UPDATE OF NO_x CONTROL TECHNOLOGIES AT RILEY STOKER

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ABSTRACT

Recent design and operating experience with Riley Stoker low-NO_x combustion systems in pilot scale and commercial furnaces is reviewed. The performance of several commercial low-NO_x burner installations in wall- and Turbo-fired furnaces is described. Both emissions reductions from uncontrolled levels and the impact of the combustion process modifications on furnace temperatures are discussed. Pilot scale results focus on in-furnace NO_x and SO_2 control processes such as reburning and sorbent injection.

Recent activities include CCV burner design refinements, and developing staged combustion systems for utility boilers, industrial stoker-fired boilers and circulating fluidized bed combustors. Since jet aerodynamics influence combustion and NO_x reduction efficiencies, two-phase jets in furnace enclosures are discussed.

INTRODUCTION

In the past several years, interest in NO_x control has broadened to include a wider range of technologies and fuels. Because of the relatively stable boiler population, retrofit NO_x controls have become increasingly important for both large industrial and utility boilers. Combustion controls such as low NO_x burners and overfire air systems appear to be significantly more cost effective than post combustion control techniques. The recent promulgation of new federal NO_x standards for boilers below 250×10^6 Btu/hr in size will require the implementation of controls on smaller industrial boilers. Riley Stoker Corporation has recently field tested new NO_x control combustion systems on industrial coal-fired Turbo, as well as straight wall boiler designs. As a result of major changes in fuel prices, there is also renewed interest in NO_x controls for gas and oil-fired boilers. This interest applies to both the industrial and utility sectors.

In addition to traditional boiler systems, new technologies are being developed to utilize other types of fuels. New stoker-fired resource recovery boilers are being constructed and brought on-line to burn waste fuels such as municipal solid waste (MSW) and refuse derived fuels (RDF). The number of such resource recovery systems in the U.S. is expected to increase dramatically over the next five to ten years. Commercial fluidized bed boiler systems are also emerging in both industrial and utility boiler applications. Fluidized bed combustion systems have the unique ability to burn a wide variety of fuels with reduced emissions. There is a growing awareness that along with the destruction of harmful toxic materials, air emissions such as NO_x must be controlled during waste incineration.

Recent commercial applications of combustion modifications for NO_x reduction have raised system operation and design concerns. Low NO_x operation has the potential to adversely affect both performance and unit life. Pilot and full-scale efforts are underway to identify and assess these impacts, and to develop practical solutions.
The following is a summary of recent Riley experience and efforts to develop NO_x control technology for a variety of boiler combustion systems:

LOW NO_x BURNER FIELD TESTS

Riley Stoker manufacturers two low-NO_x burner systems: the Controlled Combustion Venturi (CCV) burner (U.S. Patent No. 4,479,442) for wall-fired boilers, and the Tertiary Staged Venturi (TSV) system (U.S. Patend No. 4,517,904) for Turbo furnaces. Both systems have been operating at utility and industrial installations for several years. Typical NO_x emissions achieved with these systems are summarized in Figure 1. Details of recent field experience with these burners follow.

The Controlled Combustion Venturi (CCV) burner was originally developed for retrofit on pulverized coal wall-fired boilers. NO_x control is achieved through a patented venturi coal nozzle design, which utilizes both a venturi section and a four bladed coal spreader to control fuel/air mixing. This nozzle design provides swirl to the primary air/coal stream, while separating the stream into fuel-rich and fuel-lean layers before mixing with the secondary air. Results of a recent utility test program on the CCV burner are presented in Figure 2. Since this unit also has an overfire air system, we obtained data at primary zone stoichiometries between 1.0 and 1.2. The data demonstrate that the burners are operating in the field as predicted by recent Riley, EPA and EPRI $100x10^6$Btu/hr test programs (1,2,3).

Mechanical improvements to the CCV burner are also being developed. This burner was originally designed as a replacement coal nozzle and spreader for our pre-NSPS Flare burner design. No modifications in the Flare burner secondary air system are made in the retrofit. We are now developing a new secondary air register and control system for the CCV burner. Our objective is to design a new generation burner that is easier to operate and reliable over a wide range of register settings. This is important since pilot and field testing have shown that achieving low-NO_x emissions and effective carbon burnout depends upon consistently controlling secondary air design conditions. The new generation CCV burner system will be tested in our $100x10^6$Btu/hr combustion test facility this year. A single burner will then be installed in a 300 MW boiler and operated for a year to evaluate its reliability in a commercial application.

Experience with the CCV burner and staged combustion systems led to the development of a low-NO_x burner for Turbo fired systems, the Tertiary Staged Venturi (TSV) burner. The TSV burner has a coal nozzle and spreader assembly resembling the CCV burner. The TSV burner is designed for two stage combustion. It operates with a fuel rich recirculation zone near the burner throat (40 to 70% of theoretical air). Four tertiary air ports equipped with directional vanes are used to raise the total burner front stoichiometry between 70 and 100% of theoretical air. The balance of the combustion air is provided through the overfire and underfire air systems shown in Figure 3. NO_x emissions of 300 ppm have consistently been achieved with this system in large industrial boiler operations.

IMPROVED OVERFIRE AIR SYSTEMS

Overfire air is an important application of staged combustion to reduce NO_x emissions in utility and industrial boilers. It is also used to control furnace temperatures and burnout in stoker-fired industrial systems. In all of these applications, a thorough understanding of the mixing process between the overfire air and combustion zone products is critical to achieving desired system performance. Riley has been employing both computational fluid dynamics and laboratory flow modeling to design overfire air systems for a variety of firing systems.

Riley will install a new air staging system on a 425 MWe Turbo fired boiler in April. The design objectives were: 1) increase boiler load to 105% Maximum Continuous Rating (MCR); 2) reduce NO_x emissions to 0.65 lb/10^6 Btu while overfiring; and 3) achieve efficient carbon burnout with the low NO_x combustion system. An additional objective was utilizing as much of the existing equipment as possible to minimize retrofit costs.

Our design to achieve these objectives requires modification of the existing 24 Directional Flame burners, and diversion and control of additional combustion air to the air staging system. The existing overfire air system is being upgraded to include separate overfire air ductwork with a new air control system. Underfire air ports are being installed to provide additional staging and improve lower furnace combustion efficiency. Extensive computer simulations were performed to design the staging system and predict performance.

The location of the overfire air ports in the furnace venturi, combined with the Turbo furnace burner flow pattern, readily allows separating the final OFA combustion zone from the primary burner zone. However, the proximity of the underfire air (UFA) ports to the burners is critical. If the underfire air ports are too close to the burners, UFA will be entrained rapidly into the main combustion product flow. If this occurs, minimal staging will be achieved and final NO_x reductions could be disappointing. Burnout considerations require well-controlled mixing of all three flow streams. To further improve burnout efficiency, additional wing overfire air ports have been installed near the furnace side walls. Flow model studies (4) suggest that the increased mixing achieved with these wing ports promotes carbon burnout under staged firing conditions.

A computational fluid dynamics code that predicts temperatures, flow streamlines, turbulence parameters, and post-combustion oxygen concentrations was used to analyze the furnace performance impacts of these combustion system modifications. An isometric view of the furnace section studied in the computer model is shown in Figure 4. Figure 5 presents some results of this analysis. The temperature profiles shown predict no major changes in furnace temperatures will occur when this retrofit is completed. Similar profiles of staged air jet penetration and jet velocities were generated during the design study.

RESOURCE RECOVERY

Riley has been active in the design and manufacture of resource recovery boiler systems for many years. In 1968, Riley supplied a municipal solid waste (MSW) fired stoker and recovery boiler to the Town of Braintree, Masachusetts. The design of stoker-fired systems for waste fuels is subject to several constraints. Waste fuels such as MSW have widely variable heating value and moisture contents. Refuse systems, therefore, require a flexible combustion air system to insure complete combustion and to minimize the formation of pollutants such as CO and NO_x. Overfire air is often used in these stoker-fired systems to enhance incineration, combustion flexibility, and control. The same computer code used to analyze OFA systems for suspension fired systems is also being used to evaluate the effectiveness of OFA stoker fired refuse systems. Figure 6 represents oxygen profiles computed for a traveling grate stoker firing a refuse derived fuel (RDF). Comparing these oxygen concentration profiles is an invaluable tool in evaluating furnace mixing and in designing efficient combustion systems for the destruction of toxic constituents in these waste fuels.

