urea Circulating Pump Suction Strainers

One site had trouble losing flow on the concentrated urea circulating loop. They always found the suction strainers on the urea circulating pumps plugged with debris. They noticed that it typically happened right after a delivery had been made into the urea storage tank. The pluggage was worse if the tank level was low.

Further investigation found that the debris consisted of soybeans, grass, straw, and similar materials. They also found that the agribusiness that was supplying the urea solution sent trucks full of soybeans in one direction for delivery. They then picked up a load of urea prills (without sweeping out the trailer) for the return trip. They dumped the prills and dissolved them in water. There was no strainer on the line from the solution tank to the delivery tank trucks.

The soybeans and other debris were delivered into the station's urea storage tank. After a delivery was made, the material in the tank was stirred up and drawn into the circulating pumps' suction strainers.

The solution was to clean the debris out of the station's urea storage tank and to make sure the urea supplier had a strainer on the delivery tank truck fill line to keep any debris at the urea supplier's facility.

Plugged Injector Nozzles and Lances, Plugged Metering Valves, Clouded Rotameter Glasses

These problems have been reported at numerous locations. The root cause has been determined to be the quality of the dilution water used in the SNCR system. If one is using water that has high calcium content (hard water), the calcium compounds will precipitate out as the water is heated. These deposits will then plug nozzles and valves and cloud sight glasses.

If the water is passed through a salt regenerated water softener, the calcium will be replaced with sodium. In this "soft water" the sodium compounds will not precipitate out as the water is heated, so the problems will disappear. Other locations have chosen to install "reverse osmosis" equipment to remove most of the minerals from the water.

Condensate or demineralized water is even better, but the additional benefit may not be great enough to justify the extra cost to produce this quality of water. But there will be no problems if one chooses to use this quality of water.

One utility reported that they were able to continue using filtered river water by adding a "stabilizer" type water treatment chemical to the water to minimize the pluggage issue.

One location using high calcium well water had experienced significant pluggage and clouding issues in their SNCR system. They reported the system cleaned up in just a few weeks after they changed to condensate quality water as a test of the concept.

Some locations will pull an injector out of the boiler and then turn it on to check the spray pattern. This is effective but messy. It can be hard to see the spray patterns looking through an observation door into the boiler at the injectors in service due to the brightness of the flames. Enertechnix has demonstrated using its infrared camera to look at the spray patterns through the observation doors. The spray shows up as a cool zone that is fairly easy to see on the camera's screen.

Multi Nozzle Lance Cooling Systems

The lances require a cooling system to keep them from overheating. The reports have been that any failure of the lance cooling system results in an immediate severe droop of the lance. One should look at the design of the lance cooling system with an eye towards system reliability. Some of the systems that have been used are:

- Steam as the dilution fluid as well as the cooling media

- Once through condensate flow with the drain returning to the boiler water cycle

A closed circulating loop with a cooling fluid, circulating pumps, and a heat exchanger piped to some source of cooling water

One issue can occur if there is any leak in the cooling jacket of the lance. Ammonia can enter the cooling media. If it is a once through condensate system, the ammonia can end up in the boiler feed water driving the boiler pH up. If it is a closed system, the ammonia can build up in the circulating fluid. This can raise the fluid pH and also cause corrosion of any copper based materials in the circulating loop.

Air Heater Fouling or Plugging

Review the discussion of this issue in Chapter 20.

The Breen Energy Solutions AbSensor - AFP probe can be used to investigate the source of the problem. The probe can be inserted through boiler inspection doors or any sampling ports that may be present in the ducts to investigate different areas of the system and indicate where the sources of ABS will be as the gas reaches the dew point. This may allow one to reduce the ammonia feed in certain areas of the boiler without reducing it everywhere. This will minimize the impact to NOX removal while reducing air heater problems.

A complete tuning of the ammonia feed points can also be done as described in Chapter 17. After doing a tuning, some utilities have still had to reduce the expected NOx removal in order to prevent air heater problems.

ABBREVIATIONS

ABS - Ammonium bisulfate - NH_4HSO_4

AEGI - Amine Enhanced Gas Injection

AGR - Advanced Gas Reburning

AH-SCR - Air Heater Selective Catalytic Reduction

AIG - Ammonia Injection Grid

AS - Ammonium sulfate - $(NH_4)_2SO_4$

BACT - Best Available Control Technology

BOOS - Burners Out of Service

Btu - British thermal unit

CAAA90 - Clean Air Act Amendments of 1990

$CaCO_3$ - Calcium Carbonate (limestone)

CaO - Calcium Oxide (lime)

Cascade - SNCR/SCR Hybrid

$CaSO_3$ - Calcium Sulfite

$CaSO_4$ - Calcium Sulfate

$CaSO_4.2H_2O$ - Gypsum

CCOFA - Closed-Coupled Overfire Air

CEM - Continuous Emissions Monitor

CFD - Computational Fluid Dynamics

CKM - Chemical Kinetic Model

CO - Carbon Monoxide

CO_2 - Carbon Dioxide

$CO(NH)_2$ - Urea

CR - Coal Reburning

CTR - Combustion Controls

DOE - Department of Energy

EPA - Environmental Protection Agency

EPRI - Electric Power Research Institute

ESP - Electrostatic Precipitator

FCC - Fixed Charge on Capital

FEGT - Furnace Exit Gas Temperature

FF - Fabric Filter

FGD - Flue gas Desulfurization

FLGR - Fuel Lean Gas Reburn

GR - Gas Reburn

H_2O - Water

H_2SO_3 - Sulfurous Acid

HSR - Hybrid Selective Reduction

IPPs - Independent Power Producers

kW - Kilowatt

kWh - Kilowatt hour

LAER - Lowest Achievable Emission Rate

L/G - Liquid to gas ratio

LNB - low-NOx Burners

LNCB - low-NOx Cell Burners

LNCFS - low-NOx Concentric Firing System

LOI - Loss of Ignition

LPA - Large Particulate Ash

MMBtu - Million Btu

MWe - Megawatt of Electrical Generation (generator gross output)

N_2 - Nitrogen

NGR - Natural Gas Reburn

NH_3 - Ammonia

$(NH_4)_2SO_4$ - Ammonium Sulfate (AS)

NH_4HSO_4 - Ammonium Bisulfate (ABS)

NO - Nitric Oxide

NOx - Nitrogen Oxides (NO + NO_2)

NOxOUT - SNCR Technology designed by Fuel-Tech N.V.

NPDES - National Pollutant Discharge Elimination System

NSPS - New Source Performance Standards

NSR - New Source Review

NUG - Non-Utility Generator

O&M - Operation & Maintenance

OEM - Original Equipment Manufacturer

OFA - Over Fire Air

OLF - Operating Costs Levelization Factor

ppm - Parts per million

psig - Pounds per square inch gauge

PRB - Powder River Basin Coal

RACT - Reasonably Available Control Technology

SCR - Selective Catalytic Reduction for NOx Control, Silicon Controlled Rectifier for Particulate Control Circuits

SNCR - Selective Non-Catalytic Reduction

SOFA - Separated Overfire Air

SO_2 - Sulfur Dioxide

SO_3 - Sulfur Trioxide

SOx - Sulfur Oxides

TiO_2 - Titanium Dioxide

V_2O_3 - Vanadium Pentoxide

WO_3 - Tungsten Trioxide

GLOSSARY

Abrasion - Flex - Fabric weakness created by repeated fiber bending.

Abrasion Resistance - Ability of a fiber or fabric to withstand surface wear.

Abrasion - Surface - Fabric wear on the surface created by particulate erosion, rubbing or scuffing.

Absorption - The operation in which one or more soluble components of a gas mixture are dissolved in a liquid.

ACFM - Actual cubic feet of gas per minute. The volume of the gas flowing per minute at the operating temperature, pressure and composition. *Note - in the metric system, the corresponding value may be expressed in actual cubic meters per hour, ACM (H).

Acid Deposition - The process by which acidic particles, gases, and precipitation leave the atmosphere. More commonly referred to as acid rain, acid deposition has two components: wet and dry deposition.

Acid dew point - The temperature at which combustion gases are saturated with sulfuric acid.

Acid rain - The result of sulfur dioxide (SO_2) and nitrogen oxides (NOx) reacting in the atmosphere with water and returning to earth as rain, fog, or snow. Broadly used to include both wet and dry deposition.

Additive - Substance added to a liquid or gas stream to cause a chemical or physical reaction to enhance SO_2 sorption.

Adipic Acid - An organic acid used as a performance enhancing chemical in absorber towers.

Adsorption - The operation in which a solid substance retains on its surface a layer of gaseous or liquid substance by which gas molecules are selectively removed from a gas stream.

A/E - Architect / Engineer

Air Heater - A heat exchanger, which transfers heat otherwise wasted from the flue gases to the incoming furnace air. It may be regenerative (Ljungstrom or Rothemuhle) or direct (tubular) air heaters may also be heated with fuel (direct fired) or steam.

