STATUS OF NO_x CONTROL TECHNOLOGY AT RILEY STOKER

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ABSTRACT *An overview of on-going efforts at Riley Stoker to develop improved low-NOx combustion technologies for both new and existing boilers is presented. A new Controlled Combustion Venturi (CCV) burner design is described along with full-scale burner test data from the Riley Research coal burner test design. In addition, recent overfire air system operating experience is discussed. Field test data from a 400 MW coal-fired utility boiler retrofitted with new overfire air NOx controls are presented.*

The application of NO, controls to incineration and fluidized bed combustion are also reviewed. Pilot-scale test results from a municipal solid waste (MS W) combustor are compared with full-scale field data. Experiments have also been conducted addressing the effectiveness of gas reburning applied to mass burn incineration systems. The paper concludes with a brief summary on the status of NOx controls for circulation fluidized bed boilers.

The average age of the U.S. utility and industrial boiler population continues to rise, while acid rain legislation becomes increasingly likely. Several states have, or will enact NOx control legislation of their own. NOx control, therefore, may soon be required on boilers not currently regulated under Federal New Source Performance Standards (NSPS). NOx control research, therefore, has remained an important element in Riley Stoker's pro-duct development and overall business strategies.

This paper provides an overview of recent efforts at Riley Stoker to develop low-NOx combustion control technologies for both existing and new utility and industrial boiler systems. Overfire air and low NOx burners continue to represent two of the most cost effective retrofit low-NO, combustion control technologies for pre-NSPS boilers. In our update given at the 1987 Joint Symposium we discussed plans to upgrade our low-NOx coal burner technology, the Controlled Combustion Venturi (CCV) burner, and to improve overfire air system performance on an existing utility coal-fired boiler. The results of these activities are presented here.

We will also discuss the development of NOx controls for several new boiler technologies. Pilot-scale studies are underway to investigate the effectiveness of natural gas reburning in reducing NO, emissions from municipal solid waste combustion. A new combustion test facility has been constructed to support this research. Circulating fluidized bed boilers have become the combustion technology of choice in many new industrial coal-fired boiler applications. Low combustion temperatures combined with staged combustion offer the potential for achieving significant lower NOx emission levels than conventional coal-fired systems. Riley Stoker is currently under contract with the U.S. Department of Energy to develop an advanced coal-fired fluidized bed combustion system capable of controlling NOx emissions to 0.1 lb/106 Btu or less.

COY BURNER DEVELOPMENT

The Riley Controlled Combustion Venturi (CCV) burner (U.S. Patent No. 4,479,442) was originally developed as a low-NOX coal burner for wall-fired boiler retrofit applications. Our initial retrofit experience on three utility boilers was first discussed at the 1982 Joint Symposium(». In order to extend the performance of this low-NO, burner technology over a wider range of operating conditions additional design improvements have been developed and implemented. The performance objectives for this second generation CCV burner design were as follows:

- Improved mechanical reliability and operability of the secondary air register system.
- Reduced air side pressure drop requirements for wider retrofit application.
- Improved low-load operation.
- Maintain low-NOx characteristics.

The second-generation CCV burner design is illustrated in Figure 1. NOx control is still achieved through a patented venturi coal nozzle and low swirl coal spreader design. Control of fuel and air mixing is achieved by separating the primary air/coal stream into fuel-rich and fuel-lean layers before mixing into the secondary air. In addition to the venturi nozzle, the second-generation CCV burner incorporates a new secondary air register design for swirl and air flow control. Curved, overlapping air register turning vanes provide improved swirl control at lower pressure drop. Secondary air flow is controlled by a movable shroud that slides over the secondary air register entrance. Independent control over both the shroud and air turning vane positions offers significant flexibility in controlling combustion even at low load. Inlet secondary air velocity is controlled at low loads by partially closing the shroud. As a result, swirl and flame stabilization are maintained even under low load staged combustion operation. The entire air register mechanism has been redesigned and moved to the burner plate away from the hot firing wall for improved mechanical reliability.

