RECENT LOW-NOx GAS AND OIL BURNER APPLICATIONS

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ABSTRACT

An overview of Riley Stoker low NOx gas and oil burner technology is presented. Riley has introduced the Axial Staged Return (ASR) flow burner for industrial packaged boiler applications. NOx performance data are provided for several recent package boiler installations with ratings of over 230 million Btulhr. Field data are used to examine the influence of flue gas recirculation and external air staging on NOx reduction in commercial operating systems. A new burner concept, the Axial Flame Staged (AFS) burner, is also described for small industrial boiler applications. The AFS burner combines the NOx reduction benefits of both air and fuel staged combustion. In addition, an update is given on the development and application of the Riley STS gas and oil burner for larger wall-fired boiler systems. Both pilot and full-scale STS burner emission data are presented.

INTRODUCTION

Over the past several years Riley has introduced several new low NOx gas and oil combustion systems to the U.S. Power Industry. These systems are now being installed on commercial operating systems.

Riley Axial Staged Return (ASR) flow burners have been installed on several large gas-fired package boilers. The ASR burner is based on patented Deutsche Babcock technology, and has been used successfully on new and existing power plants in Europe since 1984. Low NOx ASR burners are installed on more than 70 gas and liquid fired boilers in various firing arrangements. Following extensive large scale prototype testing at the Riley Research Center, Riley also now offers its Swirl Tertiary Staged (STS) burner for boiler retrofit applications. The STS burner can be retrofitted within existing burner openings on most multiple burner wall-fired boiler installations. Six STS burners were recently retrofitted on an industrial process steam wall-fired boiler. Currently 30 STS burners are being retrofitted on a 638 MW oil. and gas-fired utility boiler.

This paper describes the design and operating principles of both the ASR and STS burners. Recent field emission test results from several U.S. boiler installations are presented. In addition, a new burner concept, the Axial Flame Staged (AFS) burner is described. The AFS burner employs both air and fuel staged combustion to control NOx emissions. AFS burners are currently being installed in Europe in burner sizes up to 40 million Btu/hr.

ASR Burner Description

The basic features and operating principles of the Axial Staged return flow (ASR) burner are illustrated in Figure 1. Development of the ASR burner began in 1983.[12] The ASR burner is a parallel flow burner design with the combustion air divided into primary and secondary air streams. An air register is used to impart swirl to the primary air entering the inner burner throat. Secondary air is introduced axially through secondary air tubes located concentrically in the annular space between the inner primary air throat and the burner periphery. The primary and secondary air stream velocities are designed to aspirate hot furnace flue gas into the annular space between the primary and secondary air streams. Depending on the specific burner design, approximately 20 to 30% of the flue gas produced is recirculated in this manner. This internal flue gas recirculation is an important feature of the ASR burner. Initially the aspirated flue gas acts as a dividing layer between the primary and secondary air streams. Later, as fuel and air mix this flue gas serves to lower both temperature and the oxygen concentration in the primary flame zone.

In summary, NOx control in the ASR burner is achieved through:

- Axial staging of the primary and secondary air streams
- Recirculation of self-aspirated hot furnace gases

The ASR burner can also be integrated with other combustion control measures for additional NOx reduction. For example, ASR burners can be combined with furnace air staging ports such as tertiary or overfire air ports. ASR burners can also be combined with external or separate recirculated flue gas extracted from the furnace stack and mixed with the incoming combustion air.

ASR burners are designed to fire a wide range of gaseous and liquid fuels. As shown in Figure 1, gas is fired through a series of gas lances that can be axially positioned and individually rotated in the burner throat. These can be made while the burner is in operation. The gas lances in combination with the primary air swirler are designed to produce stable flames across a wide operating range. Burner turndown ratios of 8 to 1 or better have been achieved even with gas supply pressures as low as 3 psig. ASR burners can also be designed for turndown ratios of 20 to 1 or more if required.

Both light and heavy liquid fuels are fired through a centrally located steam assisted atomizer. This atomizer is designed to minimize steam flow. Steam atomization flow requirements are on the order of 4 to 5% of the oil flow.

ASR BURNER PERFORMANCE

Package Boiler Applications

Riley has supplied ASR burners on four boilers at three locations. Each is a Riley MH watertube package boiler equipped with a single burner. One of the installations is a burner retrofit application while the other two represent new unit construction. Burner firing capabilities range from 230 to 275 million Btu/hr on these units.

Furnace plan views for two new boiler installations are shown in Figure 2. Unit A has a capacity of 180,000 lb/hr steam flow. It is designed to fire both natural gas and No. 2 fuel oil. In addition to a single ASR burner rated at 230 million Btu/hr, it is equipped with an external flue gas recirculation (FGR) system. Flue gas is extracted from the economizer outlet and mixed with the combustion air entering the burner. This external FGR system provides 13 to 20% flue gas to the burner in addition to the flue gas aspirated by the burner itself. Air foil mixing devices are installed in the supply ductwork to insure good mixing of flue gas with the combustion air.

A second new ASR burner furnace installation is also illustrated in Figure 2. Unit B is a 200,000 lb/hr Riley MHW package boiler fired with natural gas. It is equipped with a single ASR burner with a maximum firing capacity of 275 million Btu/hr. The Unit B furnace design is notably different than the more conventional Unit A design. Unit B has a wider furnace in the flame zone region. This wider furnace design serves to: (1) decrease burner area heat release, thereby reducing flame zone temperature, and (2) improve the flow of flue gas internally recirculated through the burner nozzle. This unique furnace design is intended for applications with more severe NOx control requirements.