Air, Standard - Dry air at 70 degrees F and 29.92 in Hg pressure. Equivalent to 0.075 lb/ft3

Air-To-Cloth (A/C) Ratio - The ratio between ACFM, flowing through a filter, and the square feet of filter area available. This can also be thought of as the velocity of the gas passing through the filter area in feet per minute (FPM). The typical A/C ratios for various types of cleaning systems are:

- Cleaning System A/C Ratio*
- Shaker 2.5 - 3.0 to 1
- Reverse Air 2.0 - 2.5 to 1
- Pulse-Jet 5 - 6 to 1
- Plenum Pulse 3.5 - 4 to 1

* NOTE: The term usually used in the metric system is filtration velocity instead of air-to-cloth ratio, defined as the relation between the cubic meters per min of air flowing through a filter and the square meters of filter area available. The typical filtration velocities are:

- Cleaning System Filtration Velocity
- Shaker 0.76 - 0.91 m3/m2/min
- Reverse Air 0.61 - 0.76 m3/m2 min
- Pulse-Jet 1.52 - 1.83 m3/m2/min
- Plenum Pulse 1.07 - 1.22 m3/m2/min

Alignment - Refers to how well optimum clearances are maintained between the high voltage discharge electrode system and the grounded collecting plate surfaces. Uniform corona current distribution, maximum use of installed plate area, highest possible operating voltages and best precipitator performance occur when proper discharge electrodes are everywhere centered within collecting plate gas passages or ducts. Reasonable maximum tolerances are considered +1/4 (+ or - 6 mm) off center for discharge electrodes and +1/4" (+ or - 6 mm) from flat for collecting plate surfaces. Clearance from corona source to vertical projecting plate baffles or edges should be a least 0.75 duct width. The sharper the edge or projection on the collecting surface anode, the greater the clearance to discharge corona. Good alignment depends upon good and reliable overall system mechanical integrity without thermal distortions. High voltage discharge elements and frame must be held plumb with respect to vertical collecting plate surfaces. Uneven foundation settling cannot be tolerated.

Allowance - A tradeable permit to emit a specific amount of a pollutant. For example, under the Acid Rain Program, one allowance permits the emissions of one ton of sulfur dioxide (SO_2).

Ammonia Injection Grid (AIG) - is a device that consists of multiple pipes with adjusting valves used in conjunction with nozzles, static mixers or delta wings to spread a mixture of ammonia and dilution air evenly across the cross section of the SCR inlet duct.

Ammonia Slip - This is the ammonia that is not consumed reacting with NOX and exits the NOX removal process.

Ammonium Bisulfate - A common side reaction of concern in SCRs.. At relatively cool temperatures, within and downstream of the air preheater, ammonium bisulfate can form from the reaction of residual ammonia (ammonia slip) and SO3 where the SO3 level is comparable to or higher than the ammonia slip level.

Ammonium Carbamate - This is an intermediate reaction product as urea decomposes into ammonia.

Ammonium Sulfate - Another common side reaction of concern in SCRs.. At relatively cool temperatures, within and downstream of the air preheater, ammonium sulfate can form from the reaction of residual ammonia (ammonia slip) and SO3 where the SO3 level is lower than the ammonia slip level.

Anemometer - A device for measuring small air velocities. See hot-wire anemometer and rotating vane anemometer.

Anhydrous Ammonia - This is the most concentrated form of ammonia. It is a gas at ambient pressure and can become a liquid when compressed. It absorbs readily into water. Therefore, contact of ammonia with eyes or mucous membranes can cause severe irritation and burning of these tissues. A full faced respirator with ammonia cartridges or a self contained breathing apparatus should be worn if one will be exposed to gaseous ammonia.

Anode - Positive electrical terminal of high voltage power supply; this is the collecting plate surface, which is maintained at ground potential. Precipitator (ESP) sparking starts at the anode.

Anti-Sneak Baffles - A gas distribution device in which, internal baffle elements within the precipitator prevent the gas from bypassing the active field or causing hopper re-entrainment.

Anti-Sway Insulator - Ceramic insulators used to prevent the bottom guide frame for the discharge wire tensioning weights from swinging and causing periodic misalignment of discharge electrodes resulting in premature sparking, poor precipitator performance. Two types in common use with two-point, high-tension (HT) frame support design: (1) vertical shaft 36" long supported off hopper walls; (2) horizontally mounted ceramic, positioning bars between bottom guide frame and precipitator outer steel shell. In some cases, teflon is used instead of ceramics.

Anthracite - A hard, black lustrous coal, often referred to as hard coal, containing a high percentage of fixed carbon and a low percentage of fixed volatile matter. Anthracite contains approximately 22 million to 28 million Btu per ton.

Apex - The tip, point, vertex; the narrowest point at the bottom of a hydroclone or thickener.

Aqueous Ammonia - In this form, concentrated ammonia has been dissolved in water. The concentration is expressed as what percentage of the liquid is ammonia. The higher the concentration, the more chance there will be of ammonia fumes being present in the air. Very low concentrations of aqueous ammonia are sold as a household cleaning product. Some localities have required the use of aqueous ammonia instead of anhydrous ammonia due to its lower health and safety hazards.

AR - Aspect ratio; ratio of ESP total collecting plate length to plate height.

Arc - A relatively long, large discharge of high voltage, which is not immediately self-extinguishing.

Ash - Impurities consisting of silica, iron, alumina, and other noncombustible matter that are contained in coal. Ash content is measured as a percent by weight of coal on an "as received" or a "dry" (moisture-free, usually part of a laboratory analysis) basis.

Aspect Ratio - The length of a precipitator divided by its height. The aspect ratio normally ranges from approximately 0.5 to 1.5 and affects the amount rapping re-entrainment contributes to the outlet burden.

ASTM - American Society for Testing Material

Automatic Power Supply Control - The automatic regulation of high voltage power for changes in precipitator operating conditions using feedback signal(s).

Auxiliary Control Equipment - The electrical components required to protect, monitor and control the operation of precipitator rappers, heaters and other associated equipment.

AVC - Automatic Voltage Control is an electrical or electro mechanical system to regulate the precipitator voltage requirements because of changes in operating conditions.

Back Corona - A localized corona discharge, which occurs when the gas within a high resistivity dust on the collecting surface breaks down and becomes ionized. Back corona starts at a critical bulk dust resistivity, e.g. = 1.0E+10 ohm cm. In the incipient early stages it causes ESP sparking at reduced voltages and current densities; severe back corona (5.0E+11 - 5.0E+12 ohm) causes heavy positive ion back current, greatly reduces particle charge and destroys the ESP particle collection process.

BACT - Best Available Control Technology

Baffle - A device, usually consisting of a plate or series of plates, which evenly distributes airflow and dust within a dust collector to protect filter bags from direct abrasion by dust.

Baghouse - An air filtration structure utilizing filter fabrics for the purpose of removing solid particulate from direct abrasion by dust.

Balanced draft - The condition where the absolute pressure in the boiler furnace is exactly equal to the absolute atmospheric pressure outside the furnace or is slightly negative.

Ball Mill - Equipment used for pulverizing limestone as well as for slaking of lime. It consists of a rotating cylindrical or conical casing charged with metal balls or slugs along with water and the material to be pulverized or slaked.

Batch cleaned - Usually refers to that process used in heat-cleaning glass cloth in roll form by exposing it to 500 degrees F - 600 degrees F temperatures for prolonged periods to burn off the starches.

BDAT - Best Demonstrated Available or Achievable Technology

Bituminous Coal - The most common coal. It is dense and black (often with well-defined bands of bright and dull material). Its moisture content usually is less than 20 percent. It is used for generating electricity, making coke, and space heating. The contents of bituminous coal range from 19 million to 30 million Btu per ton.

Bleedthrough - Particulate migration through the interstices of a woven filter bag fabric or through the needled fibers of a felt bag.

Blinding - Fabric blockage by dust, fume or liquid not being discharged by the cleaning mechanism, resulting in reduced gas flow or increased pressure drop across the media.

Blowpipe - Pipe connected to the pneumatic pulsing system with holes to distribute cleaning air to bag rows in pulse-jet units.

Boiler - A device that generates steam for power. Heat from an external combustion source is transmitted to a fluid contained within the tubes in the boiler shell. This fluid is delivered at a desired pressure, temperature and quality.

Breeching - The rectangular opening in a chimney wall where a duct enters the chimney.

Bridging - The blockage of a hopper by the formation of an arch or "bridge" of compacted dust over the hopper exit.

Btu (British Thermal Unit) - A standard unit for measuring the quantity of heat energy equal to the quantity of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

Buffering - When a substance in solution has the ability to react with and neutralize large amounts of acid, thus preventing the pH from changing substantially with small additions of acid.

Bulked yarn - Filament yarn that has been processed by high-pressure air passing through the yarn and relaxing it into gentle loops, bends, etc.

