ADVANCED LOW NO_x COMBUSTION SYSTEM CASE STUDY DOW CHEMICAL CORPORATION

by

Lawrence J. Boucher
Sr. Project Manager
Firing Systems Department
Riley Stoker Corporation

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Riley Stoker Corporation
P.O. Box 15040, Worcester, MA 01615-0040
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L.J. Boucher

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ABSTRACT

In 1990 Dow Chemical Corporation in response to future State emission regulations began investigating low NO_x systems to maximize emission reduction while firing natural gas and hydrogen. Dow's objective was to meet the intention of "MACr maximum available control technology. The system purchased included Riley designed overfire air and flue gas recirculation systems and Todd ***"Van-Flame" burner modification (Unit*** *#2) or new "Vari-Flame" burners (Unit # 1).*

Dow Chemical, Plaquemine LA, first retrofitted Unit #2 in 1991 with Unit # 1 following in 1992 with the above described systems. Emission results will be summarized for each system component. Finally ***included*** *will be emission results from three (3) additional installations, a face fired gas unit in the south, and two package boilers, one a retrofit the other a new installation.*

INTRODUCTION

Dow's Plaquemine Units 1 & 2 were designed and manufactured by Riley Stoker Corporation in the mid 1950's, under original Contract Number 2314. The boilers were designed to operate at a maximum continuous rating (MCR) of 500,000 lbs steam/hour burning natural gas. Steam conditions are 1300 psig, 950°F with a feedwater temperature of 275°F. The original burners, (10) were furnished by Peabody.

In 1987, Dow removed the Peabody burners **and** replaced them with Todd "Dynaswirl", (low excess air) burners capable of firing natural gas and **hydrogen.**

In 1990, Dow Chemical Corporation in response to future State emission regulations began investigating low NO_x systems to maximize emission reduction while firing natural gas and hydrogen. Meetings were conducted between Riley Stoker Corporation, Todd **Combustion** and Dow **Chemical** to **discuss** available alternatives.

State environmental concerns **in the** Mississippi River Valley prompted Dow Chemical to retrofit two (2) existing units with low NO_x combustion systems. Unit #2 was converted first in 1991, **mainly** due to the fact that a **burner modification had** been completed in the recent past **and** the installed **equipment** was in reasonable repair. Existing **burners** were **upgraded and** flue gas recirculation **and** overfire air systems **added (Figures** 1, 2, & 3). The following is a brief description of each system installed:

Riley Flue Gas Recirculation System (FGR). This system extracts flue *gas* from the air heater outlet and mixes it with the combustion air upstream of the windbox. Sixteen (16) air foil mixing devices **(Figure** 4) were installed, devices are either open or closed as load changes to ensure proper mixing is being achieved.

Riley Overfire Air System (OFA). Overfire air ports are located approximately one (1) **burner** height **spacing** above the **upper** row of **burners.** The OFA system consists of seven (7) **individual nozzles, each divided** into one third and two third flow areas **(Figures 2 & 3).** Each area is once **again** controlled separately to ensure proper mixing and penetration velocity.

Modification to the existing Todd " Dynaswirl" burners **(Figure 4) upgrading** them to latest Todd low NO_x design "Vari-Flame" Burners, (Unit #2). Installation of new Todd "Vari-Flame" burners, (Unit #1).

Industry experience indicates that low NO_x **burners** alone can reduce stack NO_x emission between 30 and 45 percent **depending** upon unit heat release rates and the fuel being fired. Overfire air can reduce emission by an additional five (5) to thirty (30) percent, and flue gas recirculation another five (5) to thirty-five percent (35). Once again, depending upon fuels being fired and furnace heat liberation rates.

Flue gas recirculation is extremely effective in the reduction of NO_x **when firing natural** gas. Overfire air when firing oil and hydrogen. The combined systems can result in emission reduction in the order of seventy (70) percent, when gas firing, and sixty (60) percent when firing oil.

Dow's emission reduction initiative was to achieve at least a seventy (70) percent NO_x reduction while maintain reasonable combustion efficiency and maintaining current unit performance levels. The combined systems, designed correctly can and did achieve the desired results.

OVERVIEW OF DOW UNITS AND LOW NO_x SYSTEM

Riley Stoker Corporation was asked by Dow Chemical USA, **Plaquemine,** Louisiana Operations to review Boiler #1 & #2 performance in regards to NOx control. The units were originally furnished to Dow Chemical under Contract 2314 and **designed** to fire natural gas, hydrogen firing was added in 1987 in sufficient quantities to produce 500,000 lbs/steam per hour.

The contract objective was to reduce NO_x emissions to 0.1 lbs/10^6 btu while maintaining the steam temperature at 950°F when firing the design fuels.

Riley **proposed utilizing** the latest state-of-the art **combustion control technology available. This required** the **installation** of a new **combustion** system **incorporating** low NO_x gas burners, overfire air, (OFA) and flue gas recirculation (FGR) systems.

Dow **purchased** ten (10) low NO_x **(Todd Combustion) natural gas/hydrogen burners, and advanced overfire air and flue gas recirculation systems. Todd Combustion designed and fabricated burners, Riley Stoker was responsible to incorporate them into the existing windbox configuration, as well as the design and fabrication of the integrated overfire air and flue gas recirculation systems. Installation** was by Dow Chemical.

Description of Todd Burners:

The existing Todd **Combustion Dynaswirl were installed in 1986 in conjunction with a low excess air and hydrogen addition project. They replaced the originally installed Peabody burners.**

The existing Dynaswirl burners were reused. Modifications were **required at the burner** front wall **end, and within the burner throat area. Throat modifications were essential to accommodate increased** air **and** flue gas flows **through** the **burner,** as well as elevated pre-mixed air temperatures. Design considerations included re-using the existing forced and induced draft fan configurations, as well as eliminating any need for pressure part modifications. A tertiary air zone was added to minimize burner pressure drop, and create internal burner staging. Todd Combustion's burner design met Dow's objectives, reasonable pressure drop, hence eliminating the need for fan changes, **and** fit-up into the existing burner throat area.

Unit #1 was retrofitted with new Todd Combustion Vari-flame burners. Information can be obtained from Todd directly.

DESCRIPTION OF FLUE GAS RECIRCULATION SYSTEM

Gas Recirculation System

The gas recirculation system was designed with two (2) objectives in mind. The first objective was to

the boiler control range from 350,000 lbs/hr to 500, 000 lbs/hr of steam. The second, controlling NO_x through balanced air/gas mixing. Balancing the air/flue gas recirculation flow to each burner is critical to minimizing emissions and maximizing burner performance. This required a system design capable of maintaining the desired steam temperature at low unit load, (load FGR flows) and still achieve adequate flue gas mixing to ensure efficient combustion and emission reduction. This was accomplished by installing seventeen flue gas mixing devices, (Figure #1) fed independently from a gas plenum located just below the existing combustion air duct. The design incorporated multiple channels made from stainless steel, which the flue gas is forced through. Along the sides these truncated channels are multiple orifices, which flue gas flows through and mixes intimately with the combustion air. Through damper control individual mixing devices can be isolated during low load operation, maintaining adequate gas to combustion air velocities promoting excellent mixing, hence adequate combustion performance and emission reduction.

The system was designed to mix twenty (20) percent of the total flue gas with the air required for combustion. The burners were designed to accommodate this amount of flue gas without flame stability problems and without increasing the burner pressure significantly enough to warrant a forced draft fan change. Introduction of flue gas into the combustion process results in the following beneficial effects.

Reduction of the peak flame temperature, particularly on the surface of the primary combustion zone.

The oxygen concentration in the primary combustion zone is significantly diluted.

Combustion process is delayed.

