

## NO<sub>x</sub> Control on a Budget: INDUCED FLUE GAS RECIRCULATION

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### COMPETITIVE FORCES ARE COMPELLING ASSET OWNERS TO CONSIDER LOW-COST EMISSIONS CONTROL TECHNOLOGIES SUCH AS INDUCED FLUE GAS RECIRCULATION

National, regional and local regulations to reduce NO<sub>x</sub> emissions have prompted the development and implementation of a number of NO<sub>x</sub> control technologies – from selective catalytic reduction and low-NO<sub>x</sub> burners to overfire air and flue gas recirculation. Induced flue gas recirculation (IFGR), a design derivative of conventional forced flue gas recirculation, has demonstrated NO<sub>x</sub> reductions as high as 85 percent and NO<sub>x</sub> levels as low as 0.04 lb/MMBtu on gas-fired boilers, at costs of less than \$3/kW.

#### THE NO<sub>x</sub> CONTROL PARADIGM SHIFT

Historically, NO<sub>x</sub> control retrofits have involved equipment-intensive technology such as low-NO<sub>x</sub> burners (LNB), overfire air (OFA), forced flue gas recirculation (FFGR), and selective catalytic reduction (SCR), all of which can be very costly. Studies published by EPA<sup>1</sup> and EPRI<sup>2</sup> indicate that costs for conventional combustion modification NO<sub>x</sub> control techniques (e.g., LNB, OFA, FFGR) are in the range of \$8-35/kW, while costs for flue gas control techniques (e.g., SCR) are in the range of \$50-80/kW. Furthermore, due to the extremely mixed results from LNB installations, and the operational problems encountered with LNB, OFA and FFGR systems, the power generation industry needs an innovative, low-cost NO<sub>x</sub> control

technology that can achieve lower NO<sub>x</sub> emissions with minimal impact on performance and operation.

IFGR was pioneered in 1997 by the electric utility industry and Entropy Technology and Environmental Consultants LP (ETEC), initially through EPRI tailored collaboration programs at Entergy and Reliant Energy. Since then, ETEC has added several features to enhance its performance. ETEC initially simplified the technology by eliminating the intensive equipment modifications required with FFGR, i.e., the hot gas fans and combustion air duct mixing devices. Instead, the exhaust gas is routed through ducting directly into the forced draft fan inlet, where exhaust gas products are thoroughly mixed with combustion air prior to entering the burners. NO<sub>x</sub> reduction levels are consistent with those of FFGR technology, and since cost levels have been reduced to \$1-3/kW, IFGR technology can be the preferred NO<sub>x</sub> control technology in certain applications.

FGR technology is based on reducing thermal NO<sub>x</sub> formation by introducing inert flue gas, which reduces oxygen concentration and absorbs heat, thereby reducing peak flame temperatures. Studies indicate that peak flame temperature governs thermal NO<sub>x</sub> formation.<sup>3-4</sup> Because FGR reduces thermal NO<sub>x</sub>, its use is most effective for natural gas and low nitrogen-containing fuels, where it can reduce NO<sub>x</sub> by up

to 85 percent. On oil and coal-fired units, reductions are in the range of 20-60 percent.

In conventional applications, the recirculated flue gas is typically extracted from the boiler outlet duct upstream of the air heater. The flue gas is then returned through a separate duct and fan to the combustion air duct that feeds the windbox. The recirculated flue gas is mixed with the combustion air using airfoils or other mixing devices in the duct. Most of the cost associated with traditional FGR technology is due to an additional hot gas fan that is required to transport the flue gas. ETEC's patented IFGR technology is based on utilizing the existing forced draft fan to induce flue gas into the combustion air at the fan inlet. Since no major equipment costs are involved, the typical cost of IFGR technology is less than \$3/kW, depending on the plant layout.