Bursting Strength - General: A material's ability to resist rupture by pressure. Specific: Force required to rupture a fabric by distending it with the force applied at right angles to the fabric plane under specified conditions. Usually expressed in pounds per square inch. (kg/cm2)

Bus - A conductor enclosed within a grounded duct.

Bus Section - The smallest size high voltage assembly of discharge electrodes and minimum collecting plate area that can be independently energized by one electrical set; or one electrical output.

By-product - Saleable or usable product that has some economic value.

Cake - The dust formation developed on the surface of the filter medium during the filtration process or the layer of solids left on a filter cloth once the liquid has been drawn out of a slurry using vacuum.

Calcination - To change or burn to a powder using heat, such as changing limestone into lime in a kiln.

Calendaring - High pressure pressing of the fabric; pushes the surface fibers down onto the body of the filter medium.

Can Velocity - In a dust collector with the filter elements suspended from the tubesheet, can velocity is the upward air stream speed passing between the filters calculated at the horizontal cross-sectional plane of the collector housing at the bottom of the filters. Example:

- Air volume: 18,850 ACFM (8.9 m3/hr)
- Total cross-sectional area of collector: 15 ft x 8 ft = 120 ft2 (4.57 m x 2.43 m = 11 m2)
- Total area of filter bottoms: 20 x 12 = 240 filters at 28.27 in2/filter (0.018 m2/filter) = 47 ft2 total (4.37 m2 total)

- Open area between filters: 120 ft2 (11.2 m2) - 47 ft2 (4.37 m2) = 73 ft2 (6.64 m2)
- Can velocity: 18,850 ACFM / 73 ft2 (6.78 m2) = 258 FPM (1.31 m/sec)

Catalyst - A catalyst is a chemical substance that is used in SCRs to promote the conversion of NO and NO_2 to N_2, but the catalyst is not used up during the chemical reaction. There are three main types of catalysts:

- Plate
- Corrugated
- Honeycomb

Catalyst Pitch - When looking at the design of a honeycomb or plate catalyst, this is the distance between the centerline of one catalyst wall and the centerline of the opposite catalyst wall.

Cathode - This is the negative polarity, high voltage DISCHARGE ELECTRODE of a precipitator. It is the cathode that suffers metal erosion due to ESP repetitive sparkover - a common cause of localized wire thinning, draw-out due to weight tension, and ultimate breakage with sharp points.

Cell - A separate section of a precipitator which is energized by one TR set and which is located transverse to the gas flow. (a 4-cell precipitator would contain 4 parallel

electrically separated high voltage systems in each field) **Cell (in width)** - A cell is an arrangement of a bus sections parallel to gas flow. Note: Number of cells wide times number of fields deep equals the total number of bus sections.

Cell Plate (Tubesheet) - A steel plate to which the open end of the filter bags are connected. Separates the clear air and dirty air plenums of the baghouse.

Centrifuge - A device which separates the phases in a composite fluid stream by applying centrifugal motion to the stream and forcing the higher density component to the outside wall of the device where it is collected.

CFM (Cubic Feet Per Minute) - The cubic feet of air being moved through the system per minute. Must be expressed as actual (ACFM) Standard (SCFM) wet or dry (SCFM W or SCFM D)

Chamber - A gas-tight longitudinal subdivision of a precipitator. A precipitator with a single gas-tight dividing wall is referred to as a two-chamber precipitator. Note: very wide precipitator chambers are frequently equipped with non-gas-tight load bearing walls for structural considerations. These precipitators are by definition single chamber precipitators.

Chamber - A parallel sub-division of a large precipitator, which is sealed off from other chambers by a solid steel wall. Each chamber contains its own set of individual sections comprising CELLS and FIELDS.

Char - The carbonaceous material in dust - usually incompletely burned fuel which has larger particles than the rest of the dust.

Chemical Conditioner - A chemical used to lower the resistivity of dust to reduce or eliminate back-ionization.

Chimney Rain-out - A condition where moisture droplets leave a chimney plume and fall to the ground in the area around the chimney.

Clarifier - A large tank where slurries can be separated into a liquid stream and a solid stream. This is usually accomplished because the clarifier has a large volume that allows the dense solid particles to settle under the influence of gravity. The liquid steam exits the top of the clarifier and the more dense solid slurry is drawn from the bottom of the tank.

Clean Air Plenum - The baghouse area through which clean filtered gases are directed after filtration, located on the clean side of the bags above the tubesheet.

Cloth - In general, a pliant fabric that is woven, knitted, felted or otherwise formed from any textile fiber, wire, or other suitable material.

Cloth weight - usually expressed in oz/yd2 or oz/ft2. However, cotton sateen is often specified at a certain number of linear yd/lb of a designated width.

Coal - Low-sulfur - The EIA sulfur content category of coal with less than 0.60 pounds of sulfur per million Btu. Less than or equal to 1%.

Coal - Medium-sulfur - The EIA sulfur content category of coal with 0.60 to 1.67 pounds of sulfur per million Btu. Greater than 1% and less than or equal to 3%.

Coal - High-sulfur - The EIA sulfur content category of coal with greater than 1.67 pounds of sulfur per million Btu. Greater than 3%.

Coating - Immersing the filter medium in a solution to provide the fibers with a coating that will lubricate and thereby reduce self-abrasion; in the case of woven-glass bags, the most common coatings have been Teflon and silicone graphite

Cold side ESP - An ESP, which is installed downstream of the air heaters.

Cold spot - A point where a continuous metallic heat transfer circuit through the insulation creates an uninsulated area, resulting in an area that is colder than the surrounding area.

Collecting Surface - Describes the reinforced sheet metal, usually 20, 18 or 16 ga (0.90, 1.25 or 1.65 mm), collector plate or plates that form the gas passages of precipitator parallel ducts. The electrically charged dust particles are deposited or collected on said surfaces by means of powerful electric forces applied directly to the particles, per se.

Collection Efficiency - A measure of dust collector's ability to remove particulate from the inlet gas expressed in percent. % Efficiency = (Dust in - Dust out)/Dust in x100.

Collection Electrode (CE) - The electrode (usually grounded) on which the particulate is deposited in an electrostatic precipitator. Also called collecting plate.

Collection Surfaces - The individual elements, which make up the collecting system and provide the total surface area of the precipitator for the deposition of dust particles.

Collection Surface Area - The total flat projected area of collecting surface exposed to the active electrical field (effective length) x (effective height) x (2) x (number of gas passages).

Collection Surface Rapper - A device, which imparts vibration or shock to the collecting surface to dislodge the deposited particles.

Colloidal - Having very small, insoluble, nondiffusible particles larger than molecules but small enough so that they remain suspended in a fluid medium without settling to the bottom.

Compressed Air - Pressurized air generated by a compressor used to clean filter bags in a pulse-jet baghouse. Measured in psi (pounds per square inch). (Kg/cm2)

Concentration - Amount of dust in the gas. Usually expressed in terms of grains/ft3, lb/1000 lb of gas, ppm, mg/m3, or lb/million Btu.

Conductivity - The reciprocal of resistivity - the units are Mho-meters (Mho = Ohm, spelled backwards).

Conical Hopper - A hopper shaped like an inverted cone.

Continuous Emission Monitor (CEM) - A device that approximates a continuous measurement of certain characteristics of a gas by making separate measurements frequently. For compliance with the CAAA90, the measurements must be taken at least every 15 minutes. Two common types are an Extractive Continuous Emission Monitor and an In Situ Continuous Emission Monitor.

Control Damper - A device installed in a duct to regulate the gas flow by degree of closure. Examples: Butterfly or Multi-Louver.

Control Equipment - High voltage power supply control equipment generally consists of: electrical components required to protect, monitor and regulate the power supplied to the precipitator high voltage system.

Control Unit - Usually in an air conditioned room containing modern solid-state thyristor components for silicon-controlled-rectifier (SCR) electric power controls, microprocessor-mini computer type automatic voltage controls, instrumentation, protective devices, fault indicators, programmable inputs, various input and output signals capabilities, manual control switch, main line 1 or 3 ph, 50 Hz or 60 Hz circuit breakers, etc.

Corona - A gaseous discharge found near an ESP discharge electrode resulting in a faint glow caused by ionization of gas molecules due to the electric field.

Corona Power (KW) - The product of secondary current and secondary voltage. Power density or specific power is generally expressed in terms of: 1) Watts DC per square foot (square meter) of collecting surface. Or 2) Watts DC per 1000 ACFM or watts per 1000 AMCH of gas flow.

Coronizing - A heat cleaning process for fiberglass fabric to burn off the starches (used in processing) usually at temperatures of 1000 degrees F (537.7 degrees C) for a short duration before the finish is applied. Same as scouring.

Crimp - Waves contained in a yarn.

Curing - In finishing fabrics, the process by which resins or plastics are set in or on textile materials, usually by heating.

Current Density or Specific Current - The amount of secondary current per unit of ESP collecting surface.

Cyclone - A free vortex centrifugal separator that removes solids from liquids by combination of centrifugal force and liquid shear. Used in some systems to replace the liquid thickener/clarifier.

