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NO_x CONTROL BY GAS REBURNING IN COAL-FIRED UTILITY BOILERS

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ABSTRACT

Gas reburning has achieved NO_x reductions exceeding 60% in demonstrations on three coal-fired utility boilers. The technology has been evaluated for 4,642 hours in long-term, load-following operation on units with tangential-, wall-, and cyclone-firing configurations.

Gas reburning in a 71 MWe tangentially-fired boiler achieved an average NO_x reduction of 67% from the baseline level, in a one-year demonstration test. The nominal gas input was 18% of total heat input. A gas reburning-low NO_x burner system on a 172 MWe wall-fired boiler has achieved overall NO_x reductions of 60-73% in parametric and long-term testing. NO_x reduction has been as high as 60-65% at relatively low natural gas inputs (5-10% of total heat input). Gas reburning in 33 MWe cyclone-fired boiler has resulted in average NO_x reduction of 66% (range 52-77%), at gas heat inputs of 20-26%.

This paper presents a summary of the operating experience at each site and discusses the long-term impacts of applying this technology.

INTRODUCTION

The Energy and Environmental Research Corporation (EER) is conducting field evaluations for two U.S. Department of Energy cofunded Clean Coal Technology (CCT) projects[1-4] involving two integrated technologies (gas reburning-sorbent injection and gas reburning-low NO_x burners) on three coal-fired utility boilers. Demonstration programs, summarized in Table 1, have been carried out at the following sites:

- Tangentially-fired boiler at Hennepin Station, Unit 1, a 71 MWe unit, owned and operated by Illinois Power at Hennepin, Illinois. Long-term demonstration testing was completed in October 1992. The host utility has decided to retain the gas reburning system for future NO_x compliance.

- Cyclone-fired boiler at Lakeside Unit 7, a 33 MWe unit, owned and operated by City Water Light & Power, the municipal utility of the City of Springfield, Illinois. Long-term demonstration testing was completed in June 1994.

- Wall-fired boiler at Cherokee Station, Unit 3, a 172 MWe unit, owned and operated by Public Service Company of Colorado in Denver, Colorado. This unit was retrofitted simultaneously with a gas reburning system and Low NO_x Burners (LNB). Long-term demonstration testing, initiated in April 1993, was completed in January 1994. A second-generation gas reburning system is currently undergoing testing at this site, with results to be available by the end of 1994.

GAS REBURNING PROCESS

Gas reburning is a proven NO_x emission control technology which can be retrofitted to existing coal-, oil-, or gas-fired boilers. In the reburning process, the furnace (exemplified by a wall-fired boiler in Figure 1) is divided into the following three zones:

- Primary combustion zone: Approximately 75 to 85% of the heat is released by coal or another main fuel in this zone.

- Reburning zone: The gas (normally 15 to 25% of total heat input) used for reburning is injected higher up in the furnace to create a slightly fuel-rich zone in which NO_x is reduced to N_2. The gas may be injected with or without recirculated flue gas (FGR). Coal, fuel oil, coal-water slurry, or coke oven gas can also be used as a reburning fuel. The quantity of reburning fuel can be significantly reduced, according to the NO_x control level requirement.

- Burnout zone: In the third and final zone, additional combustion air (overfire air or OFA) is added to oxidize any remaining fuel fragments (hydrocarbons, CO, and carbon) and complete the combustion process.

Each of the zones has a unique stoichiometric ratio (SR). The typical stoichiometric ratios in the primary (SR_1), reburning (SR_2), and burnout (SR_3) zones are 1.10, 0.90 and 1.15, respectively.

Figure 2 shows expected emissions reductions due to gas reburning at the tangentially-fired unit, when using 18% gas heat. The gas reburning systems is designed to achieve NO_x reduction of 60%; reductions in SO_2 by 18% and CO_2 by 8% are also expected. The reductions in SO_2 and CO_2 are due to differences in fuel composition. Natural gas has no sulfur and a lower carbon to hydrogen ratio. The gas reburning system at the cyclone-fired unit has a design gas heat input of 24%, to achieve 60% NO_x reduction. The gas reburning system at the wall-fired unit has a design gas heat input of 18%, but since this unit is also equipped with LNB, the NO_x control efficiency due to gas reburning is not as high. The goal for NO_x reduction, due to gas reburning and LNB, is 70%.

ENVIRONMENTAL CONTROLS

NO_x Reduction

Figure 3 shows that NO_x decreases with increasing reburning fuel input (expressed as a percent of the total heat input) for all three types of utility boilers. For the tangentially-fired boiler and the wall-fired boiler with LNB, NO_x emissions level off between 12 and 22% gas input. It is desirable to use 12% instead of 22% gas input in such cases, because of gas-coal cost differential consideration.