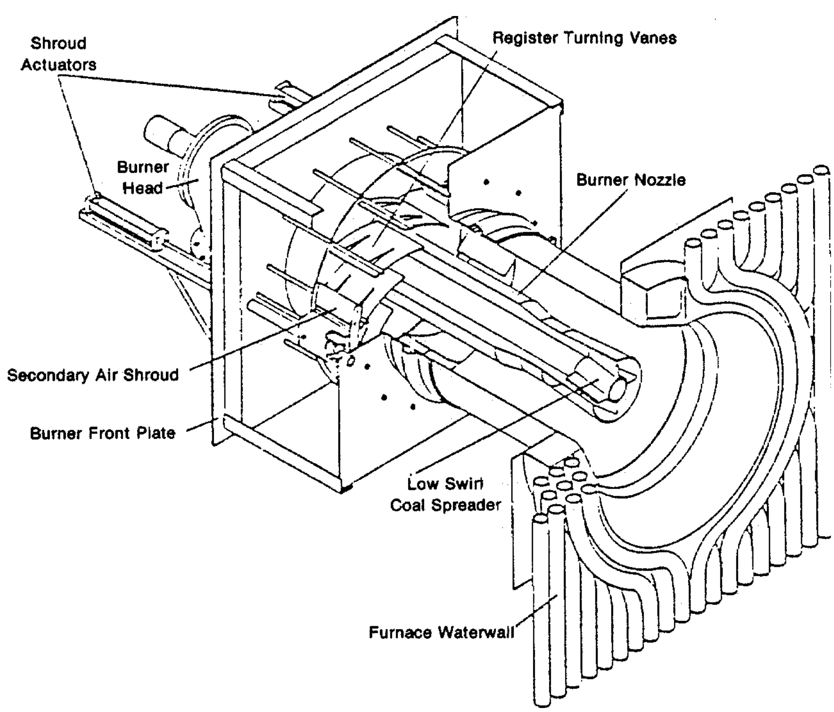

Figure 1. Second Generation CCV Burner with New Secondary Air Register and Movable Shroud

A 100 million Btu/hr prototype of this second-generation CCV burner has been built and demonstrated in Riley Research's Coal Burner Test Facility (CBTF) located in Worcester, Massachusetts. This facility is designed to simulate near field combustion conditions in full-scale furnaces. A more complete description of this facility was presented at the 1985 Joint Symposium(2). Both staged and unstaged burner tests were conducted. Staged combustion was achieved by introducing a portion of the combustion air downstream of the burner emissions with a Riley pre-NSPS Flare burner are shown in Figure 2. In these tests, primary or burner zone stoichiometry was varied from 0.8 to 1.23 (unstaged). CCV burner NOx emissions were 40 to 60 percent lower than emission levels established with the Flare burner. As found in previous studies, NOx and CO emission varied with coal spreader configuration and the amount of overfire air. Spreader design, which controls flame length, allows the burner to be tuned to various tests. Scale-up of pilot-scale emission data to field conditions also depends on other consideration such as fuel type and furnace design parameters(3).

The following burner performance characteristics were also established during the pilot-scale testing.:

- Turndown rate of 3 to 1
- Combustion efficiency of **99.6** percent
- A reduction in windox furnace pressure drop from 8-10"wc to 4"wc
- Improved mechanical reliability

Second generation CCV burners are now being proposed drop for a number of utility and industrial boiler retrofit application both in the U.S. and Far East.

NEW OVERFIRE AIR APPLICATION

Riley Stoker has retrofitted overfire air systems on both coal and oil/gas fired boilers. A recent application included field modification to an existing overfire air system on a 400MWe coal-fired Turbo furnace. This unit was designed in 1974 to meet the 1971 NSPS of 0.7 lb/106 Btu. the objective of the field modifications were: 1) increase boiler firing capacity to 105-110 percent of maximum continuous rating (MCR), 2) reduce NO, emissions to 0.6 lb/106 Btu at 105 percent MCR, and 3) maintain previous combustion efficiency at lower NOx operation. An additional objective was to retain the

