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AN INVESTIGATION TO DEFINE THE PHYSICAL/CHEMICAL CONSTRAINTS WHICH LIMIT NO_x EMISSION REDUCTION ACHIEVABLE BY REBURNING

Quarterly Report 7

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1.0 INTRODUCTION

Reburning is a combustion modification technique which removes NO_x from combustion products by using fuel as a reducing agent. Previous studies have shown that natural gas is more effective than coal as a reburning fuel. It is believed that 60 percent reduction in NO_x emission can be achieved with natural gas reburning. However, kinetic calculations indicate that emission reductions greater than 80 percent are possible using the reburning process.

The objectives of this program are to define the chemical and physical constraints which prevent the attainment of 80 percent NO_x reduction with reburning and to test improved configurations for reburning as an advanced NO_x control technique for coal-fired boilers. The program has been divided into two experimental scales. Bench scale studies are designed to screen the chemical and physical means for enhancing reburning efficiency. Subsequent pilot studies will evaluate the impacts of finite rate mixing on the effectiveness of the various concepts. These studies have been supported with chemical kinetics and boiler performance modeling to generalize the experimental data to full scale boilers. Specifically, the program consists of the following:

- Bench scale studies
  - N_2 formation in reburning zone
  - XN conversion in burnout zone
- Pilot scale studies
- Interpretation and generalization
- Final Report

This quarterly report documents the bench scale experimental results obtained in this reporting period. The focus is on the enhancement of reburning with distributed fuel addition and advanced hybrid process. The experiments were conducted in the bench scale Control Temperature Tower

(CTT). The CTT is a downfired, refractory lined furnace which is 20 cm in diameter and 2.4 m in length. The baseline conditions for these tests were:

- Primary fuel/natural gas at 80 x 10^3 Btu/hr; primary NO_x, $(NO_x)_p$ = 240 or 600 ppm (dry, 0% O_2) by doping; SR_1 = 1.1.
- Reburning gas injection at 2550°F (T_1); reburning zone residence time ($_2$) = 400 ms.
- Burnout air injection at 2300°F (T_2); SR_3 = 1.25.

2.0. EXPERIMENTAL RESULTS

In the reburning process, NO is reduced to molecular nitrogen. The process is initiated by reaction of NO with a hydrocarbon radical, and the reaction pathway passes through intermediate cyanide and amine species prior to the evolution of molecular nitrogen. Upon introduction of burnout air, the intermediate nitrogenous species can form N_2 or be oxidized to NO. The experimental results presented in this section focus on the enhancement of CH radical concentration with distributed fuel addition and the enhancement of N_2 formation in the burnout zone with the injection of nitrogenous compounds.

2.1 Distributed Fuel Addition

The use of advanced fuel and air contacting patterns was considered as a physical means for reburning enhancement. Kinetic modeling results, as shown in Figure 2-1, indicate that adding the same amount of reburning fuel over a longer time span does not result in a halving of the CH concentration. Experiments were carried out to study the effects of dividing the reburning fuel into two streams.

Figure 2-2 illustrates the various fuel distribution configurations tested. In these experiments, the amount of reburning fuel was kept constant at 20 percent and the locations of the first fuel injection and the final air injection were also held constant, representing a residence time of approximately 400 ms for all configurations. Figure 2-3 shows the results and indicated that distributed fuel addition did not produce higher reburning efficiencies than the standard reburning configuration. Again, this supports the argument that the CH radical pool appears to be sufficient in the reburning process.

2.2 Hybrid Process - Advanced Reburning

Earlier studies on the conversion of XN species in the burnout zone suggest that the key parameters for the enhancement of burnout zone chemistry are:

