SCR systems are becoming standard design features in new and existing coal-fired power plants
Credit: International Energy Agency

Applying SCR NOx reduction in high-dust environments

Designing SCR systems for treating high-dust flue gases requires special considerations to minimize blockage and erosion, writes Brad Moulton

Fossil fuel-fired power stations around the world face increasingly stringent environmental regulations to control emissions of various species.

Selective catalytic reduction (SCR) systems to reduce nitrogen oxide emissions from coal-fired power plants are becoming standard design features in new and existing coal power plants around the world.

Most coal boiler SCR systems operate in 'high-dust' environments that require detailed knowledge of how fuel ash can impact performance. Lessons learned from SCR installations over the past few decades have allowed Amec Foster Wheeler to optimize their designs to increase NOx reduction while reducing ammonia consumption, flue gas pressure loss and required maintenance.

Emissions of nitric oxide (NO) and nitrogen dioxide (NO_2) from fossil fuel-fired power stations, collectively known as NOx, are regulated in most industrialized countries. Many developing countries pursuing fossil energy options for electricity generation are also instituting NOx regulations. Nearly 50 per cent of NOx emissions originate from stationary fuel combustion sources, most notably coal-fired power plants.

The predominant NOx control technology for coal-fired power plants throughout the world is selective catalytic reduction (SCR), which involves the reduction of NOx to nitrogen (N_2) and water (H_2O) by the reaction of NOx and ammonia (NH_3) with the help of a catalyst:

An ammonia-air or ammonia-steam mixture is injected through an injection grid into exhaust gases containing NOx. The flue gases are thoroughly mixed in a turbulent zone, and then pass through the catalyst where the NOx reduction reactions take place. The process is referred to as "selective" because it takes oxygen from nitrogen compounds only and not from carbon, sulphur, or other oxygenated compounds. The catalyst promotes the reaction, but is not consumed by it.

Placing the SCR system

SCR designs are typically categorized

$$4\,NO + 4\,NH_3 + O_2 \rightarrow 4\,N_2 + 6\,H_2O$$
$$2\,NO_2 + 4\,NH_3 + O_2 \rightarrow 3\,N2 + 6\,H_2O$$

according to their position in the air quality control system. SCRs placed ahead of the particulate control system are referred to as high-dust configurations; SCRs placed behind the particulate control system are referred to as low-dust configurations. There are distinct benefits and drawbacks associated with each option.

In a high-dust configuration, the SCR typically sits between the economizer and the air preheater, upstream of an electrostatic precipitator (ESP) or baghouse. In this configuration, ash levels can exceed 18 per cent of the flue gas and, depending on the coal being fired, the flue gas can contain highly abrasive and erosive solid particulate species.

The primary benefit of the high-dust configuration is that the flue gas temperature (typically 650°F/340°C) is optimum for the catalytic NOx reduction reaction and is also above the temperature required to avoid condensation of ammonium salts onto the catalyst. The formation and presence of ammonium salts reduces the effective catalyst surface area by blocking the catalyst pores. Ammonium salt condensation also can foul heat transfer surfaces in the downstream air preheater.

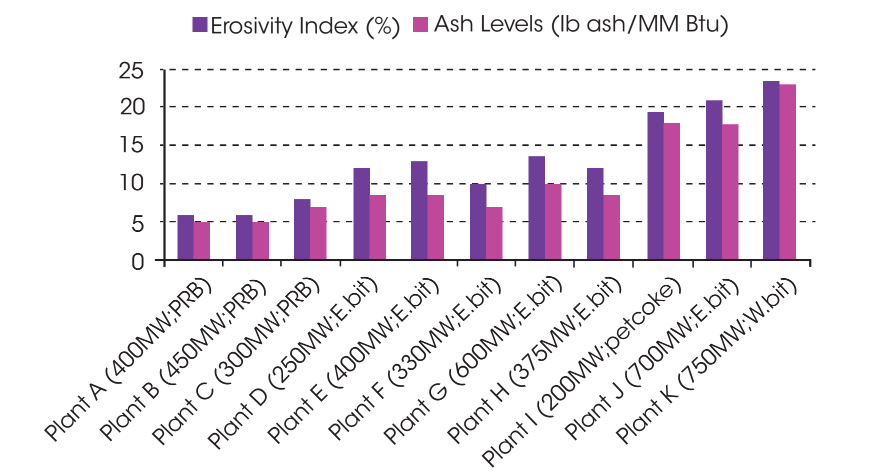

Figure 1. Erosivity index and ash levels for selected plants
Source: Amec Foster Wheeler