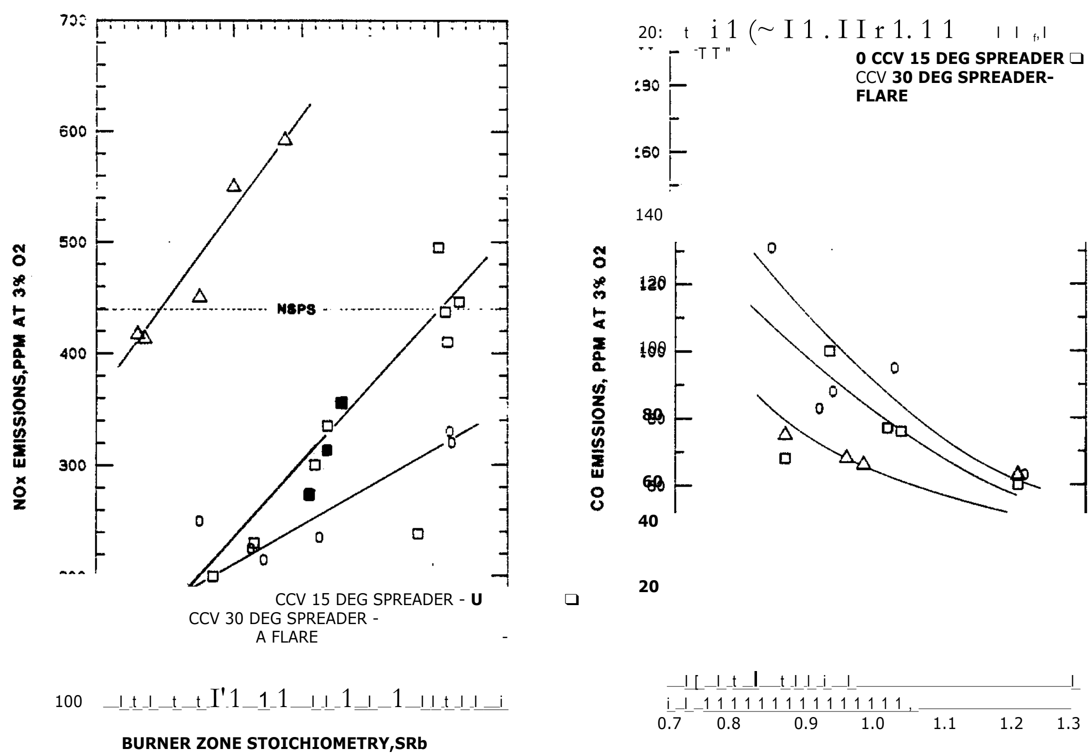

Figure 2. Comparison of 100 Million Btulhr Pilot-Scale NOx and CO Emissions for the CCV and Flare Burners (open symbols Pennsylvania bituminous, solid symbols Illinois bituminous.

existing burner openings and avoid extensive pressure part modifications.

The overfire air system design and modified design are illustrated in Figure 3. The Riley Turbo furnace is characterized by a venturi shaped lower furnace. Burners are installed in single rows on opposite downward facing arches. This particular unit is equipped with 24 Riley Directional Flame burners. Overfire air ports are installed on the vertical furnace wall directly above each burner. In the original design, overfire air was supplied from the main burner windbox. Modifications included revision to the air supply duct system and installation of separate overfire air plenum or windbox for improved air flow control. The overfire air ports themselves were redesigned for increased flow capacity based on guidelines developed under an earlier EPRI Study([4]). Overfire air velocity was increased for better jet penetration across the furnace and to enhance mixing in the burnout zone. Wing overfire ports between the end burners and furnace walls were added to improve mixing and burnout in the corners and along the furnace side walls. Underfire air ports beneath the burners were installed to improve lower furnace combustion efficiency and to maintain and oxidizing environment along the lower furnace walls during staged combustion. No additional fan capacity was required to implement these changes.

Although the original Directional Flame burners were retained, a number of burner design modifications were incorporated. Major burner modifications are described in Figure 4. These modifications were required to increase firing capacity and improve flame stability under more deeply staged combustion. The Riley Directional Flame burner utilizes axial and parallel secondary air and primary air/fuel streams. Air and fuel are introduced through slots formed in the furnace wall. Adjustable air vanes above and below each pair of coal nozzles direct secondary air into or away from the primary stream. Burner modifications included the elimination of the coal spreader and the substitution of a converging coal nozzle. The coal spreader was removed to eliminate a higher wear burner component. The converging nozzle was added to prevent flame detachment. A perforated plate was inserted in the center air slot to maintain secondary air velocity under more deeply staged conditions. Finally, turning vanes near the entrance of the coal nozzles were redesigned to provide a more uniform

