United States
Environmental Protection
Agency

Air and Energy Engineering
Research Laboratory
Research Triangle Park NC 27711

Research and Development

EPA/600/S7-86/048 Apr. 1987

EPA

Project Summary

Pilot Scale Process Evaluation of Reburning for In-Furnace NO_x Reduction

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This report gives results of coal and natural gas reburning application tests to a pilot scale 3.0 MWt furnace to provide the scaling information required for commercial application of reburning to pulverized- coal-fired boilers. Initially parametric studies were conducted in a 23 kWt bench scale reactor to quantify the impact of fuel and process parameters on reburning effectiveness. The results of this investigation confirm the potential of the reburning process for significant NO_x reduction. Process effectiveness depends strongly upon the NO_x and O_2 concentrations at the end of the main heat release zone; the stoichiometry, temperature, and residence time in the fuel-rich reburning zone; the fuel composition and mixing of the reburning fuel jet; and the temperature of the final burnout zone. This investigation has also identified and defined the optimum design criteria for reburning application and demonstrated that it is possible to scale up the process without loss in effectiveness. In addition, it has shown that simultaneous NO_x/SO_x reductions of up to 60% can be achieved with reburning combined with sorbent injection.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This report evaluates reburning on a pilot scale for in-furnace nitrogen oxides (NO_x) reduction. Reburning is a combustion modification technique in which fuel is added downstream of the primary firing zone to produce a fuel-rich zone. In the fuel-rich reburning zone, the NO_x from the primary zone reacts with hydrocarbon radicals formed by partial oxidation of the reburning fuel to produce reduced nitrogen species such as NH_3 and HCN as well as molecular nitrogen. Burnout air is provided downstream to complete combustion. In the burnout zone the reduced nitrogen species are converted to NO_x or N_2.

The objective of this program was to evaluate the impact of scale on the effectiveness of NO_x control with reburning by comparison of bench scale results with those obtained on the pilot scale facility. Program objectives included: the generation of design guidelines for reburning applications; determination of the impacts of scale and mixing on the reburning process; definition of optimal operating conditions; and comparison of reburning with other modified combustion techniques.

The tests were performed on a pilot scale reburning tower, a downfired furnace with a total load capability of 3 MW (10×10^6 Btu/hr). The furnace was refractory lined with inside dimensions of 1.2 x 1.2 x 8.0 m. Pulverized coal and natural gas were employed as fuels, with up to 30% of the load injected as reburning fuel. The tower contained seven rows of identical ports which allowed a multiplicity of air and reburning fuel injection schemes. Either air or recirculated flue gas could be used as the reburning coal transport medium. Manipulation of the temperature profile was possible by inserting stainless steel cooling panels.

Process Parameters

The first stage of tests involved the investigation of process parameter effects on reburning, with data compared to bench scale results. Utah coal was used as the primary and reburning fuel.

Parameters of major importance included reburning zone residence time, reburning zone stoichiometry (SR_2), reburning fuel injection location, primary NO_x level, reburning coal transport medium, and reburning jet stoichiometry (SR_r). Data obtained with air and flue gas recirculation (FGR) as the reburning coal transport medium are shown in Figure 1. The more fuel-rich reburning jets (i.e., lower SR_r) for FGR transport resulted in substantially lower NO_x emissions. When air was the transport medium, the high levels of oxygen premixed with the reburning jets resulted in more rapid oxidation of the reburning fuel nitrogen and hydrocarbon radicals, hindering the NO_x reduction process. The effect of SR_r was diminished when the transport line and reburning zone became very fuel rich. This suggests that a high reburning fuel ratio and/or low primary zone stoichiometry are necessary for efficient NO_x reduction with air transport. Due to the kinetics of the reduction reactions, a longer, hotter reburning zone decreased NO_x emission, as shown in Figures 2 and 3. The hotter environment (Profile 2) resulted in better primary zone burnout which appeared to improve the efficiency of reburning. In general, the results of the parametric studies agree with those found on the bench scale facility, with scale effect minimal.