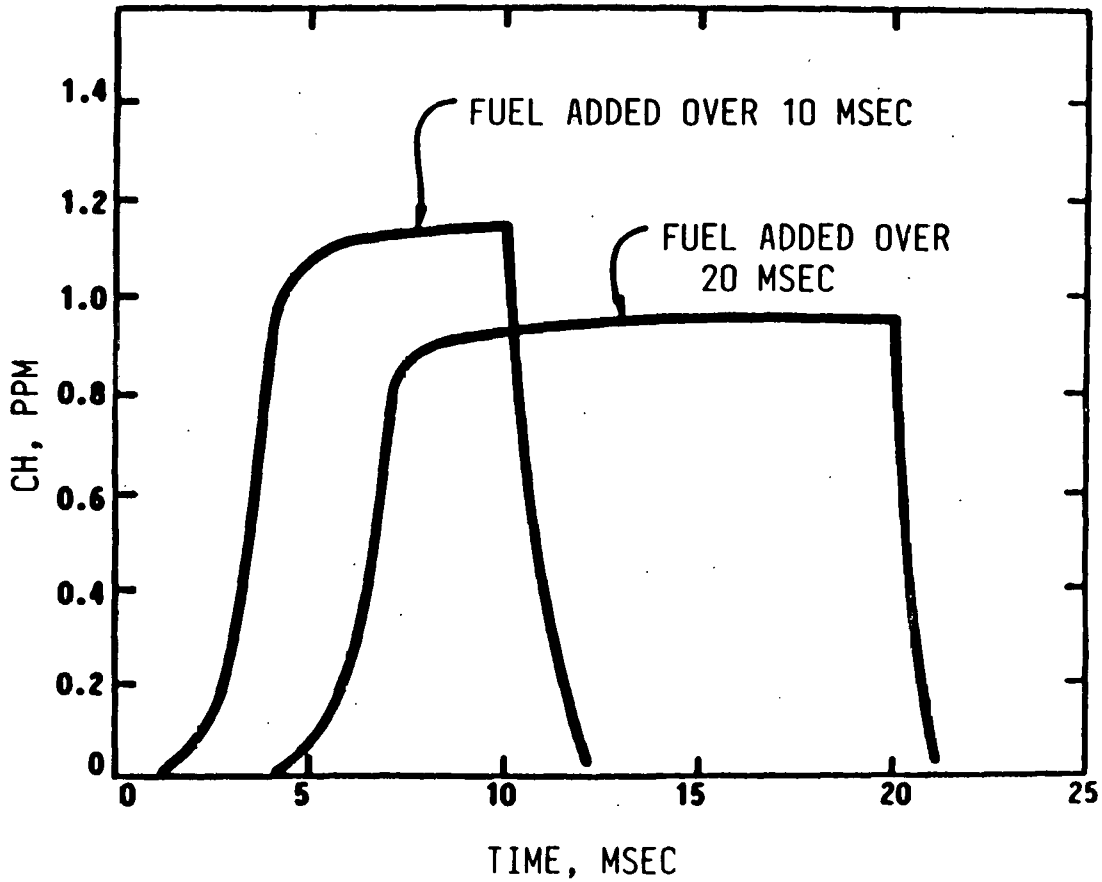


Figure 2-1. Influence of reburning fuel addition rate on CH radical concentration.