The major drawback for high-dust configurations results from exposure of SCR system components to high levels of particulates in the flue gas. The abrasive and erosive nature of the particulates can have detrimental effects on the SCR reactor inlet ductwork, large-particle ash (LPA) screens, ammonia injection nozzles, static mixers, turning vanes, and the catalyst itself. These effects can potentially increase maintenance and catalyst management costs.

In a low-dust configuration, the SCR is installed downstream of the ESP or baghouse, resulting in an essentially particulate-free flue gas stream. This eliminates the need for LPA screens and minimizes abrasion issues, extending catalyst lifetime and reducing maintenance costs.

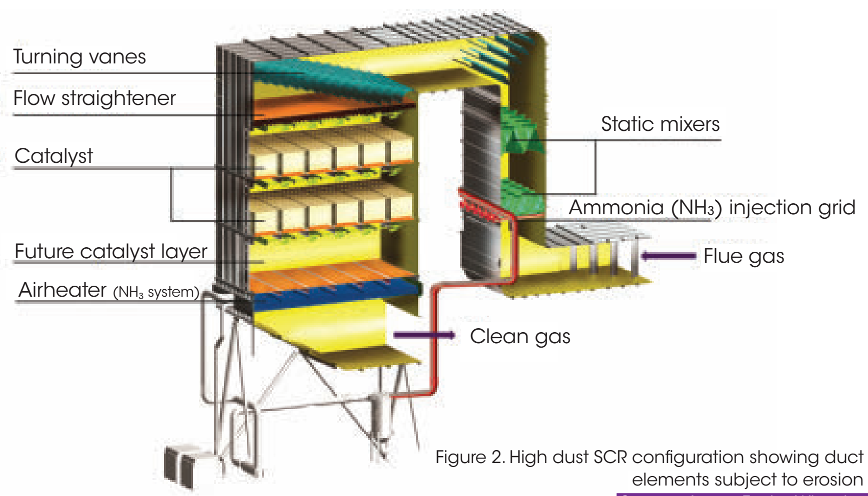

Figure 2. High dust SCR configuration showing duct elements subject to erosion
Source: Amec Foster Wheeler

Because low-dust configurations are farther downstream, however, the flue gas temperature at the SCR is below 450°F and ammonium salt condensation is likely. To avoid formation of ammonium salts, the flue gas must be reheated, which requires the installation of an SCR reheat duct burner.

Typically, multiple 5–10 MMBtu/hour natural gas-fired perimeter burners are installed across the SCR inlet duct cross-section. Each burner requires 15–20 SCFM natural gas affecting overall plant efficiency and operating costs. In addition, the lower temperature decreases the SCR catalyst activity, thus requiring additional catalyst volume for NOx reduction.

Beware of erosion

SCR system designs for coal-fired power plants have generally favoured the high-dust configuration to avoid the negative effects associated with ammonium salt formation.

Globally, over the past 25 years, SCR has been installed on 350+ GW of coal-fired capacity, and over 85 per cent of these systems are installed in high-dust applications. Several key design issues must be addressed for high-dust installations.

The high-dust configuration is characterized by ash levels that can exceed 18 per cent for the flue gas by weight. While coal ash itself has relatively low erosivity, individual constituents can be much more erosive. The Vicker's Hardness (HV) scale provides an indication of the erosivity of specific materials.