DESCRIPTION OF THE OVERFIRE AIR SYSTEM

To provide greater flexibility in controlling emission and overall combustion performance, **an** overfire air system (OFA) was installed. The system was designed to divert fifteen (15) percent of the total combustion air away from the burners for staged combustion. The system has a capability of operating with a maximum air diversion rate equal to twenty (20) percent of the total combustion air. This provides operating margins by increasing the systems ability to further off stoichiometric fire, if required by normal plant operation parameters.

Staged combustion is another proven **technique** for reducing NO_x.

The installed system was designed within pressure drop and flow rate parameters so that existing forced draft fan would not be effected.

Riley has performed significant research work for EPRI in the mid 1980's developing design guidelines for overfire air systems (RP Numbers 2154-6 **and** 2154-13). Research work **included** both three dimensional flow models **and** three dimensional computer simulations using FLUENT analysis. From the established guidelines, the following elements are considered the most critical when **designing** retrofitted **advanced** OFA systems.

Adequate separation between the primary **and** secondary combustion zone be available for NO_x **reduction.**

Rapid mixing of the overfire air and the primary combustion zone must occur to promote efficient burnout of the fuel mixture.

Adequate residence time in the secondary combustion zone must be available to complete combustion, hence minimizing CO emissions.

Independent control of the overfire air from the burner must be incorporated into the combustion system design. Excellent air control is critical to ensure efficient combustion is maintained while maximizing emission reduction.

The system **supplied** by Riley meets the above mention criteria. One overfire air port is located above each burner column approximately one burner elevation above the top burner row, while a wing OFA same elevation as the other OFA ports. Riley's experience indicates that wing OFA ports are effective in promoting mixing of the air with furnaces gases travelling **up** the **furnace sidewalls.** The ports were sized to provide sufficient velocity **and** penetration to promote rapid mixing.

Location of the ports provides the proper separation from the combustion zone necessary for NO_X reduction, as well as sufficient residence time following the **introduction** of OFA for proper **burnout.**

Automated flow control dampers were provided in **the air** duct feeding **the** OFA **header (plenum).** This damper is utilized to control the amount of OFA **being supplied** with **changing** boiler **loads. Addition** of **one third** and two third flow areas in each OFA port provide greater control of the OFA air flow and velocities, **(Figure** 5) ensuring proper mixing and control over a greater operating range.

The one third flow control dampers, as well as the two third dampers were ganged together to provide automated control of the OFA ports.

Utilizing this design configuration provides four distinct operating modes. This once again leads to efficient, effective control of the overfire air necessary to meet critical design parameters. The four distinct operating modes include:

> No overfire air flow, utilized during low load operation.
>
> 1/3 overfire air flow, utilized for load operation between thirty (30) and (60) sixty percent MCR load.
>
> 2/3 overfire air flow, utilized for loads from sixty (60) to ninety (90) percent boiler load.
>
> Full overfire air flow, for boilers loads from ninety (90) percent load to full MCR and or peak boiler load. The addition of overfire allows for greater operational flexibility when firing units in a low NO_X operating mode. This flexibility may be essential for the reduction of CO, and the assurance of good carbon burnout. Further, NO_x the addition of an OFA system is a prudent measure to ensure reasonable operating **margins.**

Unit Performance Testing Results

Included within the report are emission reduction curves, overfire air and flue gas recirculation system effectiveness curves, as well as the effects on stack temperature for your convenience. We caution that at Dow Chemical the fuel analysis can as was **changing** with off-gas **production** from **hydrocarbon** plants. The curves detail varying emission levels for similar conditions, this is attributed to the varying fuels analysis. Test data was taken over a four (4) month period and it was impossible to ensure identical fuel constituents in every test condition. However, the curves detail the effects of each system in regards to there relative effectiveness for emission reduction **(Figures** 7 **through** 12).

Acknowledgement:

I would like to express my thanks to the following individuals who contributed in various ways to the success of this project **and** paper.

Sam Allen, Dow Chemical Corporation, for his assistance and cooperation throughout the contract phase and for providing additional emission testing data once Riley Field Service had completed our efforts.

Todd Combustion Inc., for their cooperation in working with Riley Stoker Corporation to ensure a successful project/retrofit for Dow Chemical U.S.A.

To Richard Green, Amanda **Paul,** Nancy Davis, and Lori Dawson of Riley for their assistance in **preparing** the report and presentation.

Boiler #2 Schematic Showing the Addition of Flue Gas Recirculation, Overfired Air and Todd Low NO_x Burners