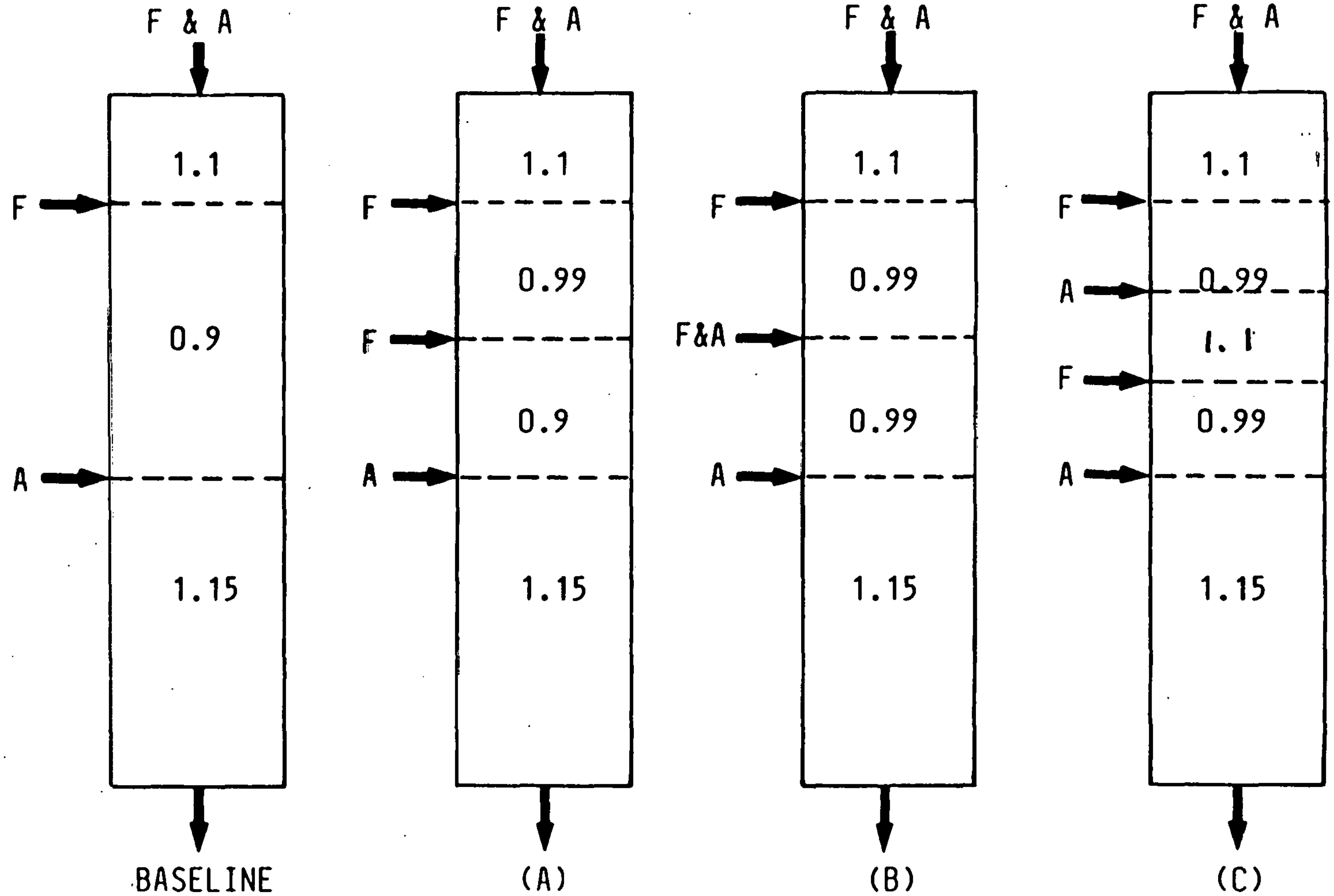


Figure 2-2. Configurations of distributed fuel addition.