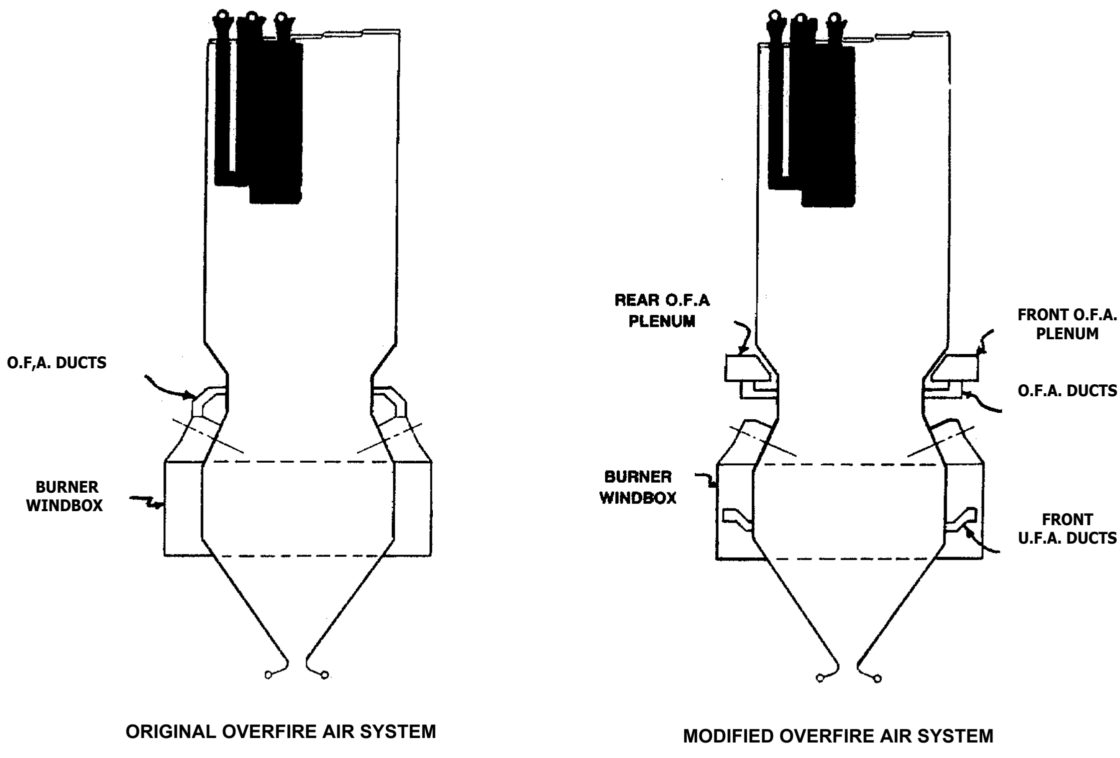

Figure 3. Comparison of Original and Retrofit Overtire Air System Designs Tested on a 400 MW Coal-Fired Turbo Furnace.

distribution of primary air and fuel within the coal nozzle. The design of each of these coal nozzle components was based on the results of cold flow model studies.

All of the retrofit objectives were met. As shown in Figures 5, the original overfire air system design, while meeting NOx compliance at 100 percent MCR, did not provide an adequate amount of air **staging** to achieve the compliance NOx level of 0.7 lb/106 Btu at 105 percent MCR. However, field testing **demonstrated** that the revised NOx limit emission of 0.6 lb/106 Btu is achieved with the modified overfire air system at 105 percent MCR. However, field testing demonstrated that the revised NOx limit emission of 0.6 lb/^{6} Btu is achieved with the modified overfire air system at 105 percent MCR. The addition of the redesigned coal pipe turning vanes, described above, further enhanced overall system NOx control capabilities. In addition to reducing NOx, these turning vanes also led to lower furnace exit gas temperature; thereby, eliminating the need for reheat spray above 100% MCR.

Carbon burnout did not deteriorate with the new system even under the higher load and low-NOx **operating conditions.** However, in addition to burner modifications, mill system tuning was required to maintain this level of performance. This facility is equipped with three Riley ball tube mill coal pulverizers.

This case study emphasizes the importance of a systems approach when evaluating retrofit low-NOx combustion control options. All aspects of the combustion system must be considered including the burners overfire air ports, windbox, combustion controls, and pulverizer system.