In 1984, Riley obtained the exclusive American license for an advanced step grate stoker refuse combustion system from Takuma Co. Ltd. of Japan. Since 1963, Takuma has installed some 250 resource recovery MSW systems throughout Japan. These facilities represent a combined capacity in excess of 50,000 tons per day. The first Riley/Takuma boiler system is currently undergoing start-up and testing in Olmstead, Minnesota.

The Riley/Takuma combustion system includes both a step grate stoker design and an automatic combustion control system (5). Schematic diagrams of the combustion system, and the combustion air and oxygen control system are shown in Figures 7a and 7b. Three grates, with individual undergrate air control systems, are used to promote drying and ignition, combustion, and burnout. Approximately 20% of the combustion air is provided by the overfire air system. Multiple levels of overfire air jets are used to control mixing above the grate and furnace temperatures. The combustion control system combined with grate speed and furnace control systems provide the flexibility to burn a variety of MSW fuels regardless of source, season, and geographic origin.

To insure complete combustion, MSW systems operate with excess air levels of 80% or more. The automatic oxygen control system serves to minimize furnace O_2 levels for improved combustion efficiency and lower NO_x emissions. NO_x emissions of 100 ppm (at 12% O_2) and lower have been acheived under this mode of operation. A number of combustion modification techniques can also be used on commercial MSW systems to further control NO_x. Water injection above the grate has achieved NO_x reductions of 20% and greater. The same level of NO_x

control has also been attained with 20 to 30% flue gas recirculation (FGR). FGR has the added benefit reducing excess air requirements. Takuma is also evaluating and testing several in-furnace NO_x reduction techniques including ammonia and UREA injection. In addition, Riley and Takuma are currently evaluating an integrated NO_x control concept based on natural gas co-firing.

FLUIDIZED BED BOILERS

Atmospheric fluidized bed combustion offers another route for achieving both low NO_x and SO_2 emissions without post combustion flue gas treatment. Riley currently designs and manufacturers fluidized bed boiler systems based on an advanced circulating fluidized bed combustion technology known as Multi-Solid Fluidized Bed Combustion (MSFBC). MSFBC boiler systems are supplied in the U.S. by Riley under a license agreement with Battelle Development Corporation.

The MSFBC system, shown in Figure 8, is a two stage combustion process (6). It consists of an entrained bed of fine ash and limestone particles superimposed on a fluidized dense bed of large particles. The lower dense bed of large particles serves to promote mixing and increase the residence time of entrained ash, fuel and limestone. The combustor operates in a fast fluidized bed mode with superficial gas velocities of 30 to 35 ft/sec. Heat transfer and combustion are decoupled in this system. Heat recovery occurs in an external heat exchange and a convective boiler. The external heat exchanger actually consists of heat exchange tubes immersed in a conventional low velocity fluidized bed. Combustion temperature is controlled between 1500 and 1700°F by recycling entrained ash through the external heat exchanger.

Low combustion temperatures and a two stage design offer the potential for achieving NO_x emissions significantly lower than current NSPS requirements. MSFBC systems are operated with the lower dense bed of the combustor under fuel rich conditions. Carbon burnout is completed in the upper oxidation zone. As in other staged combustion systems, the three most important variables affecting NO_x control in a MSFBC system include: (1) primary zone stoichiometry; (2) primary zone residence time, and (3) primary zone temperature.

The importance of each of these variables on MSFBC NO_x emissions is shown in Figure 9. Coal-fired pilot scale data and data from a $50x10^6$Btu/hr field unit are presented for a wide range of operating conditions. Given sufficient primary zone residence time under proper fuel rich conditions, NO_x emission levels approaching 0.1 lb/10^6Btu/hr can be achieved. In MSFBC systems, primary zone temperature is controlled by adjusting the solids recycle rate to the lower combustor. In addition to these primary control variables, a secondary NO_x dependence has been observed with fuel particle size, fuel nitrogen content, and excess air level.

Riley continues to design and develop MSFBC systems for new and increasingly larger boiler applications. MSFBC systems are capable of burning a wide range of waste materials, as well as coal. It's two stage design makes MSFBC well suited for the combustion of difficult to burn high nitrogen species. Currently, there are ten MSFBC boiler installations, ranging in size from 50,000 to 625,000 lb/hr of steam either operating, undergoing start up, or under design and construction throughout the world.

PILOT SCALE STUDIES

Riley is continuing to evaluate combustion modification techniques that can be retrofit to existing industrial and utility boiler systems. In addition to the $100x10^6$Btu/hr Coal Burner Test Facility (CBTF), the Riley Research Center recently began operating a $3x10^6$Btu/hr Pilot Scale Combustion Facility (PSCF). The PSCF is designed to simulate thermal conditions throughout the radiant and convective passages of a boiler. This new facility is equipped with air cooled tube banks to represent various convective heat transfer surfaces from superheater to the economizer. The PSCF has been used to investigate both in-furnace SO_2 and NO_x control techniques. SO_2 removal characteristics for both furnace injected limestone and dolomite as measured in the PSCF are shown in Figure 10. The temperature profile and sorbent injection location maintained during combustion tests on a high sulfur (3.9%) Kentucky bituminous coal is shown in Figure 11. Quench rates in the sulfactor reaction window (2300 to 1600°F) were on the order of 300°F/sec. This condition is typical of many full scale furnaces.

The PSCF has also been used to evaluate advanced NO_x control concepts such as reburning. Figure 12 summarizes the results of NO_x emissions when natural gas is injected as the reburn fuel above a pulverized coal flame. NO_x emissions are shown as a function of reburning zone stoichiometry. Uncontrolled NO_x emissions for these tests were approximately 550 ppm. Reburning zone residence times ranged from 400 to 700 mills. Figure 10 also compares PSCF results with results obtained in Riley Research's $100x10^6$ Btu/hr combustion burner test facility using coal as the reburn fuel (2). Final NO_x emissions in both cases are similar. However, in coal-fired applications where upper furnaces residence times are limited, the use of gas or oil as the reburning fuel may be preferable since faster combustion rates can be obtained.

SUMMARY

Riley Stoker is developing NO_x control systems for a wide range of boiler designs and fuel types. Combustion controls such as low NO_x burners and overfire air systems are being installed on utility and industrial wall-fired and Turbo-fired units. In addition to these traditional boiler systems, new technologies which utilize other types of fuels, are being developed. These include a circulating fluidized bed and stoker-fired resource recovery boilers to burn waste fuels.

Combustion process modification techniques such as air staging are common to all of these boiler systems. Evaluations of staged combustion operation are focusing on two areas: determining the optimum amount of staging air to limit pollutant formation, and optimizing the staging system design to maintain burnout and furnace temperature requirements. Three dimensional computer simulations of the turbulent mixing processes in overfire air applications are being used to establish commercial system designs. In additon, sorbent injection systems for in-furnace sulfur emissions control and reburning with natural gas as the staging fuel have been evaluated in our pilot scale combustion facility. Future plans include evaluating stoker firing systems in this test furnace. This combination of experimental and analytical evaluations is enabling Riley to design commercial NO_x control systems for a broad range of combustion system configurations and fuel types.