Like Unit A, Unit B is also equipped with-an external FGR system designed to mix up to 20% additional flue gas with the burner air supply. Unlike Unit A, Unit B is also equipped with air staging ports on each side of the furnace chamber. These air ports serve the same function as overfire air on large wall-fired boilers. The air staging ports are installed at two different furnace depths to promote uniform mixing of air and furnace flue gases. As in the Riley overfire air port design, each air staging port is separated into one third/two third flow areas, each with its own control damper. A front view of the boiler with the associated external flue gas and air staging ductwork is shown in Figure 3.

Field Test

Short term field tests were recently performed on package boilers A and B to characterize the emission performance of each boiler on natural gas over its operating range. The results of these tests are summarized in Figures 4 and 5.

The effects of external flue gas recirculation and amount of external air staging on full load NOx emissions are shown in Figure 4. Tests performed on Unit B demonstrated the performance benefits of air staging on NOx reduction. Increased amounts of air staging resulted in reduced NOx emissions both with and without the combined effect of external FGR. NOx versus load for various amounts of flue gas recirculation is summarized in Figure 5. Burners on both units were designed to operate with 10% excess air. Measured excess oxygen levels at full load varied from 1.4 to 2.7% during the test program. As is common on many package boiler firing systems, the combustion air on both units is not preheated.

Both units A and B achieved their specified required emission performance limits. Unit A with external FGR, but without air staging ports, achieved NOx levels of 40 ppm (dry 3% O_2) or less with carbon monoxide (CO) emission of less than 10 ppm. Unit B, which is also equipped with air staging ports and has the larger furnace design, is able to operate at NOx levels of less than 20 ppm. CO under these operating conditions was 65 ppm. Tests on Unit B also demonstrated the tradeoff between NOx and CO emissions during natural gas firing. By reducing the amount of FGR and air staging, CO can be reduced to less than 20 ppm but with a rise in NOx to 29 PPM.

STS Burner Description

Development of the Riley STS burners began in 1991. The goal of this development effort was to adapt Deutsche Babcock low NOx gas and oil burner technology for retrofit on U.S. wall-fired boilers with common windbox/multiple burner firing arrangements.[3]

An illustration of a commercial STS burner is shown in Figure 6. Because the STS burner is intended for retrofit applications, it is designed to fit within existing burner openings. In order to reduce the size of the required burner opening, the STS burner does not incorporate the ASR burner flue gas self-aspiration system. However, the STS burner does not include both primary and secondary air zones.

Primary air is delivered to the center of the burner which contains gas lances, central oil gun and a primary air fixed vane swirler. The gas lance and oil gun configurations are similar in design to the fuel injection system employed on the ASR burner. A secondary air register with curved overlapping blades provides variable swirl control for the outer secondary air. A separation gap is employed between the inner primary air core and outer secondary air annulus to help maintain distinct primary and secondary combustion zones.

The STS burner is also equipped with movable flow control shrouds which slide over the primary and secondary air inlet passages. These flow control shrouds serve two purposes. First they can be used to balance windbox air flow to each burner. A flow measuring pressure impact probe is positioned in the primary air passage as a relative indicator for balancing air flow in each burner. Secondly, the shrouds can also be adjusted to control the primary/secondary air split independently of swirl vane position. Partially closing the shroud at low loads enhances the turndown capability of the burner by maintaining sufficient swirl for flame stabilization.

STS BURNER PERFORMANCE

Large Pilot-Scale Testing

A prototype 85 million Btu/hr STS burner was tested at the Riley Research Center burner test facility located in Worcester, Massachusetts. The objectives of the test program were the following: (1) to characterize the burner on natural gas and No. 6 fuel oil under U.S. boiler operating conditions, and (2) to evaluate the sensitivity and trade-off of various burner design components and adjustments on NOx emissions and other combustion performance parameters.

Pilot-scale test results for the Riley commercial STS burner configuration are shown in Figures 7 and 8 for natural gas and No. 6 oil. The fuel oil used for these tests was a 2% sulfur oil with a fuel nitrogen content of 0.5% and an asphaltene content of approximately 12%. Combustion air for these tests was preheated to approximately 500^{o}F.

Unstaged NOx and CO emissions as a function of excess oxygen concentration are summarized in Figure 7. The combined effects of external flue gas recirculation (FGR) and air staging on STS burner performance are described in Figure 8. Flue gas for these tests was extracted from the furnace exit and introduced into the windbox with the primary and secondary air. Air staging was achieved through the use of overfire air ports (OFA) located downstream of the firing wall. NOx emissions of less than 90 ppm were achieved on No. 6 oil using OFA and less than 20 ppm on natural gas using both OFA and FGR. Due to the cooler thermal environment of the pilot single burner test facility, these emission levels are somewhat lower than those reported for European field tests.[3]

A number of burner design configurations were evaluated in the Riley pilot-scale test program including the use of a separate concentrated flue gas stream to divide the primary and secondary air streams. However, the final STS burner design configuration does not include this feature. Our testing showed that the incremental improvement in NOx reduction provided by this separation layer did not justify the required additional design or operational complexity.

STS Burner Field Application

The first U.S. commercial application of the Riley STS burner is on an existing 175,000 lb/hr process steam boiler located at a paper mill. This Babcock and Wilcox designed boiler was originally equipped with a wood-fired grate. As shown in Figure 9, the unit is now exclusively gas-fired. In 1992 this unit was retrofitted with six STS gas-fired burners with individual firing capacities of 38 million Btu/hr. Combustion air is preheated to above 400°F. The installation does not include a flue gas recirculation system.

Fuel load unstaged NOx emissions for this unit are compared with pilot-scale STS burner emission results in Figure 10. The measured field emissions are more than 50% below reported uncontrolled NOx levels. As expected, the field emission data are approximately 60% higher than pilot test NOx value due to the more than fourfold increase in burner area heat release. One of the biggest combustion problems to overcome on this older industrial boiler was the large amount of air infiltrating through casing leaks and various furnace penetrations. This is reflected in the higher measured O_2 levels in the boiler outlet duct.