#### IFGR MECHANICS

ETEC has installed its IFGR technology on more than 36 utility boilers ranging in size from 42 MW to 815 MW (Figure 1). Typical NO<sub>x</sub> reductions obtained with IFGR technology range from 50-85 percent, with NO<sub>x</sub> levels as low as 0.04 lb/MMBtu. IFGR technology has been demonstrated on a wide variety of utility boilers, including tangentially fired, turbo fired, opposed fired and face-fired units. Cyclone furnaces and wet bottom boilers are also good candidates for IFGR, since

thermal NO<sub>x</sub> formation is high for these designs. IFGR technology requires very minor modifications and can be installed in a few weeks. Physical modification includes tapping the exhaust duct to draw flue gas and recirculate it back to the fan. Minor modification to controls will also be needed for IFGR dampers. The only operational change in most applications is recalibration of the total airflow curve.

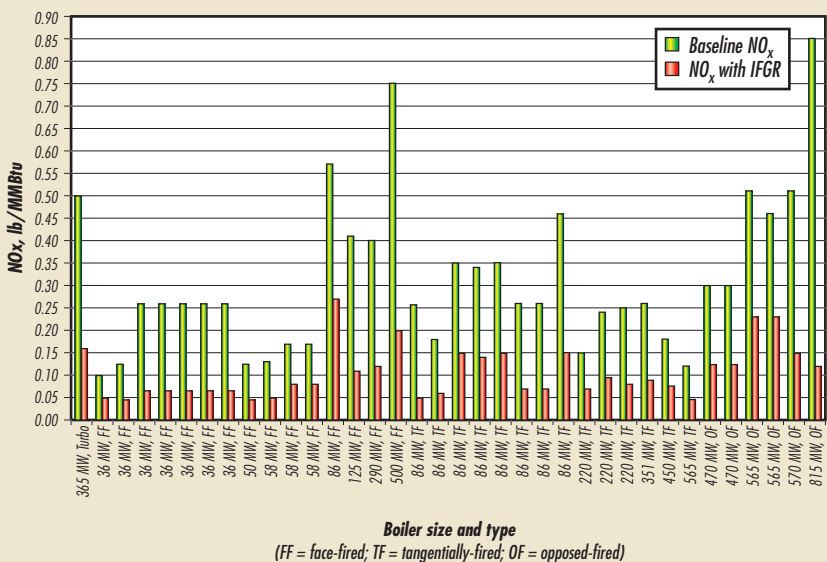
In IFGR applications, 10-25 percent of the flue gas is recycled back to the combustion zone. IFGR flow requirements are similar to those of FFGR, but NO<sub>x</sub> reductions are higher due to better mixing of flue gas and air in the fan. The extent of NO<sub>x</sub> reduction depends on the amount of flue gas recirculated. Increasing the recirculation rate causes a decrease in peak flame temperature, resulting in lower thermal NO<sub>x</sub> formation.<sup>4</sup> Many LNB vendors are packaging FGR with LNB to reduce NO<sub>x</sub>. In most applications, however, the cost of LNB with FGR is more than \$10/kW, and the typical NO<sub>x</sub> reduction of the combined system is not much greater than with IFGR. Therefore, in certain situations, the high cost of LNB for incremental reduction in NO<sub>x</sub> may not be justifiable.

Since IFGR technology uses the existing fan to induce FGR, IFGR operation at full load depends on the forced draft fan capacity. For fan limited units, IFGR capacity may need to be reduced at or near full load. Since most plants have to meet a rolling average limit, over-controlling at lower loads is one option to overcome this drawback. In many projects, IFGR has been combined with combustion modifica-

tions, such as Burners-Out-Of-Service (BOOS), to achieve dramatic NO<sub>x</sub> emissions reductions. In addition, several low-cost debottlenecking options such as re-tip-

usually be overcome cost-effectively by utilizing existing steam temperature control systems. In many cases, where units suffer steam temperature sag during lower load

**FIGURE 1**  
**NO<sub>x</sub> REDUCTION WITH IFGR TECHNOLOGY**



ping fan blades and/or rewinding fan motor are available to accommodate IFGR flow.

IFGR flow rates achievable at high loads also may depend on steam temperature conditions. IFGR causes an increase in mass gas flow through the boiler, resulting in increased heat transfer in the convection sections. At high loads, therefore, steam temperatures are increased, but can

operation, the increased steam temperatures have provided substantial improvement in net heat rate, as well as substantially improved turndown capability. In fact, in some cases IFGR has been primarily considered for its turndown enhancement for standby boilers, operating at minimum capacity, reserved as emergency backup for main steam supply interruption.