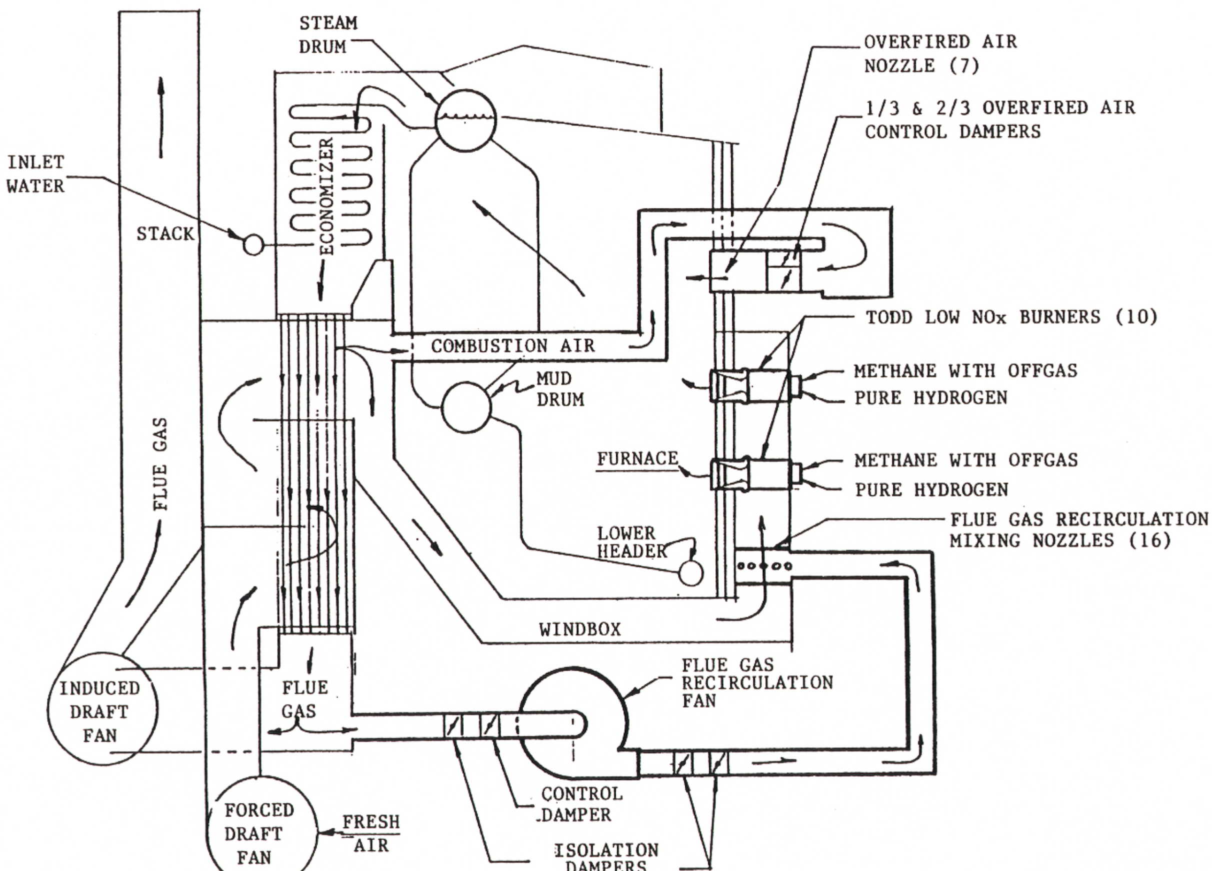

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FIGURE 1

L.H. Side View

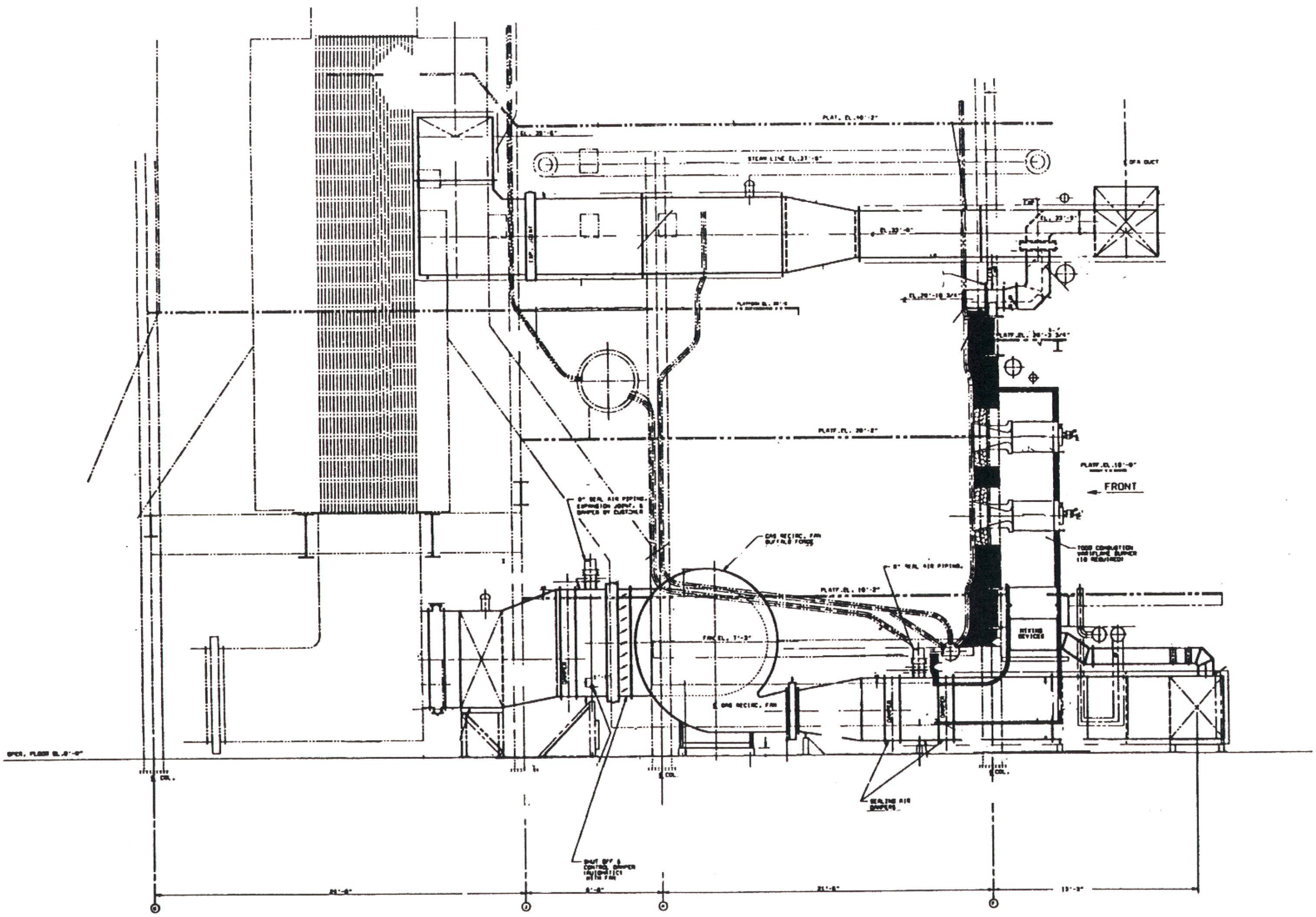

FIGURE 2

Front View

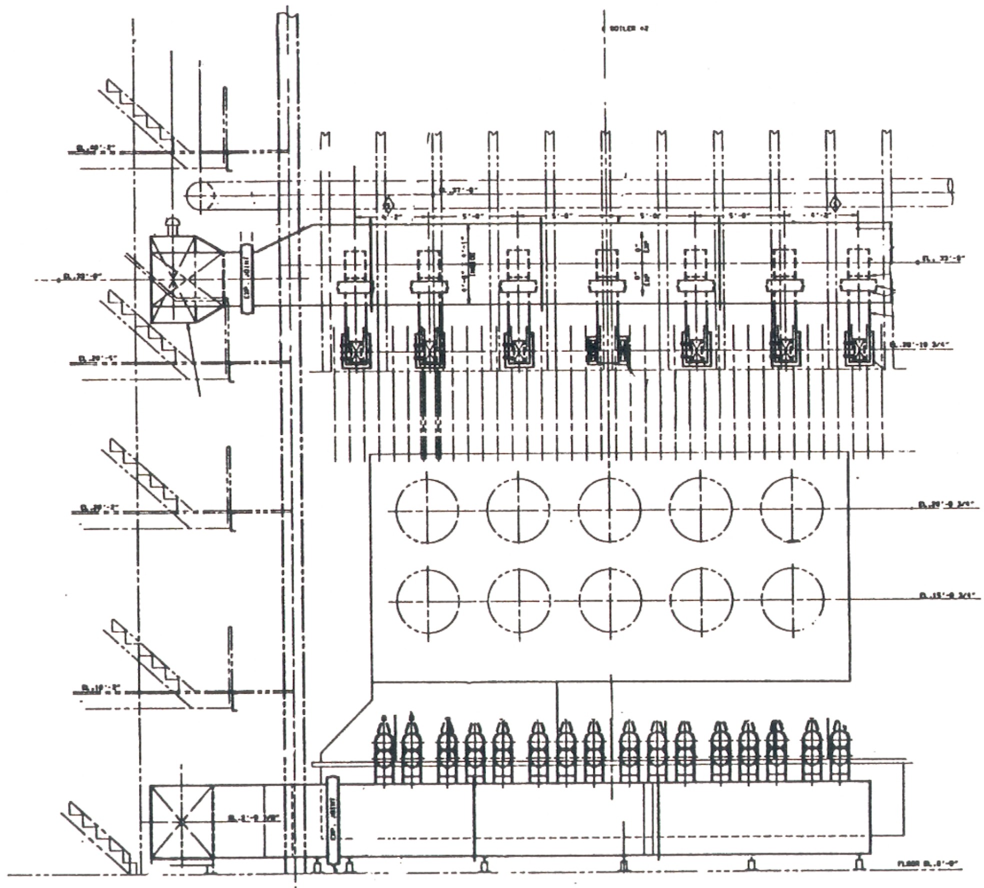

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FIGURE 3

Riley Stoker Flue Gas Mixing Device