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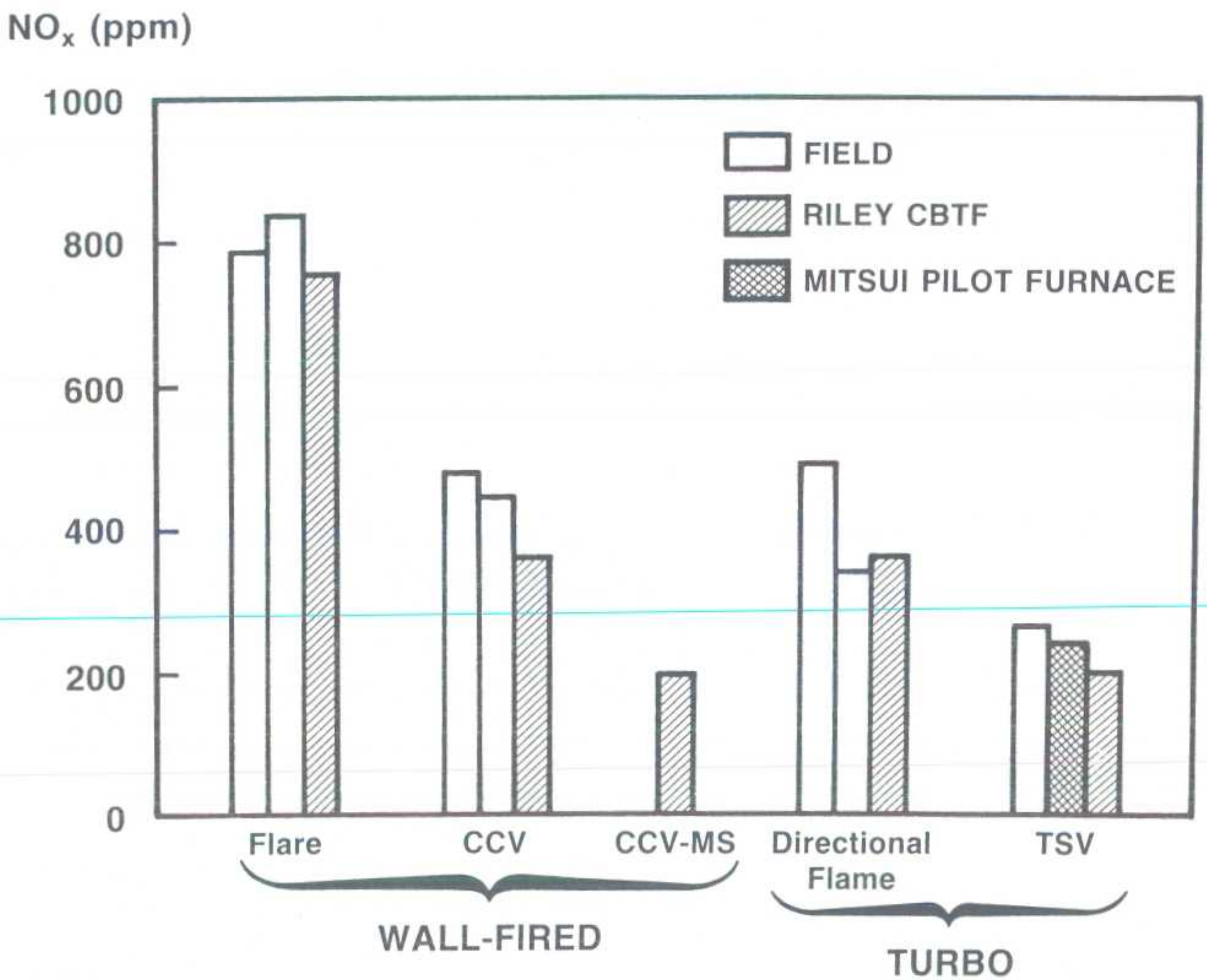