Long-term NO_x data for the three types of boilers are shown in Figures 4, 5, and 6. Average NO_x data are summarized in Table 1. The average NO_x reductions ranged from 64 to 67% based on "as-found" baseline NO_x levels, before the installation of gas reburning systems. For the tangentially-fired boiler, NO_x reductions were 67% and 55% at 18% and 10% gas heat inputs, respectively. For the wall-fired boiler with LNB, NO_x reduction was as high as 60-65% even at relatively low gas heat inputs (5-10%). For the cyclone-fired boiler, NO_x reductions were 67% and 50% at 25% and 15% gas heat inputs, respectively.

Title IV Phase 1 of the Clean Air Act Amendments of 1990, states NO_x limits for tangentially-fired and wall-fired boilers of 0.45 and 0.50 $lb/10^6$ Btu (or 194 and 215 mg/MJ), respectively, on an annual average. Any over compliance can be averaged with other affected boilers or the compliance level can be met by lowering the gas input. No similar limit for cyclone-fired units is stated.

CO Emissions and Carbon Loss

As shown in Figure 7, gas reburning reduced CO emission and for the wall-fired boiler from LNB levels, with or without OFA. Figure 8 shows the impact of gas reburning on carbon-in-ash. At boiler exit oxygen of 2.8% and above, gas reburning reduces carbon loss. These benefits of gas reburning are derived from the use of gas and optimized OFA as integral parts of the gas reburning system.

SO_2, CO_2, Opacity, and Particulates

Table 2 shows impacts of gas reburning on the tangentially-fired boiler emissions. SO_2 and CO_2 were reduced by 18% and 8%, respectively, at 18% gas input. There was essentially no change in opacity or particulate emissions. Particulate loadings into the electrostatic precipitator were decreased with gas reburning in proportion to the percent gas heat input.

BOILER PERFORMANCE IMPACTS

Table 2 also shows that gas reburning has minor impacts on thermal performance and durability of the tangentially-fired boiler. Gas reburning resulted in reduction in thermal efficiency of 0.3 to 1.1%, over a wide range in load. Steam temperatures were maintained at a constant level by adjustment of attemperation spray. Extensive tube wall thickness measurements, taken before and after completion of testing, showed no increase in wastage of tube walls. Metallurgical examinations of tube wall samples showed no change in metallurgy. Similar trends have been observed for the thermal performance of the wall-fired (Table 3). Gas reburning in this application had positive impacts on steam temperature and net heat rate. For the cyclone-fired boiler, gas reburning resulted in a small increase in attemperation heat absorption, but constant main steam temperatures were maintained (Figure 9). The durability impacts of gas reburning on the wall-fired and cyclone-fired boilers will also be evaluated.

HIGHLIGHTS OF GAS REBURNING EXPERIENCE

The following are highlights from the gas reburning demonstrations for over 4600 hours:

- NO_x level can be varied according to the regulatory requirement by changing the gas input.
- Gas input can be decreased from the design point for maximum NO_x reduction without substantial loss in NO_x control.
- CO emissions can be minimized by optimizing OFA flow under gas reburning.

- Part replacement of coal with natural gas results in modest reductions in SO_2 and CO_2 emissions.

GAS REBURNING APPLICABILITY

Gas reburning can be applied to tangentially-, wall-, and cyclone-fired boilers, as shown in Figure 10. The expected NO_x levels and percent reductions for several gas technologies are shown. Gas reburning has been integrated with other technologies to boost NO_x control[5]. These include:

- Advanced Gas Reburning (AGR): Gas Reburning (GR) and Selective Non-Catalytic Reduction (SNCR)

- CombiNO_x: Gas Reburning (GR) + SNCR + Methanol Injection

The NO_x control by GR and GR-LNB is in the 50-70% range. AGR and CombiNO_x, which have been evaluated at pilot scale, reduce NO_x by 82% (AGR) and by over 90% (CombiNO_x). When more stringent NO_x limits are promulgated, gas reburning or technologies integrated with gas reburning or SCR can be applied to all types of boilers.

CONCLUSIONS

The following conclusions are drawn from the three gas reburning demonstrations:

- Effective NO_x control (>60%)
- NO_x control flexibility
- Consistent and reliable operation
- Simultaneous SO_2 and CO_2 control due to gas firing
- Minor thermal impacts
- Commercially available with performance guarantees

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- Illinois Power Company
- City Water, Light and Power Company of Springfield, Illinois
- Public Service Company of Colorado
- Energy and Environmental Research Corporation

REFERENCES

1. Angello, L. C., Engelhardt, D. A., Folsom, B. A., Opatrny, J. C., Sommer, T. M., and Ritz, H. J., "Gas Reburning-Sorbent Injection Demonstration Results," presented at the U.S. Department of Energy First Annual Clean Coal Technology Conference, Cleveland, Ohio (September 22-23, 1992).

2. Hong, C. C., Light, J. M., Moser, H. M., Sanyal, A., Sommer, T. M., Folsom, B. A., Payne, R., and Ritz, H. J., "Gas Reburning and Low NO_x Burners on a Wall-Fired Boiler," Second Annual Clean Coal Technology Conference, Atlanta, Georgia, September 7-9, 1993.