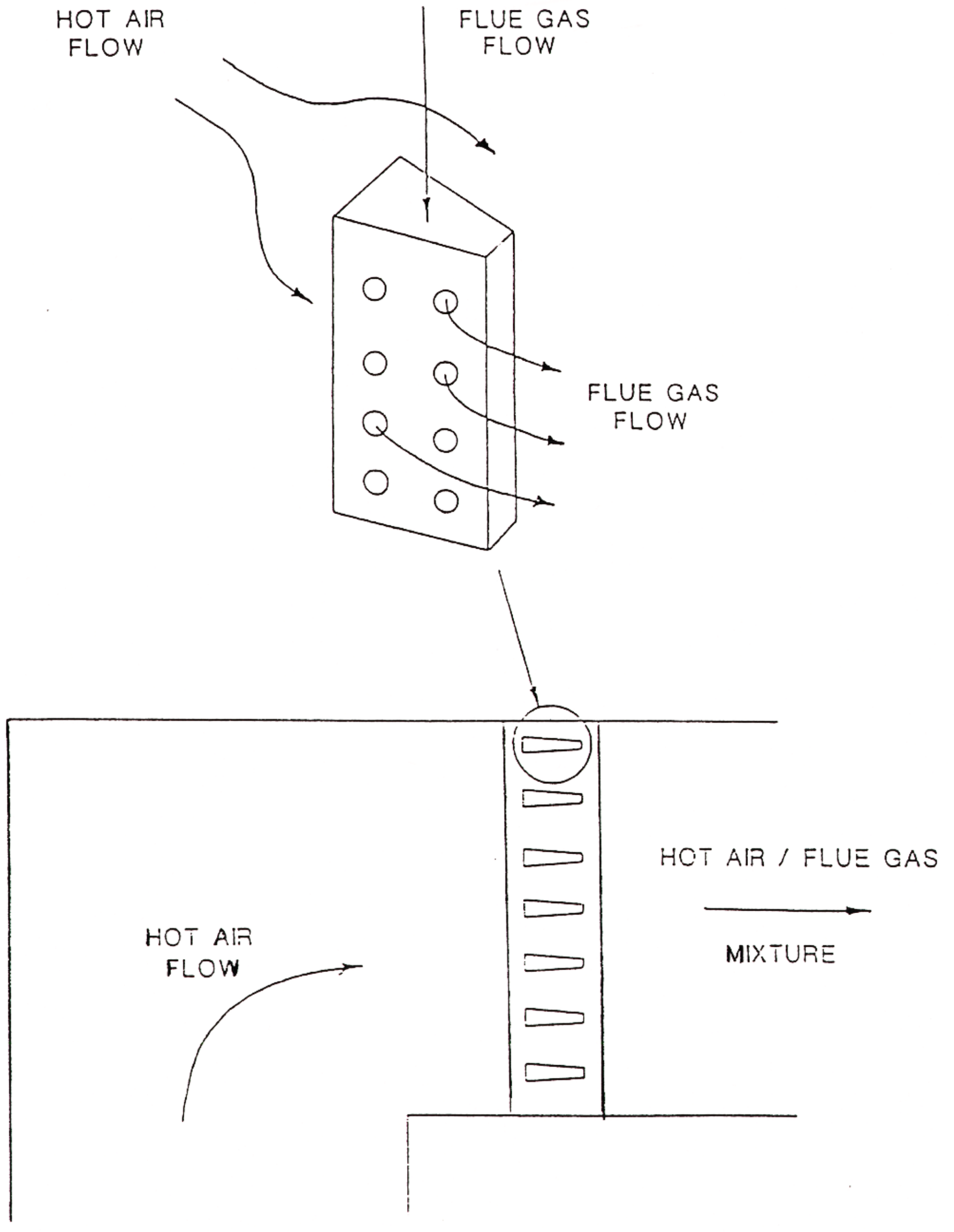

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FIGURE 4

Common OFA Header Arrangement

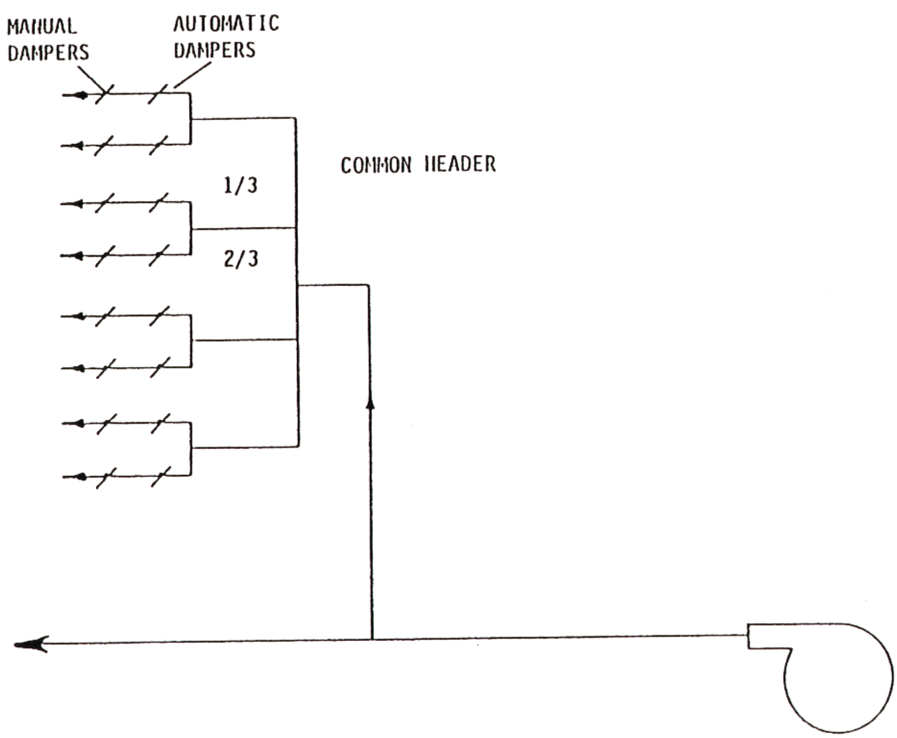

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FIGURE 5

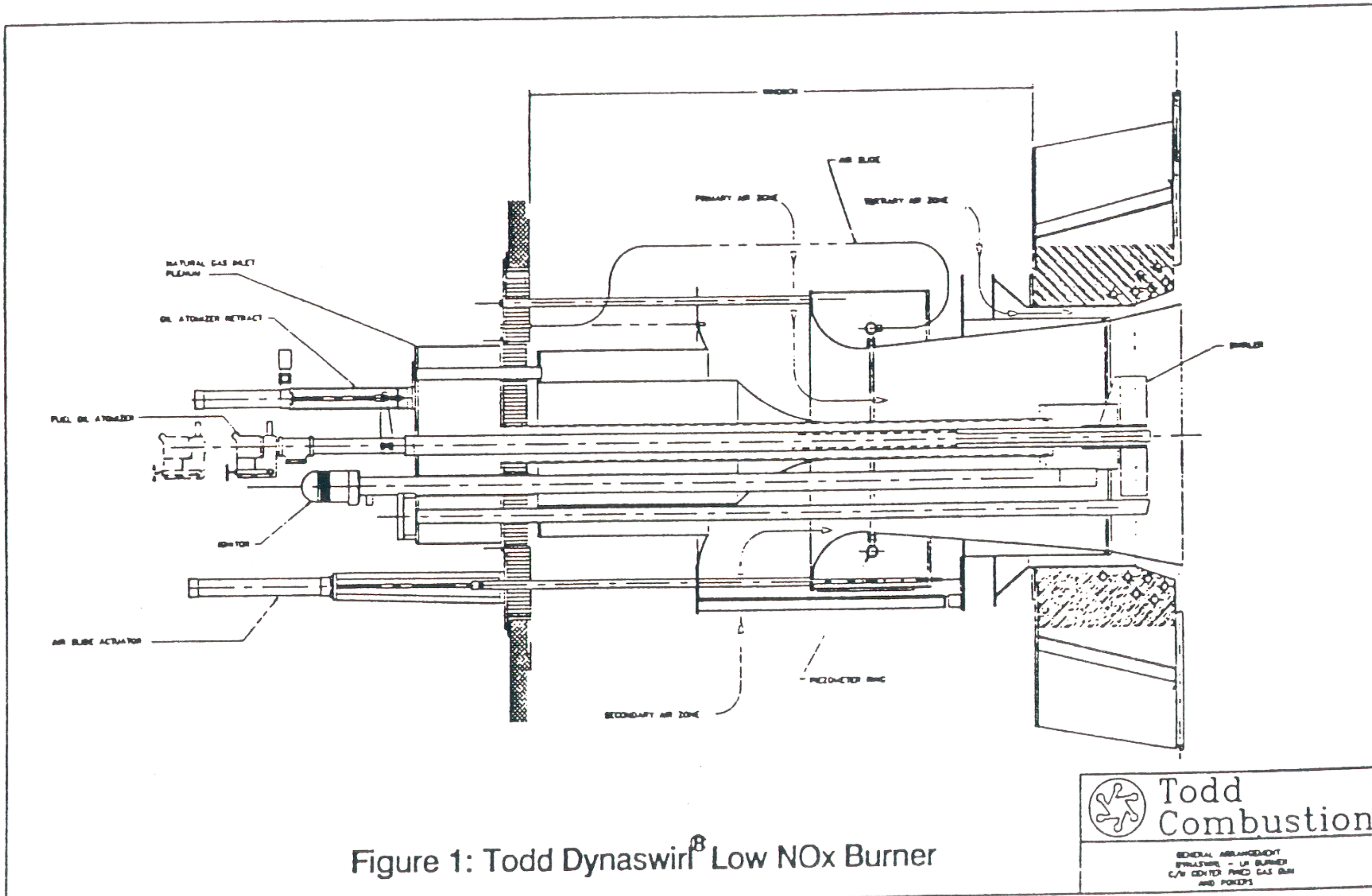

Figure 1: Todd Dynaswirl® Low NOx Burner

