

Oxygen-Enrichment for NO_x control in coal-fired utility boilers

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ABSTRACT

This paper describes a cost-effective oxygen-based low-NO_x technology applicable to coal-fired boilers. The technology has been developed by Air Liquide and The Babcock & Wilcox Company (B&W) and enables existing coal-fired power plants to reduce their NO_x emission without any need for a flue gas cleaning process. Compared to flue gas treatment technologies, which remove NO_x formed during the combustion process, oxygen injection directly impacts the NO_x formation process, reducing the NO_x generation rate. Experimental data resulting from pilot-scale tests are presented. 30% NO_x reduction from an air-fired baseline equipped with low-NO_x burners and overfire air (OFA) has been observed using a western sub bituminous coal. Up to 50% NO_x reduction is expected via further optimization of key parameters like oxygen introduction arrangement, oxygen input, and coal type.

INTRODUCTION

Coal provides 23% of worldwide primary energy needs, and generates about 38% of the world's electricity. It is the major fuel used for generating electricity, and countries heavily dependent on coal include Australia (77% of power originates from coal), China (78%), India (70%), U.S.A. (56%), South Africa (78%) and some European countries (52% in Germany, 96% in Poland, 72% in Czech Republic, 67% in Greece, etc.)

Coal will continue to be a prime source of electric power generation, and the coal-fired plants will have to operate well into the future. However, in many countries the plants are being subjected to tighter and tighter environmental regulations, restricting the amount of compounds emitted into the atmosphere.

With more than 1,500 coal-fired power plants and 320 GWe of power generation fired by coal in the U.S., limitation of NO_x emissions is one of the most immediate areas of concern for coal-fired power plants owners and operators. The present and pending NO_x emission limits and compliance programs set up by both the Environment Protection Agency (EPA) and various state regulatory agencies have created the impetus for industrial implementation of competitive NO_x reduction technologies.

By April 15, 2004 EPA will officially designate all areas of the U.S. as either attainment or non-attainment with respect to achieving the new, more stringent ambient ozone standard established in 1997 (0.08 ppm averaged over eight hours).

Bringing the existing U.S. coal-fired power plants into compliance with the tighter NO_x emission regulations will require new technological advancement to supplant use or supplement the performance of the existing available technologies.

This paper briefly reviews the specifics of NO_x emissions in pulverized coal-fired combustion systems. Existing NO_x control technologies are then analyzed, and some limitations are identified which open opportunities for new low-NO_x technologies. Oxygen-enrichment is described as a breakthrough technology for NO_x control, and experimental results supporting this statement are provided.

BACKGROUND

NO_x Formation Chemistry in Coal Fired Boilers

Some basics of NO_x formation chemistry in combustion processes are required to understand the operating principle of continuously developing NO_x control techniques and equipment.

Nitrogen oxides (NO_x) generally refers to nitrogen monoxide NO and nitrogen dioxide NO₂. Both are main contributors to acid rain or to smog (ground level ozone) issues. The NO_x partition in the flue gases of pulverized coal-boilers is typically more than 95 % NO and the remainder NO₂ ^[13].

During coal-combustion, the NO_x production originates from three different mechanisms:

- Fuel-NO_x mechanism,
- Thermal-NO_x mechanism, and
- Prompt-NO_x mechanism.

In pulverized coal (PC) boilers, 70% to 80% of NO_x is formed from the fuel-bound nitrogen species (fuel-N) via the fuel-NO_x mechanism, and the remaining NO_x is formed from atmospheric nitrogen (N₂), via the thermal-NO_x mechanism (5-25%) and via the prompt-NO_x mechanism (less than 5%) ^[2].

In coal-fired combustion processes other than PC boilers, the fuel/thermal/prompt NO_x partition may differ. While fuel-NO_x may be considered as the only source of NO_x in fluidized bed combustion (FBC) boilers, due to the low temperature levels, thermal NO_x contribution significantly increases in high temperature processes such as cyclone boilers.

The following sections are dedicated to fuel-NO_x formation and provide more detailed information regarding their origin, formation process, and the strategies for their limitation. For information and comparison, the main parameters affecting thermal- and prompt-NO_x formation are outlined in Table 1, along with the desirable conditions leading to their minimization.