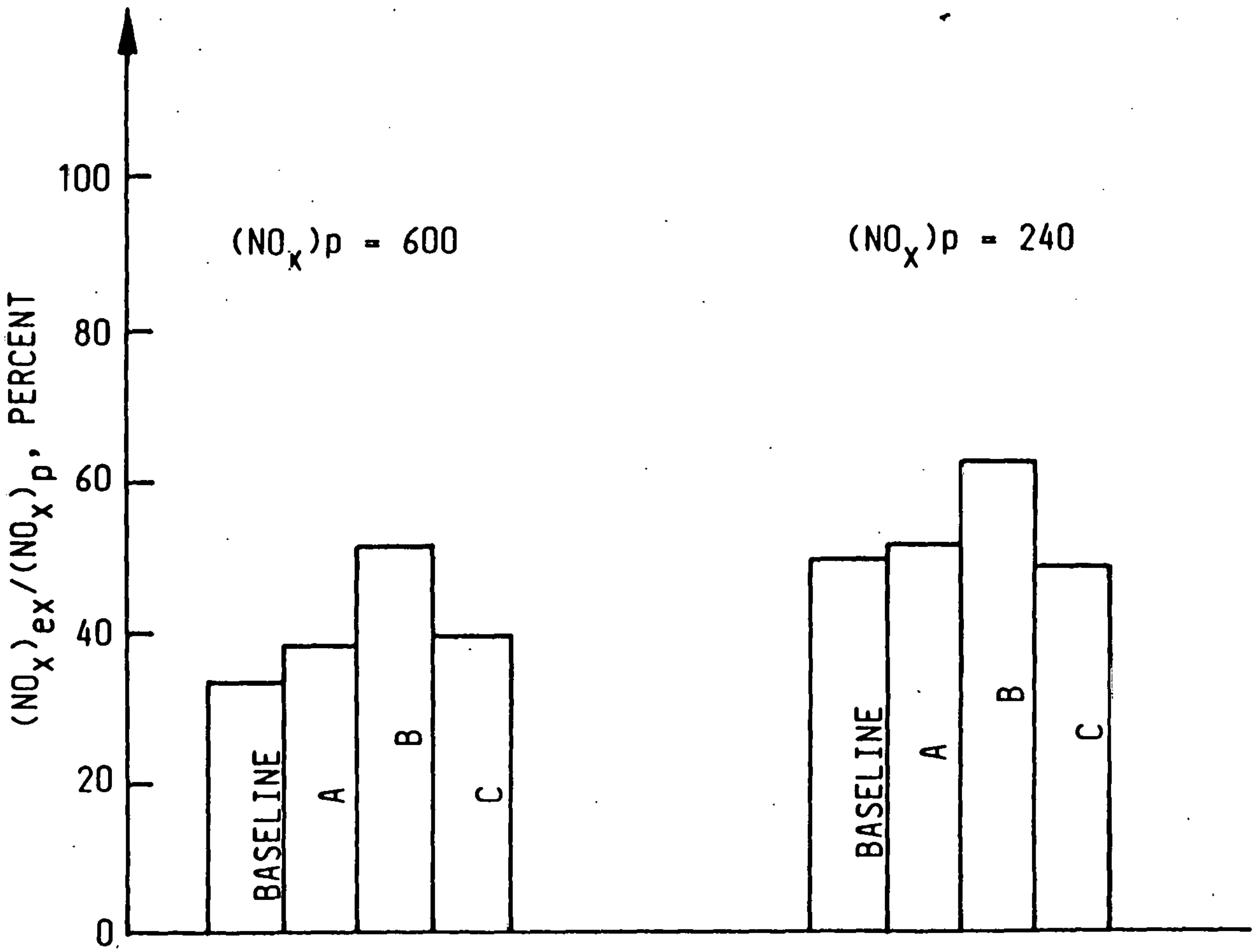


Figure 2-3. Results of distributed fuel addition.

- reaction temperature (1500°F)
- CO concentration (0.5 percent or less), and
- NH_3 species,

Apparently the conventional reburning process does not provide the required environment. A hybrid process, which combined reburning with selective NO_x reduction (SNR) via ammonium sulfate injection, was designed and tested. Figure 2-4 shows the two hybrid schemes with 20 percent and 10 percent gas reburning, respectively. With 20 percent reburning (SR_2 = 0.9), the burnout air was divided into two streams to yield an SR_3 of 0.99 and an SR_t of 1.15. With 10 percent reburning, the reburning zone stoichiometry (SR_2) was 0.99 and the burnout zone stoichiometry (SR_t) was 1.15. In both cases, an aqueous solution of ammonium sulfate was atomized with the final burnout air and injected at 1500°F at an N to NO (measured at SR_3 = 0.99 and SR_2 = 0.99, respectively) molar ratio of 1.5. Figure 2-5 presents the results obtained with natural gas as the primary fuel. The natural gas was doped with NO to provide two levels of primary NO_x, 600 and 240 ppm (dry, 0 percent O_2). Twenty and 10 percent reburning were applied separately in both cases. These data indicate that a hybrid process which utilizes 10 percent reburning fuel can achieve similar overall efficiency to a process using 20 percent reburning. It is apparent that there exists a tradeoff between natural gas premiums and the cost of ammonium sulfate.

A series of verification tests were subsequently carried out with Illinois coal as the primary fuel. The coal produced a primary NO_x level of 970 ppm (dry, 0 percent O_2) at SR_1 = 1.1. As shown in Figure 2-6, these results again indicate that in a hybrid process, 10 percent reburning is as effective as 20 percent reburning. Ninety percent overall reduction in NO_x emissions was achieved in both cases. Figure 2-7 summarizes the coal and natural gas test results and illustrates that the efficiency of the hybrid process depends upon initial NO_x concentration measured at SR = 0.99.

