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AN ADVANCED LOW-NOx COMBUSTION SYSTEM FOR GAS AND OIL FIRING

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ABSTRACT

A new low NOx combustion system for gas and oil fired industrial and utility boilers is discussed. The system consists of an advanced Riley low-NOx STS ***burner*** *used in conjunction with over/ire air and recirculated flue gas. One of the distinctive features of the low-NOx STS burner is the use of recirculated flue gas to form a separation layer between the primary and secondary flame zones.*

This advanced low-NOx combustion system has been implemented on several power boilers in Western Europe. Combustion system modifications and emission test results are summarized for two recent retrofit applications. Field emission data are presented for ***both gas and oil-fling. NOx emission levels*** *of less than 50 ppm have been demonstrated on a natural gas-fired 220 MWe utility boiler. The application of this advanced system to U.S. gas and oil wall-fired boilers is also discussed.*

INTRODUCTION

Environmental concern over power plant stack emissions has grown steadily over the past decade. In spite of this concern, the 1980's saw little change in U.S. NOx regulations. However, recent passage of new federal Clean Air amendments and proposed new state regulations make it likely that U.S. industry will soon be required to meet revised emission standards on both new and existing boilers.

Unlike the United States, Europe and Japan did impose new emission regulations during the 1980's. In 1984, German legislators recommended stringent NOx emissions standards for new and existing boilers (1). These standards defined new emission limits for all large combustion systems firing gas, oil and coal. As a result, large numbers of industrial and utility boilers in Germany and other European countries have been retrofitted with low-NOx systems. We believe this recent European low-NOx retrofit experience is of particular interest to the U.S. power industry. This paper focuses on some of this experience applied to gas and oil fired systems.

Deutsche Babcock, the parent company of Riley Stoker Corporation, has had consider-able experience in supplying combustion systems to meet the demands of German and European air pollution codes. Low-NOx combustion systems have been implemented by

Deutsche Babcock on a wide variety of industrial and utility boilers. Since 1984, Deutsche Babcock has supplied low-NOx systems to over 110 liquid and gas-fired boilers. More than 520 low-NOx burners have been retrofitted to a variety of boiler configurations. In order to meet stringent emission limits many of these retrofit applications incorporate combustion modification techniques, such as flue gas recirculation and overfire air, in combination with new low-NOx burners (2). NOx reductions of over 80% have been demonstrated with these new systems. New fuel injectors have also been developed in response to the changing quality of heavy fuel oils. This technology and experience is now available to the U.S. power industry through Riley Stoker.

One new burner system - the Swirl Tertiary Separation (STS) burner - is particularly well suited to U.S. wall-fired boiler retrofit applications. This new burner system is the subject of this paper. In addition to presenting operating results from recent European retrofit installations, we will also discuss the application of this new combustion system to U.S. boiler design configurations.

DESCRIPTION OF LOW-NOx BURNER SYSTEM

New STS burner systems have been recently retrofitted on gas and oil wall-fired boilers in both Germany and Sweden. In addition to reducing NOx, the burners were designed to both minimize boiler pressure part changes and maintain acceptable combustion conditions.

Figure 1 is an illustration of the STS burner equipped with swirl control. As is typical in many European boiler designs, combustion air is controlled individually to each burner. A spiral box, or scroll (shown in Figure 1) is used to supply the combustion air to the burner. The scroll is divided between primary and secondary air passages with control dampers and flow metering installed immediately upstream. Total air flow to the burner is divided between the primary and secondary air passages. The exact distribution of primary and secondary air can be adjusted depending on the level of internal burner staging required for NOx control and overall combustion performance.

The ability to independently control swirl imparted to the primary and secondary air streams provides great flexibility in controlling flame length and shape. It also ensures flame stability under low-NOx firing conditions. Adjustable air vanes within the scroll are used to control the degree of swirl and subsequent fuel air mixing. Between these two swirling air streams a separate recirculated flue gas stream can be introduced forming a distinct separation layer between the primary and secondary air.

The introduction of this separating layer of inert flue **gas** acts to delay the combustion process and reduces NOx in the following manner:

- Peak flame temperatures, particularly on the surface of the primary combustion zone, are reduced by a surrounding blanket of inert flue gas.

- The rapid mixing of secondary air is prevented; thereby reducing the oxygen concentration in the primary combustion zone.

Unlike flue gas mixed with the primary or secondary air streams, the flue gas separation stream is unswirled and concentrated. This serves to delay secondary air mixing until after first stage oxygen has been consumed and the flame has cooled. The intent of the separation layer, therefore, is to control both thermal NOx formation and NOx produced from nitrogen contained in the fuel.

Additional NOx reduction is achieved through staged combustion. A portion of the total combustion air can be introduced through overfire air ports above the burners to provide external air staging. This overfire air is controlled and metered **independently of the** combustion air to the burners. Low-NOx burners combined with flue gas recirculation and overfire air offer an integrated approach for maximizing the reduction of NOx emissions on gas as well as oil firing.