Reburn Fuel, %	SR_1	FGR		Air	
		SR_r	SR_2	SR_r	SR_2
10	1.0	0.65	0.95	1.56	1.04
	1.1		1.05		1.13
20	1.0	0.32	0.86	0.78	0.95
	1.1		0.84		1.05
30	1.0	0.22	0.77	C.52	0.86
	1.1		0.83		0.93

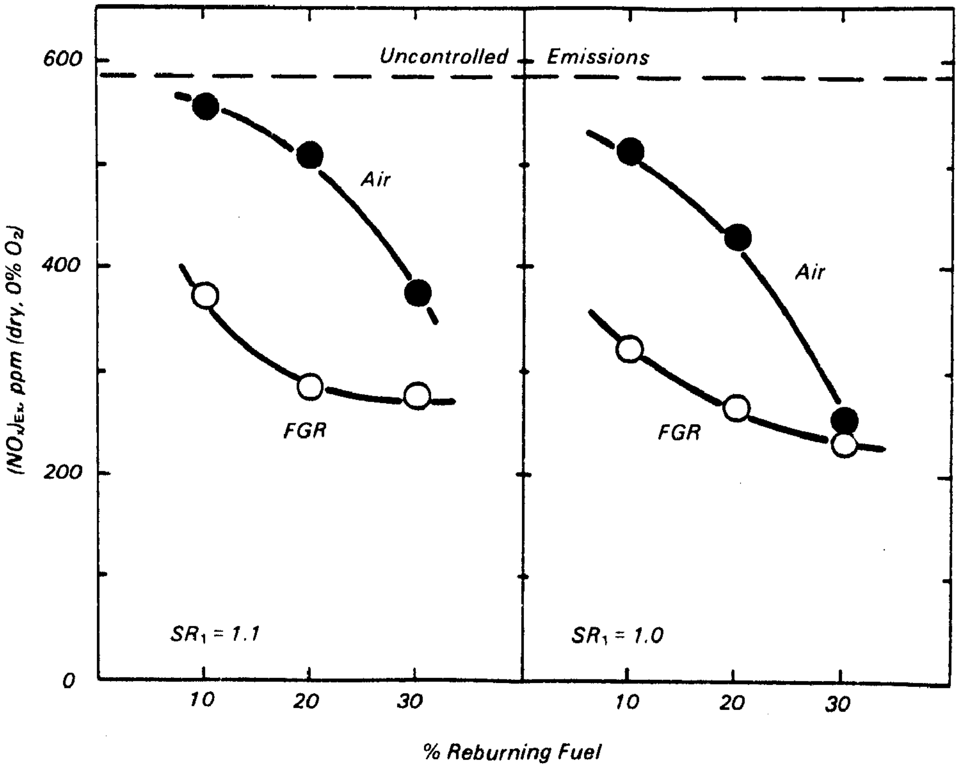

Figure 1. Effect of transport media on emissions.

Mixing Studies

The second stage of tests examined mixing effects. The studies conducted investigated several injection configurations for both the reburning fuel and burnout air. Configurations included: one and four single wall-fired jets; eight opposed jets (four on each wall); and four staggered jets (two on each wall). For burnout air injection, the injection configuration had no significant influence on emissions. For reburning fuel injection with FGR, four wall-fired jets were the most efficient. The results obtained with four wall-fired and one large jet are compared in Figure 4. NO_x emission decreased, then leveled off as jet penetration increased. The penetration, which was calculated from empirical correlations and verified visually, corresponding to the minimum flowrate required was approximately 70 to 100% of the furnace depth for four jets and one jet, respectively. The complete jet penetration achieved with one jet is detrimental to furnace operation due to excessive slag buildup from jet impingement on the opposite wall. With four jets, any further enhancement to NO_x reduction by increased mixing obtained by deeper penetration was countered by negative SR_r and SR_2 effects on NO_x reduction. A NO_x concentration map of the reburning zone showed extensive NO_x reduction in regions with a high concentration of hydrocarbon radicals.