3. Keen, R. T., Hong, C. C., Opatrny, J. C., Sommer, T. M., Folsom, B. A., Payne, R., Ritz, H. J., Pratapas, J. M., May, T. J., and Krueger, M. S., "Enhancing the Use of Coal by Gas Reburning and Sorbent Injection," Second Annual Clean Coal Technology Conference, Atlanta, Georgia, September 7-9, 1993.

4. Sommer, T. M., Hong, C. C., Moser, H. M., and Ritz, H. J., "Integrating Gas Reburning with Low NO_x Burners," (U.S. Department of Energy First Annual Clean Coal Technology Conference, September 22-24, 1992, Cleveland, Ohio).

5. Sanyal, A., Sommer, T. M., Hong, C. C., Folsom, B. A., Payne R., Seeker, W. R., and Ritz, H. J., "Advanced NO_x Control Technologies," Tenth Annual International Pittsburgh Coal Conference, September 20-24, 1993.

TABLE 1. GAS REBURNING DEMONSTRATIONS

Boiler	MWe	Location	Long-term Testing	Hours	% Gas	Average NOx $lb/10^6$ Btu	% Reduction
Tangentially Fired	71	Hennepin, IL	Completed	1,154	Nominal 18	0.245	67
Cyclone-Fired	33	Springfield, IL	On-going	469	20-26	0.344	66
Wall-Fired	172	Denver, CO	On-going	3,019	5-19	0.260	64
				4,642			

TABLE 2. TANGENTIALLY FIRED BOILER IMPACTS

Variable	Change from Baseline	Comments
Emissions		
NO_x	-67% Average	With 18% gas heat input
CO	-1 to +9 ppm	At 70 and 60 MW
CO_2	-8%	Less carbon in gas than coal
SO_2	-18%	Zero sulfur in gas
Opacity	No change	Below 20%
Particulates	No change	Below 0.04 $lb/10^6$ Btu (17 mg/MJ)
Thermal effects		
Thermal efficiency	-0.3 to -1.1%	Latent heat losses due to hydrogen
Carbon in Ash	+0.5 to 1.7%	Minimal impact on boiler efficiency
Steam temperature	No change	Controlled by attemperation
Heat distribution	Minor changes	Within normal ranges
Durability		
Tube wastage	No increase	Extensive ultrasonic surveys
Tube metallurgy	No change	Destructive tests of tube samples
Projected life	No change	Boiler life unaffected

TABLE 3. THERMAL PERFORMANCE OF A WALL-FIRED BOILER AT FULL LOAD

Operation	**LNB**	**GR-LNB**
Process Variables:		
Load, MWe net	148	148
Boiler exit O_2, % dry	3.90	3.60
Gas heat input, %	0.0	12.6
Overfire air, % of total air	0.0	19.3
Steam Side:		
Main steam temperature, °F (°C) (Design 1,005°F or 540°C)	965 (518)	992 (533)
Superheat attemperation, lb/hr (kg/h)	5,030 (2,280)	14,200 (6,440)
Hot reheat steam temperature, °F (°C)	942 (506)	985 (529)
Reheat attemperation, lb/hr (kg/h)	0 (0)	91 (41)
Economizer outlet gas temperature, °F (°C)	694 (368)	711 (377)
Thermal efficiency, %	88.00	87.55
Gross heat rate, Btu/kWh (kJ/kWh)	9,487 (10,010)	9,316 (9,828)
Net heat rate, Btu/kWh (kJ/kWh)	10,261 (10,825)	10,093 (10,648)