NOx CONTROLS FOR MUNICIPAL SOLID WASTE COMBUSTION

The Riley Research Center is currently engaged in a research and development program with the Institute of Gas Technology and the Gas Research Institute to reduce emissions from mass burn resource recovery boilers. The primary objective of this program is to determine the effectiveness of an in-furnace control technology known as reburning in reducing NOx formed during municipal solid waste (MSW) combustion. In this study natural gas is introduced as a reburning fuel above a modern mass burn combustion grate. Pilot-scale studies on

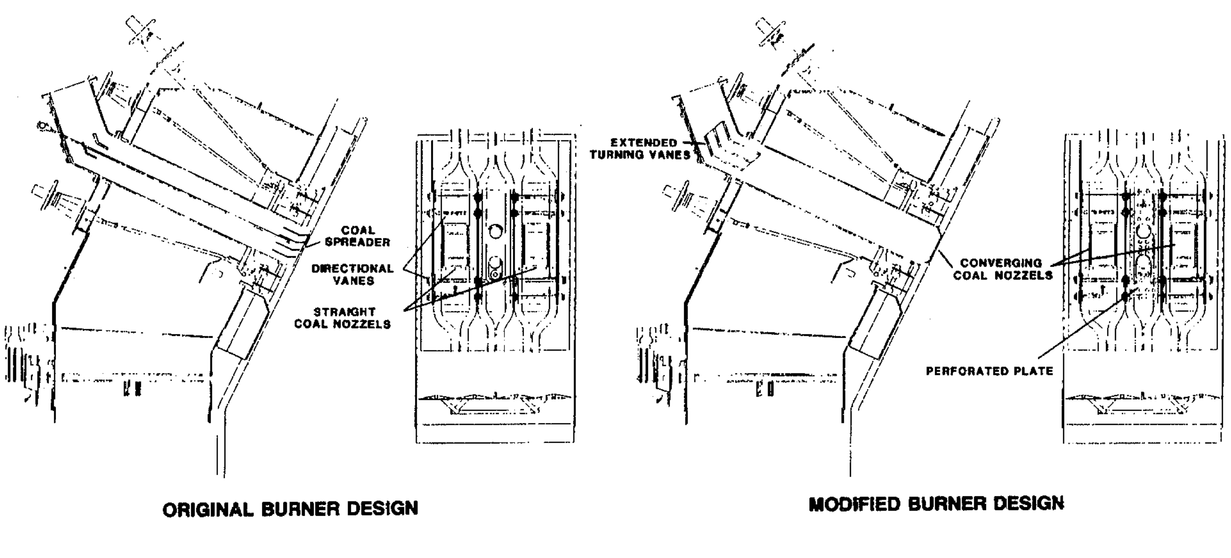

Figure 4. Original and Modified Direction Flame Coal Burner

oil and coal-fired systems have shown natural gas to be an effective reburning fuel, particularly at low-NO_X emission levels(5).

Riley recently modified its 3 million Btu/hr pilot combustion facility to include MSW. As shown in Figure 6, the lower furnace has been reconfigured to accommodate a Riley/Takuma mass burn combustion system. The combustion system consists of a step grate stoker (Figure 7) equipped with individual undergrate air control for drying and ignition, combustion and burnout. Overfire air is used to complete combustion. The pilot facility is capable of burning approximately 450 lb/hr or 5.5 tons/day of shredded refuse. The grate and lower furnace are designed to simulate conditions at a 100 ton/day Riley/Takuma resource recovery boiler located in Olmsted County, Minnesota. A comparison of pilot-scale baseline emissions data with full-scale emission data is given in Table 1.

The test facility also has provisions for introducing natural gas and recirculated flue gas at various locations above the grate in order to create a fuel rich NO_X reduction zone above the main heat release zone. Up to 40 percent of the total furnace load can be fired in the reburning zone. Flue gas is introduced with the natural gas to enhance mixing and reduce excess air requirments. Conventional MSW systems operate with excess air levels of 80% or more.

Tests have been conducted in this facility to determine the influence of various MSW combustion and reburning zone parameters on reburning efficiency. Preliminary test results are shown in Figure 8. These results will be discussed in greater detail later in this Symposium(6). However, a 50 percent reduction in MSW NO_X emissions was achieved with 7 to 15 percent natural gas as a reburning fuel. The effectiveness of reburning was found to be a function of reburning zone stoichiometry and residence time, and gas injection location. Future testing will further explore the impact of these parameters on the reburning process.