Utility Boiler Retrofit

Thirty STS burners are currently being installed on a 638 MW gas and oil fired utility boiler. This retrofit is taking place at Consumers Power Company's Karn Unit No. 4, located near Essexville, Michigan. Karn Unit No. 4, shown in Figure 11, is a Riley wall-fired boiler installed in 1974. It is equipped with thirty burners arranged in three rows on a single firing wall. Each burner has a firing capacity of approximately 240 million Btu/hr. This unit was originally designed to fire crude oil but later switched to No. 6 oil firing.

The purpose of the retrofit is to convert Karn Unit No. 4 to natural gas firing. Because of gas supply limitations at the Karn Station, only the lower two rows of STS burners will be capable of gas firing. The top STS burner row, or one third of the burners, will continue to fire No. 6 oil only. The retrofit does not include the installation of OFA or FGR. Unit restart with the STS burner firing system is scheduled for May of 1993.

AFS Burner

Riley's parent, Deutsche Babcock, has introduced a newly patented low-NOx multi-fuel burner design for small industrial and commercial firing applications. This is the Axial Flame Staged (AFS) burner. The AFS burner incorporates two low-NOx combustion control features:

- Axial staging of primary and secondary air.
- Staged fuel addition.

As shown in Figure 12, the AFS burner employs both internal and external gas injection nozzles. Fuel staging is achieved by splitting the gas input between the internal gas nozzles located in the primary air passage and the outboard external gas nozzles located around the burner periphery.

Deutsche Babcock is currently installing modular AFS burners with firing capacities of 20 to 40 million Btu/hr on firetube boilers and small industrial watertube boilers in Germany. AFS burners are designed for combustion air temperatures of up to 200°F, but can be altered for air preheat applications up to 500°F.

Gas staged burner results for several recent commercial installations are compared in Figure 13 for various operating loads. Test results from Deutsche Babcock's 35 million Btu/hr pilot test facility are also shown. Each of these results represent differences in furnace heat release rates and operating conditions. The results also show the effect of combustion fuel staging with flue gas recirculation. NOx emissions of less than 25 ppm can be achieved with increasing amounts of flue gas recirculation. CO emissions of 5 to 30 ppm have been achieved on gas-fired field operating units. AFS burner performance on light fuel oil is summarized in Figure 14.

Summary

Riley offers several low-NOx gas and liquid burner systems designed to meet a wide range of industrial and power industry combustion requirements. ASR burners have proven themselves on several recent package boiler applications. ASR natural gas fired burners are able to achieve NOx emission levels of <0.1 lb/MM Btu. Considerably lower emission levels can be achieved when the ASR burner is combined with other combustion modifications such as external flue gas recirculation and air staging.

Riley STS burners are now being retrofitted on multiple burner wall-fired boilers. The first commercial STS burner retrofit has achieved NOx reductions greater than 50% on natural gas.

Compact AFS burners, employing fuel staging techniques, are now being installed on small industrial boilers in Europe. These burners have been shown to be capable of meeting German gas and oil emission standards.

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3. R. Lisauskas and C. Penterson, "An Advanced Low NOx Combustion System for Gas and Oil Firing," presented at the 1991 Symposium on Stationary Combustion NOx Control - EPA/EPRI, Washington, D.C. (March 1991)

4. R. Lisauskas et al, "Experiment Investigation of Retrofit Low NOx Combustion Systems", Proceedings: 1985 Symposium on Stationary NOx Control. Vol 1, EPRI CS-4360 (January 1986)