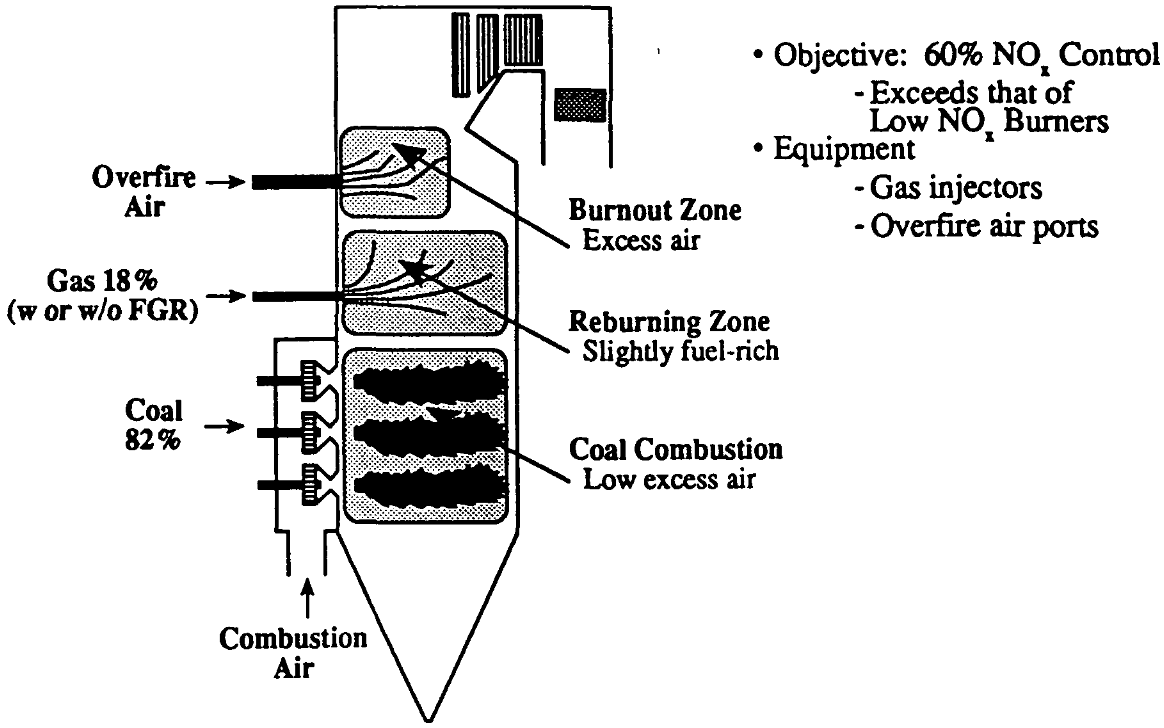

Figure 1. Overview of gas reburning process.

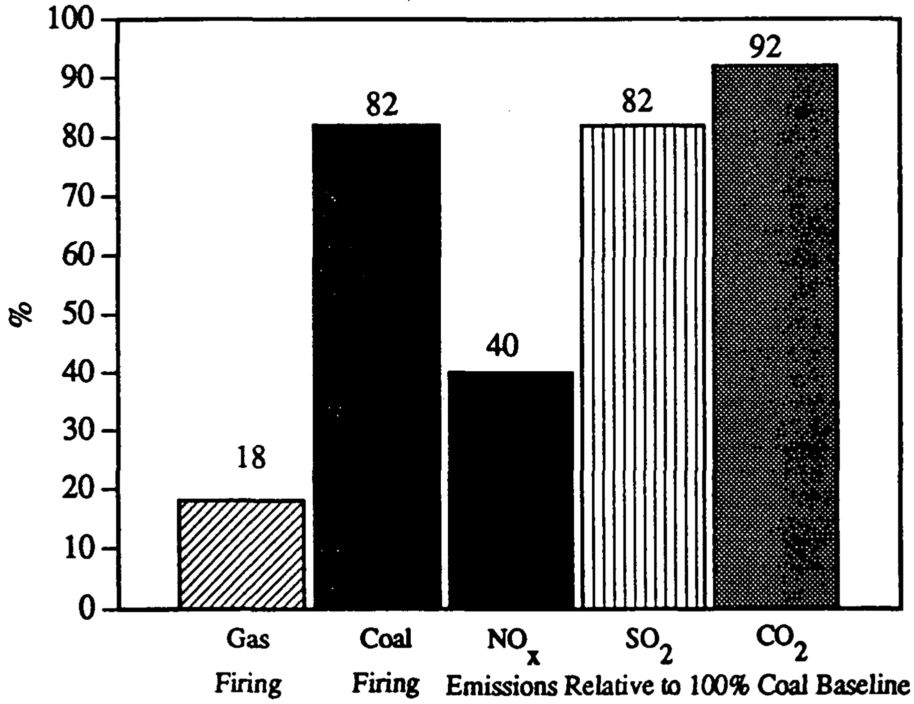

Figure 2. Typical gas reburning performance.

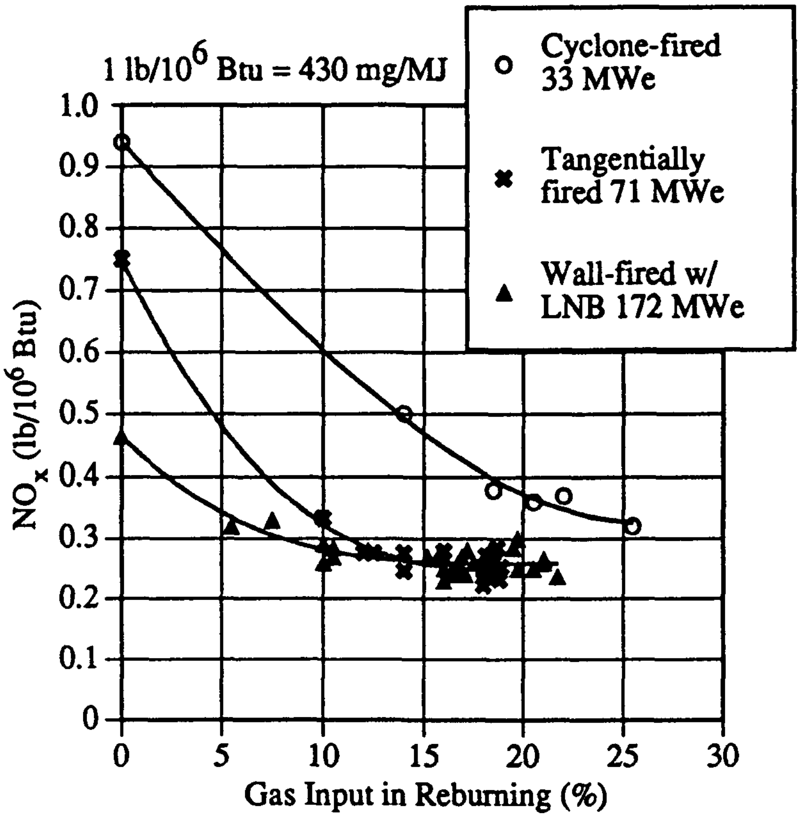

Figure 3. NO_x emissions from three utility boilers equipped with gas reburning systems.