	Thermal NO_x	Prompt NO_x
Nitrogen Source	Atmospheric nitrogen N ₂	Atmospheric nitrogen N ₂
Parameters impacting NO _x emission	-Temperature T -Oxygen concentration [O ₂] Formation rate ^[3] : $\frac{d[\text{NO}_x]_{\text{thermal}}}{dt} = \alpha \cdot \frac{e^{-\frac{B}{T}}}{\sqrt{T}} \cdot [\text{N}_2] \cdot \sqrt{[\text{O}_2]}$	
Contribution to overall NO _x in PC boilers	5-25%	Less than 5%
Main chemical reactions involved	Zeldovich mechanism: N ₂ + O ⇒ NO + N (1) Requires high Temperature N + O ₂ ⇒ NO + O (2) N + OH ⇒ NO + H (3) In reducing conditions	Hydrocarbon radicals + N ₂ ⇒ HCN HCN ⇒ NO _x (complex series of gas phase reactions)
Strategy for NO _x minimization	-Reduction of the peak temperature (Temp. control). -Reduction of the available oxygen (Dilution) -Removal of atmospheric nitrogen (Oxycombustion)	Prompt NO _x decreases along with thermal- and fuel-NO _x (same control technologies)
Main applications with dominant contribution to overall NO _x emission	-Natural Gas fired systems (no fuel-bound nitrogen) -High temperature processes (whatever the fuel) such as cyclone boilers, cement kilns...	

Table 1: Thermal NO_x and Prompt NO_x formation mechanism and control strategies

Specifics of fuel-NO_x formation mechanism

As opposed to thermal or prompt NO_x, the fuel-NO_x does not originate from molecular atmospheric nitrogen (N₂) but from the nitrogen species already contained in the fuel (fuel-N). A complex series of reactions explains the transformation of generally organically bound fuel-nitrogen into NO_x or N₂, including more than 50 intermediate species and hundreds of reactions.

The two main parameters affecting the fuel-NO_x formation process are the nitrogen content in fuel and the stoichiometry (air/fuel ratio).

As reported in Table 2, coal typically contains 0.5% to 3% nitrogen by weight on a dry basis. For comparison, natural gas also contains some nitrogen, however it is molecular nitrogen N₂, and thus is not affected by the fuel-NO_x mechanism.

Fossil Fuel	Nitrogen content (dry basis)	Nitrogen Form in Fuel
Coal	0.5% – 3%	Mainly organically bound / Some inorganically bound: NH ₄ ⁺
Oil	<1%	Organically bound
Natural Gas	0.5% – 20%	N ₂
Light fuel oil	~ 0.2%	Organically bound
Heavy fuel oil	~ 0.5%	Organically bound
Petroleum coke	~ 3%	Organically bound

Table 2: Typical nitrogen content (weight basis, dry basis) in fossil fuels ^[6]

Figure 1 below summarizes the main reactions affecting fuel-nitrogen in the combustion process.

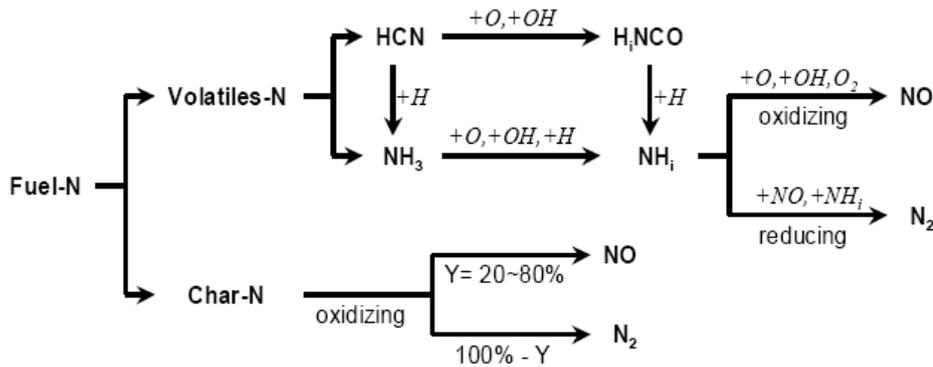


Figure 1: Schematic of oxidation of fuel nitrogen to NO and N₂^[6].