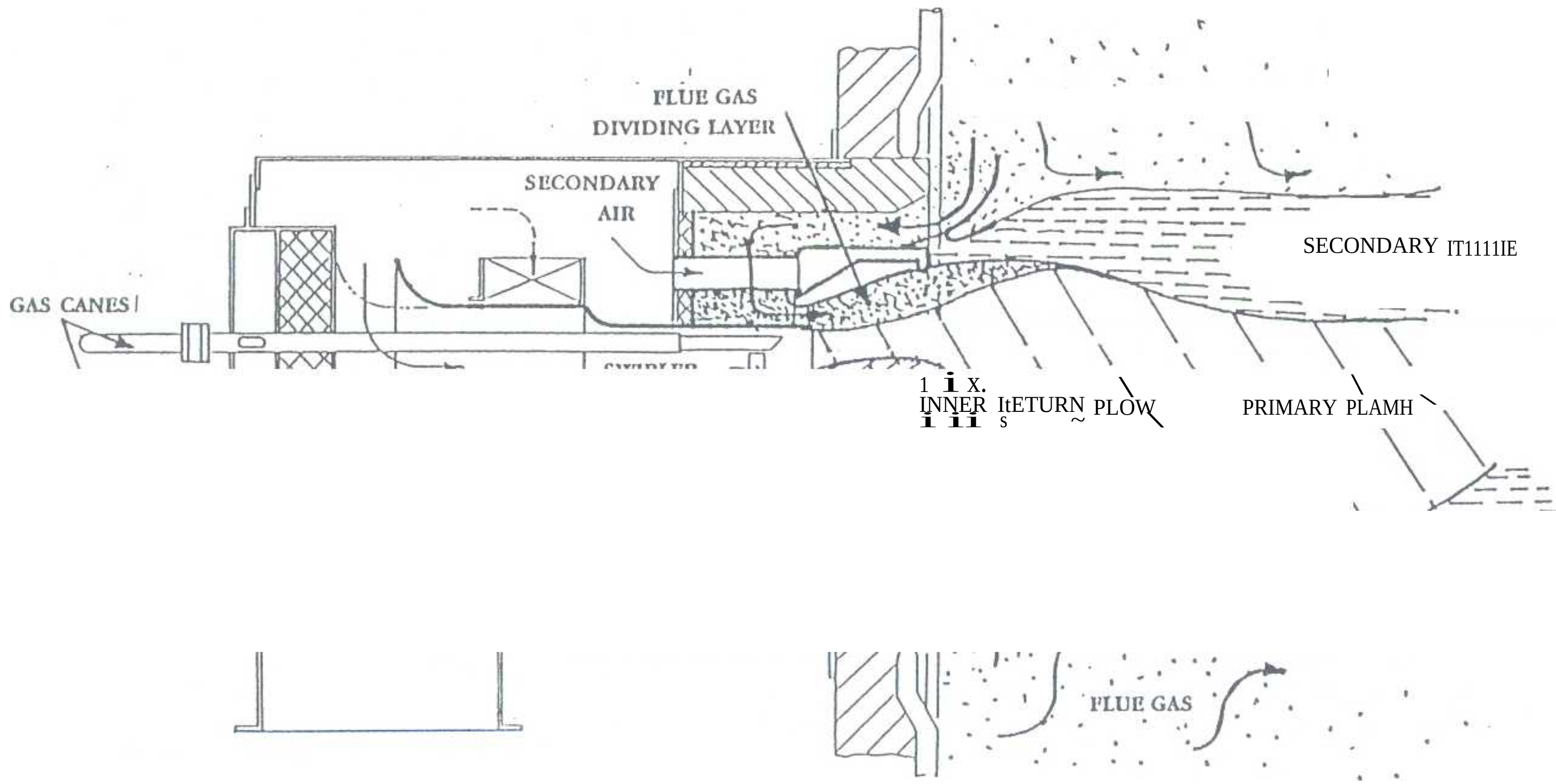
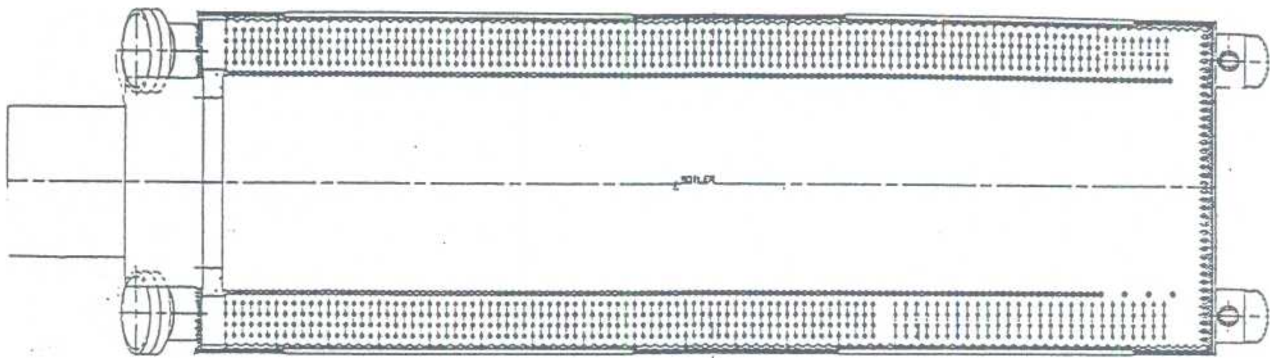
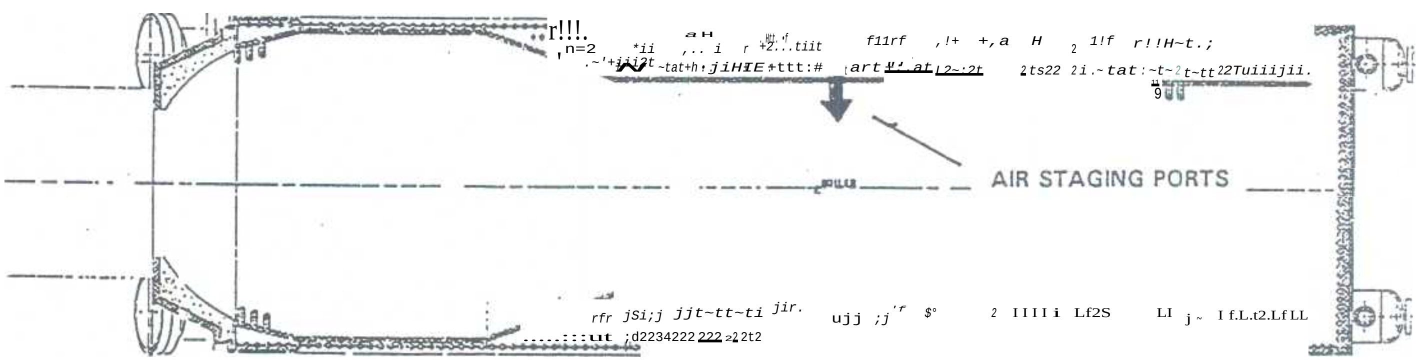


Figure 1. Low-NO_X ASR Burner.



INSTALLATION A - PLAN VIEW
PACKAGE BOILER - CONVENTIONAL FURNACE



INSTALLATION B - PLAN VIEW
PACKAGE BOILER - WIDE FURNACE .

Figure 2. ASR Burner Package Boiler Applications.