Figure 1. Burner Performance Comparison

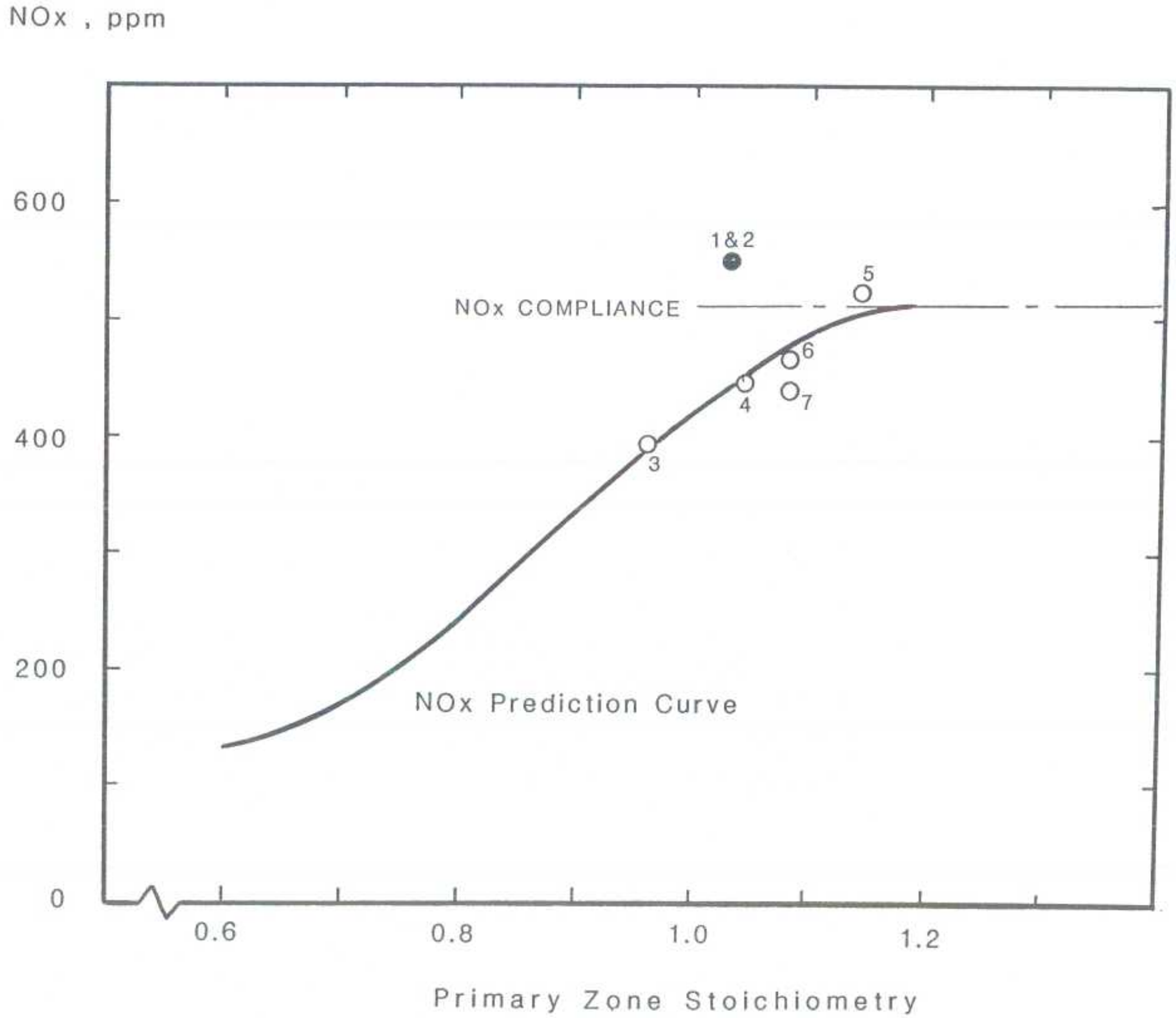


Figure 2. CCV Burner Performance at a 360 MWe Unit

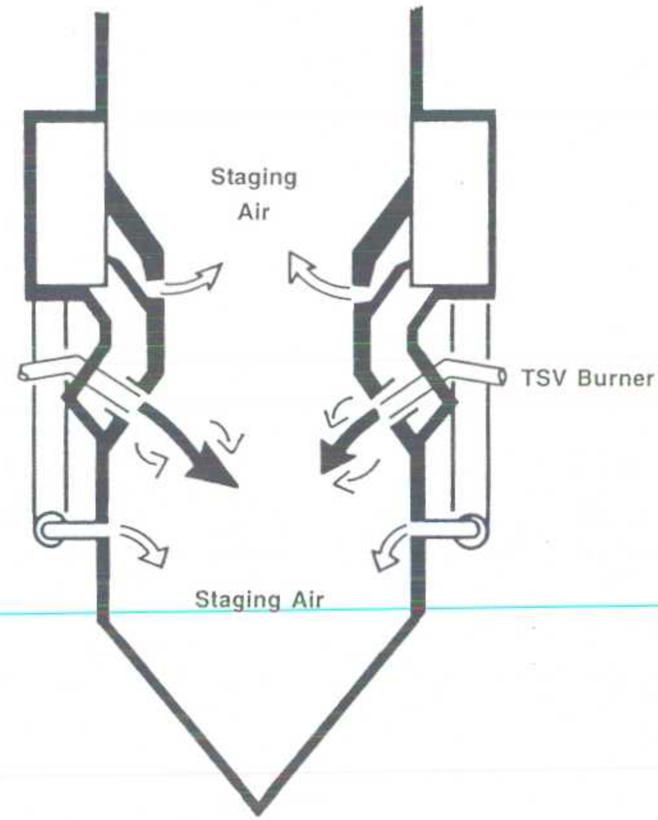


Figure 3a. Advanced Turbo Furnace Staging System

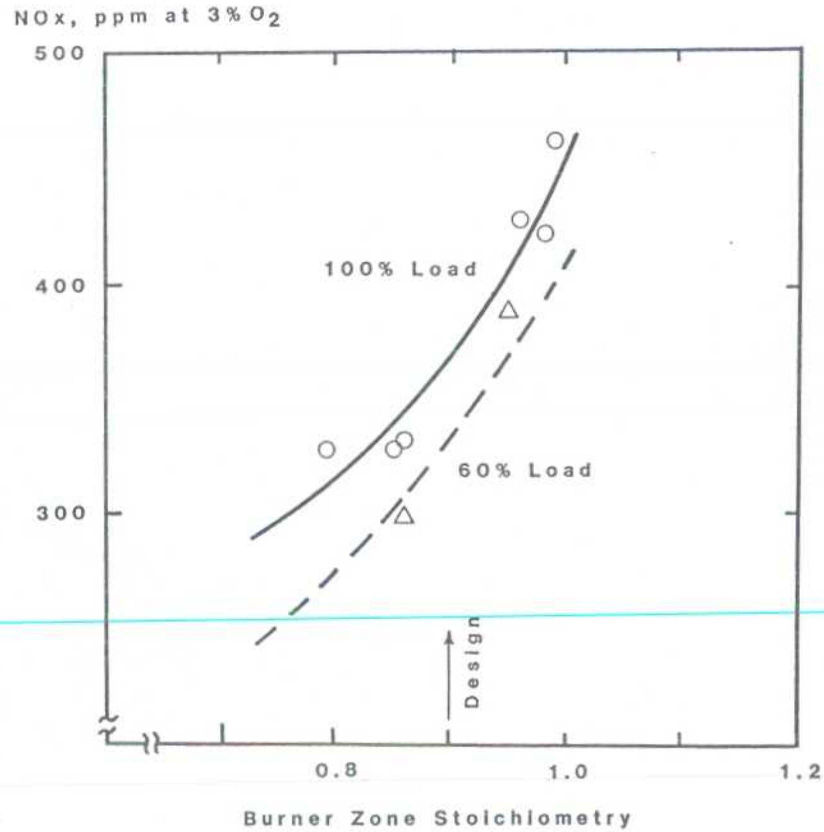


Figure 3b. NOx vs. Burner Zone Stoichiometry for the TSV System (Coal Firing at 100% and 60% Load)

