Power-Cost Alternative De-NOx Solutions for Coal-Fired Power Plants

By Bin Xu, David Wilson, and Rob Broglio

Traditionally, large coal-fired generating units have complied with NOx emissions standards by retrofitting a selective catalytic reduction (SCR) system. Using such a system, a NOx emission reduction of 90 percent or better can typically be obtained. In view of the current regulatory and legislative challenges faced by coal-fired power generation, in addition to the age and limited remaining operating life of many coal-fired assets, the capital and operating costs of retrofitting an SCR system to a unit may not be economically viable.

This situation has resulted in demand for other more cost-effective NOx compliance measures including fuel selection, low-NOx burners (LNB), over-fire air (OFA) systems, combustion optimization systems, selective non-catalytic reduction (SNCR) technology, and in-duct or advanced SNCR technology. While individually these measures cannot deliver the NOx reduction levels of a traditional full-flow SCR systems, in combination with one another they can deliver significant reductions in NOx emissions at a fraction of the installed cost of an SCR.

Background

NOx is produced by three mechanisms during the coal combustion process:

- Fuel NOx results from the oxidization of nitrogen compounds in the fuel. NOx formed in this way is difficult to minimize. The level of fuel NOx is directly related to the amount of Nitrogen in the fuel.
- Thermal NOx results from the thermal dissociation of nitrogen and oxygen molecules in combustion air. Thermal NOx formation can be effectively reduced by keeping the temperature of combustion as low as possible.
- Prompt NOx results from chemical reactions between nitrogen and carbon radicals generated during combustion. For coal-based combustion, prompt NOx production is generally considered to be minimal.
Available Technologies

Available NOx removal technologies generally fall into two categories: combustion and post-combustion. Combustion control methods can achieve NOx reduction by controlling fuel combustion environmental conditions like flame temperature, fuel:oxygen ratio, and fuel residence time to suppress NOx production in the combustion stage.

**Low-NOx Burners**: LNB use internal air staging to control the mixture of fuel and air. This achieves reduced peak flame temperatures and results in less NOx formation. In a low-NOx burner, the initial fuel combustion occurs in a fuel-rich, oxygen-deficient zone in which NOx is formed, followed by a reducing atmosphere where hydrocarbons react with NOx to turn it into Nitrogen gas. The combustion is completed in an oxygen-lean environment to minimize additional NOx formation.
A low-NOx burner retrofit can achieve NOx reduction on the order of 40 to 70 percent, at an installation cost of $5 to $10 per kilowatt (kW).

**Over-Fire Air:** Furnace OFA technology separates combustion air into two separate streams. A primary flow of between 70 to 90 percent of the total combustion air is routed to the burners, and a secondary flow of 10 to 30 percent of the total combustion air is injected above the burner elevation. This allows two-stage combustion to take place.

In the first stage, the air flow to the burner is mixed with the fuel at the burner, producing an oxygen-deficient, fuel-rich zone in which the formation of fuel NOx is minimized, and the fuel is partially combusted.

In the second stage, the balance of the combustion air is injected through the OFA nozzles into the furnace, where the combustion is completed.

Optionally, boosted over-fire air (BOFA) can be used, where a fan is used to inject the OFA into the unit at a higher velocity. This promotes improved mixing of the OFA and the furnace gases.

OFA technology alone can achieve NOx reduction on the order of 20 to 45 percent, at an installation cost of $4 to $7 per kW.

**Fuel Reburning:** Fuel reburning is a form of fuel-staged combustion usually combined with LNB and OFA. This method separates the combustion into three stages: the primary combustion zone, the reburn zone, and the burnout zone.

In the primary zone, coal is fired through conventional burners or LNB in low excess-air conditions to reduce initial NOx formation. A secondary fuel is injected into the upper section of the furnace to create a secondary sub-stoichiometric reburn zone without combustion air. Natural gas is widely used for this purpose, although coal and oil are being demonstrated.