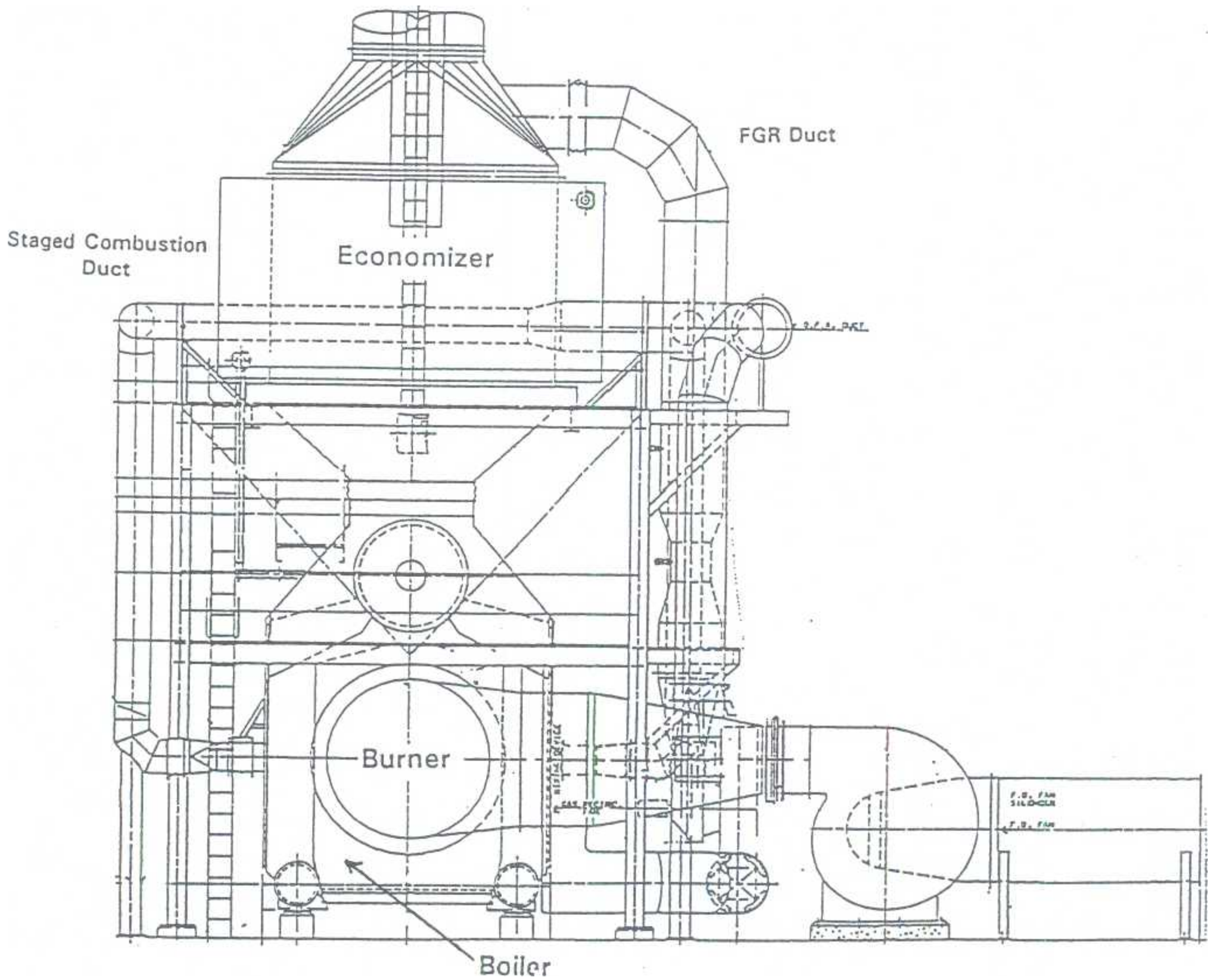
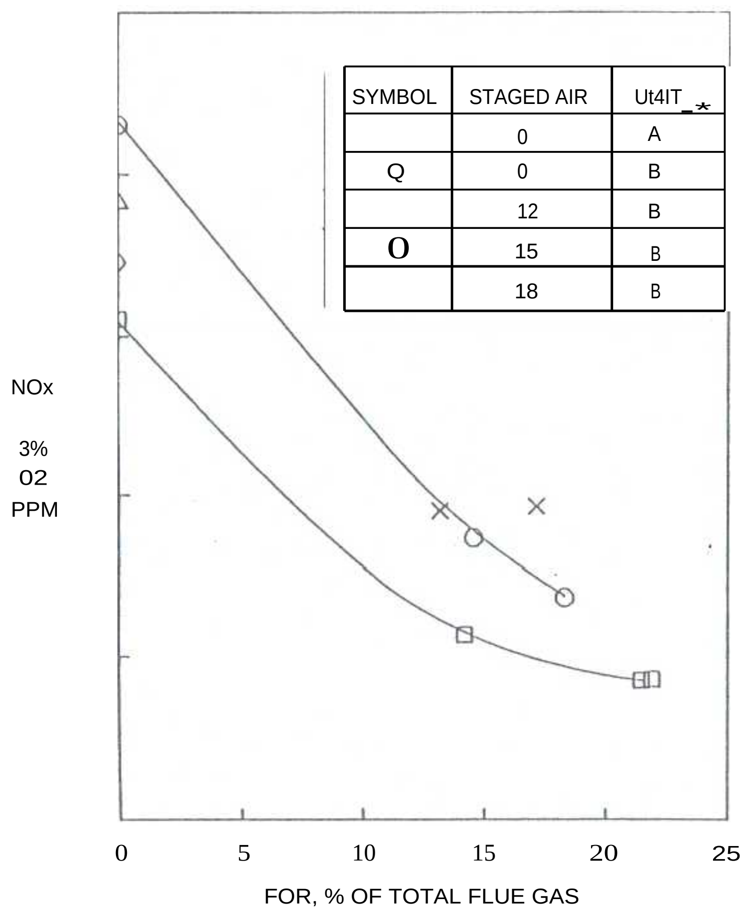


Figure 3. Riley MHW Boiler With ASR Burner Low NO_X Combustion System With External Flue Gas Recirculation And Air Staging.