Three main steps can be identified:

- 1- **Devolatilization** leading to HCN (mainly) and NH₃ release in the gas phase, and some remaining nitrogen-bound compounds in the char (solid)
- 2- **HCN evolution to NH_i** species while contacting free O, OH radical then H radicals
- 3- **NH_i oxidation to NO** or **reduction to N₂** depending on local conditions

Both volatile-N and char-N can be evolved as NO or as N₂. Fuel-NO_x formation is minimized by implementing the conditions leading to N₂ rather than NO.^[1,3,4,5]

How to limit volatile-nitrogen oxidation into fuel-NO_x

NH species under fuel lean conditions are oxidized to form NO, while under fuel rich conditions they react with other nitrogen containing species (NH, NO, etc.) to form N₂. In that respect reducing NO formation from oxidation of NH_i is achieved by arranging “zones” with fuel-rich conditions (reducing atmosphere) in the furnace during the devolatilization stage, at the very beginning of the combustion process. This can be obtained via low-NO_x Burners that create a locally fuel rich condition near the burner throat and air staging via OFA. With this technique, 10 to 50% of volatile-N can be converted to N₂.

Temperature level also impacts the evolution of volatile-N species. As already observed by Sarofim et al. in 1976^[7], fuel rich conditions, although needed to overcome the thermodynamic constraint and get N₂ from volatile-N, are not sufficient. High temperatures are also required to overcome the kinetic constraint since the volatile-N to N₂ conversion is faster than volatile-N to NO conversion at high temperature. Those results have been confirmed in 1988 by Bose et al.^[11] from tests performed on brown and bituminous coals. Moore and Ellison^[10] listed some examples of recent developments of NO_x control technologies based on the principle of fuel-rich conditions and high temperature. They also highlighted the limitations that those technologies are facing as of today. Dykema^[9] claims a method enabling to increase the residence time in fuel rich conditions and at elevated temperature in a specific two chamber burner.

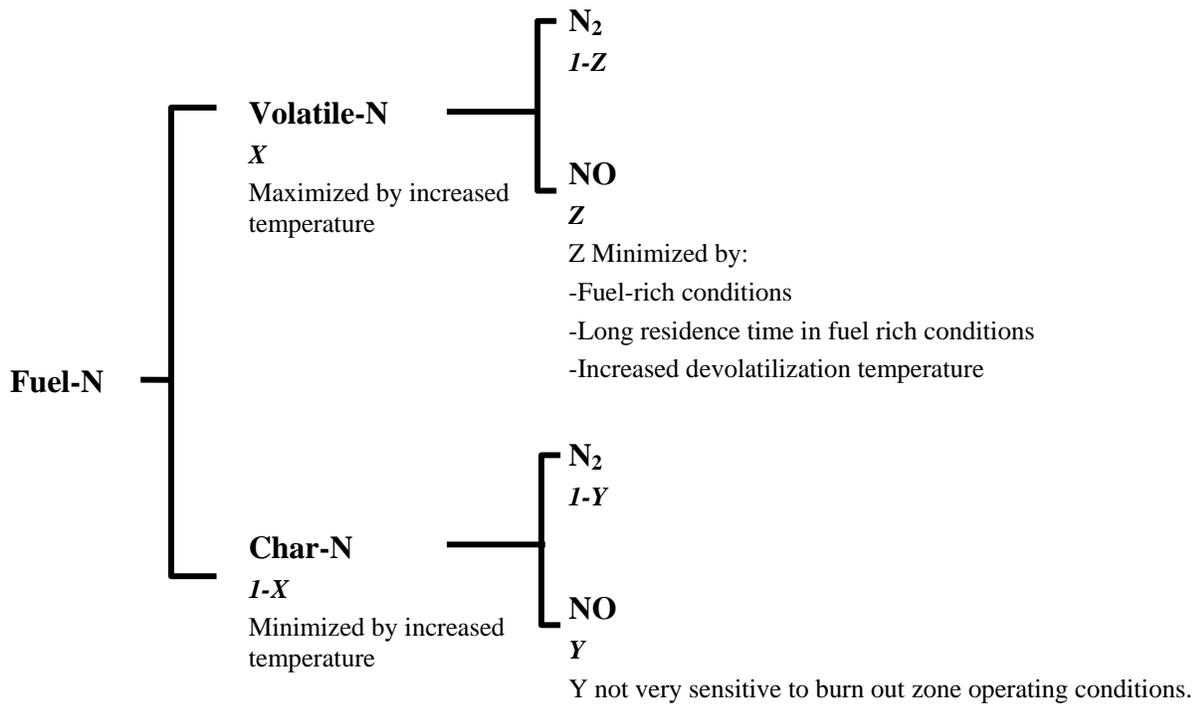
How to limit char-nitrogen oxidation into fuel-NO_x

Under oxidizing conditions char-nitrogen reacts with O₂, producing NO, N₂O and N₂. In reducing conditions, char-nitrogen remains mostly un-reacted. Due to late char burnout, occurring in oxidizing conditions (with secondary and overfire air), char-NO cannot be directly controlled by air staging.