In 2001, an evaluation by the U.S. Department of Energy (DOE) of fuel gas reburning combined with LNB on a wall-fired boiler reported that 70 percent NOx reduction could be achieved, with estimated installed capital cost of around $26 per kW for a hypothetical 300-MW cyclone boiler fired with 3 percent sulfur coal.

**Fuel Biasing:** Fuel biasing diverts fuel from the upper-level burners to the lower ones to create a fuel-rich lower zone and a fuel-lean upper zone in operation, resulting in a reduction in NOx emissions of up to 30 percent.

**Flue Gas Recirculation:** Flue gas recirculation (FGR) recirculates 20 to 30 percent of the boiler flue gas from either the air heater inlet (hot FGR) or the ID fan outlet (cold FGR) into the furnace or burner. The resulting dilution in the flame reduces flame temperature and availability of oxygen, thereby reducing thermal NOx formation. The FGR technique is used mainly in low-NOx gas burners in gas-fired plants. In coal-fired plants, the FGR can inhibit the combustion efficiency to an unacceptable degree, though FGR injected elsewhere and used as a reheat steam temperature control measure can offer an additional NOx reduction benefit.

FGR technology alone may achieve NOx reduction on the order of 20 percent, at an installation cost of $3 to $5 per kW.

**Combustion Optimization:** Combustion optimization ties combustion control methods together to produce a consistent, controllable furnace combustion process. Often OFA systems and LNB are installed and initially tuned to provide the best NOx performance at a given load on a particular fuel. But when a variable changes (unit operating profile, fuel source, weather), the unit’s NOx performance decreases. When this happens, there is no permanently installed analysis instrumentation like that used in the initial setup of the OFA system and burners. Because of this, the plant operations and maintenance staff cannot retest and further optimize the equipment in a timely or efficient manner. To assist in the maintenance of NOx performance combustion optimization systems, which utilize online gas temperature monitoring and analysis systems that are integrated into the boiler control systems can help to maximize NOx control performance in response to changing conditions.

**Post-Combustion Control Methods**

Post-combustion control methods can reduce NOx emissions by neutralizing the NOx into nitrogen gas via chemical reactions either with or without the use of a catalyst.

**Selective Catalytic Reduction:** SCR is a method of converting NOx into nitrogen and water via chemical reactions that utilize ammonia or urea, with the aid of a catalyst. Typically, the ammonia or urea is injected into the flue gas stream after the economizer and before the air heater. After the reagents are mixed with flue gas in a static mixing device, the flue gas is passed evenly through the catalyst.

Excessive carryover of ash from the furnace can cause the catalyst to plug. Carryover of catalyst-poisoning elements such as potassium...
can also lead to reduction in efficiency of the catalyst. The SCR process is also temperature-dependent, which causes a loss of reaction efficiency at both low and high temperatures.

An SCR system may achieve a NOx reduction on the order of 85 to 90 percent, at a cost of about $100 to $200 per kW.

**Selective Non-Catalytic Reduction:** SNCR is a method used to reduce NOx by injecting either ammonia or urea into the boiler furnace at locations where the flue gas is between 1,600 and 2,100°F. As its name suggests, an SNCR system does not require a catalyst. However, effective SNCR is dependent upon sufficient reaction time within the flue gas temperature window and adequate mixing of the reagent with the flue gas.

It is critical to design an SNCR system to operate within this temperature window. If the temperature is too high, the ammonia will decompose to produce additional NOx. If the temperature is too low, the reaction will not occur, resulting in wasted ammonia. So-called ammonia slip will react with sulfur from the fuel to form ammonium sulfate and ammonium bisulfate, which has a tendency to condense on the cooler surfaces of the air heater and can cause significant loss of efficiency, in addition to mechanical damage.