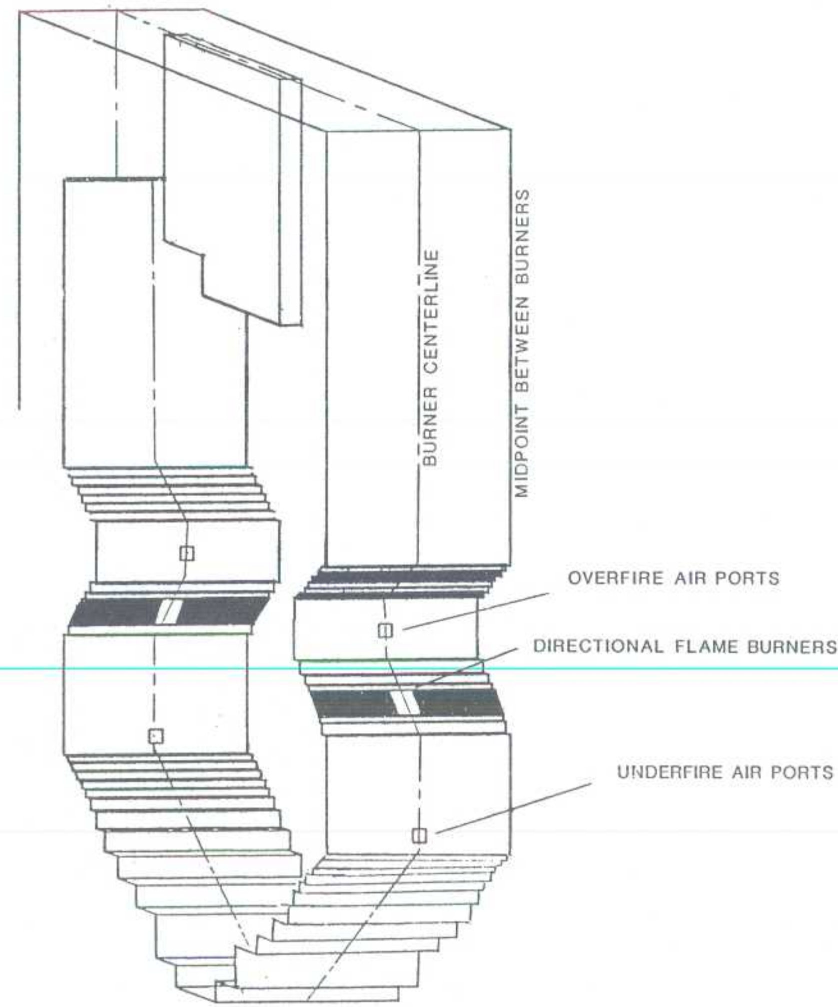


Figure 4. Isometric View of Furnace Modeling Domain

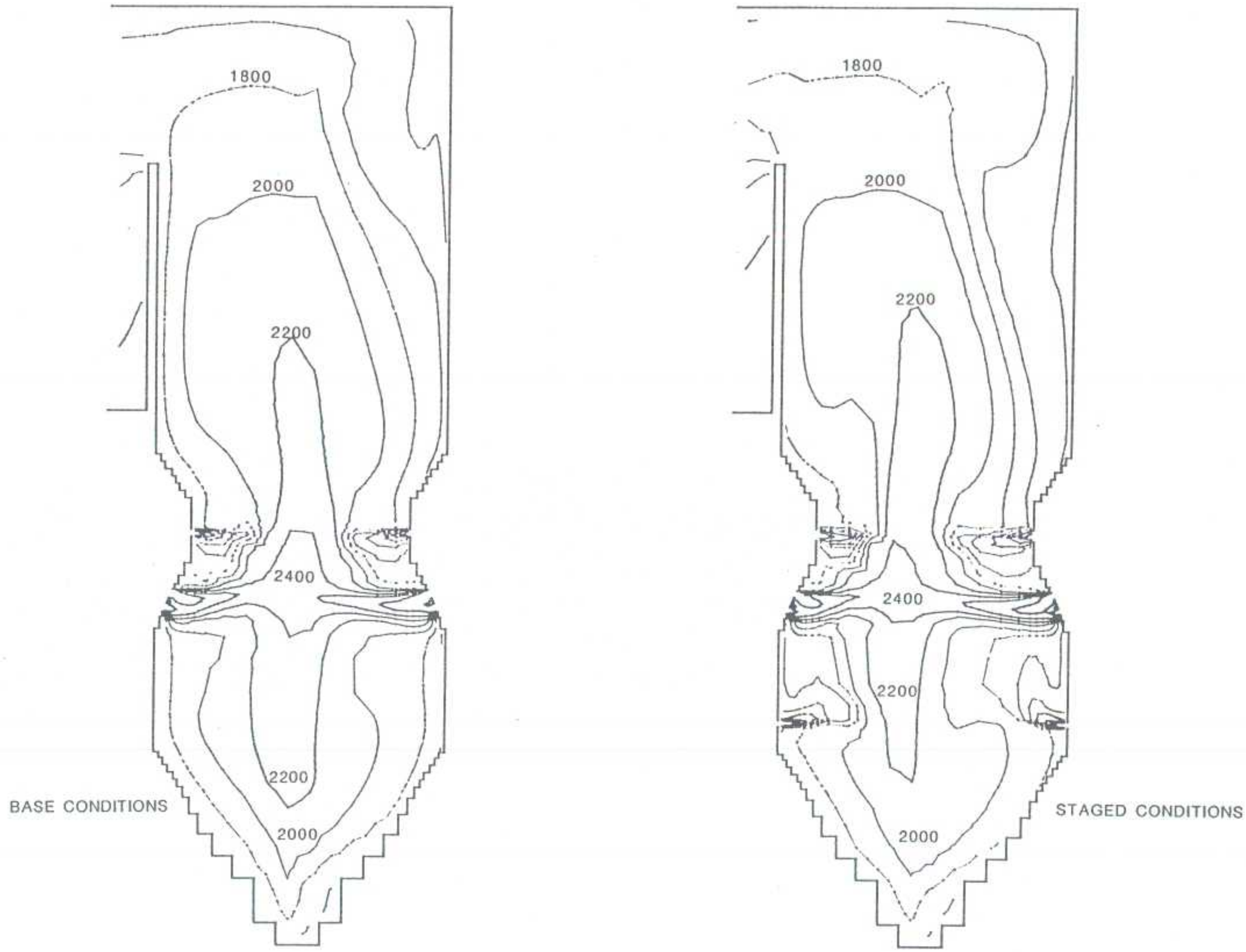


Figure 5. Temperatures for Original and Staged Operating Conditions

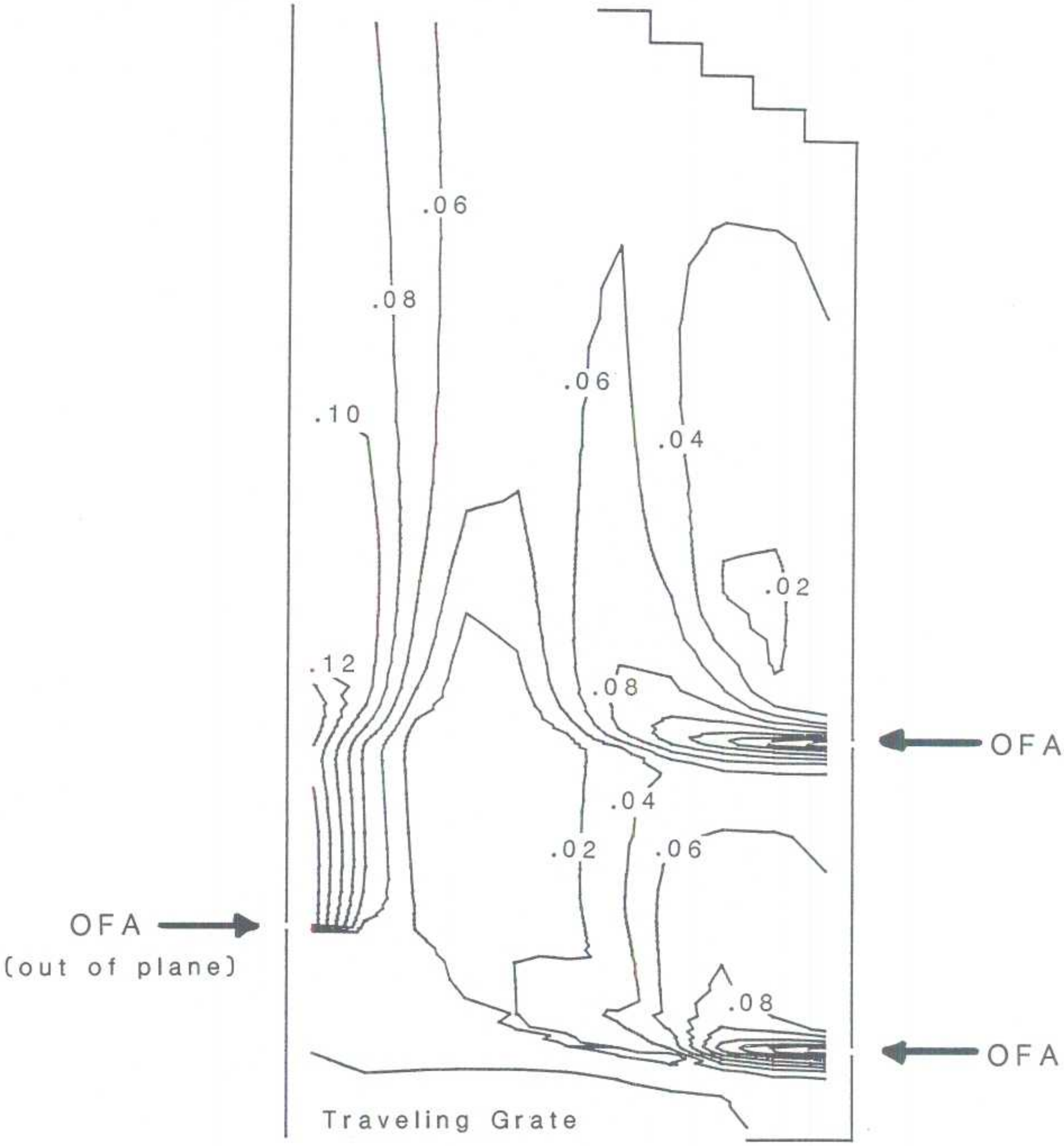


Figure 6. Predicted Oxygen Mass Concentration Profiles for an RDF-Fired Boiler with Multiple Levels of Overfire Air Injection