Results obtained with air as the reburning coal transport medium are shown in Figure 5. NO_x emissions decreased as the air flowrates, and thus SR_r and SR_2, decreased. At low penetration depths, NO_x emission leveled off, as any further benefit from lower stoichiometries was negated by inadequate mixing. Contrary to FGR results, NO_x emissions were lower with one large reburning jet. Utilization of one jet resulted in less rapid dispersion of the reburning fuel, which promoted the existence of locally fuel-rich "pockets" in which oxidation of reburning coal

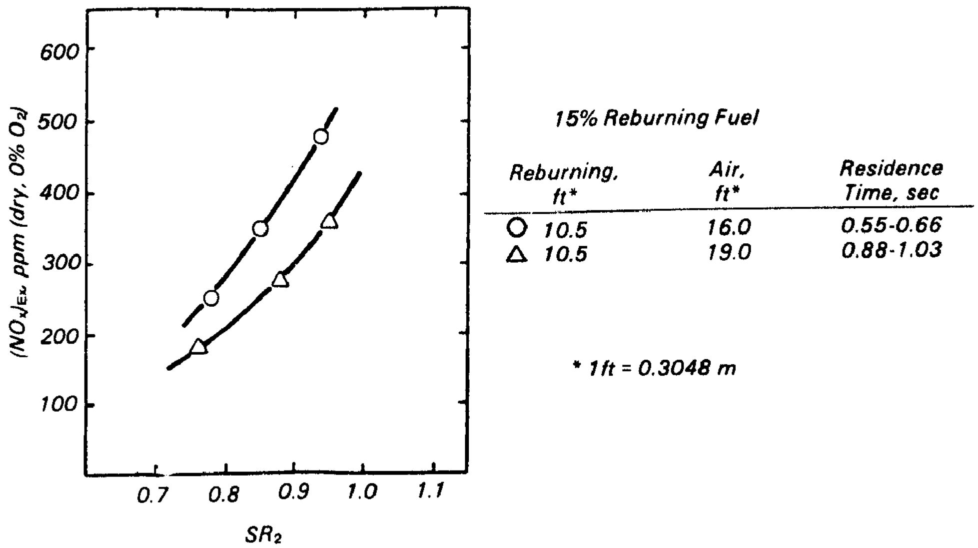

Figure 2. *Influence of rich-zone residence time.*

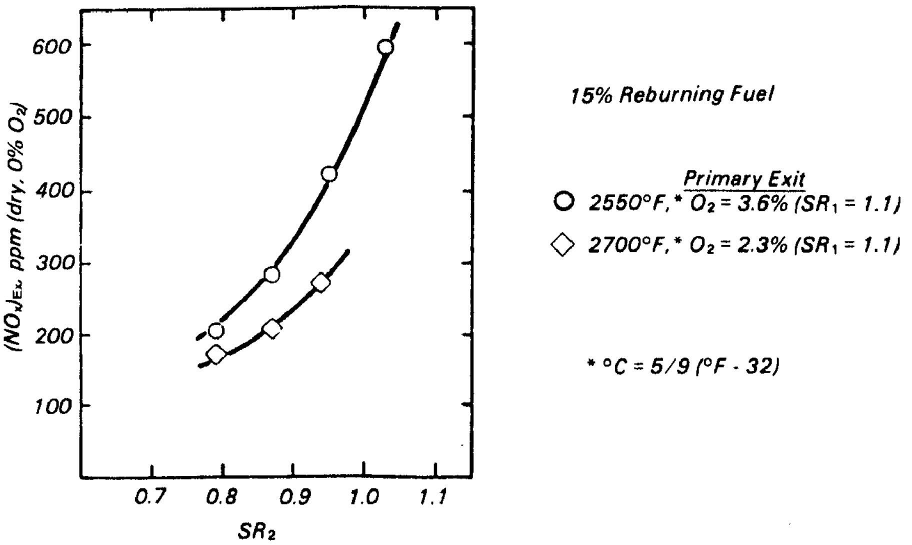

Figure 3. *Impact of thermal environment.*

nitrogen and hydrocarbon was inhibited. As the reburning zone became more overall fuel rich, this effect was diminished. These results demonstrate that, with a reburning fuel which contains nitrogen, there exists a tradeoff between high dispersion rates for enhanced primary NO_x destruction, and low reburning jet mixing rates to minimize reburning coal nitrogen oxidation.

Scale Effects

Results of parametric studies on the pilot scale furnace agree with bench scale data. To verify that the critical scaling parameters had been identified and properly defined, identical bench and pilot scale experiments were conducted to provide directly comparable scaling data under optimized, commercially acceptable reburning conditions. In Figure 6, exhaust emissions are shown as a function of the NO_x concentration existing the primary combustion zone. Variations in the primary NO_x were obtained using an ammonia-doped natural gas flame. Optimal pilot scale mixing configurations were employed to minimize deviations in mixing between the two facilities.