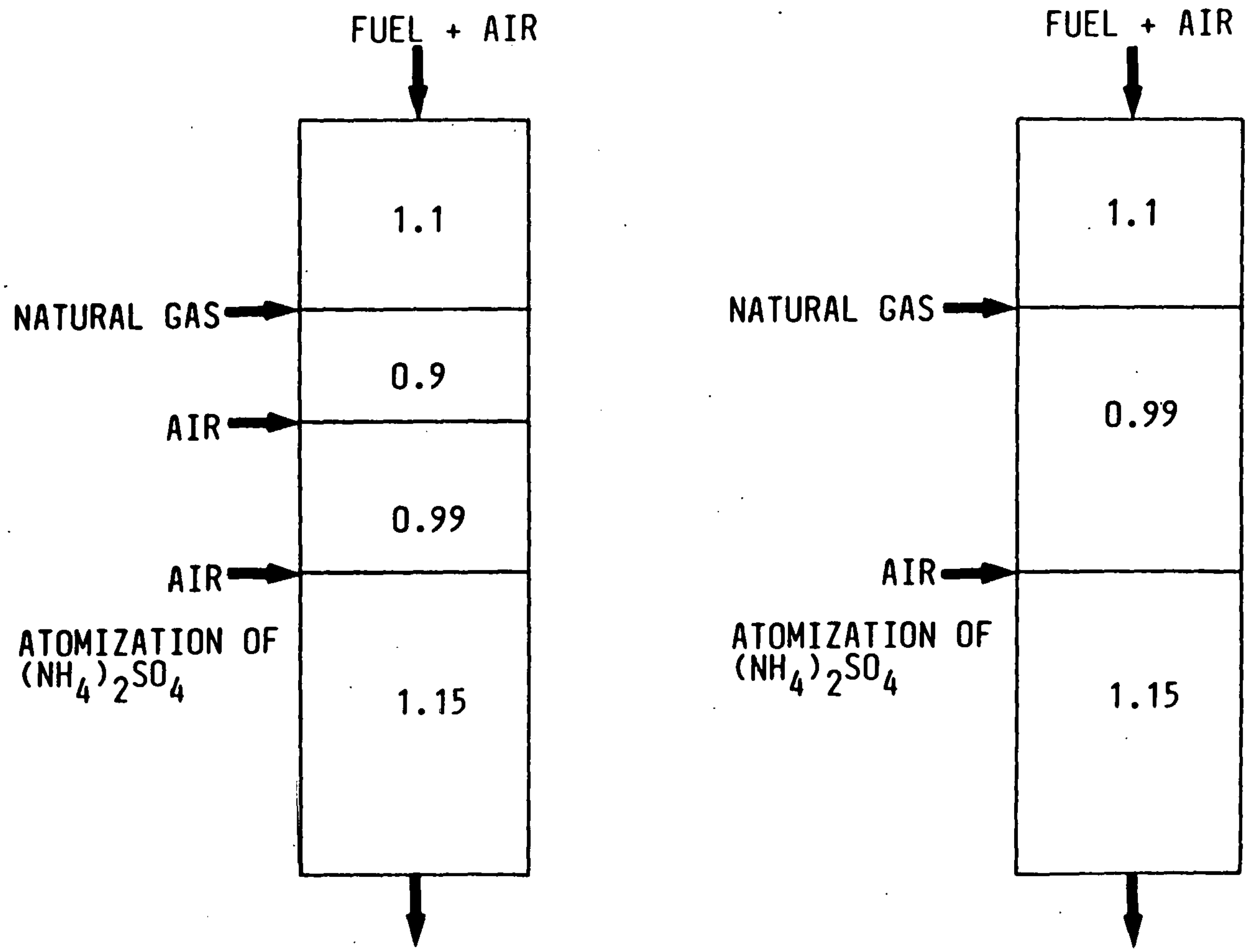


Figure 2-4. Reburning plus reducing agent injection.