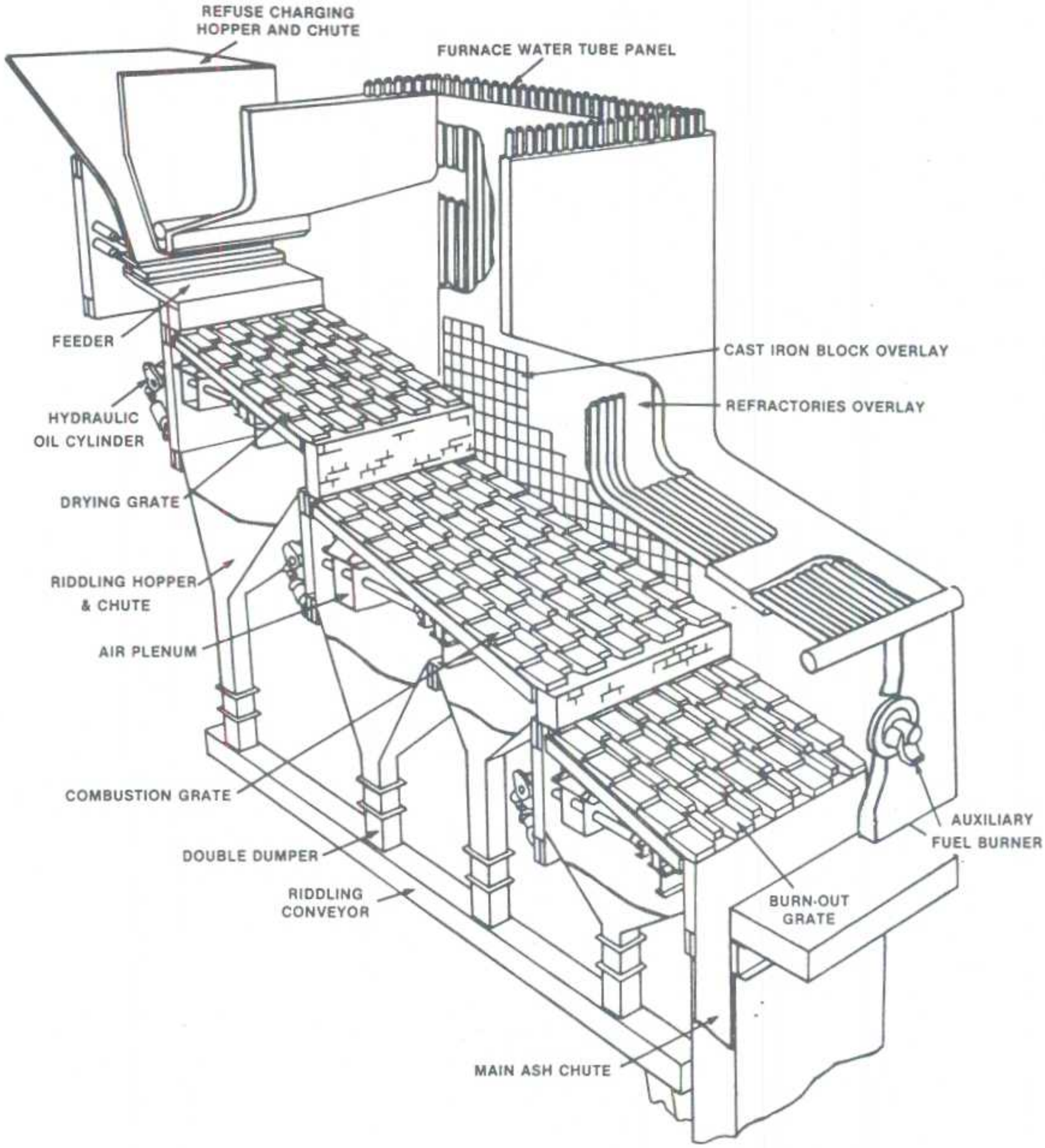


Figure 7a. Riley/Takuma Municipal Solid Waste Combustion System

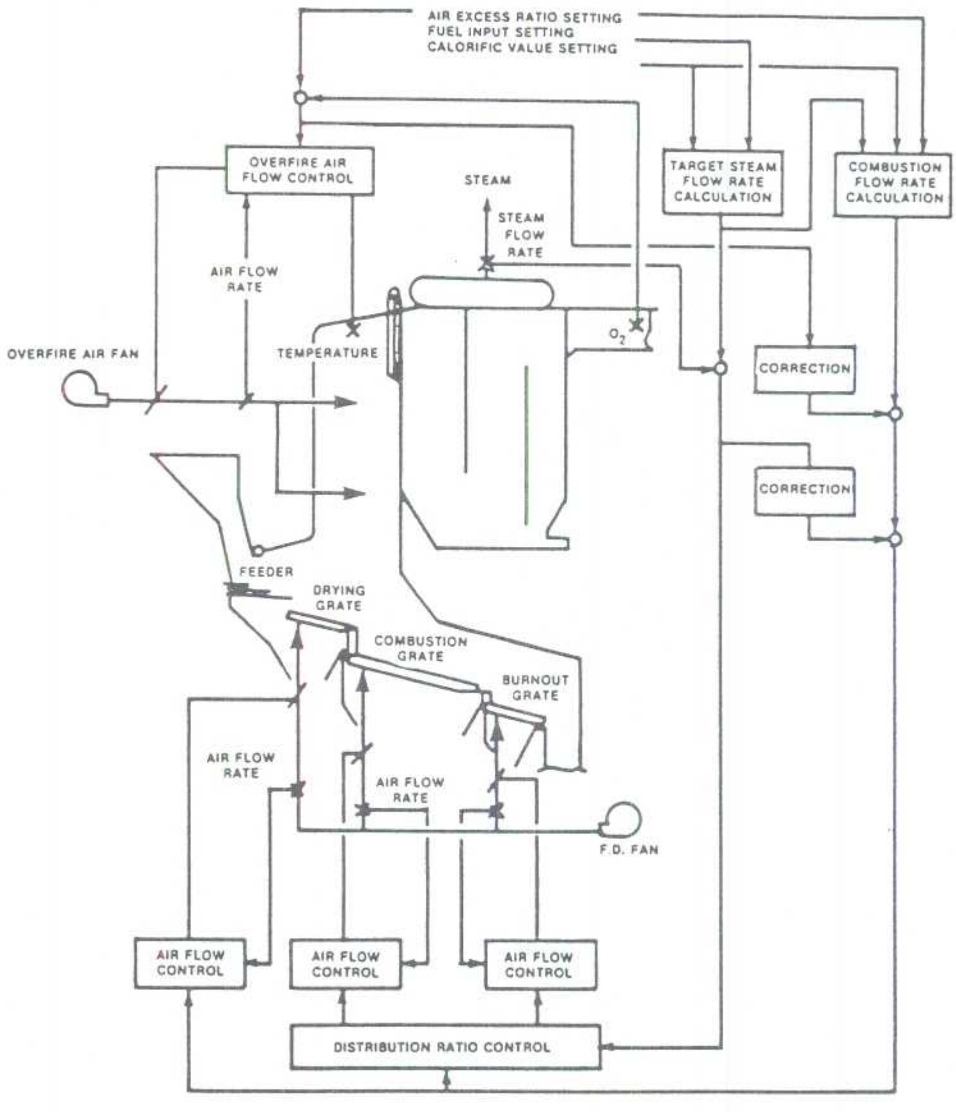


Figure 7b. Schematic Diagram of Riley/Takuma Combustion Air and Low Oxygen Control System