**TABLE 1**  
**SUMMARY OF IFGR INSTALLATIONS AT RELIANT ENERGY**

Unit	Unit Rating and Boiler Type	Baseline NO <sub>x</sub> , lb/MMBtu*	IFGR NO <sub>x</sub> , lb/MMBtu**	% NO <sub>x</sub> reduction
P.H. Robinson 1 and 2	470 MW, B&W opposed fired, supercritical	0.3	0.125	58
P.H. Robinson 3	565 MW, Foster Wheeler opposed fired, supercritical	0.46	0.200	57
W.A. Parish 3	290 MW, Foster Wheeler face fired	0.4	0.120	70
W.A. Parish 4	565 MW, CET-fired	0.12	0.045	63
Webster 3	390 MW, Riley Stoker tubo fired	0.5	0.160	68
Greens Bayou 5	420 MW, CET-fired	0.19	0.070	63
S.R. Bertron 3	240 MW, CET-fired	0.135	0.070	48
S.R. Bertron 4	240 MW, CET-fired	0.25	0.090	64

Note: \* = Baseline NO<sub>x</sub>, represents operations with BOOS or OFA

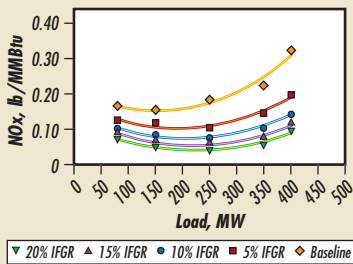
\*\* = NO<sub>x</sub> reductions at guaranteed load levels. At lower loads, NO<sub>x</sub> reductions are great than those shown above. IFGR designed to meet NO<sub>x</sub> limit specified by the plant.

## IFGR AT RELIANT ENERGY

Prompted by requirements for NO<sub>x</sub> RACT compliance in the Houston area, Reliant Energy widely implemented IFGR technology on oil and gas-fired boilers within its system (Table I). It should be noted that the baseline NO<sub>x</sub> emissions were relatively low due to the fact that these units had been operating with combustion modifications, i.e., BOOS and/or OFA. For many of the units, the combination of combustion modifications and IFGR has resulted in an effective NO<sub>x</sub> reduction on the order of 90 percent from the original baseline levels.

To characterize NO<sub>x</sub> reduction as a function of load, ETEC and Reliant conducted performance testing at P.H. Robinson Unit 2 (Figure 2). The baseline data, collected prior to the IFGR installation, show relatively lower NO<sub>x</sub> formation at lower loads. At higher loads, the unit fires harder, increasing peak flame temperature and increasing NO<sub>x</sub> formation. This behavior is typical of thermal NO<sub>x</sub> formation. Figure 2 indicates that IFGR is very effective

**FIGURE 2**  
**NO<sub>x</sub> REDUCTION AT**  
**P.H. ROBINSON UNIT 2**



at controlling NO<sub>x</sub> emissions through the load range and that effectiveness increases with the amount of recirculation rate.

## ENERGY SABINE UNIT 4

Entergy hosted the first utility boiler application of IFGR at Willow Glen Unit 3,<sup>3</sup> and based on this success, implemented IFGR at nine additional units. During a 2002 outage, Entergy incorpo-

rated IFGR at Sabine Unit 4 to reduce NO<sub>x</sub> emissions. Two IFGR ducts were installed from the exhaust duct to the two forced draft fan inlets. Each IFGR duct has three sets of dampers. The first damper, located closest to the exhaust duct, is mounted horizontally and is manually controlled with a chain. The IFGR flow control damper, also mounted horizontally, comes next and is used for making IFGR flow adjustments to optimize system performance. The last damper, mounted vertically, is referred to as the "fresh air" damper. The IFGR control damper and the fresh air damper are designed to operate together such that as the IFGR control damper is opening, the fresh air damper is closing. The total open position of both dampers is always 100 percent, i.e., if the IFGR control damper is 30 percent open, then the fresh air damper is 70 percent open.