DBA (Dibasic Acid) - A mixture of organic acids (adipic acid, succinic acid, glutaric acid) used as a performance enhancing chemical in absorber towers.

Dead Band - In control circuits, the zone between the start of an action and when the action is reversed. This prevents the control action from cycling back and forth too quickly. In a home, the furnace starts when the temperature reaches a certain point. It continues to run until the temperature rises several degrees. This range of temperature is the dead band of the furnace control.

Denier - A weight-per-unit-length measure of any linear material. The size of yarns used in woven fabrics including scrims is defined or designated by denier.

deNOx - An abbreviation used to refer to the destruction of NOx by some process.

Density - The weight of a material divided by the volume of the material.

Dew point - The temperature of a gas at which condensation occurs. May be water dew point or acid dew point.

Diaphragm Valve - A compressed air valve operated by a pilot solenoid valve used to clean the filters in pulsejet or plenum pulse collectors.

Differential Pressure - The change in pressure or the pressure drop across a component or device located within the airstream;

the difference between static pressures measured at the inlet and outlet of a component, compartment or device (i.e., between the dirty and clean sides of filter bags and tubesheet).

Dimensional stability - Ability of the fabric to retain its size in hot or moist atmosphere.

Discharge Electrode (DE) - The part, which is installed in the high voltage system to perform the function of ionizing the gas and creating the electric field. Typical configurations are: rigid frame, weighted wire, rigid discharge electrode.

Discharge Electrode Rapper - The device for imparting vibration or shock to the discharge electrodes in order to dislodge dust accumulation.

Dolomite - A mineral composed of calcium carbonate and magnesium carbonate found in limestone deposits. It has the chemical formula $CaMg(CO_3)_2$.

Drag - Normalized value for pressure drop wherein pressure drop is normalized by dividing by the gas velocity. This property allows comparison of one dust/filter medium to another on a common basis and at various parts of the filtration cycle.

Dry FGD - An FGD process comprised of contacting a sulfur oxide containing flue gas with an alkaline material without saturating the flue gas and producing a dry waste product or dry by-product.

Duct - A gas passage or space between two parallel collecting plate surfaces. Duct widths now typically vary from 9 to about 16 inches (229-400 mm). An electrostatic precipitator forms an electrical capacitor between the DE assemblies and the grounded collecting plates on each side thereof in each duct. Effective capacitance of typical ESP is 30 - 40 picofarad/m2 plate area (9-10" ducts, wire DE).

Durometer - A device for measuring the firmness of a material. A spring forces a small diameter foot into the material being tested. The amount of force required to push the foot down until the material is exerting the same force back is the Durometer reading measured on a scale specified by the size of the foot. Rubber is typically measured using the Shore A scale.

Dustcake - Dust layer on filtration surface. A certain amount of porous dustcake is necessary for filtration purposes unless the fabric is a surface filtration type (BHA-TEX or spun bonded fabric).

Dust (or Mist) Concentration - The weight of dust or mist contained in a unit of gas, e.g., pounds per thousand pounds of gas, grains per actual cubic foot of gas, or grains per standard dry cubic foot (the temperature and pressure of the gas must be specified if given as volume). Metric equivalents are grams or milligrams/Kg of gas or milligrams/m3 of gas.

Dust Loading - The amount of solid particulate suspended in an air (gas) stream, usually expressed in terms of grains per cubic foot, grams per cubic meter or pounds per thousand pounds of gas.

Effective Cross-Sectional Area - Effective width times effective height.

Effective Height - The total height of collecting surface measured top to bottom.

Effective Length - The total length of collecting surface measured direction of gas flow.

Effective Migration Velocity - This parameter, defined by the Deutsch-Anderson relationship, is related to the average speed with which dust particles in an electrostatic precipitator move towards the collecting electrode. Values are generally stated in terms of ft/min. or cm/sec.

Effective Width - Total number of gas passages multiplied by spacing dimension of the collecting surfaces.

Electrical Set - May refer to the complete high voltage power supply energizing a precipitator section, or to the TRANSFORMER-RECTIFIER SET, per se, which is a major part of said power supply. The other principal parts of the complete ESP power supply include the special LINEAR REACTOR connected in series with the transformer primary circuit, and the CONTROL UNIT.

Electrostatic Precipitator (ESP) - A unit comprised of a series of parallel vertical plates through which the flue gas passes. It electrically charges the ash particles in the flue gas to collect and remove them.

End - same as warp thread

End count - Same as warp count

Energy - Most of the world's convertible energy comes from fossil fuels that are burned to produce heat that is then used as a transfer medium to mechanical or other means in order to accomplish tasks. Electrical energy is usually measured in kilowatt-hours, while heat energy is usually measured in British thermal units.

EPA - Environmental protection Agency.

ESP - Abbreviation short form of ELECTROSTATIC PRECIPITATOR or ELECTRO FILTER.

Ex situ oxidation (wet FGD) - Forced oxidation that occurs outside of the scrubber and is used to produce FGD gypsum.

Excess Air - This is the amount of air in a boiler combustion zone that is in excess of the amount of air that is required to completely burn the fuel.

Exothermic - A chemical change in which there is a liberation of heat, as in combustion.

Extractive Continuous Emission Monitor - A CEM that draws exhaust gas away from the combustion system to the measurement equipment through special ducts.

Evaporative Gas Cooling - Water is sprayed into a hot gas stream. Energy is absorbed by the water as it is transformed from a liquid to gas, thus reducing the temperature of the gas stream. This technology is used to condition a gas stream to optimize the efficiency and reliability of air pollution control equipment. Also called adiabatic gas cooling.

Extensibility - Stretching characteristics of fabric under specified conditions.

Fabric - A collective term applied to cloth no matter how constructed and regardless of the kind of fiber used. In the commonest sense, it refers to a woven cloth.

Fan - A device for moving air and dust through the system. If the fan is on the dusty side of the collector pushing the dust-laden air through the collector, it is called a positive system. If the fan is on the clean airside of the collector pulling the air through the collector, it is called a negative system. (Most collectors are negative systems)

Federal Energy Regulatory Commission (FERC) - A quasi-independent regulatory agency within the Department of Energy having jurisdiction over interstate electricity sales, wholesale electric rates, hydroelectric licensing, natural gas pricing, oil pipeline rates, and gas pipeline certification.

Felt (Needled) - A fabric produced by using barbed needles to interlock carded fibers.

Felted bag - Type of bag frequently used on pulse-jet dust collectors. Features a thick mat of fibers supported by a woven backing or scrim.

FGD Material - This wet thixiotropic sludge from limestone-based reagent wet scrubbing process is predominantly calcium sulfate dihydrate, which is gypsum. This material readily dewaters, and there are systems in use where the slurry is transported to a pond and construction equipment is used to excavate and stockpile the gypsum.

Fiber - A slender, elongated structure of synthetic material. A group of fibers that form a single substance, such as flax.

Field (In depth) - An arrangement of bus sections perpendicular to gas flow energized by one or more high voltage power supplies.

Fill - crosswise threads woven by loom. Yarn running from selvage to selvage at right angles to the warps in woven fabrics.

Fill count - Number of fill threads per inch of cloth.

Fill Yarn - An individual yarn, which interlaces with the warp yarn at right angles in a woven fabric. Also known as a pick or filling pick. These run around the circumference of the bag.

Filter cake - the accumulation of dust on a bag which often assists in the filtration process or the material produced by filtering equipment such as vacuum filters for dewatering wet FGD material.

Filter Drag - The ratio of differential pressure across the filters (differential pressure, inches or mm W.C. to velocity through the filters (air-to-cloth ratio, MPM meter/minute)

Filter Media - The permeable barrier employed in the filtration process; the fabric on which the filter cake is supported.

Filtration - A process by which particles are separated from a fluid stream by use of a permeable barrier.

Fixation - A process of stabilization of sludge involving the addition of reagents causing chemical reactions with the sludge, generally of a cementatious nature.

Flange-to-flange - The APC equipment from inlet flange to outlet flange.

Float - The position of a yarn that passes over two or more yarns passing in the opposite direction.

Flocculant - Charged polymers used in industry for clarifying suspensions. They cause suspended colloidal matter to aggregate, forming particles that are large enough to settle out under gravity.

Flue Gas Desulfurization Unit (Scrubber) - Equipment used to remove sulfur oxides from the combustion gases of a boiler plant before discharge to the atmosphere.

Fluoroelastomers - A class of synthetic rubber which provide extraordinary levels of resistance to chemicals, oil and heat, while providing useful service life above 200 degrees C. The outstanding heat stability and excellent oil resistance of these materials are due to the high ratio of fluorine to hydrogen, the strength of the carbon-fluorine bond, and the absence of unsaturation.

Fly ash - Dust from a furnace; the term distinguishes the ash that is entrained in the gas from bottom ash which drops to a grate or pan at the bottom of the furnace. The fly ash particle diameter is less than .0001 meter. This is usually removed from the flue gas using flue gas particulate collectors such as baghouses and electrostatic precipitators.