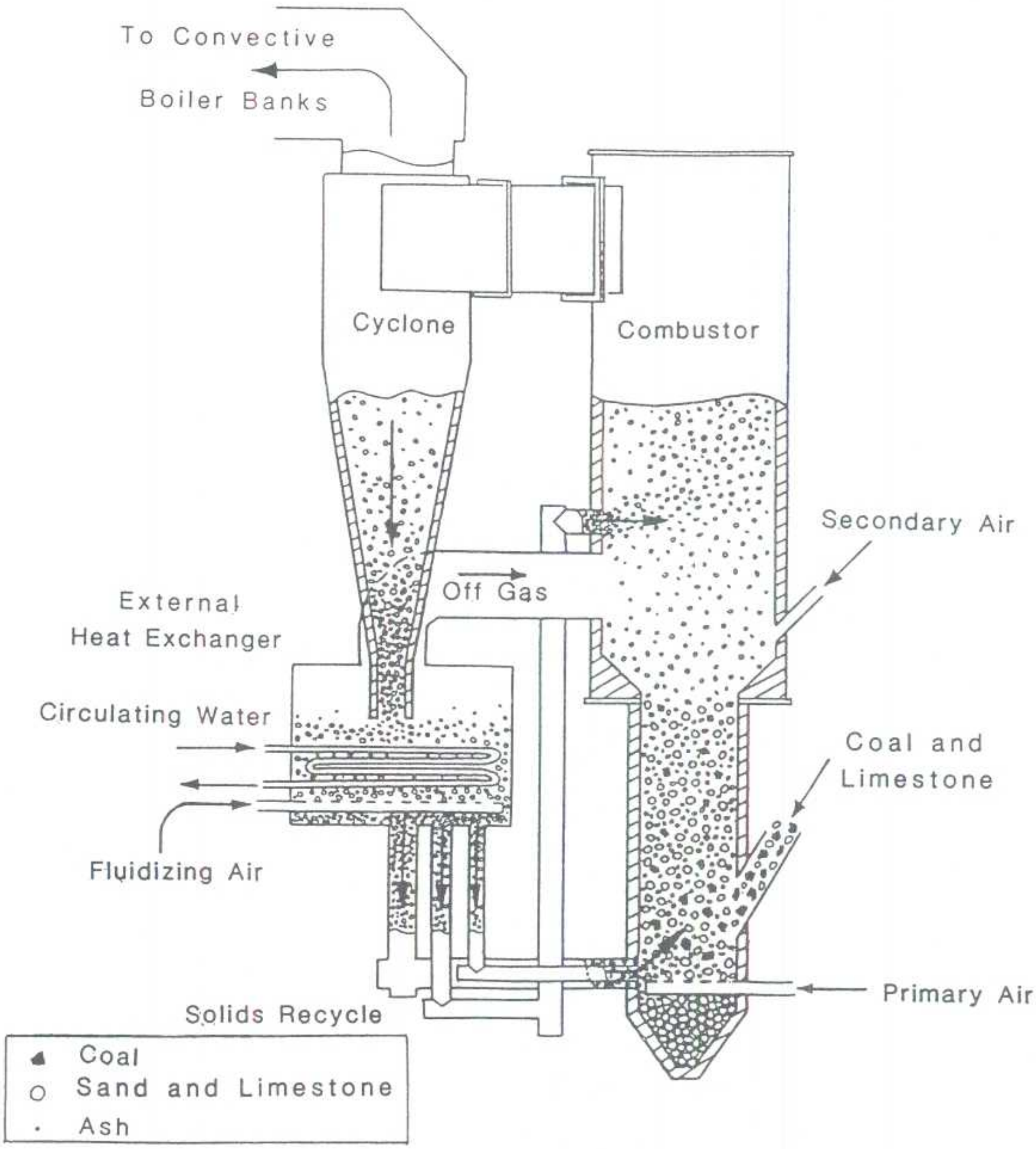


Figure 8. Multi-Solid Fluidized Bed Combustion Process

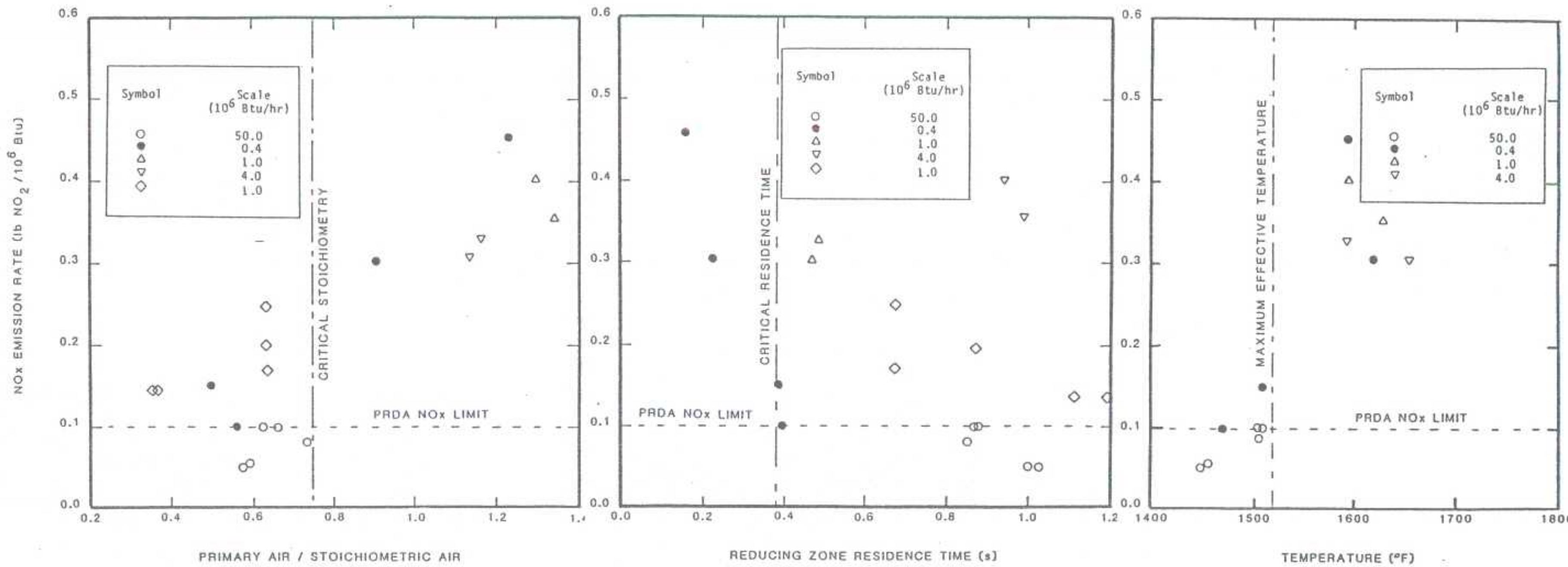


Figure 9. NOx Emissions Data from MSFBC Systems

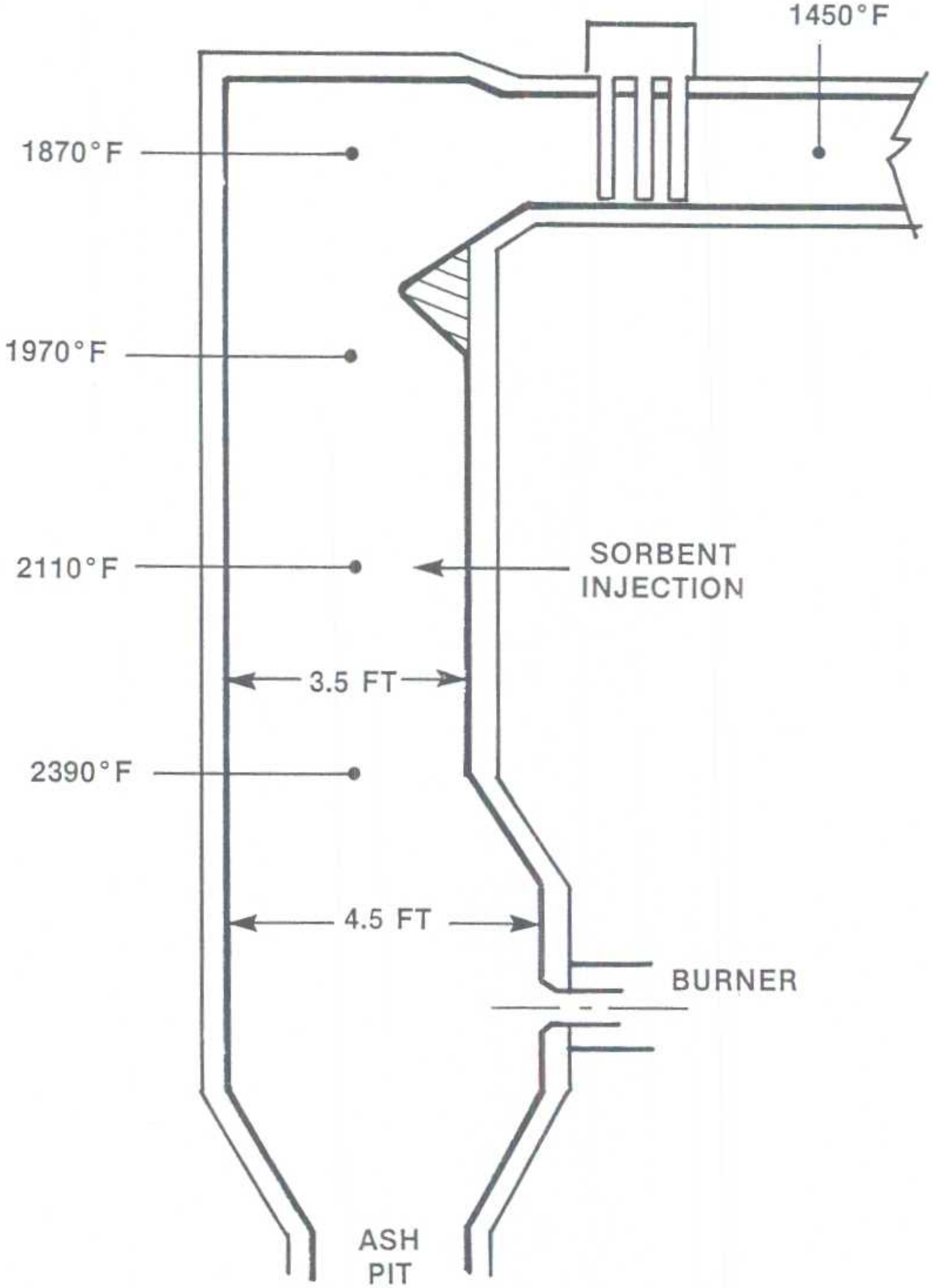
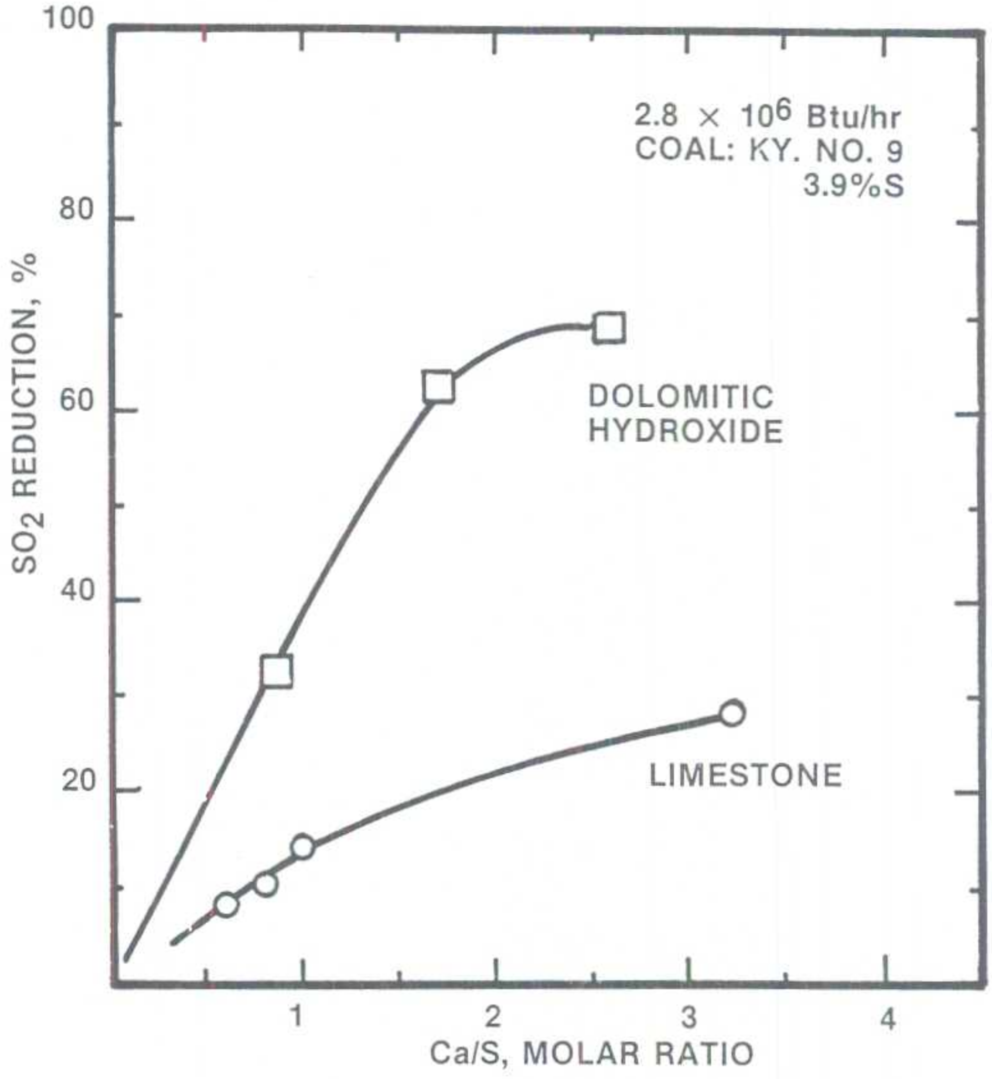


Figure 10. 3 x 10^6 Btu/hr. Pilot-Scale Combustion Facility