Indirect control is possible by controlling the nitrogen distribution between volatile and char: high temperatures and long residence time during devolatilization will increase the fraction of nitrogen compound released during devolatilization and lower the nitrogen remaining in the char.

As schematically summarized in Figure 2, three conditions will independently or in combination promote fuel-bound nitrogen conversion into molecular nitrogen N_2 rather than NO_x :

- **Fuel rich conditions** at the burner level (air staging) to enable nitrogen species in gas phase (volatiles) to be reduced to molecular nitrogen N_2 rather than oxidized to NO
- **Long residence time** in reducing conditions for higher fuel-N to N_2 conversion
- **High temperature** in the early stage of the combustion for increased volatiles yield. It will also increase the conversion rate of volatile-N into N_2 .



TOTAL FUEL-NO_x FORMATION	Fraction of fuel-N converted to NO: $XZ+(1-X)Y$
	Minimized by: <ul style="list-style-type: none"> -Fuel-rich conditions -Long residence time in fuel rich conditions -High temperature at burner zone in fuel rich conditions
$X = \text{fraction of fuel-N released in volatile}$ $Z = \text{fraction of volatile-N converted to NO}$ $Y = \text{fraction of char-N converted to NO}$	

Figure 2: Schematic of fuel- NO_x formation process and conditions for minimization.

In addition to stoichiometry, residence time and temperature, Van der Lans et al.^[1] have investigated other parameters (particle size, coal moisture content...) with more limited effect on NO formation. This analysis has a strong dependence on coal rank. Volatile yield and fuel nitrogen content are controlling factors in NO_x emissions from coal-fired boilers.

Table 3 recaps the main information on fuel-NO_x origin and formation in coal-combustion.

Fuel- NO _x	
Nitrogen Source	Fuel-Bound Nitrogen
Parameters impacting NO _x emission	-Nitrogen content in fuel -Volatile Matter in coal -Burner stoichiometry (reducing/oxidizing conditions) -Residence time in primary zone
Contribution to overall NO _x emission in PC boilers	70 to 80%
Main chemical reactions involved	Very complex process. Simplified: (1) Devolatilization (2) Volatile-N ⇒ HCN (mainly) and NH ₃ (3) HCN + O, OH ⇒ CN, NCO, HNC + H ⇒ NH, NH ₂ (4) NH _i ⇒ NO or N ₂
Strategy for NO _x minimization	-Fuel rich conditions during devolatilization -Increased residence time in fuel rich conditions -High temperature for maximum devolatilization rate and NH _i ⇒ N ₂

Table 3: Fuel-NO_x formation mechanism and control strategy

Available NO_x Control Technologies in Pulverized Coal-Fired Utility Boilers

NO_x reduction technologies available and referenced on the market today can be grouped into two broad categories: combustion modifications and post-combustion processes ^[1,2,4].

Combustion modification technologies:

Combustion modification technologies include low-NO_x burners (LNB), overfire air (OFA), reburning and flue gas recirculation (FGR). Those technologies have been developed to limit the fuel-NO_x formation, as the most important source of NO_x type in pulverized coal combustion.

Low-NO_x Burners (LNB) are based on the air-staging principle, yet at the burner level. Local staging is achieved by splitting the main combustion air into independently swirled air streams (usually concentric around the primary air pipe), creating a region of low stoichiometry close to the burner. LNB designs enable controlled mixing of fuel and air while trying to optimize some key parameters: maximize the volatile release time (and thus the total volatile yield), create oxygen depleted zones to minimize nitrogen species oxidation, optimize residence time and temperature in the oxygen-depleted (reducing) zones, maximize the char residence time under fuel rich conditions, and properly add the remaining air (usually concentrically around the primary air + coal duct) to achieve complete fuel burnout. This staged combustion also reduces the flame temperature, lowering thermal NO_x production.

Overfire Air (OFA) technology is based on the air staging principle, and consists of diverting some of the main combustion air from the burners to “overfire air ports” located above the burners. When OFA is used, the burners are operated in fuel-rich conditions enabling to increase the residence time in a reducing environment and thus to promote the formation of N₂ rather than NO from the volatiles-nitrogen. Furthermore flame peak temperature is reduced which decreases the already low level of thermal NO_x emissions.

The **Reburning Process** is based on the fuel staging principle. Part of the boiler fuel input (typically 10-25%) is added in a separate reburn zone. The fuel-rich reducing conditions in this zone lead to the chemical reduction of NO_x formed earlier in the primary combustion zone. OFA is injected above the reburn zone, in the so-called burnout zone, to complete the combustion.