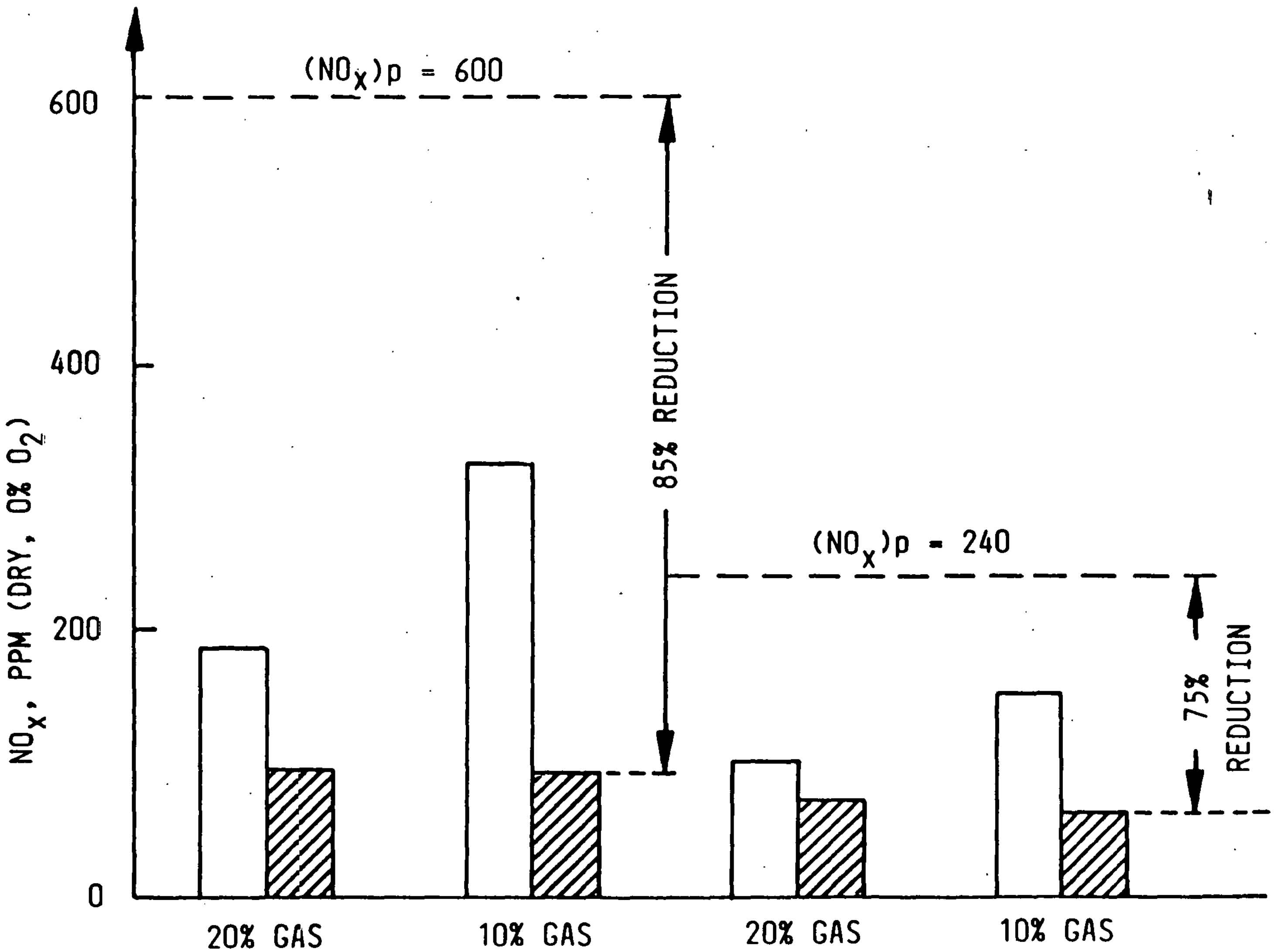
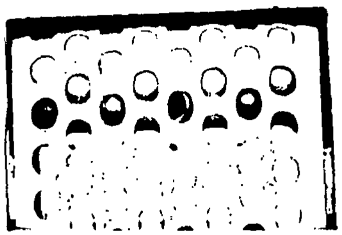