As shown in Figure 1, oil is burned using a centrally located steam or mechanically atomized oil gun. Natural gas is burned using spuds or canes located within the primary core of the burner.

FIELD RESULTS

<u>Arzberg Power Station</u>

Low-NOx STS burners have been installed at Arzberg Power Station Unit NO.6 in Arzberg, West Germany. The boiler, shown in Figure 2, is a once-through Benson boiler rated at 1.58 million lbs steam per hour and generates 220 MW of electricity. The unit is currently equipped to fire natural gas or light NO 2 oil. In 1988, the boiler was retrofitted with sixteen low-NOx burners, each rated at 153 million Btu/hr heat input. Burners are arranged horizontally for opposed firing on four levels. As stated earlier, the STS burner design was selected to fit within existing burner openings.

NOx emission limits for this retrofit project were 50 ppm * for natural gas firing and 75 ppm for light oil. The retrofit combustion system was designed with the flexibility of introducing recirculated flue gas through either the burner zone separation annulus or having it mixed directly with the combustion air to the burners. One tertiary air port was also installed in close proximity to each burner but was later found to be ineffective for NOx control. A level of overfire air ports was added on **both** front and rear waterwalls above the burner array for staged or off-stoichiometric firing. As shown schematically in Figure 3, all flows **including** primary, secondary, tertiary and recirculated flue gas were independently controlled and metered.

Prior to the retrofit, NOx emissions from natural gas firing averaged 300 ppm. Testing was conducted following the retrofit to optimize the operation and to commission the boiler. Figure 4 illustrates the effect of mixing flue gas recirculation into the combustion air on NOx emissions for natural gas firing. NOx FGR and 10% OFA flow, NOx emissions were reduced to 75 ppm. By increasing the amount of recirculated flue gas to 30%, NOx decreased to 50 ppm.

Additional testing was then performed to evaluate the effect of introducing FGR flow **through** the **burner annulus** for NOx control. The total amount of FGR flow remained at 30% with 10% OFA. Figure 5 illustrates the effect of introducing increasing percentages of FGR flow through the burner annulus or separation layer. When more than 50% of the total FGR flow was introduced through the separation layer (the remaining amount being mixed in with the combustion air) NOx de-creased significantly. The lowest measured NOx emission approached 25 ppm when nearly all of the FGR flow was passing through the burner annulus. CO emissions remained less than the 15 ppm **throughout** this testing and flame stability or scanability was not a problem.

A limited amount of testing was performed on NO. 2 fuel oil. Data were collected while operating at 15% FGR and 15% OFA flow rates. NOx emissions of 75 ppm were achieved at full load and decreased to approximately 60 ppm at 50% boiler load. CO emissions remained below 25 ppm for all test conditions.

Vartan Power Station

An advanced STS burner system has also been retrofitted at the Vartan Power Station in Stockholm, Sweden. The Vartan unit, commissioned in 1976, is rated at 250 MW. It is a once-through Benson style boiler designed for heavy oil firing. As shown in Figure 6, the burners are mounted on a single wall in a 4 X 4 array. Each burner is supplied individually with air and is equipped with a Deutsche Babcock oil pressure/steam pressure atomizer. In addition to STS burners, the retrofit combustion system includes both OFA and FGR. The existing FGR system was modified to supply flue gas to each burner as well as the lower furnace.

The post-retrofit NOx uarantee limit for the Vartan unit is 0.27 lb/10 Btu or approximately 210 ppm. NOx emissions measured during recent commissioning tests are shown in Figure 7. Emission levels (at high load) for the new system are 30 to 40% lower than the guarantee value. The data spread is due to differences in operating conditions and varying fuel oil nitrogen content. Average fuel oil nitrogen content is 0.3%. During the recent tests, high load excess oxygen measured 1.3-1.4% upstream of the air heater corresponding to an excess air level of less than 7%. CO emissions were less than 40 ppm. These results were achieved with 10-11% OFA and 15% FGR. Approximately one third of the flue gas was introduced through the burners. The remaining flue gas was introduced to the lower furnace for steam temperature control.

APPLICATION TO U.S. BOILERS

The STS burner design has been adapted by Riley Stoker to U.S. wall-fired boiler firing systems. Contrary to the European practice of individual burner air supplies, U.S. wall-fired boilers are equipped with common windbox/-multiple burner arrangements. Because of this, the burner inlet scroll, described in Figure 1, has been replaced by primary and secondary air swirl vane registers surrounded by flow control shrouds. All other burner components remain the same. As shown in Figure 8, the movable shrouds are operated by single actuators and can be automated with boiler load. The shrouds control the primary/secondary air flow split independently of swirl vane position. Flow measurement devices are positioned between the burner barrels to provide a relative flow indication between the burners.