Flue Gas Recirculation (FGR) is based on the dilution principle. Part of the flue gas is recirculated back to the furnace to reduce both the peak flame temperature and the oxygen concentration in the combustion zone and thus limit the formation of thermal NO_x . However, FGR does not significantly impact the fuel- NO_x formation rate, and its performance in terms of overall NO_x reduction is therefore limited (less than 20%) in coal-fired processes. FGR is also used as a carrier to inject the pulverized coal into a reburn zone to increase penetration and mixing of the reburn coal in fuel-rich conditions.

Post-combustion technologies, or flue gas treatment technologies:

Two main technologies have been developed to enable further NO_x abatement before stack exit when combustion modifications alone cannot limit the NO_x formation to emission levels compatible with local regulations.

In **Selective Catalytic Reduction (SCR)**, a catalyst system is installed downstream of the furnace, typically between the economizer and air preheater. Ammonia (NH_3) is injected into the flue gas before it passes over the fixed-bed catalyst. The catalyst promotes a reaction between NO_x and NH_3 to form nitrogen and water vapor. Theoretically one mole of NH_3 is needed to reduce one mole of NO_x . NO_x reductions as high as 90% are achievable, but careful design and operation, such as control of the reagent dosage and assuring good mixing, are necessary to keep NH_3 emissions (referred to as NH_3 slip) to a low ppm concentration.

In **Selective Non-catalytic Reduction (SNCR)**, a reducing agent (typically NH_3 or urea) is injected into the furnace above the combustion zone, where it reacts with NO_x to form N_2 . Critical factors are sufficient residence time in the appropriate temperature range and uniform distribution and mixing of the reducing agent across the full furnace cross-section.

Other technologies referred to as hybrid processes or operational modifications use combinations of the above combustion and post-combustion solutions for retrofitting boilers.

Why Develop Another Low- NO_x Technology?

The previously listed combustion modifications for NO_x reduction come with some limitations:

Overfire Air (OFA) techniques generally have three limitations. While diverting some air from the burner to the overfire air ports, the potential temperature reduction at the burner level may slow down the devolatilization process and reduce the maximum achievable volatiles yield, which limits the potential fuel-N to N_2 conversion. In addition, the burner stoichiometry can usually not be decreased below 0.8 for flame stability purpose. Finally, potential lower flame temperature and shorter residence time of overfire air reduce the combustion efficiency, leading to increased fuel consumption and higher carbon content in the ash.

Low NO_x Burners (LNB) have been very effective for NO_x reduction. However, they tend to reach their limit since further local staging becomes hard to manage while properly stabilizing the flame, keeping the boiler turn down ratio, maintaining an acceptable combustion efficiency, enabling some coal type flexibility, and taking care of other combustion characteristics such as high temperature corrosion issues.

In most coal-fired plants, the NO_x levels achieved through installation of Low-NO_x burners and other combustion modification technologies are in the range of 0.3 to 0.5 lb per million Btu for high volatile eastern bituminous coals. The emission limit imposed by the stricter regulations is 0.15 lb per million Btu.

At present, and as shown in Table 4, the only commercial NO_x control technology capable of achieving the required reduction in pollutant removal is Selective Catalytic Reduction (SCR). This technology can remove approximately 80 to 90% of the NO_x pollutants, compared with 30 to 50% for SNCR and Low-NO_x burners.

Retrofit Technology on Coal-fired boiler	Typical NO_x reduction rate
Overfire Air (OFA)	10% – 30%
Low-NO _x burners (LNB)	30% – 50%
Reburning + Overfire Air	40% – 50%
Selective Non-Catalytic Reduction (SNCR)	20% – 50%
Selective Catalytic Reduction (SCR)	70% – 90%

Table 4: Basic Performances of NO_x Emissions Control Technologies [2]

While SCR is considered the leading technological option, it can also be an expensive technology depending upon the difficulty of the retrofit. In addition to an initial heavy investment for the system, and to the ammonia costs, the expensive catalyst has to be replaced approximately every four years. Furthermore, SCR catalysts and ammonia are toxic and require disposal equipment, contributing to the total cost of SCR NO_x control.

For all of those reasons, SCR implementation has been somewhat controversial, and the coal power industry can benefit from better alternatives.