Figure 6 demonstrates that a 100x scale-up was without loss in process efficiency if the critical stoichiometry, fuel, thermal environment, and reburning fuel dispersion parameters are matched. At normal primary NO_x levels, 20% reburning produced a 50% reduction in the exhaust emissions; however, at low primary NO levels the percentage of reduction decreased somewhat due to the oxidation of reburning fuel nitrogen. If a nitrogen free reburning fuel, such as natural gas, is used, efficient reduction of NO_x can be attained when primary NO_x is low.

Conclusions

Results of this study on the pilot scale reburning tower indicate that many physical and chemical parameters affect NO_x exhaust emissions. The data generated on the reburning tower generally agreed with bench scale results, which implies that the influence of major process parameters is independent of scale.

The following guidelines should be observed for optimal reburning results:

- minimize excess air levels in the main burner zone,
- maximize the fuel-rich zone residence time,
- allow complete burnout of the primary fuel before injecting the reburning fuel,
- inject the reburning fuel into as hot a furnace environment as possible,
- use FGR as the reburning coal transport medium with approximately 20% reburning fuel,
- with FGR as transport medium, inject the reburning fuel so that jet penetration is greater than two-thirds of the furnace depth, and coverage of the furnace cross section is thorough, and
- if air must be used for reburning fuel transport, increase the reburning fuel ratio to 30% and decrease the mixing rate of the reburning jets.

Overall, the reburning process was shown to be an effective method for in-furnace NO_x reduction, substantially decreasing NO_x emissions relative to an uncontrolled system.