Historically, the need to control reagent injection to meet the constraints of temperature, mixing, and reaction time has limited SNCR effectiveness and application in utility-scale, coal-fired boilers where gas temperatures are relatively high and temperature profiles are dynamic. However, recent developments in acoustic- and laser-based furnace gas temperature measurement systems have allowed accurate real-time mapping of furnace temperature profiles, which can be integrated into the SNCR control scheme, allowing reliable NOx reductions ranging from 30 to 50 percent.

SNCR has significant economic advantages over SCR. It is a simpler system, does not require an expensive catalyst, and can be installed within a regular plant outage schedule. Installing an SNCR system on a utility boiler typically costs $10 to $20 per kW.

**NOx Reduction Technologies: Capability vs. Cost**

The cost effectiveness of individual NOx reduction methods vary depending on boiler size, fuel type, and design and operation conditions. The table below compares the technical capabilities and economics of available de-NOx solutions for coal-fired power plants. Combustion control methods generally have the lowest installed cost, but do not provide the NOx reduction levels achievable with more traditional full-scale SCR systems. However, when one or more combustion control methods are combined with a relatively inexpensive SNCR system, it is possible to achieve NOx reduction rates similar to that of an SCR system, and at a fraction of the cost.
Some measures are already in place, but the cost-benefit ratio of existing technologies can be further improved. While this approach may not be valid in all cases, clearly a significantly lower-cost solution for NOx compliance may be available for the right application.

**Real Life Experience**

An advanced SNCR de-NOx process was recently demonstrated in two similar large coal-fired units. Both units were designed for firing a wide variety of coals using LNB with boosted OFA, but one unit had been modified to fire 100 percent wood pellet biomass. These two units provided ideal platforms for assessing the performance of the SNCR system with alternate fuel blends and varied combustion/BOFA conditions.

The advanced SNCR process utilized state-of-the-art chemical injection control integrated with a laser-based or acoustic pyrometer system to provide real-time temperature mapping over the furnace cross-section above the burner zone, but below the SNCR chemical injection points. The utilized laser-based sensor array and acoustic pyrometer systems both provided rapid response to transients in furnace conditions, and injection of the SNCR urea reagent was targeted on a zonal basis to areas where the flue gas temperature was within the optimum range. As a result, the maximum NOx reduction could be achieved with minimal ammonia slip.

The performance of the advanced SNCR system on the biomass-fired unit showed a general NOx reduction rate of 30 to 40 percent, with less than 5 ppm average ammonia slip at the economizer outlet, in loads ranging from full-size down to 50 percent MCR. Approximately 50 percent NOx reduction was achieved in two test runs that demonstrated the potential of the performance optimization system.

On the primarily coal-fired unit, the advanced SNCR performance test results indicate that a 30 to 40 percent reduction in NOx could be achieved with less than 5 ppm average ammonia slip. The unit fires a wide variety of coals from the United States and elsewhere. On some of the tests a 30 to 35 percent reduction in NOx emissions was achieved while firing US coal with less than 2 ppm ammonia slip.

**Summary**

Recent developments in acoustic- and laser-based furnace gas temperature measurement systems allow accurate real-time mapping of furnace temperature profiles to be integrated into SNCR control schemes, allowing NOx reductions ranging from 30 to 50 percent to be reliably achieved.

When applied in conjunction with other combustion control NOx reduction measures like fuel selection, LNB, OFA, and combustion optimization, levels of NOx reduction rivaling the performance of SCR systems can be achieved which have significant economic advantages over traditional SCR schemes, especially for plants that have some other combustion control NOx reduction measures already installed.

Experience shows that the combination of LNB with other primary measures can achieve up to 74 percent NOx reduction, but it is important to understand the potential for changes in boiler performance when implementing a number of changes together.

Although a stand-alone SNCR system is unlikely to provide regulatory compliance, SCR levels of performance can be achieved at a lower capital cost if the SNCR system is applied in conjunction with other combustion controls like fuel selection, LNB, OFA, and combustion optimization.

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