CIRCULATING FLUIDIZED BED COMBUSTION

Considerable experience is now being gained on atmospheric fluidized bed boilers. In recent years, the development of this technology has focused on the circulating fluidized bed (CFB) boiler. Since 1983, 66 CFB boilers have been sold in the U.S. Those units represent over 22 million pounds per hour of steam capacity. Riley Stoker and its

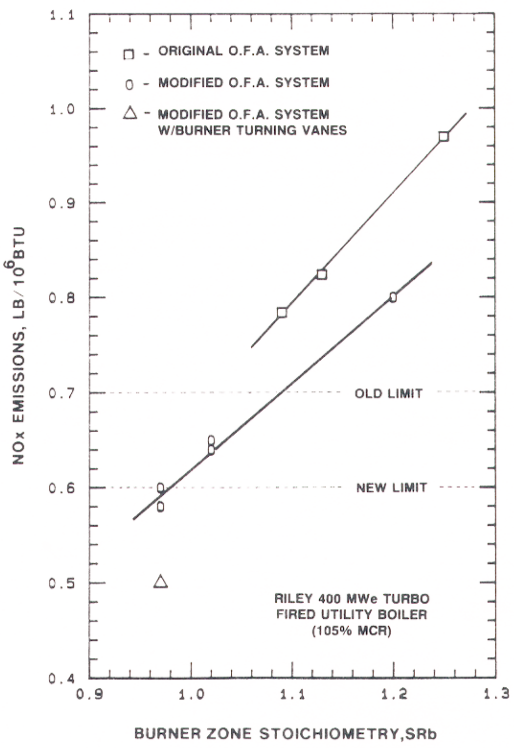