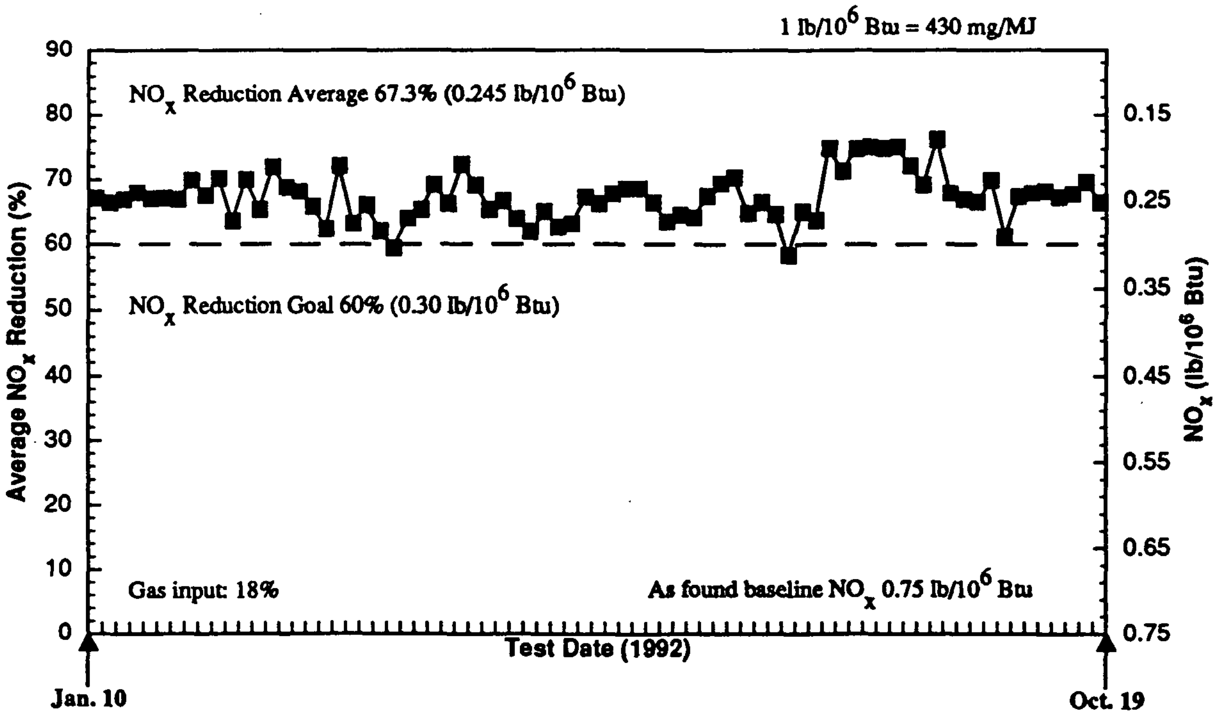

Figure 4. Long-term NO_x data for the tangentially-fired boiler .