The carbonaceous components of bituminous coal are relatively soft, with a hardness of 294 HV. Certain flue gas constituents, however, can be two to six times

Figure 3. Severe erosion of ammonia injection grid nozzle
Source: Amec Foster Wheeler

more erosive: silica (SiO_2) has a hardness of 700–1500 HV and alumina ($Al2O_3$) has a hardness of 1900 HV. These components are main contributors to an 'erosivity index' (Ei) that can be used to quantify the effects of SiO_2, $Al2O_3$ and Fe_2O_3 ash constituents:

Ei = Es + Ef + Ea where Es = % ash in coal/100 x 1.00 x % SiO_2 in ash; Ef = % ash in coal/100 x 0.80 x % $Fe2O_3$ in ash; Ea = % ash in coal/100 x 1.35 x % $Al2O_3$ in ash.

The erosivity index can help inform SCR design decisions. A high value, for example, can lead engineers to make changes to catalyst type, pitch, design velocities and sonic horn spacing. Figure 1 illustrates the erosivity index and ash loading associated with several high-dust SCR projects.

Design considerations

A typical high-dust SCR configuration is shown in Figure 2. Design considerations for specific surfaces subject to erosion and wear are described below.

Depending on the properties of the coal being burned, large particle ash (LPA), also known as popcorn ash, can form in the upper convective heat exchanger surfaces of the boiler. The LPA particles – typically 5–10 mm or more – are conveyed in the high-velocity flue gases to the SCR catalyst, resulting in catalyst erosion and reduced NOx emissions removal.

To prevent catalyst damage, LPA screens can be installed upstream of the Ammonia Injection Grid to capture the LPA, with subsequent removal in the economizer hopper. Hardened materials such as abrasion resistant (AR) plate should be utilized to provide inherent screen strength and minimize erosion effects. Wear-resistant coatings including materials made with chromium oxides, tungsten carbides,etc also can be applied to the screens to reduce erosion and prolong the screen life. An economic analysis is usually warranted to determine if it makes sense to apply the coatings or simply supply an extra screen that would need to be replaced during a later outage – essentially treating the LPA screen as a consumable with a specified replacement schedule. Finally, the frequency of screen rapping with discharge to the economizer hopper should be analyzed given the LPA loading and properties.

The ammonia injection grid (AIG) downstream of the economizer outlet is susceptible to erosion as well. The AIG nozzles protruding into the flue gas stream present an easy target for erosion if abrasive silica and aluminum species were present.

Several protective measures may be needed to limit degradation, such as the severe AIG lance erosion shown in Figure 3. These measures include:

- Erosion allowances – designing the lances with an additional 1/8 inch of materials to account for expected wear;
- 304SS nozzles – using a more wear-resistant material such as 304 stainless steel;
- Wear shields – installing sections of pipe around each AIG header pipe (see Figure 4), penetrating about one foot into the duct; these shields can counteract the effects of high localized velocities near the duct wall where the AIG penetrates into the flue gas.

Flow distribution devices – including turning vanes, static mixing elements, and distribution plates – are installed in the SCR inlet ductwork to ensure homogenous ammonia distribution and uniform flue gas velocity ahead of the SCR catalyst bed. These

Figure 4. Ammonia injection grid lance showing protective wear shield installed near wall
Source: Amec Foster Wheeler

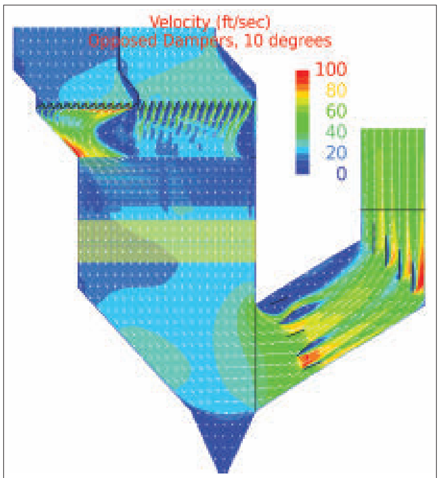

Figure 5. CFD model outputs showing flue gas velocity distribution
Source: Amec Foster Wheeler