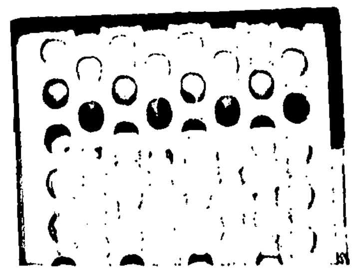
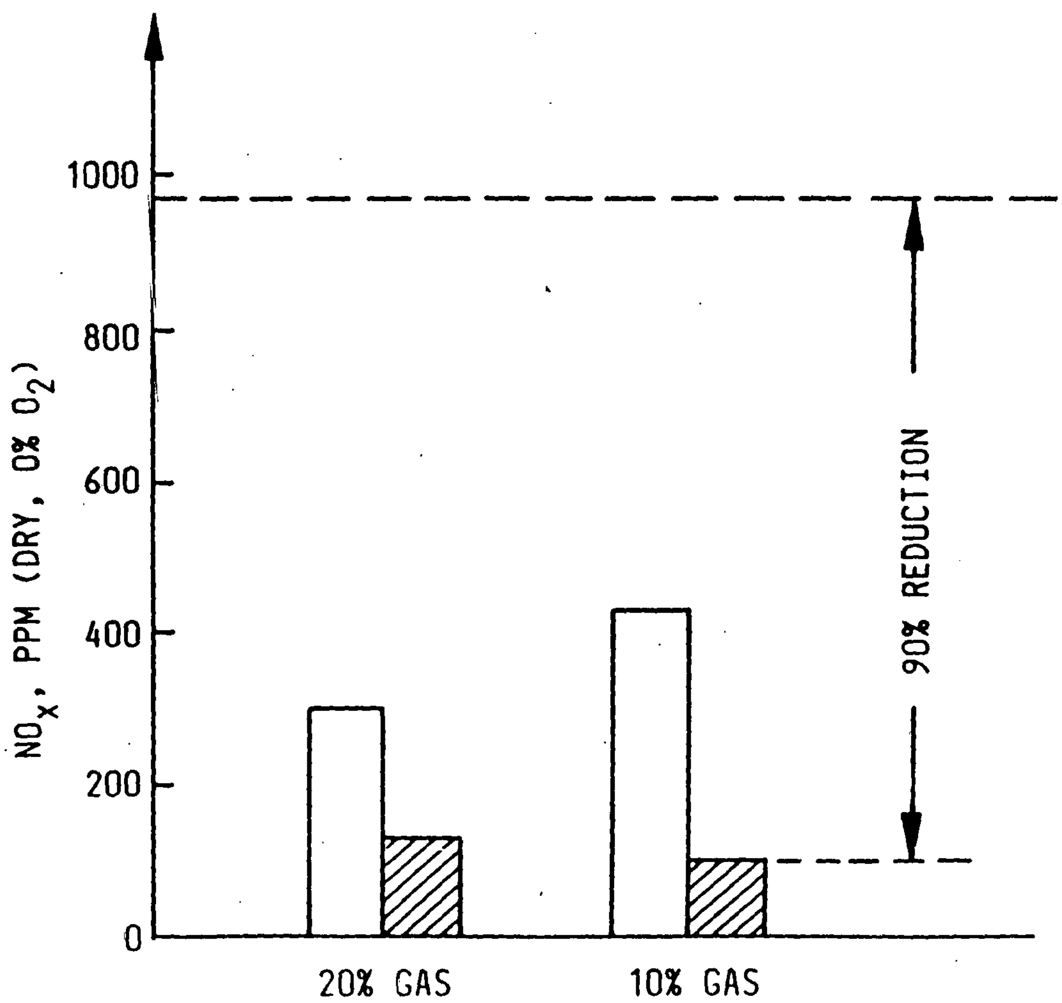