Figure 5. The Effect of Overfire Air on Coal-Fired Turbo Furnace No_X Emissions

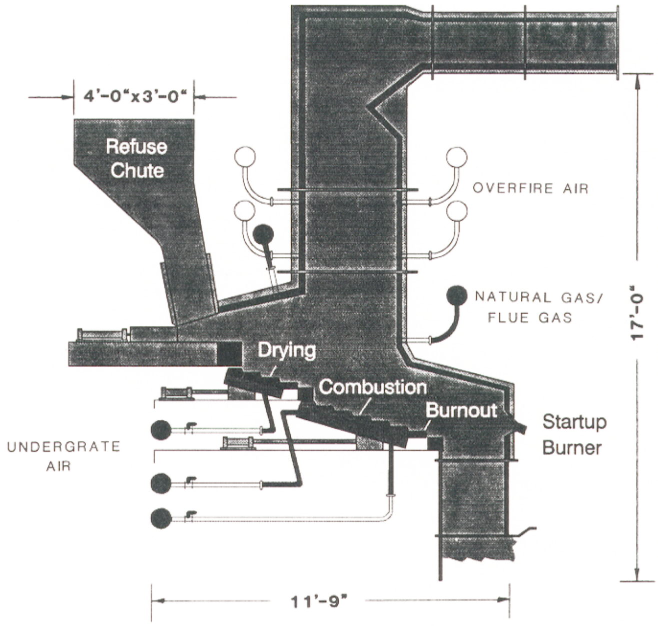

Figure 6. Riley 3 Million Btu/hr Pilot-Scale MSW Combustion Facility

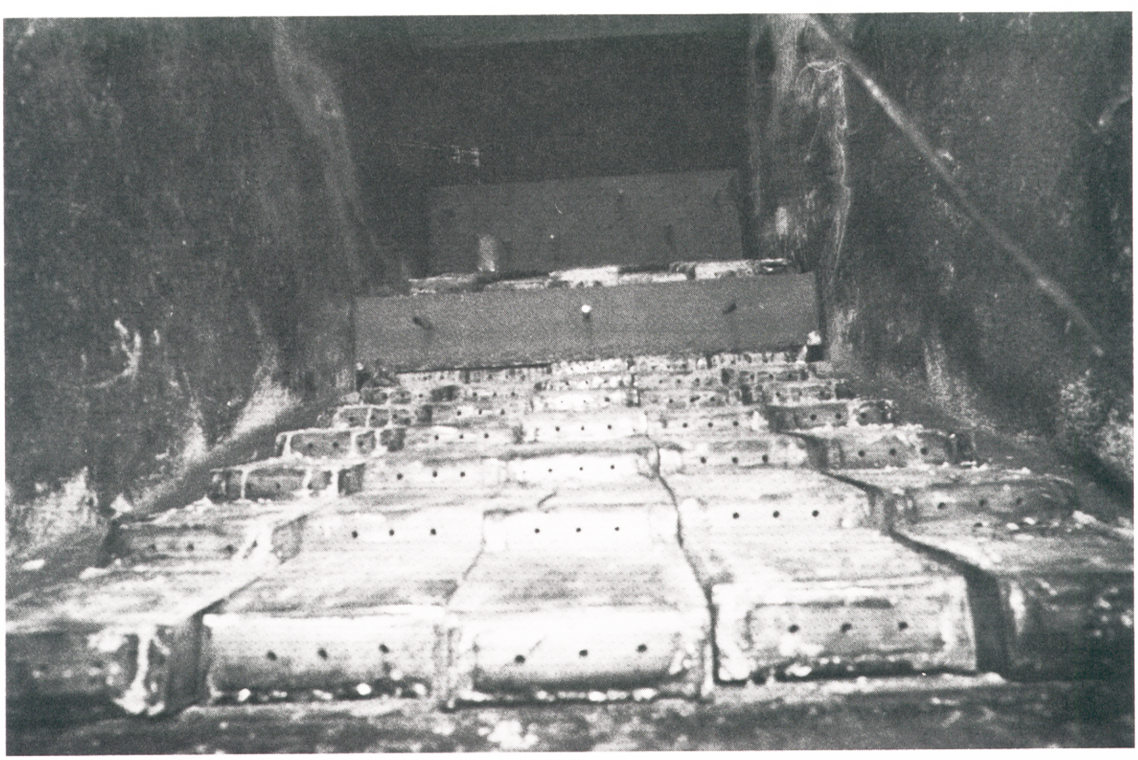

Figure 7. Pilot-Scale Stepped Combustion Grate

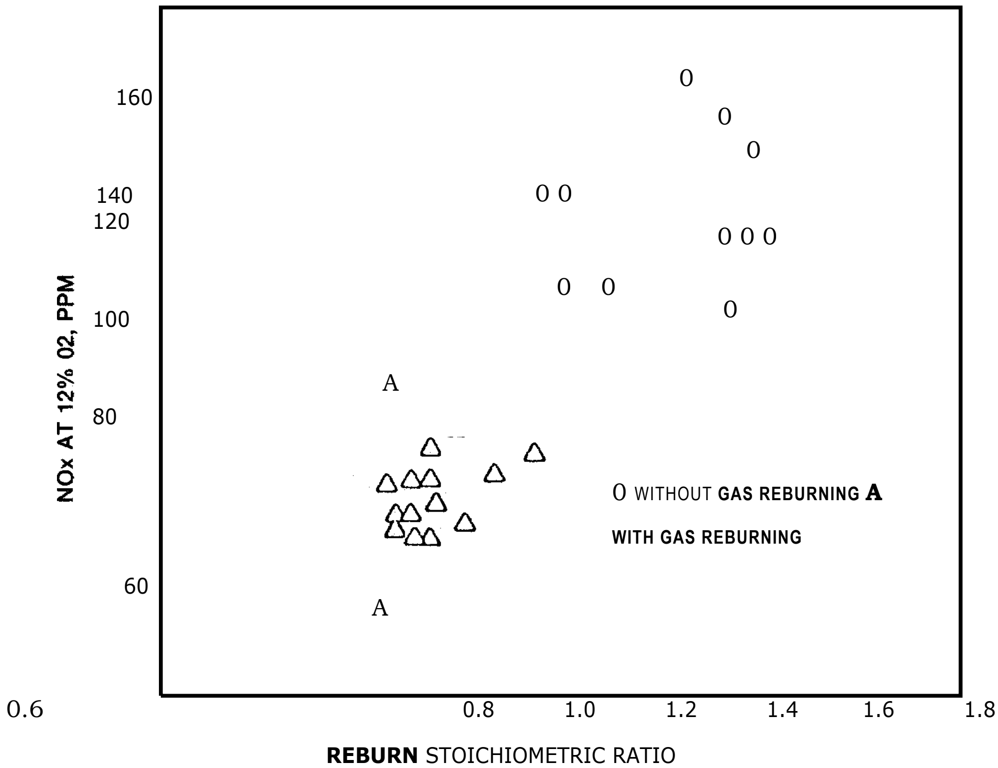

Figure 8. The Effect of Natural Gas Reburning on Pilot-Scale NOx Emissions from Municipal Solid Waste Combustion.