Flywheel - A heavy wheel for regulating the speed and uniformity of motion of the machine to which it is attached.

Fossil Fuel - Any naturally occurring organic fuel, such as petroleum, coal, and natural gas.

Fouling - The formation of high temperature bonded deposits on convective heat absorbing surfaces.

Gas Distribution Devices - Internal elements in the transition or ductwork to produce the desired velocity contour at the inlet and outlet face of the precipitator. (See Gas Distribution)

Gas Distribution Plate Rapper - A rapper used to prevent dust buildup on gas distribution devices.

Gas Passage - A duct formed by two adjacent rows of collecting surfaces.

Gas sneakage - Bypassing of dust laden gas around ESP electrified regions, such as through hoppers and above the collecting plates.

Gas-to-cloth ratio - Gas volumetric flow rate/cloth area...the amount of process gas entering the fabric filter dust collector divided by the amount of cloth area filtering the dust from the air. Normally the gas flow is given in CFM and the cloth in square feet.

Generating Unit - Any combination of physically connected generator(s), reactor(s), boiler(s), combustion turbine(s), or other prime mover(s) operated together to produce electric power.

Generation - Gross - The total amount of electric energy produced by the generating units at a generating station or stations, measured at the generator terminals.

Generation - Net - Gross generation less the electric energy consumed at the generating station for station to station use.

Generator Nameplate Capacity - The full-load continuous rating of a generator, prime mover, or other electric power production equipment under specific conditions as designated by the manufacturer.

Gigawatt (GW) - One billion watts of capacity.

Glazing - High-pressure pressing of the filter medium at elevated temperatures; fuses surface fibers to the body of the filter medium.

Grab tensile - The tensile strength, in lb/in, of a textile sample cut 4 in. by 6 in. and pulled in two lengthwise by two 1 in. sq. clamp jaws set 3 in. apart and pulled at a constant specified speed.

Grain - A dust weight unit commonly used in air pollution control equal to 1/7000 lb.

Grain Loading - The amount of particulate by weight in a given volume of air (Grains/ft3); 1 lb (0.454 Kg) = 7000 grains.

Greenfield Unit - A newly constructed generating unit.

Greige (Grey, Greige, Gray) - Cloth, regardless of color, that has been woven in a loom, but has received no dry or wet finishing operations. Unfinished woven fabric.

Grits - The hard, coarse particles that will not dissolve in a lime slaker and must be removed and disposed of.

Gypsum - Formed from forced oxidation in a calcium-based FGD process. Also, a precipitated gypsum formed through the neutralization of sulfurous acid (H_2SO_3) in FGD process at coal-fired power plants. This gypsum can vary in purity, which is defined as the percentage of $CaSO_4*2H_2O$, and generally is over 94% for use in wallboard manufacturing.

Hardgrove Grindability Index (HGI) - A measure of the relative ease with which coal can be pulverized or ground. Higher grindability indicates coal which are easier to grind.

Header - A pressurized pipe that contains the compressed air supply for a pulse type baghouse.

Heat Set Finish - Heat finishing treatment that will stabilize many man-made fibers so that there will be minimal change in shape or size.

High Voltage Bus - A conductor enclosed within a grounded duct.

High Voltage Conductor - A conductor, which carries the high voltage from the transformer-rectifier to the precipitator high voltage system.

High Voltage Power Supply - The supply unit, which produces the high voltage required for precipitation, consisting of a transformer-rectifier and controls.

High Voltage System - All parts of the precipitator, which are maintained at a high electrical potential.

High Voltage System Support Insulator - A device, which physically supports and electrically isolates the high voltage system from the grounded structure.

Hopper - The vessel at the bottom of a precipitator where dust falls as it is rapped from the electrodes.

Hopper Capacity - The total capacity of a hopper measured from a point some distance below the high voltage system or plates, whichever is lower.

Hot side ESP - An ESP, which is installed upstream of the air heater.

Hot-Wire Anemometer - A device that measures gas flow by its cooling effect on a heated element. Air velocities of centimeters per second can be measured by this method.

Hydrated Crystal - The natural form of many crystalline materials. Some water has been chemically combined in the crystal matrix.

Hydrated Lime - Calcium Hydroxide ($Ca(OH)_2$) that is formed by reacting quicklime and water in a lime slaker.

Hydroclone - A device for separating particles of varying densities in a liquid steam by spinning the liquid rapidly in a cyclonic manner and drawing off product steams at various locations in the cyclonic profile.

Hydrogen Sulfide - H_2S is a colorless highly toxic gas that is heavier than air and has a "rotten eggs" odor.

Hydrolyzer - This kettle reboiler style heat exchanger is used to convert a solution of urea into a mixture of ammonia, carbon dioxide and steam.

Hydrophilic fibers - Fibers that do not readily absorb water.

Hydroxyl Group - The term used to describe the functional group -OH when it is a substituent in an organic compound. Organic molecules containing a hydroxyl group are known as alcohols and have the formula $C_nH_{(2n+1)}$-OH, the simplest of which is methyl alcohol (CH_3-OH)

Hygroscopic - Attracting or absorbing moisture from the air.

Impedance Device - A linear inductor or current-limiting reactor required to work with SCR-type controllers. A transformer with a specially designed high impedance core and coils. Saturable core reactor. Resistors.

Impingement - the physical contact of dust laden gas flow against a filter media. Typically referring to an abrasive wear caused by this impact.

Inch of Water - A unit of pressure equal to the pressure exerted by a column of liquid water one inch high at standard conditions(70 degrees F or 21 degrees C @ sea level); 27.7 inches of water (703 mm w.c.) = 1 psi (69 mbar); usually expressed as inches water gauge (w.g.) or inches water column (w.c.)

Inlet dust loading - A measure of the particulate matter entering an ESP expressed in grains of particulate matter per actual cubic foot of flue gas.

Inside Collection - Particles are collected on the inside surface of the bag (most reverse air and most shaker baghouses).

In Situ Continuous Emission Monitor - A CEM that makes measurements directly in the flue or exhaust pipe.

In Situ Oxidation (wet FGD) - A process in which both SO_2 absorption and oxidation are carried out within the scrubber.

In-situ Resistivity - Particle resistivity as determined by a probe inserted into the flue gas stream.

Insulator Compartment - An enclosure for the insulator(s) which supports the high voltage system (may contain one or more insulators).

Interfacing - Openings between the interlacings of the warp and filling yarns in a fabric.

Interstices - The opening between the interlacings of the warp and filling yarns, i.e. the voids in the fabric through which air/gas passes.

Isokinetic Sampling - A sampling of the flue gases drawn from the mainstream of the gas into the sampling apparatus with no change of velocity.

Kiln - A furnace or oven for drying, burning, or baking something.

Kilowatt (kW) - One thousand watts of capacity.

Kilowatt-hour (kWh) - One thousand watthours.

Linear Reactor - A vital element for assuring reliable, stable electric energization at optimum current densities and highest ESP performance capability. It is an iron-core, convection-cooled inductance whose value is chosen according to rated power supply DC current output. The reactor has several important functions:

1) Essential series circuit impedance in the primary of the HV transformer acting as a ballast for stability with sparking load and limiting peak power supply current flow during ESP sparking to safe values.

2) ESP current waveform control adjustment capability to match power supply ratings to load demands for the best ESP performance and to prevent premature sparking.

3) Proper inductance values for TR Set ESP current conduction times of 70-86% maximum time between current pulses of 8.333 milliseconds (FW energization) provides for fast voltage and current recovery following a spark.

4) Slow down otherwise very steep rate of rise of currents when main SCRs are turned on and off 120 times a second, and protect silicon diodes in HV rectifier from damage by securing a nearly half sine wave shape for the ESP current pulses.

It is not the installed TR Set capacity that does the job; it is only the actual voltages and currents drawn under optimum conditions of electrode geometry, electrode alignment, and TR Set match to load that counts. In cases where high power TR Sets are running at only 10-50% of rated current capacity that major gains in useful electrical energy and ESP performance can often be realized by using an appropriately larger size reactor inductance to match a revised TR Set rating more closely to the ESP current needs at hand. The larger inductance is chosen to increase the ESP current conduction time to the optimum range of 70-86% instead of the original short conduction time of perhaps 25-55%. The broader current pulses result in significant increases in average DC precipitator currents and voltages, reduce premature sparking due to narrow current pulses and peaky voltage waveforms which limit useful current unnecessarily. Achieving the best possible electrical energization quality pays off handsomely in high ESP performance. In cases where proper operating currents are unknown, or to accommodate possible shifts in coal quality, etc., from time to time, it is convenient to use tapped linear reactors to cover a range from say one-half to full load in three taps.

Landfill - A site for the disposal of all conducive wastes. Landfill configuration may be heaped, side hill or valley fill.

L/G - Liquid to gas ratio which is defined as the recirculated absorbent liquid flow rate (gpm) divided by the absorber outlet gas flow rate (acfm/1000).