OXYGEN-ENRICHED LOW-NO_x TECHNOLOGY

Oxygen-Enrichment for NO_x Emissions Reduction

The conversion of NH_i species resulting from devolatilization into molecular nitrogen N₂ rather than NO_x requires fuel rich conditions and is significantly increased by high temperature, which enables a high devolatilization rate (fuel-N to volatile-N) and a higher volatile-N to N₂ conversion rate. As mentioned in the previous section, fuel rich conditions are obtained by staging the flame, but usually result in a reduced temperature at the burner level.

To overcome this limitation and increase, or at least maintain, the burner zone temperature while staging the air, Sarofim et al.^[7] recommended in 1976 to use highly preheated air. Instead of preheating the air, another idea consists of oxygen-enriching the air, while keeping local fuel-rich conditions. In 1988, Bose et al.^[11] successfully tested this idea with various coal types at the lab-scale.

Although oxygen-enrichment looks like a new concept in the utility industry, its development will benefit from a wide range of successful applications of oxygen in industrial combustion processes. Technologies based on oxygen-enrichment have significantly reduced emissions and increased efficiency in a variety of industrial combustion applications, such as glass melting and forming, cement/lime kilns, steel reheating furnaces, etc.

To scale up the concept of oxygen-enrichment for NO_x control from lab-scale experiments to utility-scale technology, Air Liquide (AL) has teamed with The Babcock & Wilcox Company (B&W). The combination of AL's expertise in oxygen production, delivery and handling in industrial environments and B&W's expertise in coal-fired boilers will enable the team to optimize the performances and cost-efficiency of the O₂-enriched low-NO_x technology, while addressing the specifics of the utility industry and insuring the safety of the proposed solution.

Description of the Oxygen-Enriched Low-NO_x Technology

The technology developed by AL and B&W is targeting the existing coal-fired boilers that need a safe, easy to implement and cost-effective retrofit solution to meet the NO_x regulations.

The technology consists of local injection of oxygen-enriched air in existing coal-fired boiler to promote the conversion of fuel-bound nitrogen into molecular nitrogen N₂ and to limit its conversion into NO_x. It requires the installation of proprietary oxygen injection equipment. Air remains the main oxidizer in the retrofitted boiler, with more than 90% of the oxygen molecules needed for complete coal burnout being provided by combustion air. Less than 10% of the stoichiometry, or less than 10% of the total oxygen molecules, is provided by pure oxygen. The overall enrichment level only slightly increases from an initial level of 21% in air-fired conditions to 22 to 23% in oxygen-enriched conditions.

Table 5 illustrates the oxygen-enrichment concept with the example of a 100MWe air-blown coal-fired boiler retrofitted with oxygen-enriched low-NO_x technology. The calculations have been made on Powder River Basin (PRB) coal, and assuming 33% plant efficiency.

	Air-blown PC boiler		Oxygen-enriched retrofitted PC Boiler	
Oxygen-Enrichment Level in % of the overall stoichiometry provided by pure O ₂	0%		5%	10%
Air Input	9,934 TPD (0%)		9,357 TPD (-6%)	8,788 TPD (-12%)
Air Removed	-		577 TPD	1,146 TPD
Pure Oxygen Input	-		115 TPD	227 TPD
Oxygen Concentration in Furnace	21%		22%	23%
Flue Gas Output	11,108 TPD (0%)		10,645 TPD (-4%)	10,189 TPD (-8%)
Overall stoichiometric ratio (adjusted to 3% O ₂ in flue gases)	1.17		1.16	1.15
Flue Gas composition (dry basis, by volume)	O ₂ 3%	CO ₂ 16%	N ₂ 81%	O ₂ 3%
				CO ₂ 18%
				N ₂ 79%

Table 5: Overall input and output streams characteristics in coal-fired boilers while operated in air-blown conditions and in oxygen-enriched conditions. TPD= metric tons per day.

Providing 5% of the stoichiometry with pure oxygen while keeping 3% oxygen content in the flue gases consists of replacing 577 tons per day of the combustion air by 115 tons per day of pure oxygen. The oxygen content in the boiler would increase from 21% to 22%.

With such a small increase in furnace O₂ concentration, the implementation of oxygen-enrichment does not require any modification to the equipment and materials of the boiler.

In addition to NO_x reduction, O₂-enriched technology provides other benefits such as:

- Improvement in flame stability and flame attachment, enabling lower burner stoichiometry (higher staging) further than in air-fired conditions, and thus further reduce the NO_x formation,
- Potential capacity increase for flue gas limited systems, and
- Higher combustion efficiency and reduced unburned carbon in the fly ash.