FIGURE 6

Comparison of Emission Reducing Systems

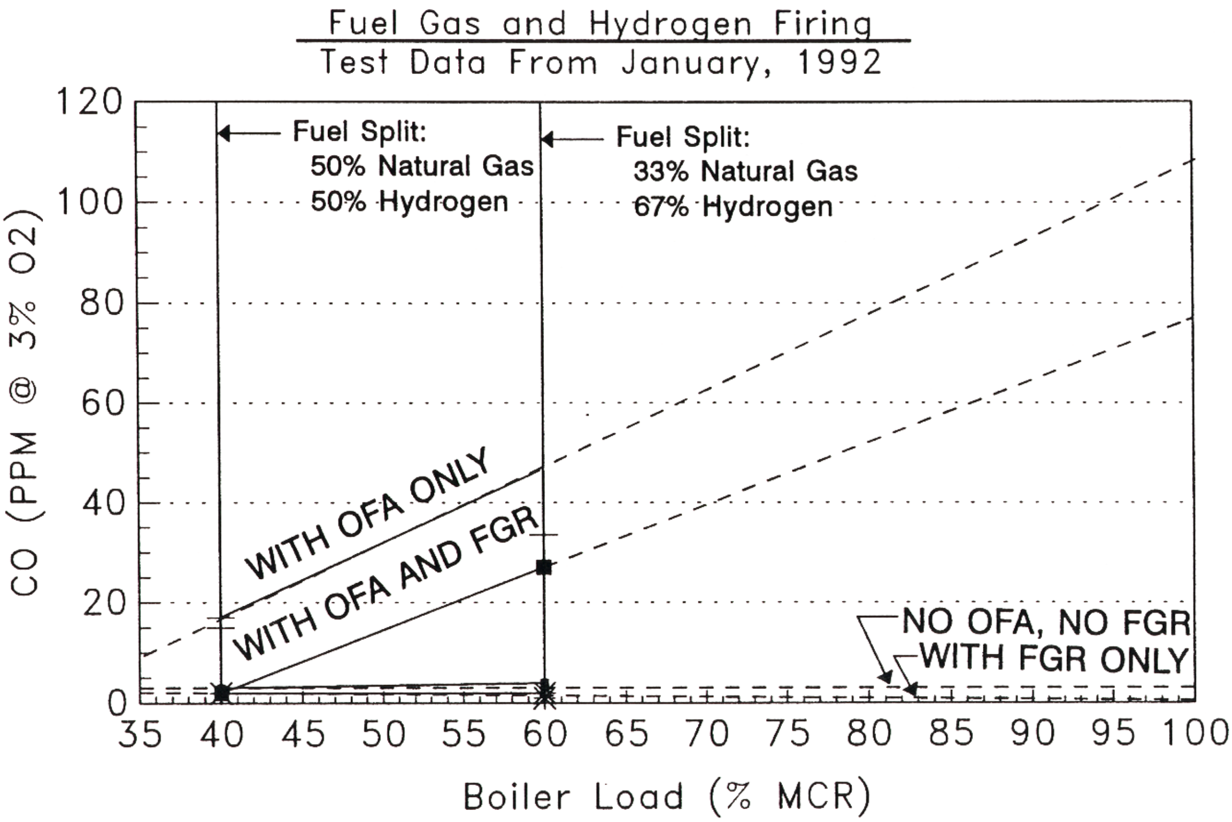

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FIGURE 7

NOx Reduction with OFA
Boiler NO 2 @ 500,000 lbs/hr

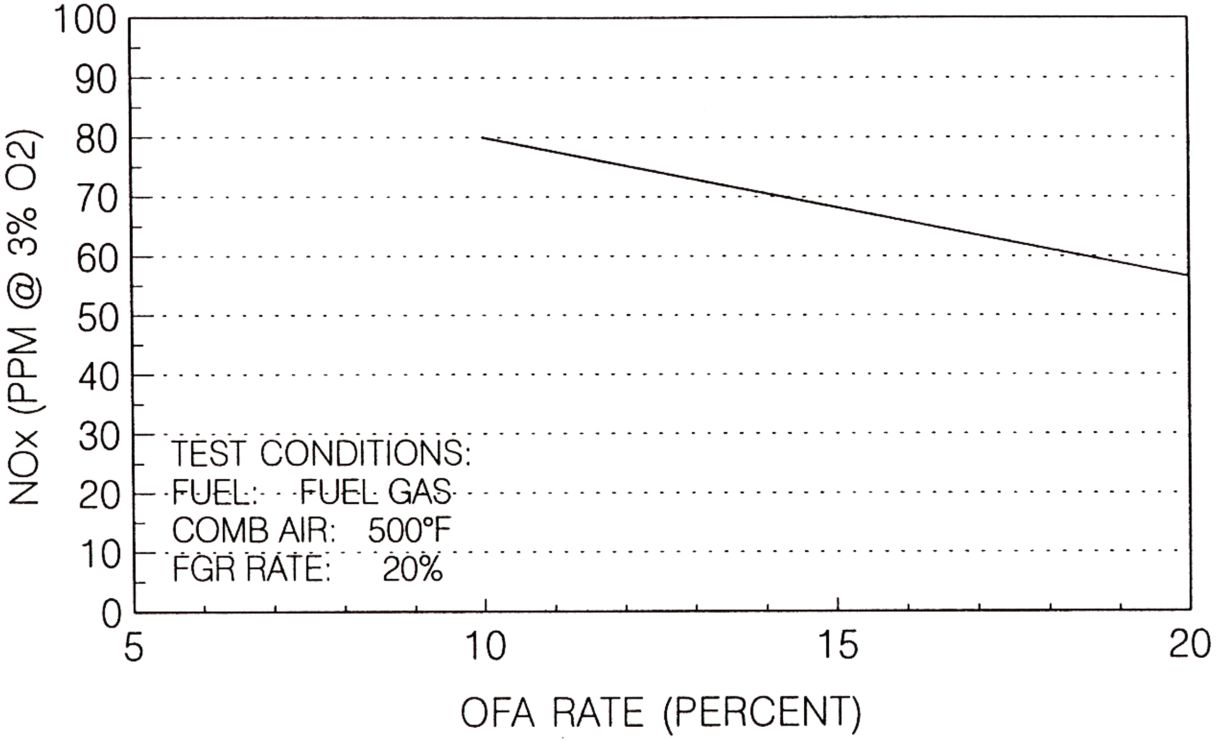

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FIGURE 8