Lignite - A brownish-black coal of low rank with high inherent moisture and volatile matter (used almost exclusively for electric power generation). It is also referred to as brown coal. Lignite contains approximately 9 million to 17 million Btu per ton.

Loom finish - Same as greige cloth.

Low-NO$_x$ Burners - Burners that utilize special arrangements of fuel and air injection ports, which reduce the formation of NO$_x$ during combustion.

Magnehelic Gauge - An instrument used to measure the differential pressure drop between two points in a system.

Maintenance Costs - Maintenance costs are the portion of operating expenses consisting of labor, materials, and other direct and indirect expenses incurred for preserving the operating efficiency and/or physical condition of utility plants used for power production, transmission, and distribution of energy.

Mandrel - A large rotating circular form used as a core around which glass fiber covered with resin is wound creating a cylinder of fiberglass reinforced plastic (FRP)

Manometer - A U-shaped tube filled with a specific liquid. The difference in height between the liquid in each leg of the tube is the differential pressure between the two points being monitored. Used to monitor differential pressure.

Manual Power Supply Control - The manual regulation of high voltage power based on precipitator operating conditions observed by plant operators.

Megawatt (MW) - One million watts of capacity.

Megawatt-hour (MWh) - One million watt-hours of electric energy.

Micron - A unit of length, 1/25,000 of an inch (1/1000 of one millimeter) here used as a measurement of the largest diameter of a particle; 74 microns are equal to a 200 mesh opening.

Migration Velocity - A parameter in the Deutsch-Anderson equation used to determine the required size of an electrostatic precipitator to meet specified design conditions. Values are generally stated in terms of ft/min or cm/sec. See also "effective migration velocity".

Mist Eliminator - That part of an absorber designed to remove entrained liquid droplets from the exiting gas stream.

Mit Flex Endurance Test - A test whereby a filter media specimen is rapidly flexed in an arc under a specified load until fabric rupture occurs. Test conditions are usually: 270 degree arc, 180 cycles/minute, 4 lb load, 1/2 inch width specimen.

Modacrylic - A synthetic polymerized fiber that contains less than 85% acrylonitrile.

Mullen Burst Test - Evaluation of the rupture strength of paper or cloth using a hydraulic diaphragm. Expressed as the pressure per square inch that will burst a two inch diameter test specimen.

Multifilament - Yarn composed of several filaments, which are continuous strands of fiber of indefinite length.

NAAQS - National Ambient Air Quality Standards (U.S.A. Clean Air Act)

Nacolite - A natural mineral form of sodium carbonate used in sodium scrubbing or converted into Soda Ash.

Napping - A scraping of the filter-medium surface that raises the surface fibers. The rupturing of the filling yarns to produce a fleecy surface on woven fabrics.

Needled felt - A felt constructed by the use of barbed needles moving up and down, pushing and pulling the fibers to form an interlocking of adjacent fibers.

Negative Pressure Baghouse - A system where fan is located after the baghouse on the clean air side, pulling air through the system.

NH_3 - This is the chemical symbol that represents ammonia.

Non-Regenerable FGD - Process that consumes the sorbent.

Nonwoven felt - felt made either by needling, by matting of fibers, or by compressing with a bonding agent for permanency.

NOx - This is the chemical symbol that represents a mixture of nitrogen oxide (NO) and nitrogen dioxide (NO_2) that is present in combustion flue gas. The subscript x symbolizes that the ratio of nitrogen oxide to nitrogen dioxide can vary and is unknown at any exact moment in time.

NPDES - As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States.

NSPS - New Source Performance Standards.

Null Period - The period during the cleaning sequence in which neither cleaning nor on-line filtering is occurring, causing a static environment to allow dust to drop into hopper or discharge area.

Opacity - The degree of imperviousness to the passage of light used to measure visual density of stack emissions, usually expressed in percent.

Operations Costs - Operations costs are the components of power production that incur cost for operations that are directly related to producing electricity. The major item is almost always fuel that has to be burned to generate electricity.

OSHA - Occupational Safety and Health Act. (U.S.A.)

Overfire Air - This is the air that is injected into a boiler combustion zone at a location above the burners to complete combustion of the fuel. This is typically done when less secondary air is being injected at the burners to reduce NOX emissions.

Oxidation - When oxygen is added to a material to chemically transform it into a different material.

Oxidation - Forced - An additional unit operation to a wet FGD process that intentionally oxidizes the sulfite specie to sulfate by the introduction of supplemental air or catalysts or both.

Oxidation - Natural - That which results from the reaction of absorbed sulfite specie with dissolved oxygen originating from flue gas and incidental contact with atmospheric oxygen.

Outside Collection - Systems that are designed to collect dust on the outside of the filter. (Pulse-jet/plenum pulse baghouses and some reverse air and shaker baghouses.)

Particle resistivity - The electrical resistance (inverse of conductivity) of fly ash particles expressed in units of ohm-cm.

Particle size - The diameter in micrometers of a particular piece of particulate matter.

Particulate matter - Solid or liquid particles entrained in a gas stream.

Penthouse - An enclosure over the precipitator, which contains the high voltage insulators.

Permeability - The property of being open to the passage or penetration of gas or liquid through a material. A measure of fabric porosity or openness, expressed in cubic feet of air per minute per square foot of fabric at a 0.5 in. w.c. (13 mm w.c.) pressure differential.

pH - A measure of acidity or alkalinity that ranges from 0 to 14. A pH measurement of 7 is regarded as neutral. Measurements below 7 indicate increased acidity, while those above indicate increased alkalinity.

Photohelic Gauge - An instrument used to measure differential pressure that has adjustable set points for starting and stopping the filter cleaning in order to maintain the desired range of operating differential pressure.

Pitot Tube - A common instrument used for velocity determination in ducts leading to and from air pollution control devices.

Pitting - An extremely localized form of corrosion that leads to the formation of small holes in metal.

Plain weave - A weave in which each warp yarn passes alternately over each filling yarn.

Plant-Use Electricity - The electric energy used in the operation of a plant.

Plenum - An enclosure typically fabricated of stiffened sheet metal; casing; housing (See clean air plenum).

Plume Rise - As flue gas exits a chimney, it is desirable for it to be buoyant and continue to rise rather than fall back towards the chimney creating a mushroom shaped cloud. Heat is sometimes added to increase buoyancy or a restriction at the chimney exit is added to increase exit velocity and insure proper plume rise.

Ply - Two or more yarns joined together by twisting

PM - Particulate Matter

Poppet Valve - A valve utilized to isolate compartments and/or allow for reverse airflow through individual compartments. Typically constructed of a flat wafer plate assembled on the end of the shaft of an air cylinder, which drives the wafer (poppet) into position against a seat or ring, which causes the seal.

Porosity - Sometimes erroneously used as a synonym for permeability. Originally a designation for the amount of air in a fabric, i.e. blankets.

Positive Pressure System - A system with a fan located prior to the collector on the dirty side, pushing air through the system.

PPB - Parts Per Billion

PPM The concentration of one material mixed with another material expressed in parts per million. A 3 ppm solution of salt in water would be 3 pounds of salt added to one million pounds of water.

Precipitate - To cause a slightly soluble substance to become insoluble and separate out of a solution.

Precipitator Current - The rectified or unidirectional average current to the precipitator.

Precipitator Gas Velocity - A figure obtained by dividing the volume rate of gas flow through the precipitator by the effective cross-sectional area of the precipitator. Gas velocity is generally expressed in terms of ft./sec. And is computed as follows:

Velocity = Gas volume (ACFM) divided by Effective cross-section area (ft2) or actual meters cubed divided by sq. meters (Effective cross-section is construed to be the effective field height x width of gas passage x number of passages.)

Precoat - Material added to the air stream on initial process startup to aid in establishing an initial dustcake on the filter bags.

Pressed felt - A type of felt manufactured by pressing fibers into a scrim.

Pressure Drop - A measure of the resistance the gas stream encounters as it flows through a collection system. May refer to pressure differential across the tubesheet, across the entire collector or the pressure drop across the entire system. Commonly referred to as Delta P; see differential pressure.

Primary Air - This is the air that is injected into a burner along with the fuel. This air transports the fuel into the burner.

Primary Current - The current in the transformer primary.

Primary Voltage - The voltage across the primary of the transformer.

PSD - Prevention of Significant Deterioration (U.S.A. Clean Air Act)

PSI - Pounds per square inch; a unit of pressure; 1 psi equals 27.7 in. (70.35 cm) water gauge or 2.04 in. (5.18 cm) mercury (Hg).

Pulse Cycle - On a pulse-jet baghouse, the interval of time between one pulsing of a row of bags and the next pulsing of the same row.

Pulse Duration (On-time) - The length of time a pulse lasts, generally described as the length of time the electrical signal holds the solenoid pilot valve open. However, due to mechanical losses, the time the diaphragm is open will vary.

Pulse Interval (Off-time) - Elapsed time between pulses in a pulse-jet collector.