Figure, 4. The Effect Of External Flue Gas Recirculation And Air Staging On ASR Burners NO_x Emissions - Natural Gas Firing.

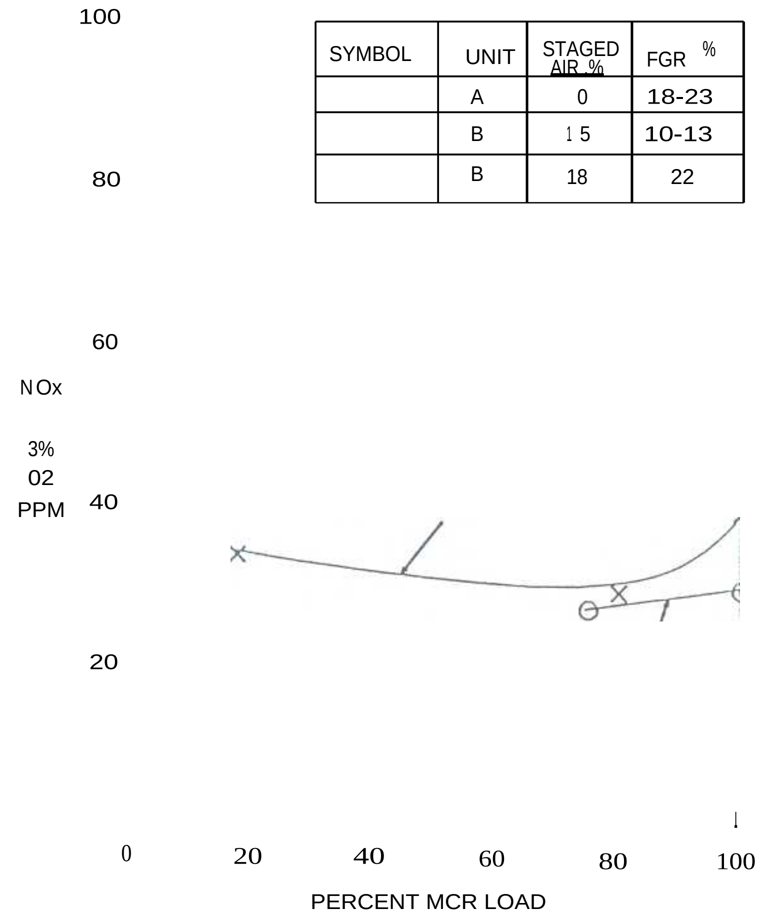


Figure S. NO_x Versus Load Field Data For Natural Gas-Fired ASR Burners.