Comparison of Emission Reducing Systems

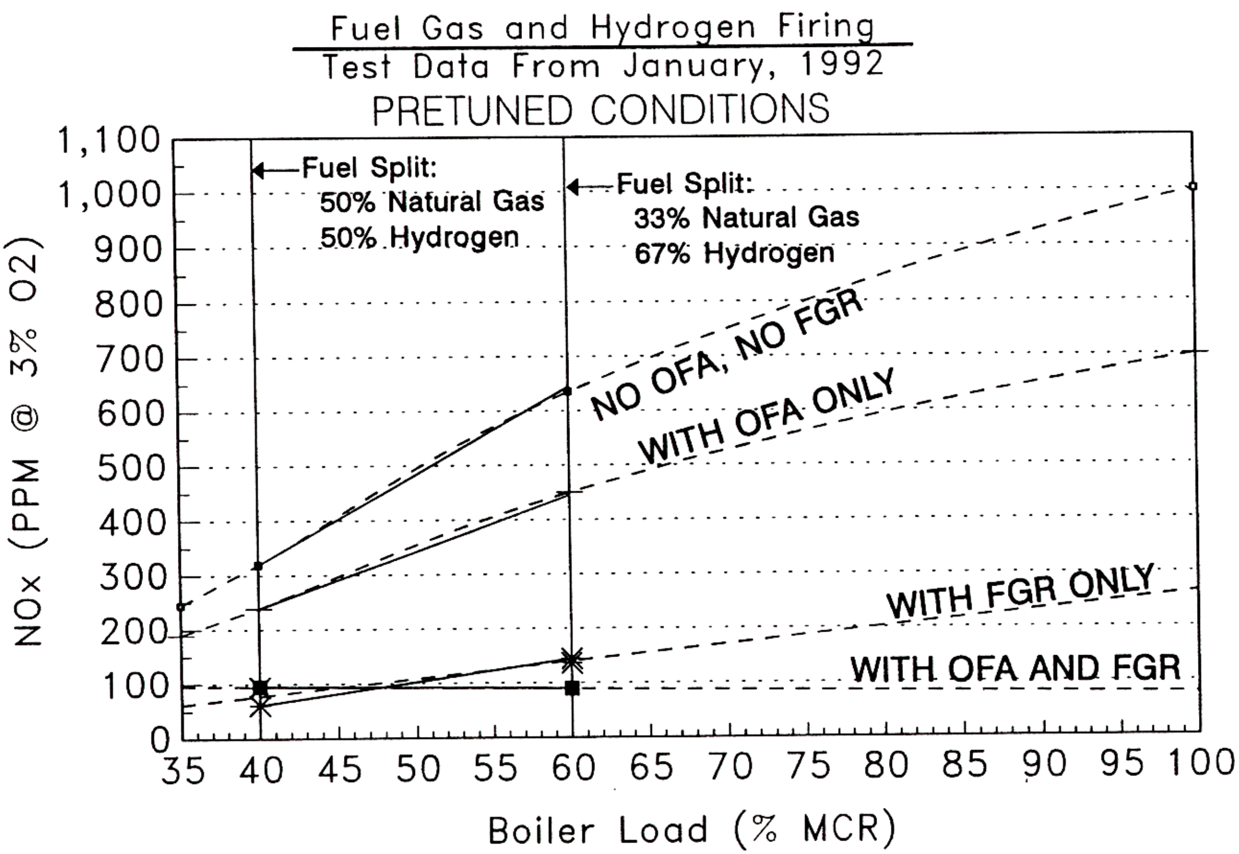

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FIGURE 9

Comparison of Emission Reducing Systems

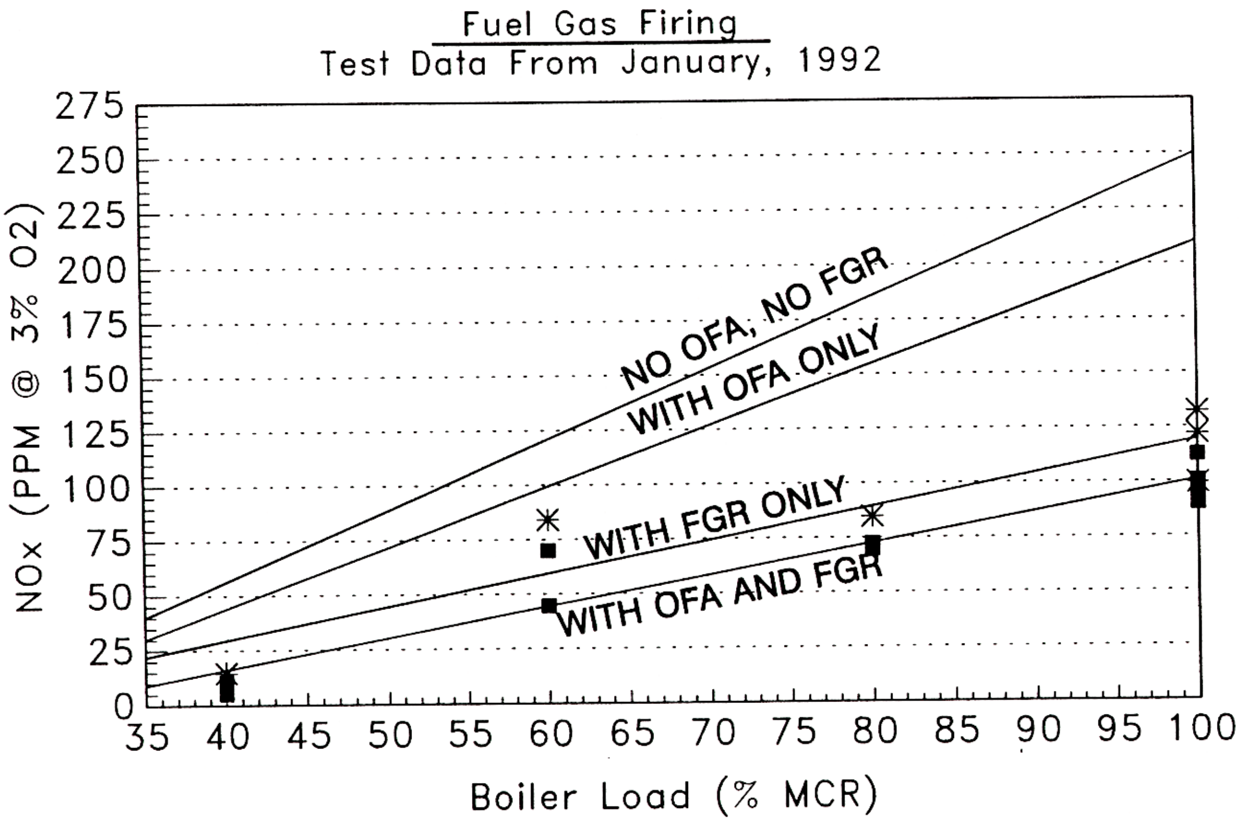

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FIGURE 10

NO_x Reduction with FGR