Experimental Results

Oxygen-enrichment tests have been performed on B&W's 1.5MWth (5 million Btu/hr) coal-fired pilot-boiler. A fraction of the combustion air has been replaced by pure oxygen; four different types of oxygen introduction arrangement have been tested; and the burner stoichiometric ratio (BSR) has been varied from 0.85 (conventional BSR in air-fired conditions) down to the minimum level while keeping good flame characteristics (stability, soot formation, etc.).

Impact of the Oxygen Introduction Arrangement (O₂ Arrangement)

Figure 3 shows the NO_x emissions in lb per million Btu obtained firing PRB coal and using four types of O₂ arrangement at various burner stoichiometric ratios. The experiments have been performed using a scaled version of B&W's DRB-4Z™ low-NO_x burner.

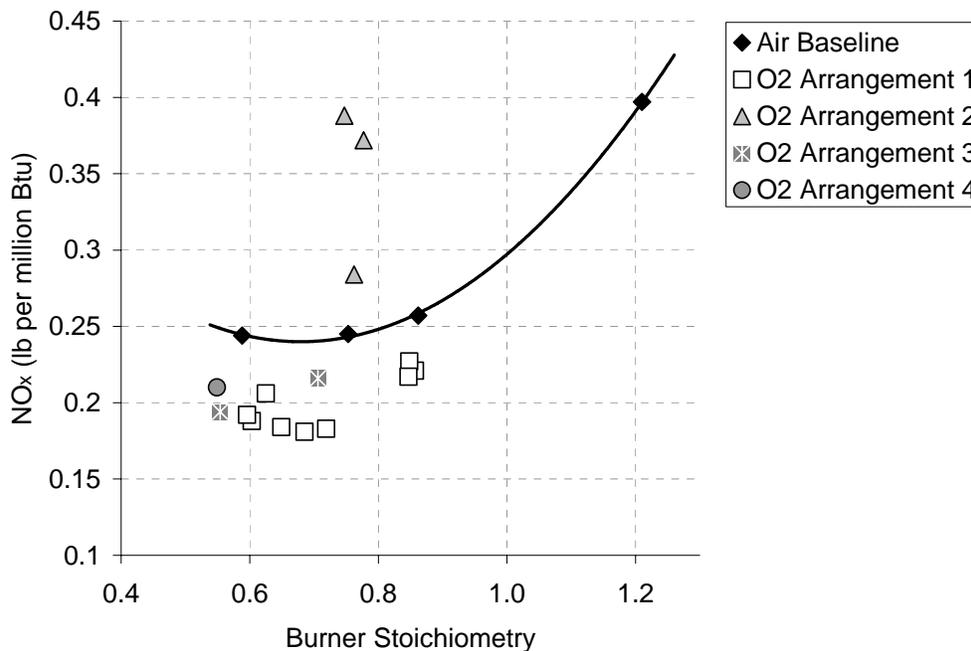


Figure 3: NO_x emission vs. burner stoichiometric ratio (BSR)

The results highlight that the selection of the oxygen injection arrangement is a key factor for a successful oxygen-enriched low-NO_x technology. While NO_x levels were reduced by 28% from a baseline of 0.25 lb per million Btu to 0.18 lb per million Btu using the O₂ Arrangement 1, the use of Arrangement 2 increased the NO_x production by 13% to 50%. The oxygen enrichment using Arrangements 3 and 4 also produced very stable flames, at burner stoichiometry as low as 0.55, and a nominal NO_x reduction of approximately 20% was observed. The baseline NO_x achieved in B&W's Small Boiler Simulator (SBS) is higher than B&W's commercial results.

Based on several large-scale installations of DRB-4Z™ low-NO_x burners on boilers firing PRB coal, NO_x emission levels of 0.16 to 0.2 lb per million Btu have been achieved.

Impact of the oxygen enrichment level

Figure 4 shows the NO_x emission in lb per million Btu using Arrangement 1, measured for three different oxygen enrichment levels referred to as E₁, E₂ and E₃.