Pulse Jet - Generic name given to all pulsing collectors.

Pulverizers - Mills of various designs used to finely grind the coal which is swept from the mills by air for pneumatic transport directly to the burners.

Pyramid Hopper - A hopper shaped like an inverted pyramid.

Quarry - A place where stone is excavated.

Quicklime - Calcium Oxide (CaO) that has been produced by a calcination process where crushed limestone is fed through a kiln and the heat of the kiln drives the carbon dioxide (CO_2) from the limestone ($CaCO_3$).

Radiant Cooling - A method of reducing exhaust gas stream temperature, which involves the use of long uninsulated ducts that allow the gas stream to cool as heat radiates from the duct walls.

Rapper Insulator - A device to electrically isolate discharge electrode rappers yet mechanically transmit forces necessary to create vibration or shock in the high voltage system.

Rappers (Both CE and DE) - May be vibrator or impact (shock) type, the latter preferred. Function is to remove collected dust from collecting plate electrodes and from discharge electrodes. Individual electric type, single impact rappers. The function is to accelerate the metal electrodes away from the deposited material.

Rapping Intensity - Acceleration in multiples of acceleration due to gravity measured at various points on collecting or discharge electrodes. Measured forces should be specified as longitudinal or transverse.

Rapping Re-entrainment - Dust, which has been rapped from the electrodes and is carried back into the gas stream. This process can substantially lower the collecting efficiency of a precipitator.

Reagents - Pure forms of chemicals that are added to a process to react with other chemicals in the process to form reaction byproducts.

Reduction - When oxygen is removed from a material to chemically transform it into a different material.

Re-entrainment - The phenomenon whereby dust, which has been removed from a filter is returned to the air stream. It occurs when dust is cleaned from a filter and then caught again by an upward moving air stream, which re-deposits it on a filter.

Regenerable FGD - Process that regenerates and recycles the sorbent.

Reheat - A heat transfer process by which the absorber outlet flue gas temperature is increased for the purpose of increasing plume buoyancy, reducing a visible plume, or preventing downstream corrosion.

Residence Time - The time period for a given volume of liquid or gas throughput to pass through a vessel. When referred to an absorber, it is defined as the absorber's internal volume through which gas passes (cu. ft.) divided by the absorber outlet flue gas flow rate (acfs).

Resistance - In airflow, caused by friction of the air against any surface or by changing the momentum of the gas.

Resistivity - The electrical resistance that a meter cube of a substance (usually of packed dust) has when measured between opposite faces of the cube. The units are ohm-meters (or ohm-centimeters - a resistivity of 1 cm is equivalent to a resistivity of 100).

Retention Tank - Provides residence time for the absorbent recirculation flow for the purpose of allowing sufficient time to complete chemical reactions.

Reverse-air Baghouse - A unit employing reverse flow flushing air to clean the dust from the bags.

Rings - metal bands sewn in the bag at various intervals to prevent bag from total collapse while cleaning.

Rotary Airlock Valve - A material handling valve that transfers material in pockets formed by vanes mounted on a turning shaft similar to a paddle wheel. This star wheel shaped shaft rotates in close fitting housing that provides a dust-tight seal while still transferring material through the valve.

Rotating Vane Anemometer - A windmill-like device, small enough to be held in the hand, for measuring air speed and direction.

Safety Ground Device - A device for physically grounding the high voltage system prior to personnel entering the precipitator. The most common type consists of a conductor, one end of which is grounded to the casing, the other end attached to the high voltage system using an insulated operating lever or handle.

Saturable rectifier - A variable impedance device to regulate the current at the transformer primary.

SCA - Specific collecting area, given by the square feet of collecting area per 1000 acfm of flue gas.

Scale - Any thin, flaky or plate like layer or coating which forms on the inside of metal containers.

SCFM - Standard cubic feet per minute. The volume of dry gas flow per minute at standard temperature and pressure conditions (70 degrees F or 21 degrees C @ sea level). Other standards such as 32 degrees F and 29.92 inches of mercury (chemical engineers) and 60 degrees F, 30 inches of mercury saturated (American Gas Assn.) may be used. Always specify which standard.

Scouring (ESP) - The process in which collected dust is removed from the collecting electrodes by the gas flow. Usually associated with a region of high velocity.

Scouring (FF) - Process of removing the starches and lubricants, which were applied to fabric to protect it during weaving. Fabrics that have been scoured are generally softer and better withstand clean action. Same as coronizing.

SCR – Selective Catalytic Reduction.

Scrim - An open mesh, plain-weave cloth used as the base in some felted fabrics.

Scrubber - Any of several forms of chemical/physical devices that remove sulfur compounds formed during coal combustion and especially from coal-fired power plants.

Scrubber Sludge - Another name for wet FGD material

Secondary Air - This is the air that enters a boiler around the periphery of the burners. This air is needed to complete the combustion of the fuel as it exits the throat of the burner.

Secondary Current - The current in the transformer/rectifier secondary is the main energy source.

Secondary Voltage - The voltage as indicated by AC voltmeter across the secondary of the transformer.

Seeding - The application of a relatively coarse, dry dust to a bag before startup to provide an initial filter cake for immediate high efficiency and to protect bags from blinding. Also called precoating.

Selective Catalytic Reduction (SCR) - The name of the process where ammonia in the presence of a catalyst bed reacts to remove NOx from a flue gas stream in a moderate temperature external vessel.

Selective NonCatalytic Reduction (SNCR) - The name of the process where ammonia reacts to remove NOx from a flue gas stream in the high temperature section of a boiler.

Selvage - The binding on the lengthwise edge of a woven fabric.

Set Point - In a control circuit, the value when an action by the control system will be initiated.

Shaker baghouse - A unit wherein cleaning is accomplished by shaking the bags.

Silicon Controlled Rectifier (SCR) - A semi-conductor, electronic switch for voltage regulation; two are used in an inverse parallel arrangement for each half cycle, positive and negative. Also called thyristor.

Silicone finish - A treatment with silicone to provide a slick finish for improved dust release.

Sine Wave - A waveform consisting of a positive and negative half cycle, each one lasting 8.33 milliseconds. Based on U.S.A. power generation at a 60 hertz cycle or European at 50 hertz.

Singeing (Singed Finish) - The process of burning off or melting fibers protruding from fabric surface by passing it over a flame or heated copper plates. Singeing gives the fabric a smoother surface, which aids in dustcake release, particularly in applications where moisture is a problem.

Sinusoidal - Moving in simple harmonic motion according to the function A sin (2 p f t) where A is the amplitude of the wave, f its frequency, and t is time.

SIP - State Implementation Plan

Sizing - A protective coating applied to yarn to ensure safe handling.

Slagging - The formation of molten, partially fused resolidified deposits on furnace walls or other surface exposed to radiant heat.

Slaker - A device to mix quicklime and water in such a manner as to cause a chemical reaction producing calcium hydroxide.

Slip - The proportion of dust escaping from the precipitator outlet. Slip may be expressed as a decimal fraction, or a percentage. It is usually estimated by dividing the outlet dust burden by the inlet dust burden. Also used to quantify conditioning materials such as sulfur trioxide and ammonia leaving the precipitator.

Slippage - The movement of yarns in a fabric due to insufficient interfacings.

Slurry - A mixture of liquid suspended solids (e.g. recycle slurry, lime slurry).

SNCR – Selective non-catalytic reduction.

Sneakage - The process in which dust-laden gas escapes through the treatment zone, either through the top, bottom or around the sides. Each percent of gas sneakage reduces the attainable precipitator collecting efficiency by almost one percent.

Soda Ash - The manufactured form of sodium carbonate used in sodium based scrubbing.

Solenoid Valve - Often times referred to as a "pilot valve", it is an electromechanical plunger energized to either a "normally closed" or "normally open" position to allow for relief of air pressure. In a baghouse, the solenoid valve is normally used to activate a compressed air device.

Soluble - Can be dissolved; capable of passing into solution.

Space-Charge - The charge present (as dust particles, gas ions, and free electrons) in the space between the electrodes. Space-charge modifies the local electric field in an electrostatic precipitator in a way analogous to spacecharge modifying the field inside a thermionic diode. The space-charge strengthens the field near the collecting electrode (anode) and weakens the field near the discharge electrode (cathode).

Spark - A short, self-extinguishing discharge from the high voltage system to the grounded system. Sparks effectively cause the gas stream to act as a conductor.

Specific Collecting Area (SCA) - A figure obtained by dividing total effective collecting surface of the precipitator by gas volume expressed in thousands of actual cubic feet per minute. In the metric system it is expressed as square meters per thousand actual cubic meters per hour.

Specific Corona Power - The quotient of the total corona power of all precipitator bus sections divided by the total gas volume handled by the precipitator, multiplied by 1000. Units are expressed as watts/1000 acfm.

Specific Gravity - The ratio obtained by taking the density of a volume of a material and dividing it by the density of the same volume of water.