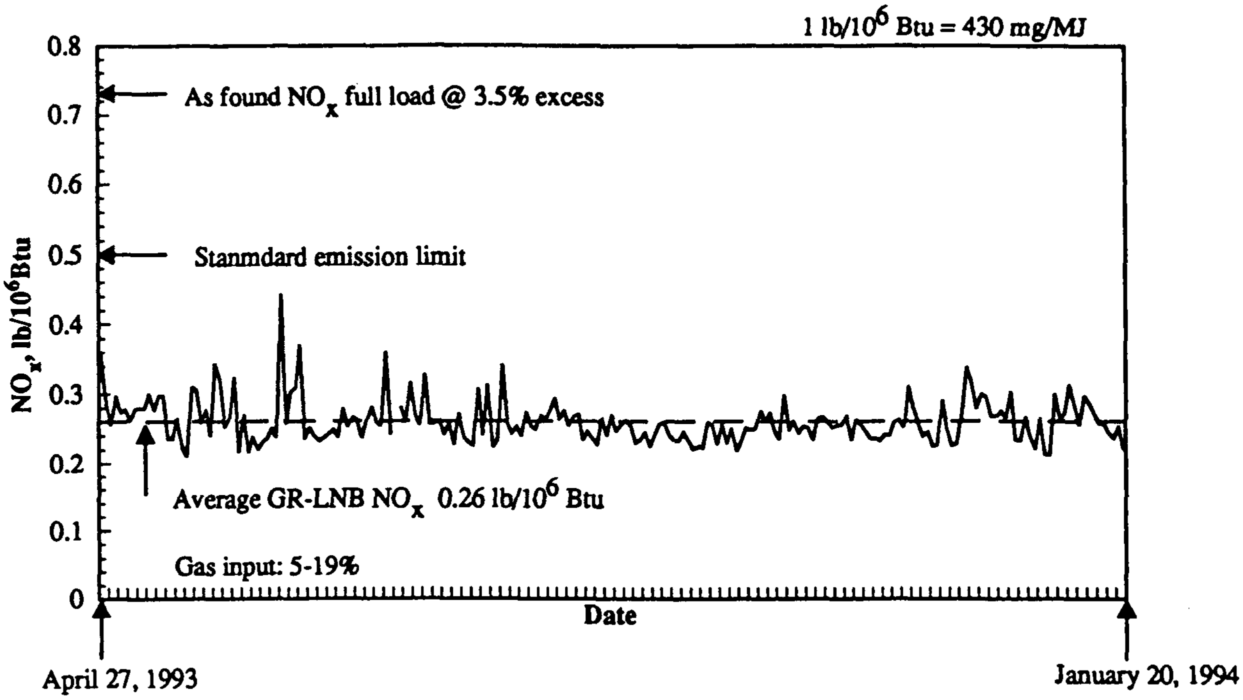

Figure 5. Long-term NO_x data for the wall-fired boiler with low NO_x burners.

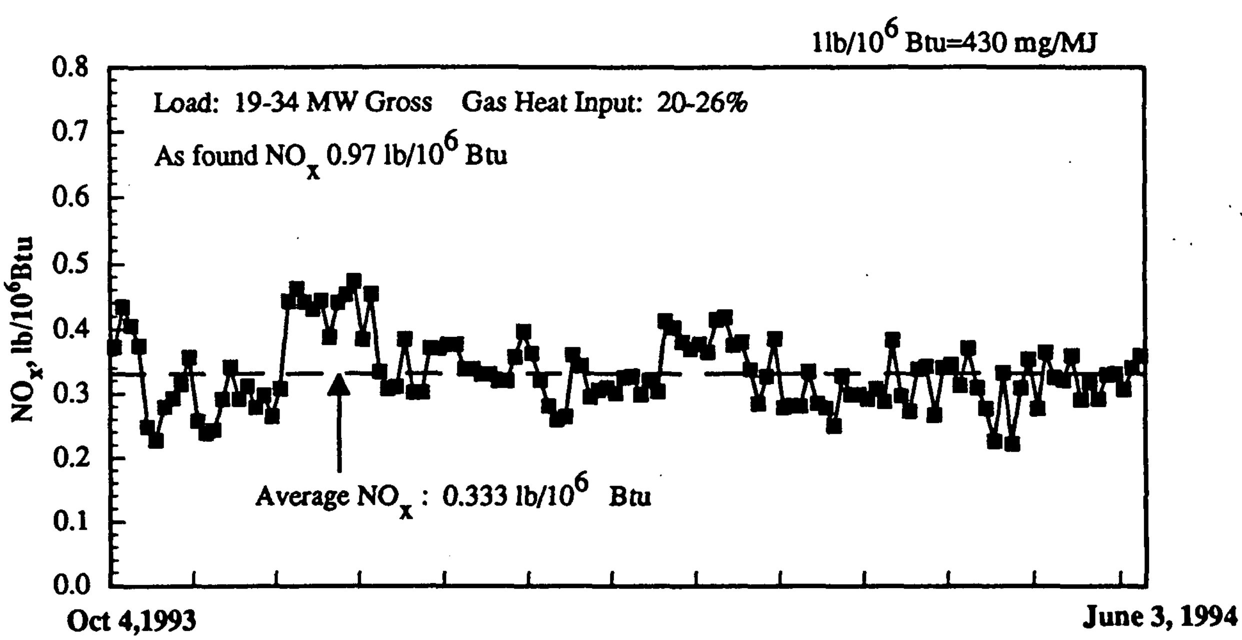

Figure 6. Long-term NO_x data for the cyclone-fired boiler.