(a) SULFUR CAPTURE

Figure 11. Comparison of Sorbents Tested in the Riley Research Pilot-Scale Furnace. Sorbent Injection at 2100°F, 2.8×10^6 Btu/hr, Kentucky No. 9 Coal

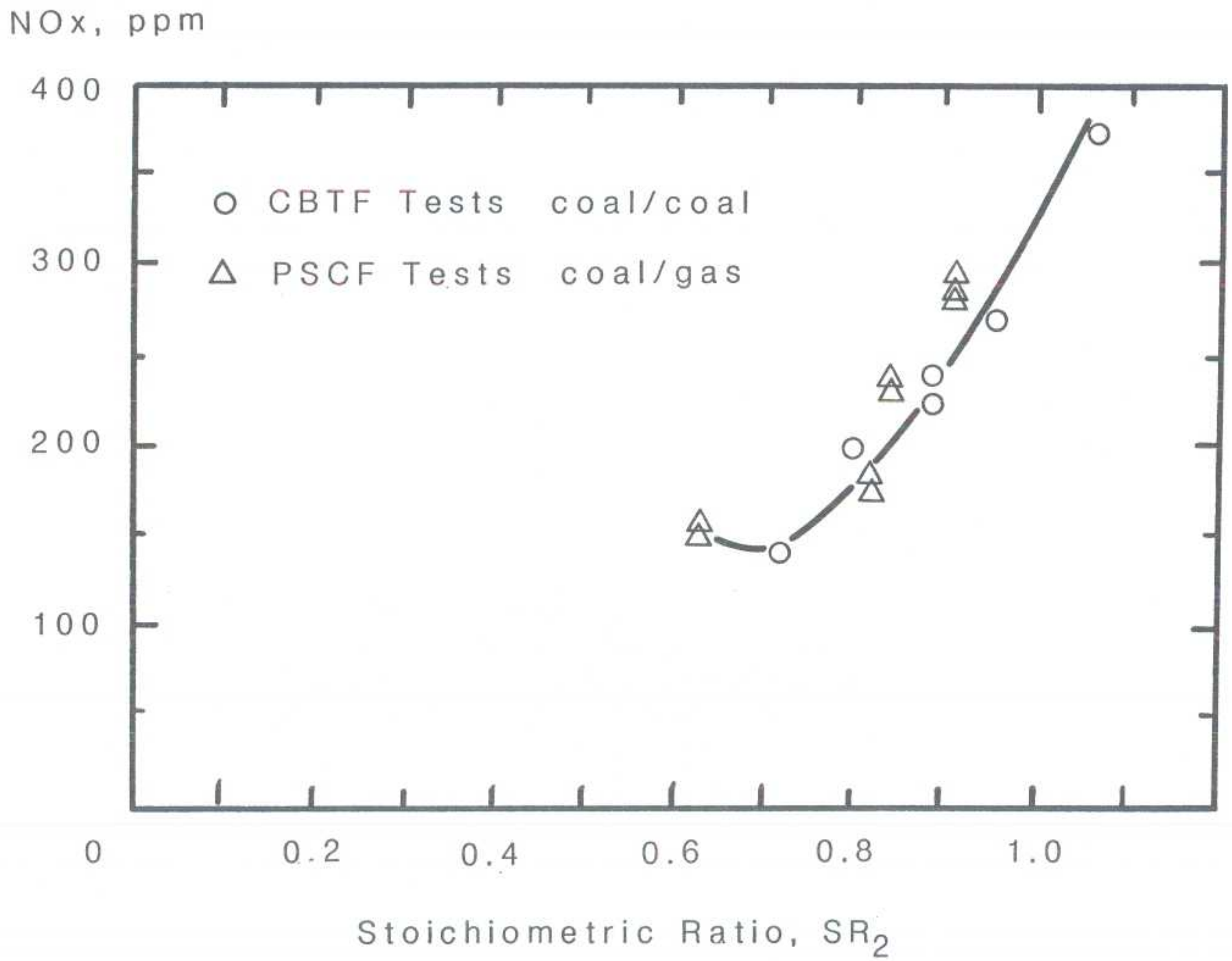


Figure 12. Reburning Test Results - 100 x 10^6 Btu/hr CBTF and 3 x 10^6 Btu/hr PSCF