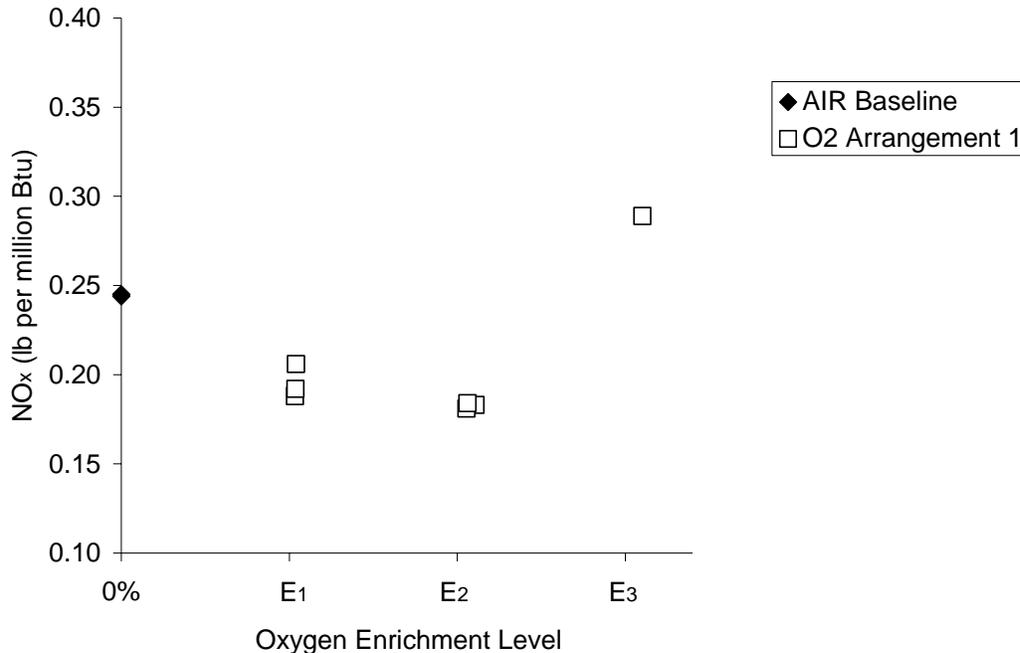


Figure 4: NO_x emission vs oxygen-enrichment level at burner stoichiometric ratio (BSR) around 0.6~0.75

Both enrichments E₁ and E₂ using O₂ arrangement 1 led to NO_x reduction as compared to the air-fired baseline: from 0.25 lb per million Btu in air-fired baseline, NO_x has been reduced to 0.19 lb per million Btu (24% NO_x reduction) and 0.18 lb per million Btu (28% NO_x reduction) respectively with E₁ and E₂. With enrichment E₃, NO_x emissions increased by 15%.

CONCLUSIONS

There is a clear need for new low-NO_x technologies, more efficient than current combustion technologies (LNB, OFA, FGR, Reburn) and less expensive.

Oxygen enriched low-NO_x technology provides a breakthrough NO_x control option to the utility industry, while enabling to reduce the NO_x emission lower than with today's most widely implemented combustion modifications for NO_x control (OFA and LNB). This technology is potentially more affordable than the current SCR technology, depending on many factors such as retrofit difficulty, size of unit, boiler capacity factor, etc. In particular, the oxygen enriched low-NO_x technology is much less capital intensive.

Preliminary experimental data confirm the potential of oxygen enrichment in terms of NO_x reduction. Results obtained at a pilot scale show NO_x emissions reduction by approximately 30% using local oxygen injection in an already air staged coal-fired boiler simulator equipped with the latest, most efficient version of low-NO_x burners and OFA ports. Those results are very sensitive to the O₂ introduction arrangement and to the oxygen enrichment level.

Based on those promising preliminary results, Air Liquide and B&W have set a goal to achieve up to 50% NO_x reduction using an eastern high volatile bituminous coal with optimized oxygen introduction arrangement and the minimum oxygen enrichment level.

In addition to the overall cost competitiveness and the reduced capital requirements, the O₂-enriched low-NO_x technology provides other significant advantages compared to existing technologies: the technology does not involve hazardous chemicals such as ammonia or catalyst, which will facilitate the permitting process and content the utility industry; the retrofit itself will be a low risk project since very little plant modification will have to be implemented; footprint requirements are smaller than for SCR which enables the technology to be implemented in room limited power plants. Finally, further benefits are expected such as combustion efficiency increase, flame stabilization, and potential plant capacity increase.

Site specifics, such as coal type, boiler design, and burner type, have to be considered for a successful implementation of the oxygen-enrichment techniques. Air Liquide and Babcock & Wilcox will combine their complementary expertise in the fields of oxygen and coal-fired boilers to address such specifics and to provide a customized solution to the utility companies.

ACKNOWLEDGMENT

The content of this paper is for informational and educational purposes only and should not be construed as providing professional engineering services or financial advice.

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