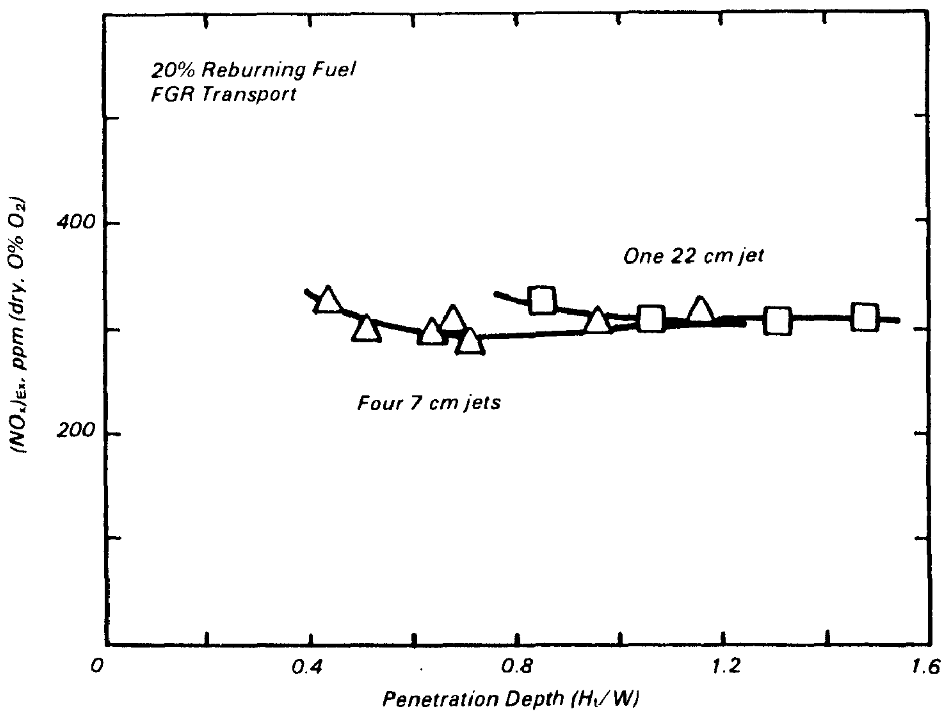

Figure 4. *Mixing effects for FGR transport.*

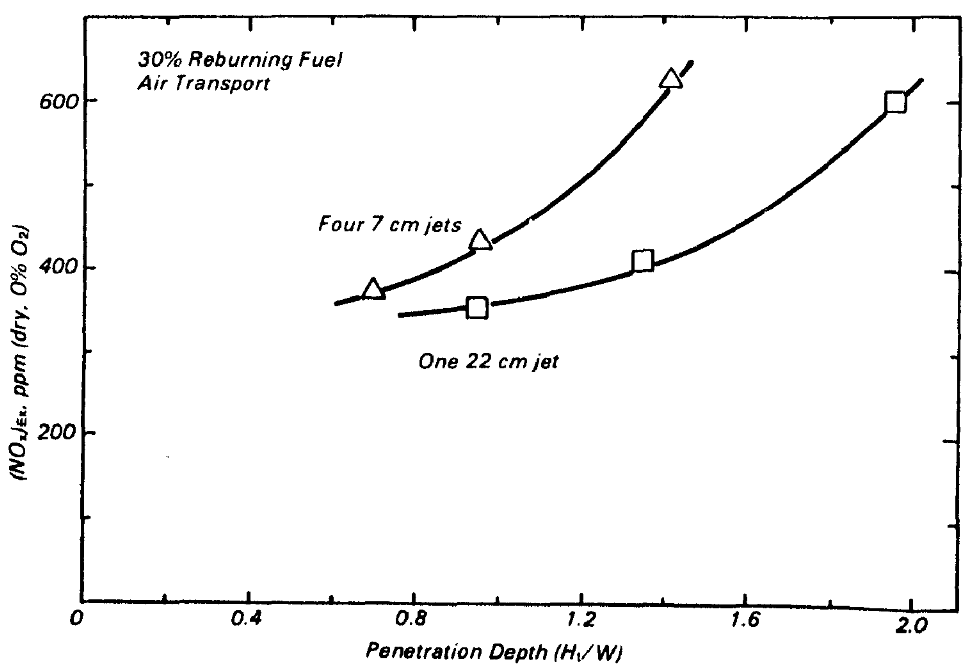

Figure 5. *Mixing effects for air transport.*

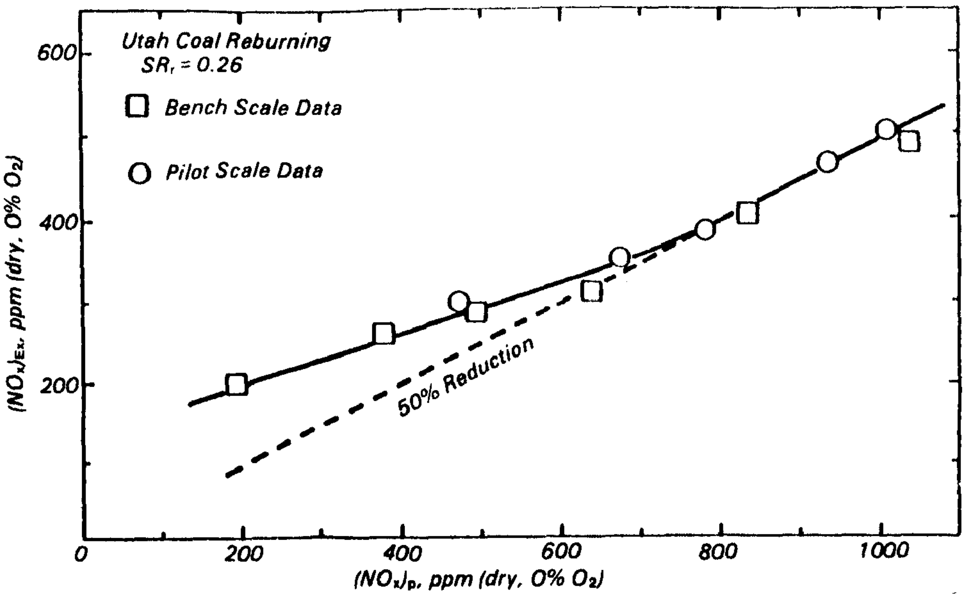

Figure 6. *Comparison of bench and pilot scale reburning effectiveness.*

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The complete report, entitled "Pilot Scale Process Evaluation of Reburning for In-Furnace NO_x Reduction," (Order No. PB 87-140 323/AS; Cost: $18.95, subject to change) will be available only from:
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