	Full Scale	Pilot-Scale
MSW Heating Value, Btu/lb.	**6037**	5447
Load, 10^6 Btu/hr.	37.5	2.36
Excess Air, %	73	70
OFA, %a	**34**	38
Combustion Products	9.3	8.7
0_2, % (1)		
CO_2, % (1)	10.1	10.9
CO, ppm (2)	29	27
^{NO}x, ^{pp}m (2)	134	142
Furnace Exit, Temp. °F	1620	1570
Residence Time to Furnace Exit, sec.	3.8	2.0

(1) As measured (2) Based on 12% 0_2

Table 1. **Comparision** of **Pilot-Scale** and Full-Scale **MSW** Test Data for a RileylTakuma Mass Burn Combustion System.

licensee, Mitsui Engineering and Shipbuilding Ltd. of Japan, have designed and constructed nine coal-fired CFB boilers varying in individual capacity from 150,000 to 660,000 lb/hr of steam. The Riley system is based on a technology known as Multi-solids Fluidized Bed Combustion (MSFBC)().

Riley coal-fired MSFBC boilers use limestone to control SO_2 emissions. MSFBC systems, therefore, are designed to operate at temperatures of 1500 to 1700°F for efficient limestone utilization and SO_2 control. Each MSFB boiler incorporates staged combustion for enhanced NOx control. As a result, NOx emissions from coal fired MSFBC units are below current emission limits. Recent field tests in both the U.S. and Japan have demonstrated that MSFBC boilers are capable of operating at NOx emission levels below 0.3 lb/10^6 Btu.Emissions vary from unit to unit as a function of fuel type and system design parameters such as primary zone stoichiometry, primary zone residence time, and temperature[s]. In 1987, Riley Stoker was awarded a U.S. DOE contract to investigate advanced fluidized bed combustion concepts applicable to small coal-fired industrial and commercial boilers. NOx emission levels of 0.1 lb/10^6 Btu or less with high combustion efficiency.

Riley Stoker is currently installing at its Riley Research Center a 7 million Btu/hr circulating fluidized bed test facility to study various staged combustion approaches. The combustor, shown in Figure 9, is over 60 feet tall and capable of simulating a variety of staged combustion configuration and operating conditions. Combustion testing will begin this spring.

SUMMARY

Retrofit combustion controls in the form of low-NO_X burners and improved overfire air systems are commercially available. NOx reductions of up to 60 percent are possible with these technologies. A second-generation CCV burner has been developed offering greater reliablity and extended operating range. Full-scale operating experience is still required on more advanced combustion techniques, such as advanced air staging and reburning, before these technologies achieve commercial status.

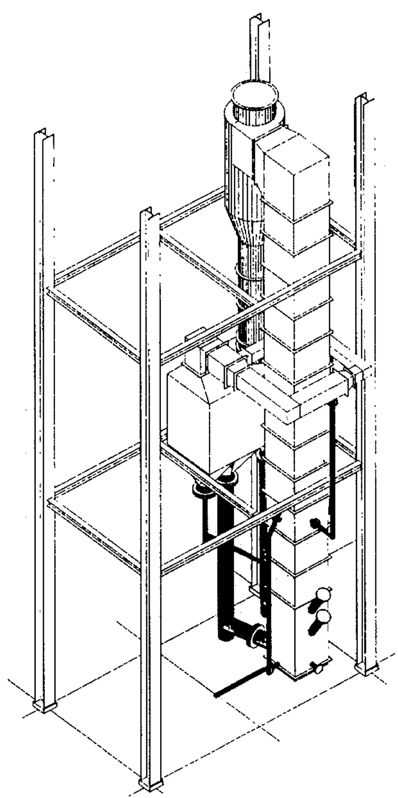

Figure 9. Riley Stoker's 7 million Btulhr Pilot-Scale Circulating Fluidized Bed Test Facility

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