Burner Out Of Service (BOOS) operation is used in conjunction with the IFGR System operation to lower NO<sub>x</sub> emissions and optimize boiler performance. BOOS

By Brad Buecker, Contributing Editor

As utilities respond to existing SO<sub>2</sub> legislation, and try to forecast the ramifications of pending legislation, flue gas desulfurization (FGD) planning and construction are taking on new life. A number of major U.S. utilities have announced plans to retrofit FGD systems to existing coal-fired units, and the McIlvaine Com-

## FGD Resurrection?

pany projects that utilities worldwide will spend \$53 billion on FGD equipment in the next eight years. This proliferation of retrofit and new scrubbers will introduce many plant personnel to a new process.

According to Paul Dyer of Burns & McDonnell, the type of scrubber selected will often depend on the coal burned at the utility. For example, plants that burn low-sulfur coal, such as that from the Powder River Basin, may be able to reach SO<sub>2</sub> reduction goals with a spray-drying scrubber followed by a particulate collection baghouse. In this process, saturated particles of lime are sprayed directly into the flue gas, absorbing SO<sub>2</sub>; the lime particles are then collected downstream in the baghouse. This technique also offers potential promise as a mercury control method, as activated carbon can be injected into the gas stream for mercury adsorption.

The spray drying process does not offer a great deal of scrubbing flexibility, especially if the utility uses multiple coals with varying sulfur contents. A more practical scrubbing technique at plants that blend coals or use high-sulfur coal is the standard workhorse, the wet-limestone scrubber. Technological advances in the last three decades have produced improvements in scale control issues, scrubbing efficiency, chemistry optimization, and byproduct disposal.

With regard to scrubbing efficiency, and often-related scale problems, first- and second-generation wet-limestone FGD systems typically were equipped with one or more layers of perforated plates or plastic packing to enhance gas-liquid mixing. Unfortunately, these materials, and especially packing, served as excellent sites for scale buildup. Scale formation restricted flow through scrubber modules and in some cases resulted in unit derating and forced outages. Scale prevention became a topic of intense research, and investigators discovered that by controlling chemistry to either completely inhibit byproduct oxidation or to fully oxidize scrubber byproducts to gypsum, scale formation could be greatly minimized. In new systems, this issue is becom-

ing a moot point as spray nozzle technology and understanding of FGD fluid flow have improved so much that open spray towers are now practical. SO<sub>2</sub> removal efficiencies in the mid- to upper-90 percent range are possible in open spray units.

Optimization of FGD chemistry starts with the use of high-purity limestone (94 percent or higher calcium carbonate concentration), which generally enhances reaction rates and limestone utilization. Chemistry enhancement with additives such as magnesium salts or organic acids is also effective in some instances. Dicarboxylic acid, commonly known as DBA (di-basic acid), has been used to tweak SO<sub>2</sub> removal rates in high-efficiency systems, and the chemical also assists in the dissolution of moderately reactive limestones at sites where high-quality stone is not available.

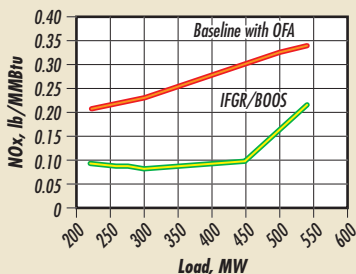
Byproduct chemistry control is another important FGD topic. The use of forced-oxidation systems, which produce a high-quality gypsum byproduct marketable to wallboard manufacturers, can greatly reduce utility waste disposal requirements. The costs for installing byproduct oxidation and drying equipment may be easily offset by the ability to sell the material, even at nominal cost, to a wallboard manufacturer. Wallboard companies now appear to favor top-grade FGD byproduct over natural gypsum. Scrubber byproduct has also served as an agricultural enhancement chemical and, at least in one case, as a component of aggregate for road fill. So, utility planners must carefully examine scrubber byproduct treatment and disposal with these ideas in mind.

Scrubber equipment redundancy remains an important issue. Single tower scrubber modules are becoming more popular, in part because open spray towers have less internal equipment that can fail or become coated with scale. However, redundant reagent preparation equipment, pumps, byproduct disposal units, and other systems are still common. Unit shutdown due to FGD difficulties is not an issue that utility managers wish to face.