Boiler NO 2 @ 500,000 lbs/hr

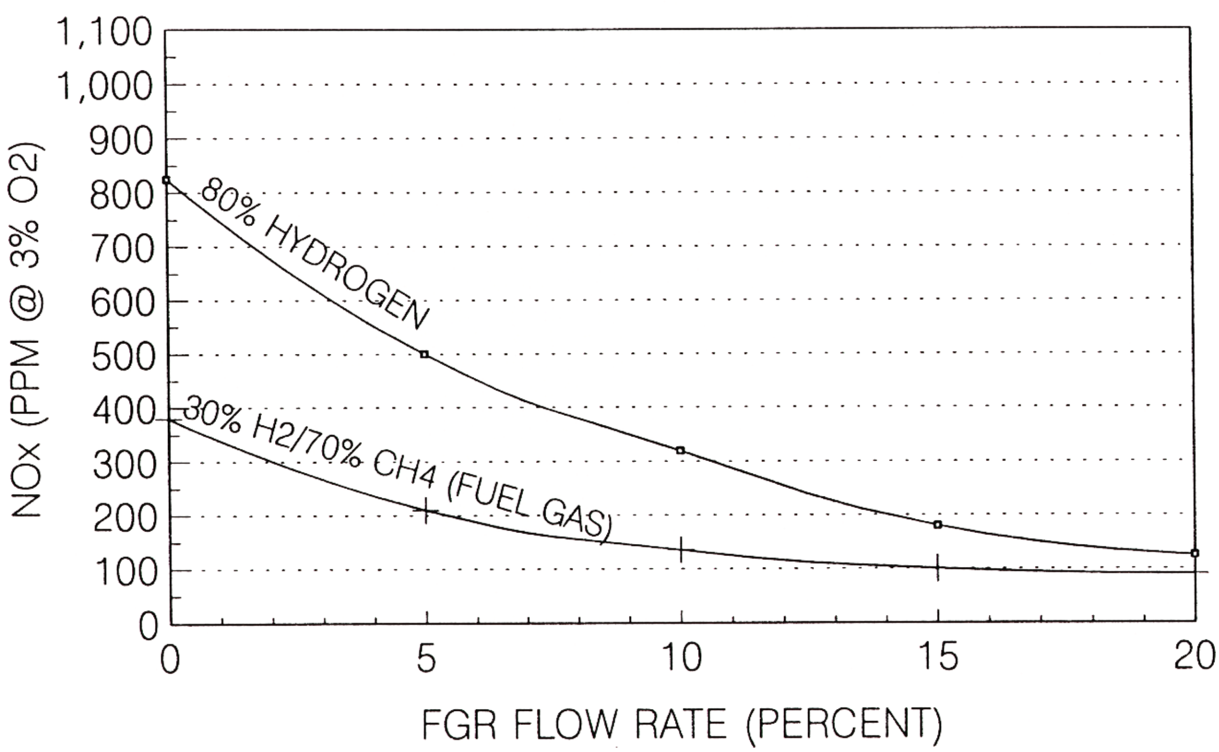

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FIGURE 11

Effect of FGR on Stack Temperatures

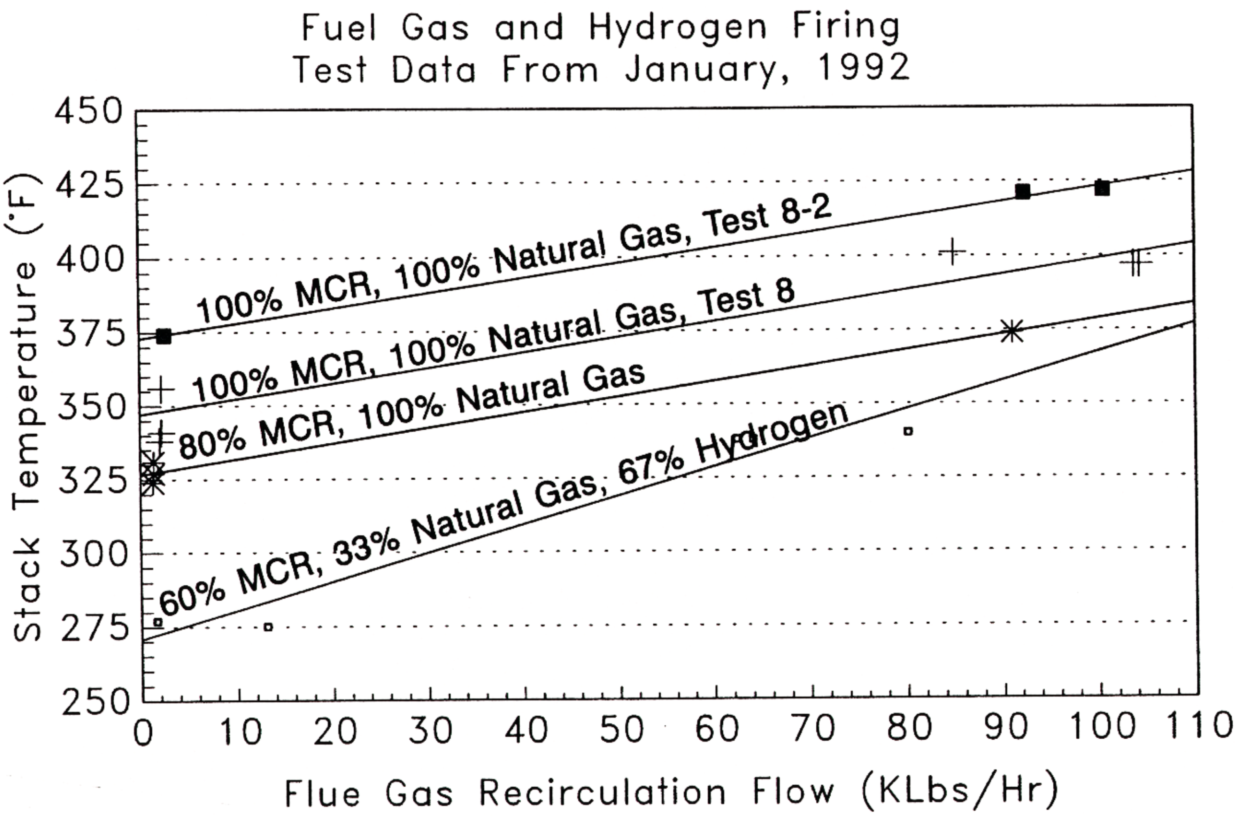

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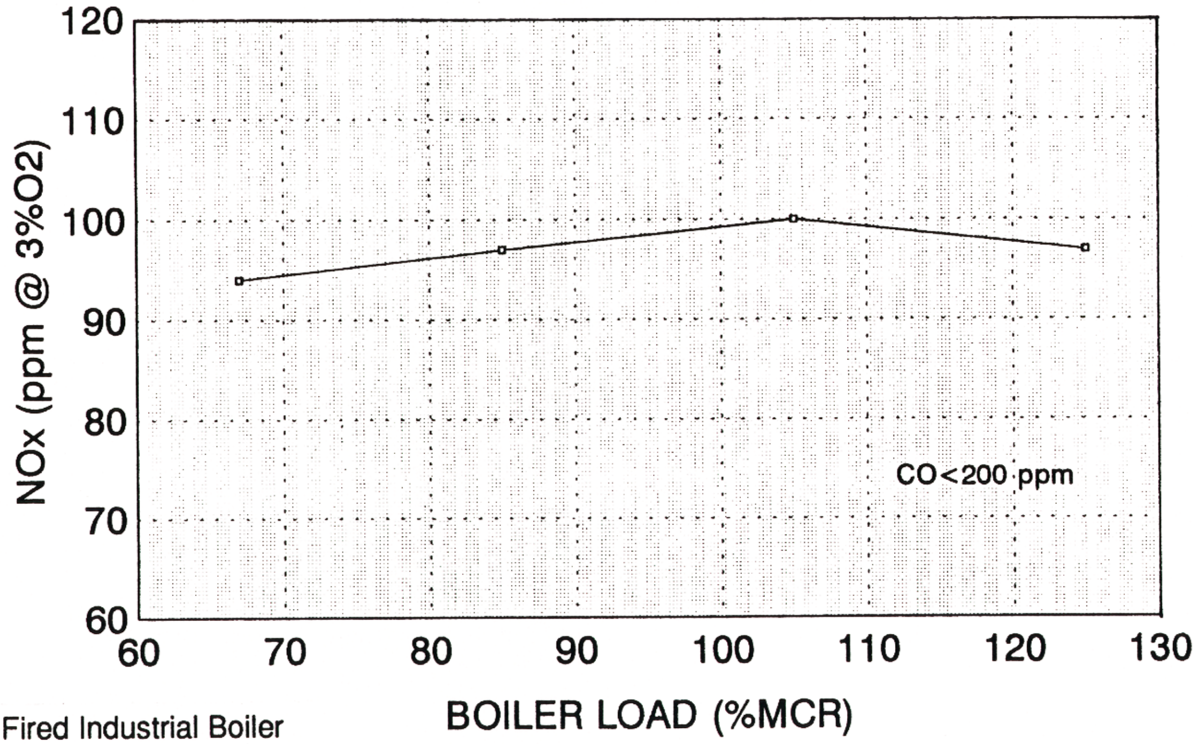
FIGURE 12