Specific Resistance Coefficient of the Filter Cake - An indicator of how rapidly pressure drop increases during filtration.

Spray Tower Cooler (Conditioning Tower) - A tower or cylinder into which a hot gas stream enters and water is sprayed. As the water evaporates, the gas stream is cooled to the desired exit temperature by adiabatic cooling.

Spun fabric - fabric woven from staple spun fiber; same as staple.

Spunbonded - A non-woven fabric formed by producing, laying and self-bonding a web of filamentous material in one continuous set of processing steps. Usually made of polyester, polyamides or olefins.

Stabilization - The addition of fly ash, soil or other similar material to induce physical changes without chemical interaction between the additive and the sludge.

Staple fiber - Short fiber cut to specific length in synthetics, 1.5 in., 2 in., 2.25 in., etc. Also, natural fibers of a length characteristic of fiber, animal fibers being the longest.

Stoichiometry - The ratio of how much lime or limestone was added to the scrubber to remove a quantity of SO_2 divided by the theoretical amount of lime or limestone that should have been used to remove that same quantity of SO_2.

Sub bituminous Coal - A dull black coal of rank intermediate between lignite and bituminous. The contents of sub bituminous coal ranges from 16 million to 24 million Btu per ton.

Sulfate Reducing Bacteria - A group of anaerobic bacteria (i.e. don't need oxygen) that obtain energy from iron or sulfur and generate hydrogen sulfide (H_2S).

Sulfate Saturation - The maximum concentration of the sulfate ion per unit volume of slurry or solution, above which the sulfate specie crystallizes as an alkali or earth alkali salt.

Sulfur - One of the elements present in varying quantities in coal which contributes to environmental degradation when coal is burned.

Sweepage - Sweepage is the process by which gases passing beneath the electrodes of a precipitator pick up dust from the hoppers and carry it out of the precipitator. Sweepage can severely limit precipitator efficiency and is usually controlled by means of baffles.

Tadpole Tape - A gasket material that has a flat cross section with a large bulbous section attached to one edge. It gets its name since this cross section looks like a tadpole.

Temperature - Adiabatic Saturation - The temperature, below which for a given mixture of gas and vapor, no additional vapor can be added at specified conditions (partial pressure of vapor is equal to vapor pressure of the liquid at the gas-vapor mixture temperature).

Temperature - Approach - The difference between the actual temperature of a given gas-vapor mixture and the adiabatic saturation temperature of that gas-vapor mixture.

Temperature - Spray Down - The difference between the inlet and outlet temperature of flue gas passing through an absorber.

Tensile Strength - The force required to pull apart the fabric; this is designated by the measure of resistance to a testing machine (in pounds) that a fabric provides before the material breaks. The test strip width depends on the type of fabric.

Tenter frame - A machine for drying cloth under tension (Tentering: also called framing).

Texturized Yarn - Filament glass yarn that has been processed by high pressure air passing through the yarn to open of the yarn bundle, providing more surface area.

Thickener - A large diameter vessel with a conical bottom used to separate solids from a liquid using the principal of gravity settling in a large still volume of liquid.

Thiosulfate - The ion S_2O_3 which is a strong reducing agent. In the photographic process, it dissolves the silver salts and is known as a fixer in developing films and prints.

Thixiotropic - A thixiotropic material is one that becomes more liquid as higher shear stresses are applied to it. When the stresses are removed, the material behaves more like a solid.

Thread count - The number of warp and filling yarns in a fabric.

Throw - A process of doubling or twisting fibers into a yarn of the desired size and twist.

T/R (TR) - Transformer rectifier.

Titanium Dioxide - This material is the primary ingredient of SCR catalyst. It forms the ceramic structure that holds the other constituents of the catalyst. The titanium dioxide does not take part in the reactions with the NOX

TR Set - Consisting of an oil or liquid insulation filled tank containing the high voltage transformer, a silicon diode, full-wave (FW) bridge rectifier assembly and usually a high voltage resistance divider calibrated for indicating the ESP operating voltage on an external kilovolt (KV) meter. On top of the tank is the high voltage output bushing, which is connected via pipe and guard to the HT frame of a typical ESP section. The TR Sets are located on the ESP roof. A nameplate on the tank specifies all connections and ratings. A tank with two HV bushings is equipped for HW (half-wave) energization - rarely used in modern ESPs.

Transformer/Rectifier - A unit comprising a transformer for stepping up normal service voltages to voltages in the kilovolt range, and a rectifier operating at high voltage to convert AC to unidirectional current (DC).

Treatment Time - A figure, in seconds, obtained by dividing the effective length in feet of a precipitator by the precipitator gas velocity figure calculated above. The length of time it takes process gas to move through the treatment zone.

TRI - Toxic Release Inventory

Trona - A natural mineral form of sodium carbonate used in sodium scrubbing or converted into Soda Ash.

Tubesheet (Cell Plate) - The steel plate with holes to which the open ends of bags and cages are connected; separates the clean air and dirty air sections of the baghouse.

Turning Vanes - A gas distribution device in which vanes in ductwork or transition guide the gas and dust flow to minimize pressure drop and control the velocity and dust concentration contours.

Turnkey - Complete APC system including all dust pickups, ducting, dust discharge auxiliaries and all equipment, which is part of the dust collection system.

Twill weave - Warp yarns floating over or under at least two consecutive picks from lower left to upper right, with the points of intersection moving one yarn outward and upward or downward on succeeding picks, causing diagonal lines in the cloth.

Twist - The number of complete spiral turns in a yarn, in a right or left direction, i.e., "Z" or "S", respectively.

U-Tube Manometer - (see Manometer)

Upper Weather Enclosure - A non-gas-tight enclosure on the roof of the precipitator to shelter equipment (T/R sets, rappers, purge air fans, etc.) and maintenance personnel.

Urea - Urea is a solid material that is typically used as a fertilizer. If it is dissolved in water and then subjected to heat and pressure, it can be converted to ammonia for use in the SCR process. Some localities have preferred this system because the amount of ammonia present in the system at any moment in time is very small.

Utilization - A measure of the extent to which the alkali added to the absorber reacts with SO_2.

Vacuum Filter - A mechanical continuous dewatering device, usually of a rotary drum design, which draws air and filtrate through a filter cloth coated with cake or sludge to be dewatered.

Valeric Acid - An organic acid produced by the degradation of dibasic acid in an absorber tower. Valeric acid can have a noticeably unpleasant odor.

Vanadium - This metal forms the active catalytic sites in the SCR catalyst where the reaction between the ammonia and NOx takes place.

Venturi - A cone-shaped device located at the top of each filter in pulse-jet collectors into which compressed air is blown. A negative pressure at the top of venturi is created to help pull additional volumes of air down into the filter element during pulsing.

Viscosity - The internal fluid resistance of a substance, caused by molecular attraction, which makes it resist a tendency to flow. Water has a low viscosity, tar has a high viscosity.

VOC - Volatile Organic Compounds

Voltage - The average DC voltage between the high voltage system and grounded side of the precipitator.

Vulcanization - A chemical process in which individual polymer molecules are linked to other polymer molecules by atomic bridges. The end result is that the springy rubber molecules become locked together to a greater or lesser extent. This makes the bulk material harder, much more durable and also more resistant to chemical attack. It also transforms the surface of the material from a sticky feel to a smooth soft surface which does not adhere to metal or plastic substrates.

Warp - The yarn running lengthwise (machine direction) in a woven fabric.

Warp count - Number of warp threads per inch of width.

Waste Product - Waste material that has little or no economic value and must be disposed.

Water Gauge (W.G.) - See "Inch of Water."

Watt-hour (Wh) - An electrical energy unit of measure equal to 1 watt of power supplied to, or taken from, an electric circuit steadily for 1 hour.

Weather enclosure - A non-gas tight enclosure on the roof of the precipitator to shelter equipment and maintenance personnel.

Weave - The pattern of weaving, i.e. plain twill, satin, etc.

Weft - Same as filling.

Weight (fabric) - The nominal weight per square yard of fabric. There is always a manufacturing tolerance on either side of this average weight, which may range from 3% to 8% depending on the product. Example: A 16 oz. (453.6 g) polyester felt has a weight tolerance + or - 1 oz. (28.5g).

Wet/Dry Interface - The zone at the absorber tower inlet where the hot flue gas first comes in contact with the slurry droplets.

Wet FGD - An FGD process comprised of contacting a sulfur oxide containing flue gas with a SO_2 sorbent liquid, saturating the flue gas, and producing a wet waste product or wet by-product.

Woof - Same as filling.

Wovens - Filter media fabrics constructed solely by weaving or interlacing yarns more or less at right angles into a uniform structure.

Yarn - A term for an assemblage of fibers or filaments forming a strand, which can be woven or otherwise formed into a textile material.

Yarn Size (Denier or Count) - A relative measure of fineness or coarseness of yarn. The higher the denier of a filament year, the coarser (heavier) the yarn is. Count is the number of yarns in a weave pattern per lineal inch.