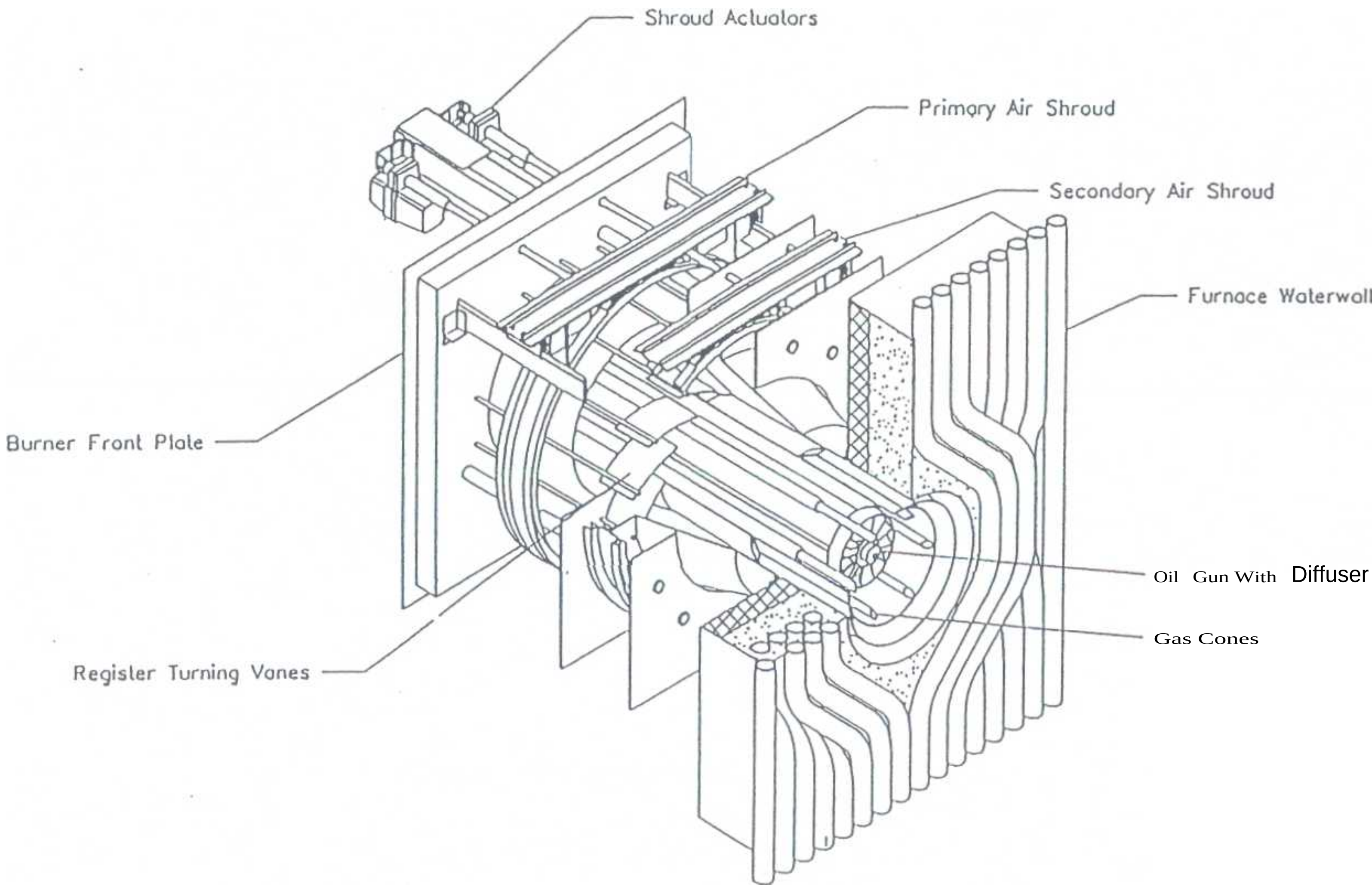


Figure G. *Riley STS* Burner.

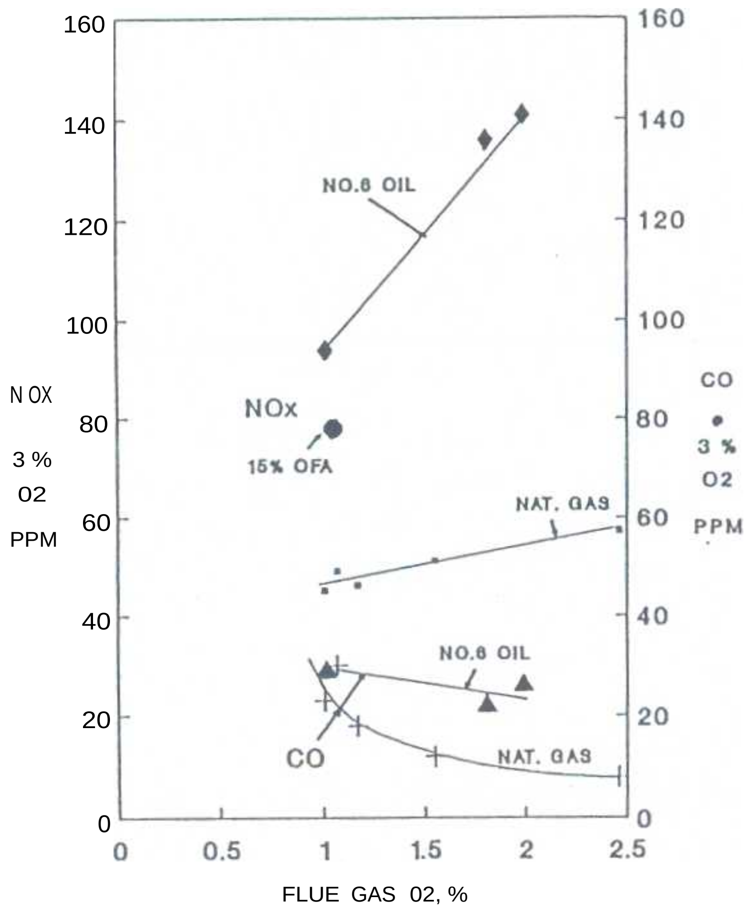


Figure 7. The Tvt Of Excess Air On Prototype (85 x 10 Btu/hr) STS Burner NO_x And CO Emissions - Riley Pilot Facility, No FGR.

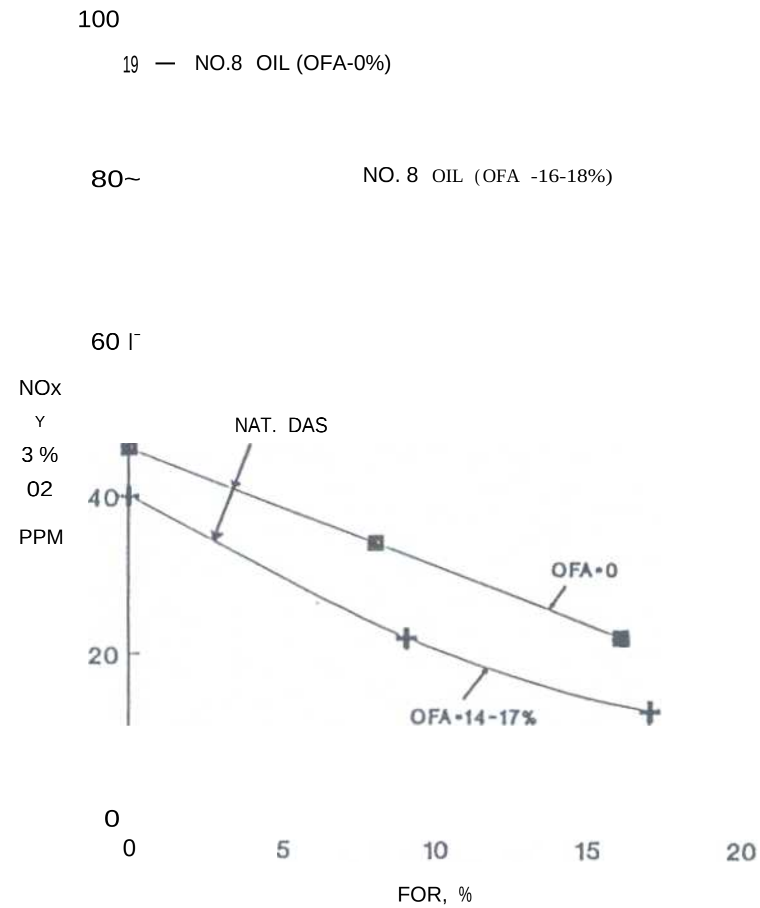


Figure 8. The Effect Of Flue Gas Recirculation And Overfire Air On STS Burner NO_x Emissions.