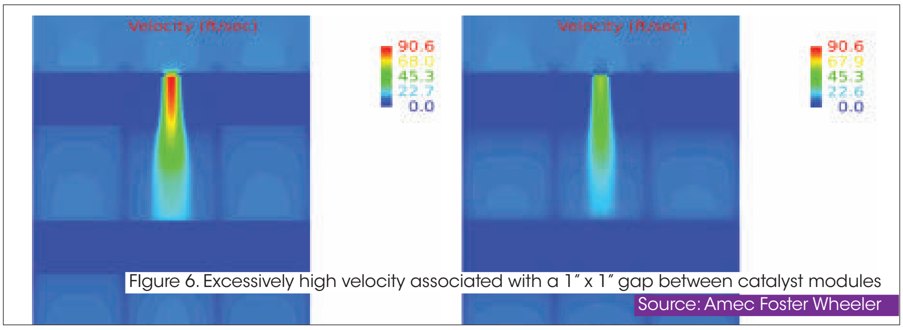

Figure 6. Excessively high velocity associated with a 1″ x 1″ gap between catalyst modules
Source: Amec Foster Wheeler

Figure 7. Proper sealing between catalyst modules
Source: Amec Foster Wheeler

duct additions present another high erosion point within the SCR ductwork. Leading edges of turning vanes, flow mixers, and duct transition sections (constrictions, expansions) should be designed using erosion-resistant wear plate and/or extra thickness (1/16 inch) as deemed necessary.

Reactor sizing

The design size of the catalyst reactor also must consider the erosivity of the intended application. Computational fluid dynamics (CFD) modeling can help in properly sizing SCR systems for high-dust configurations and in determining appropriate velocity distributions.

SCRs that will be used in high-dust environments should be designed with a larger cross-sectional area such that the catalyst face velocity is on the lower end of the design range (8–10 ft/s). This ensures sufficient contact between flue gas and catalyst to effect the NOx reduction reactions. For low erosivity applications, a typically design velocity through the catalyst is in the 12–18 ft/s range.

CFD modeling is particularly useful in determining velocity distributions to minimize pressure drop and particulate dropout. As important, CFD modeling is used to identify high velocities and, therefore, expected high wear locations within the SCR and associated ductwork.

The CFD image in Figure 5 indicates areas of high wear, typically where flue gas velocities exceed 80 ft/s. The model also indicates zones of high velocity near the duct wall. Also, the CFD image shows, as expected, relatively higher velocities at the turning vanes. But it also identifies an expected high wear area in the vertical duct, immediately after the turning vane. Based on this, designers might consider adding additional erosion protection in this section of ductwork.

CFD modeling also can help evaluate potential operational issues, such as those that might occur due to the physical gaps between catalyst modules. The CFD images in Figure 6 illustrate the high-velocity zones caused by a 1″ x 1″ gap between catalyst modules. The SCR inlet ductwork flue gas velocity at full load (90 ft/s) and partial load (61 ft/s) are shown on the left and right images, respectively. Such localized spikes can lead to accelerated catalyst deactivation and increased maintenance costs.

As noted above, velocities in the catalyst bed should be in the 8–10 ft/s range for fuels with high erosivity indices. To tighten the gaps between the catalyst modules, a sealing plate can be installed, as shown in Figure 7.

Full understanding

SCR system design in high dust applications requires a full understanding of the fuel ash constituents and their effects on erosivity. Flue gases containing highly erosive ash components, notably silica and alumina, will contribute to excessive wear on ductwork, LPA screens, AIG nozzles, flow distribution devices, and the SCR catalyst. In turn, this can lead to poor velocity distribution into the catalyst, accelerated catalyst deactivation, and increased catalyst management costs.

Abrasion resistant coatings, erosion resistant wear plate, and wear shields on AIG lances are measures that can alleviate the effects of high erosovity fuels. Proper reactor sizing and catalyst module sealing also will minimize these effects.

For complete design and supply of an SCR system, it is important to select a supplier with the requisite capabilities for addressing a wide range of fuels and operating conditions.

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