Figure 2-5. Advanced reburning - natural gas as primary fuel.







NO_x, PPM (DRY, 0% O_2)
1000
800
600
400
200
0
90% REDUCTION
20% GAS
10% GAS

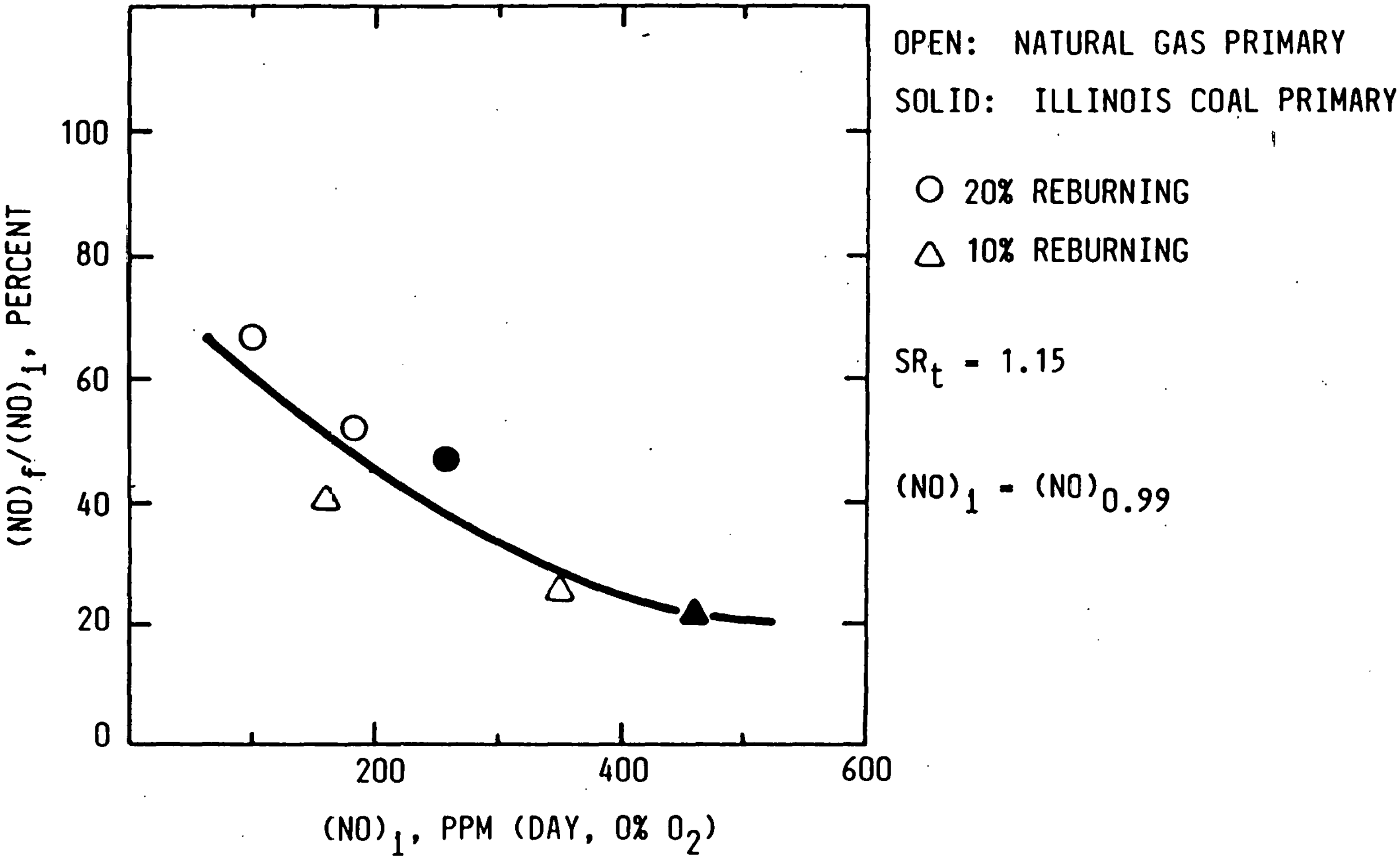


Figure 2-7. Importance of initial NO concentration.

3.0 FUTURE WORK

To date the bench scale studies have been completed. The pilot scale studies will be conducted at a 10 x 10^6 Btu/hr facility and a series of preparation work has been planned, including:

- fuel acquisition,
- modification of fuel and additive delivery system,
- reconfiguration of furnace section, and
- design and construction of reburning fuel and burnout air injectors.