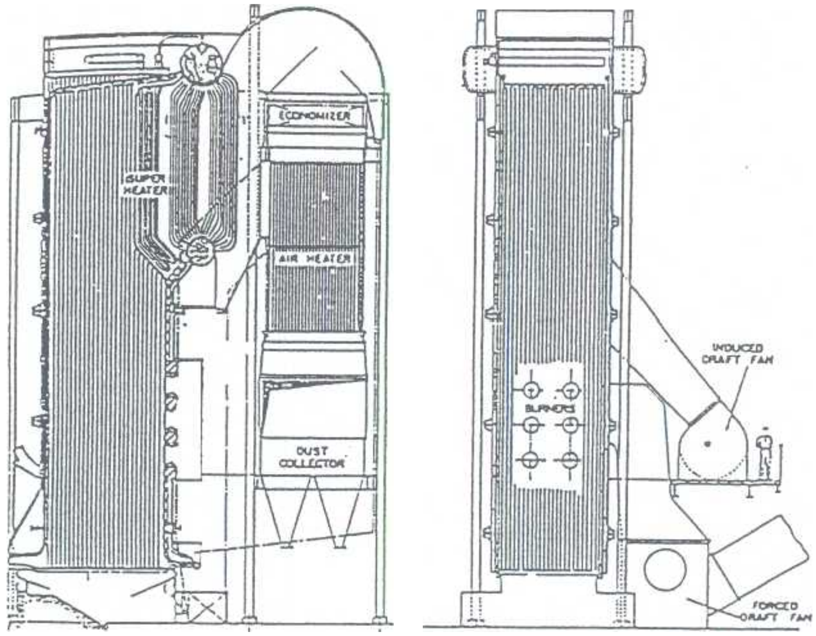


Figure 9. Industrial 175,000 lb/hr Boiler Retrofitted With STS Burner.

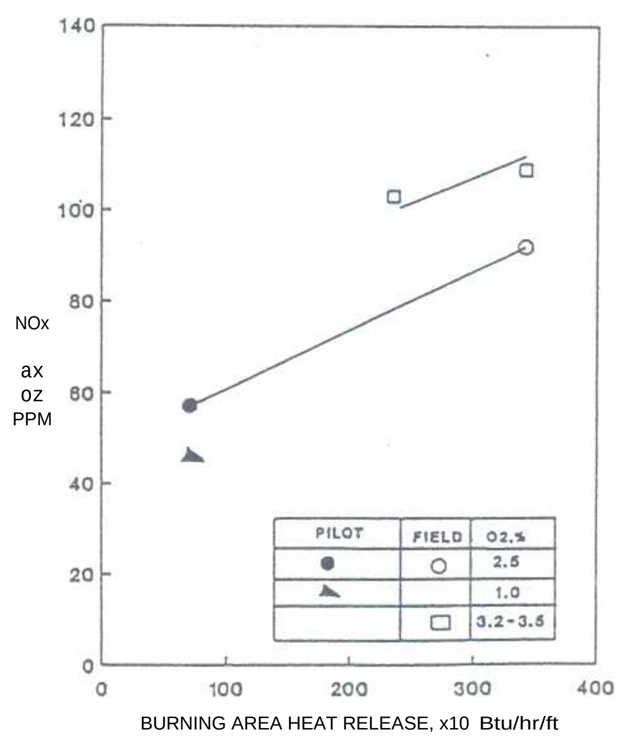


Figure 10. Comparison Of Pilot And Field STS Burner NO..

Figure 11. STS Burner Retrofit Under Construction - 638 NIW Gas And Heavy Oil Fired Consumers Power Company Karn Unit No. 4.

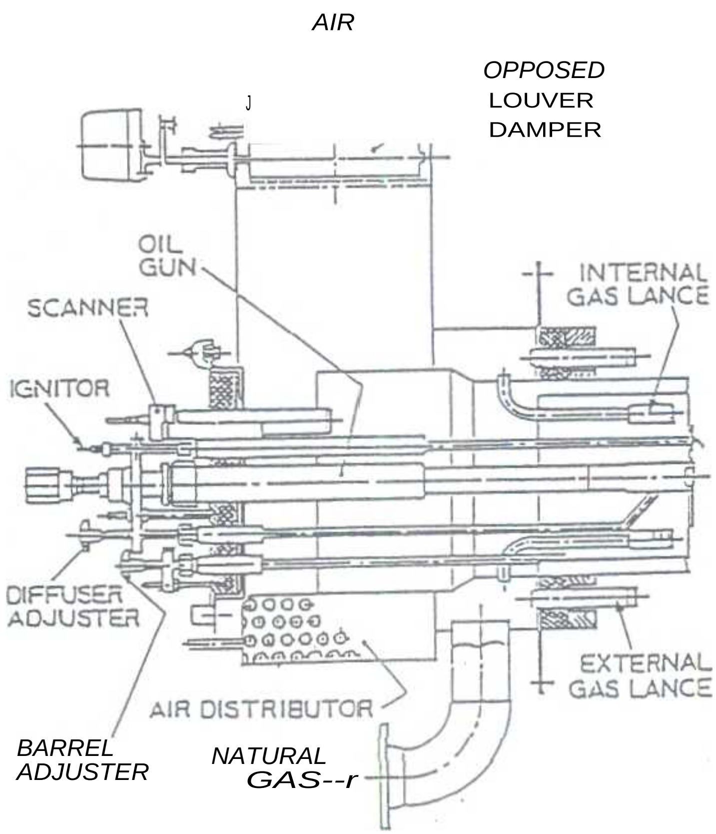


Figure 12. AFS Air And Fuel Staged Burner.