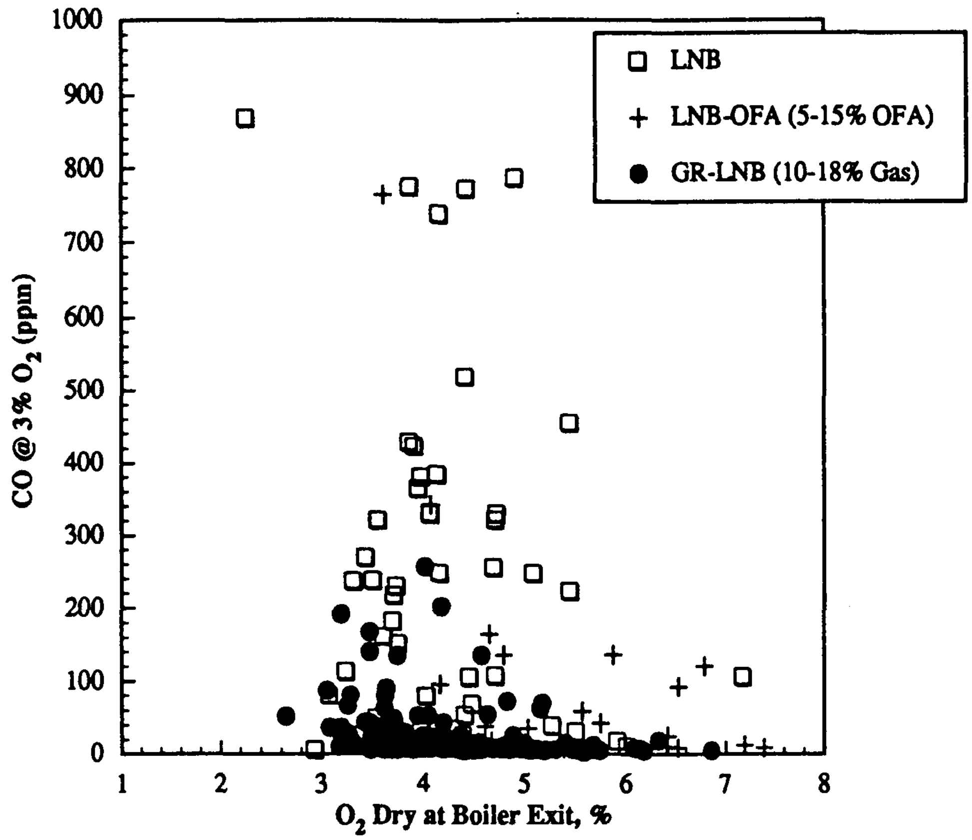

Figure 7. Impact of gas reburning on CO emissions for the wall-fired unit.

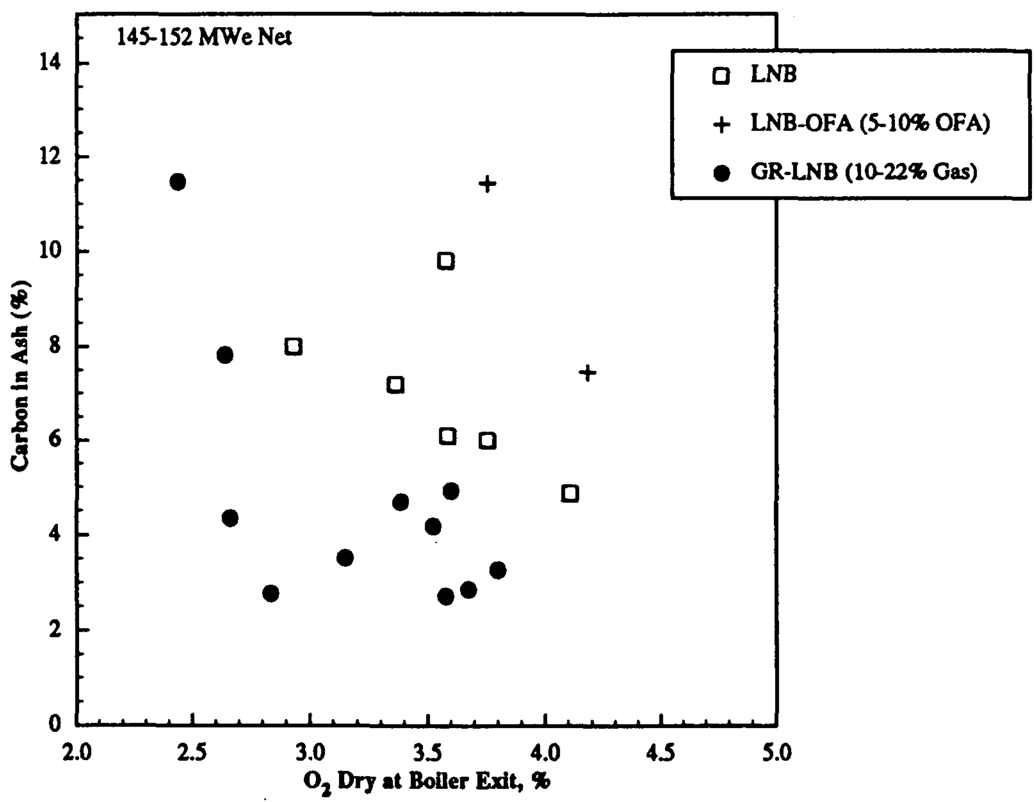

Figure 8. Impact of gas reburning on carbon loss for the wall-fired unit.