Designs other than traditional scrubbing are also beginning to influence pollutant control planning. Some firms, such as Powerspan, are diligently working on multi-pollutant control systems to remove particulates, SO<sub>2</sub>, NO<sub>x</sub>, and mercury in one process. Another company, BOC Gases, is scaling up a process to treat flue gas such that NO<sub>x</sub> and perhaps mercury can be removed in wet-limestone scrubbing systems. This technique could be particularly effective as a retrofit technology at utilities with existing scrubbers. Should these methods prove successful, they could potentially allow utilities to save much money over more recognized technologies, most notably selective catalytic reduction (SCR) for NO<sub>x</sub> control and activated carbon/baghouse particulate removal for mercury control.

operation involves terminating the fuel flow to selected burners while leaving the air registers open. The remaining burners operate fuel-rich, thereby limiting oxygen availability, lowering peak flame temperatures, and reducing NO<sub>x</sub> formation. The unreacted products combine with the air from the terminated fuel burners to complete burnout before exiting the furnace.

**FIGURE 3**  
**NO<sub>x</sub> REDUCTION AT**  
**SABINE UNIT 3**



At Sabine, the upper level burners on Unit 4 were modified to enhance the flexibility of BOOS operation. Originally, each burner gas valve controlled the gas flow to two burner cells, which is still the configuration for the lower level burners. In the

modified configuration, ETEC replaced the piping downstream of the double block and bleed valves with piping to each cell, with each pipe run containing a manual gas valve and a flow control orifice.


Figure 3 shows the NO<sub>x</sub> emissions profile for baseline operation and for IFGR/BOOS operation at Sabine. It should be noted that the baseline NO<sub>x</sub> emissions include OFA operation. The NO<sub>x</sub> emissions level increases above 450 MW with IFGR/BOOS operation because the IFGR control damper begins closing as full load conditions are approached in order to provide forced draft fan capacity. The NO<sub>x</sub> emissions reduction requirements are calculated on a 24-hour and a 30-day rolling average basis.

## HYBRID CONFIGURATIONS

In some cases, power plants may have to use SCR to control NO<sub>x</sub> levels below 0.01 lb/MMBtu. In such a case, costs can be reduced by combining IFGR installation with SCR. ETEC has recently patented the use of FGR with post-combustion flue gas clean-up technologies such as SCR. Analysis has shown that SCR costs can be reduced as much as 65 percent with a hybrid system combining IFGR and SCR.<sup>4</sup> Studies published by EPA<sup>5</sup> and the TCEQ<sup>6</sup> also show that hybrid systems can effectively reduce the costs and improve performance of the SCR. Hybrid



Typical power plant IFGR installation.

systems lower the concentration of NO<sub>x</sub> to the SCR, resulting in reduced requirements for catalyst and ammonia handling systems. Due to lower NO<sub>x</sub> concentrations to the SCR, ammonia consumption can be reduced by as much as 80 percent. For a 300 MW unit, reduction in ammonia usage alone could result in a payback of the IFGR installation cost in less than 6 months! Thus, hybrid systems can lower not only capital costs but also reduce operating costs significantly. 

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### References:

1. "Nitrogen Oxides, Why and How They are Controlled," EPA-456/F-99-006R (1999).
2. Lange, H., Himes, R., and Jantzen, T., "Retrofit NO<sub>x</sub> Control Guidelines for Gas and Oil Fired Boilers," EPRI TR-108181 (1997).
3. Wood, S., "Reliant Energy Induced Flue Gas Recirculation Program," EPRI (June 2000).
4. Agrawal, R.K. and Wood, S.C., "Cost-Effective NO<sub>x</sub> Reduction," Chemical Engineering, 108(2), 78-82 (2001).
5. Petroleum Refinery Tier 2 BACT Analysis Report, U.S. EPA (Jan. 2001).
6. "Control of Air Pollution from Nitrogen Compounds," Texas Register, Chapter 117, August 25, 2000 and January 12, 2001.