NO_x vs Load

Retrofit-Gas Fired Industrial Boiler



Retrofit-Gas Fired Industrial Boiler
Riley STS Burners Only

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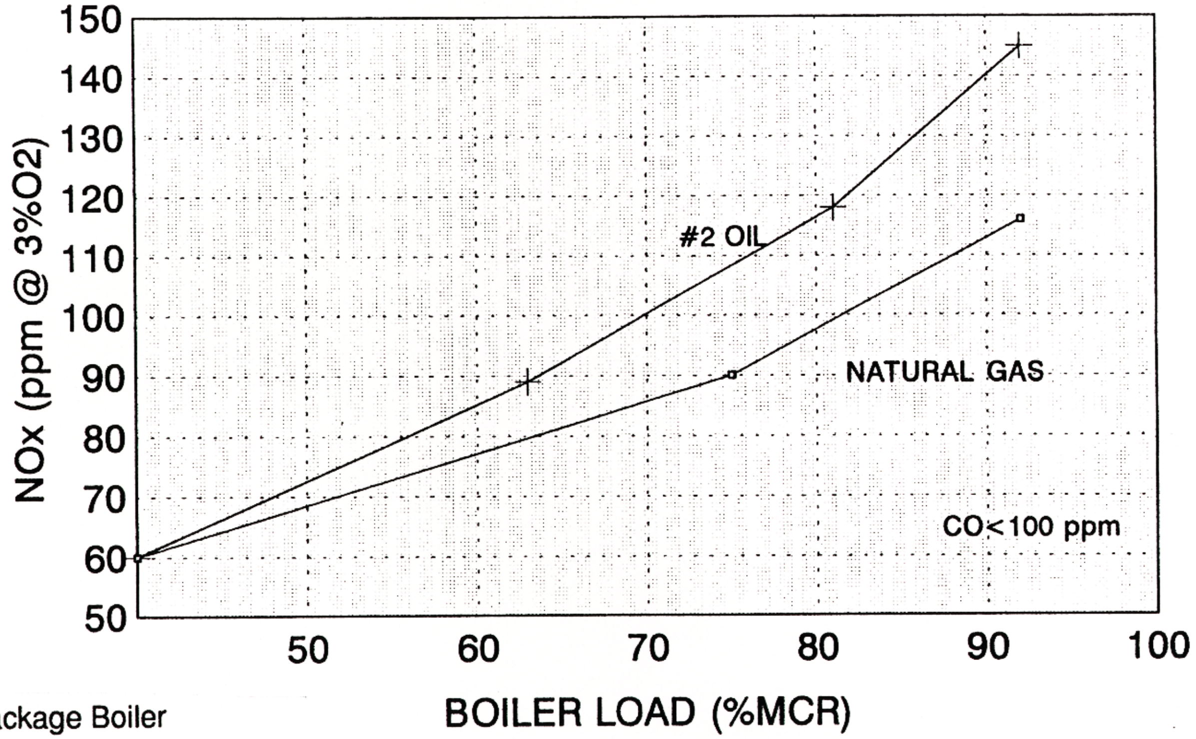
FIGURE 13

NO_x vs Load

Retrofitted Package Boiler-no external FGR or OFA



Retrofitted Package Boiler
Riley ASR Burner
No External FGR & OFA
Tangent Tube Furnace Construction

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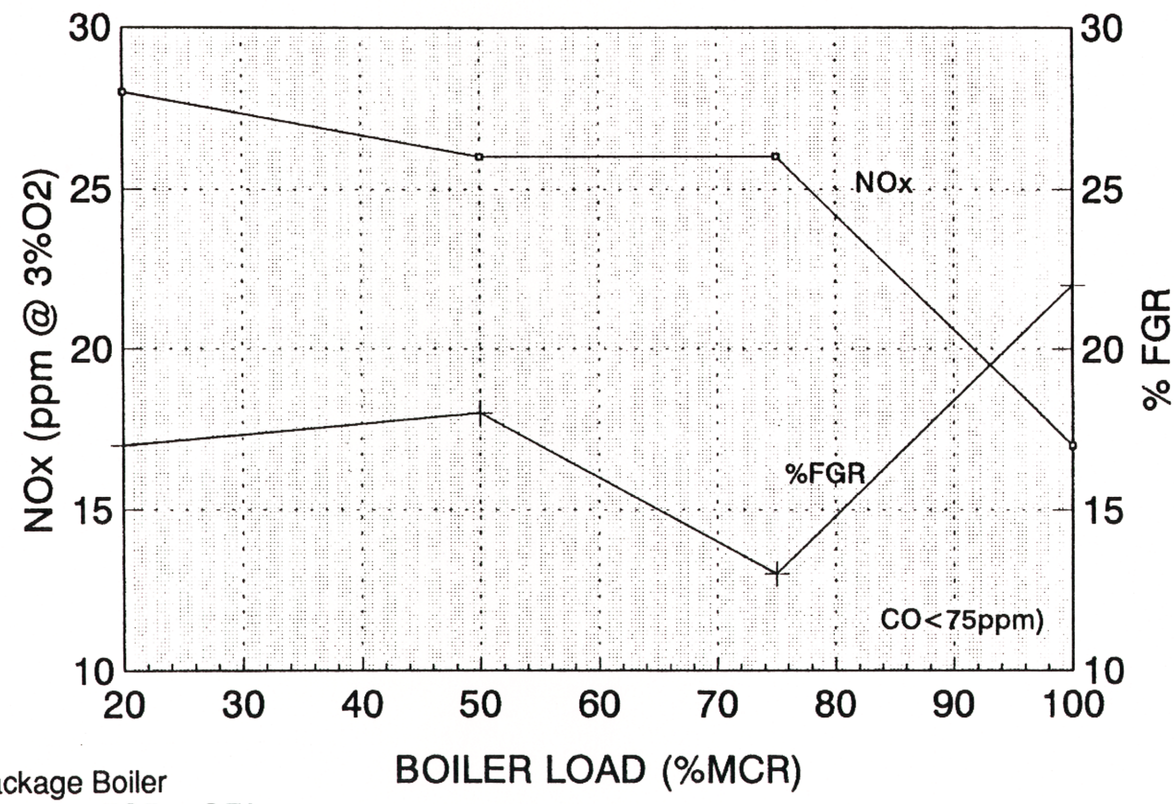
FIGURE 14

NO_x vs Load

Gas Fired Package Boiler w FGR and OFA



Gas Fired Package Boiler
Riley ASR Burner w FGR & OFA

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FIGURE 15