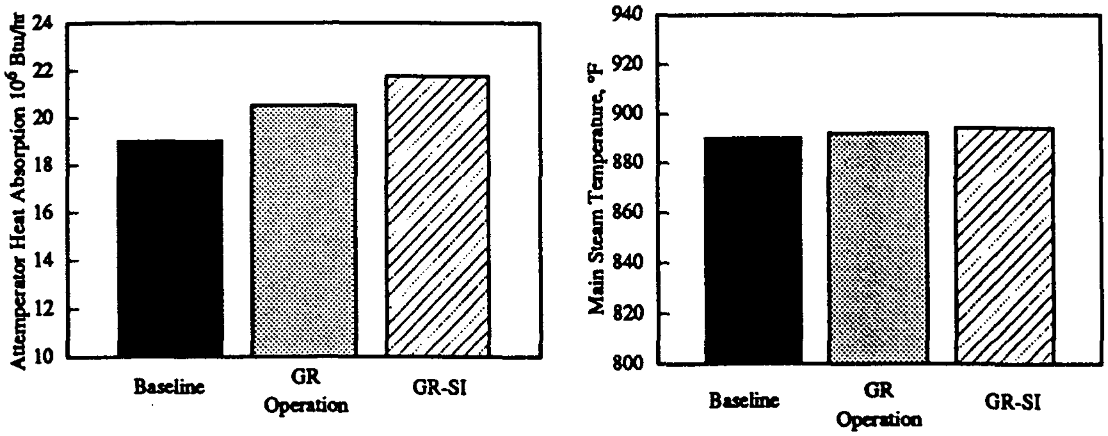

Figure 9. Attemperation heat absorption and steam temperatures for the cyclone-fired unit.

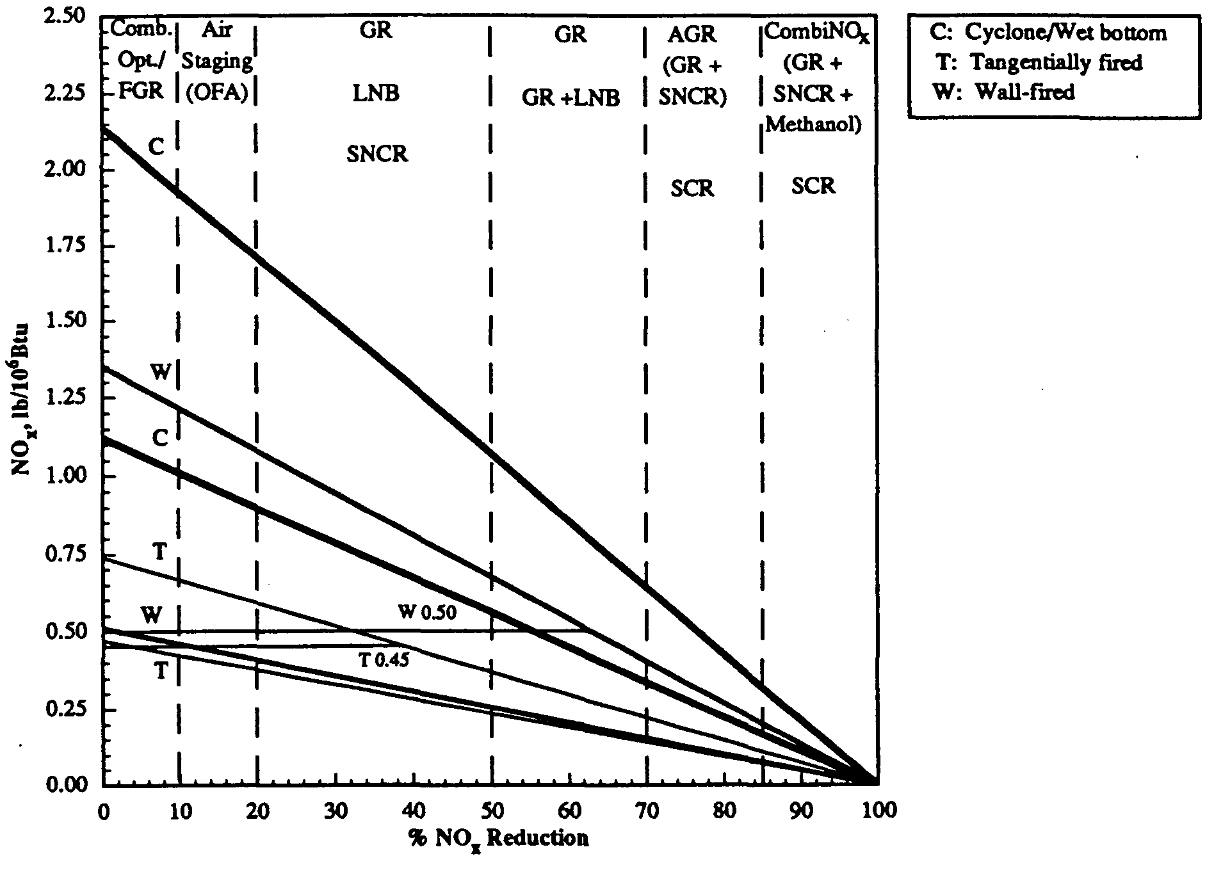

Figure 10. NO_x reduction technologies for meeting U.S. emissions standards.