A prototype 85 million Btu/hr STS burner designed for windbox applications (Figure 8) is currently being tested in Riley Stoker's large pilot combustion test facility located at the Riley Research Center in Worcester, Massachusetts. This facility is designed to simulate the near field combustion conditions of full scale furnaces (3). Test variables include firing rate, flow biasing ratios, the amount of flue gas recirculation and injection method, level of burner staging, swirl setting, excess air and oil/gun positions. The test program has several objectives: (1) to fully characterize the burner's low-NOx capability under U.S. boiler operating conditions, and (2) to evaluate the sensitivity and trade-off of various burner adjustments on NOx control and other combustion operating parameters such as flame shape and particulate emissions. The prototype burner is being tested on natural gas and NO. 6 fuel oil. The fuel oil selected for the test program is a 2% sulfur oil with an asphaltene content of approximately 10%. Test results will be available within the next several months.

SUMMARY

Advanced ST'S burners have been successfully retrofitted on several gas and oil fired power boilers in Western Europe. These retrofits have been achieved within existing burner openings. STS burners in combination with overtire air and flue gas recirculation have exceeded their emission goals. NOx levels of less than 0.06 lb/10^6 Btu on natural gas and less than 0.2 lb/1 0^6 Btu on heavy oil have been demonstrated.

The introduction of a separate flue gas stream, or dividing layer through the burner throat has been shown to be effective in reducing NOx on natural gas. Additional testing is required to evaluate the effectiveness of this separation layer during heavy oil combustion.

STS burner designs have been developed for U.S. wall-fired boiler burner/windbox arrangements. Prototype burner tests are being carried out to ensure that European experience is **duplicated** under U.S. boiler operating conditions.

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(1) P.W. Dacey, "An Overview of International NOx Control Regulations" Proceedings: 1985 Symposium on Stationary Combustion NOx Control, Vol. 1, EPRI CS-4360, January 1986.

(2) R. Oppenberg, "Primary Measures Reducing NOx Levels on Oil - and Gas-Fired Water Tube Boilers", Conference of the Association of German Engineers, Duisberg, FGR, September 26, 1986.

(3) R. Lisauskas, et al., "Experimental Investigation of Retrofit Low-NOx Combustion Systems", Proceedings: 1985 Symposium on Stationary Combustion NOx Control, Vol. 1, EPRI CS-4060, January 1986.

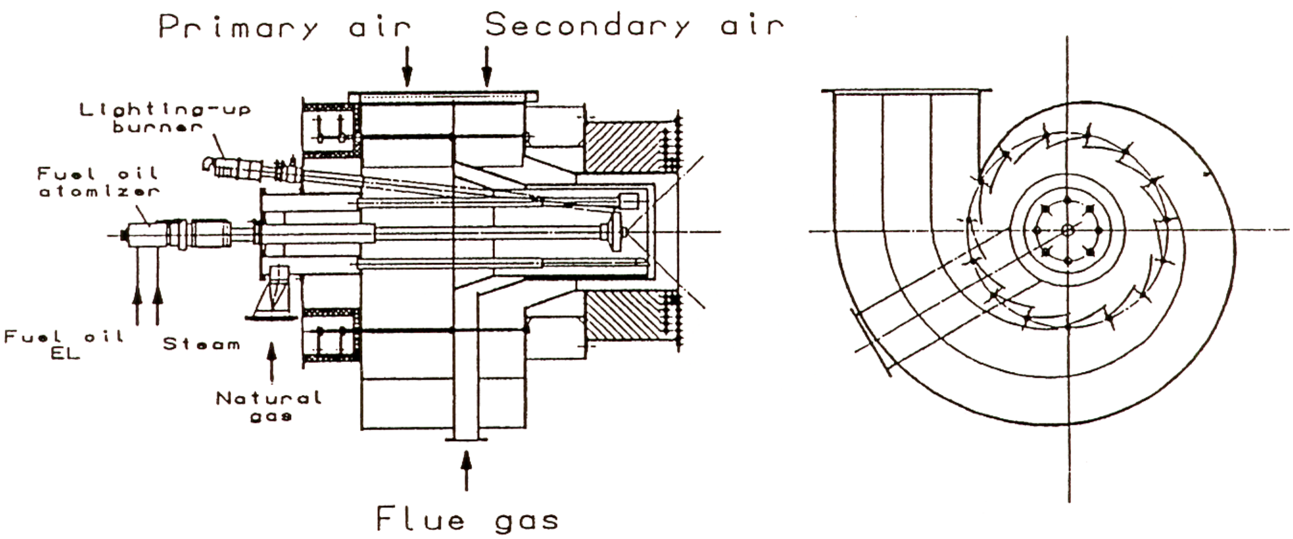


Figure 1. Low-NO_x STS Burner Equipped for Gas and Oil Firing and Individual Air Supply

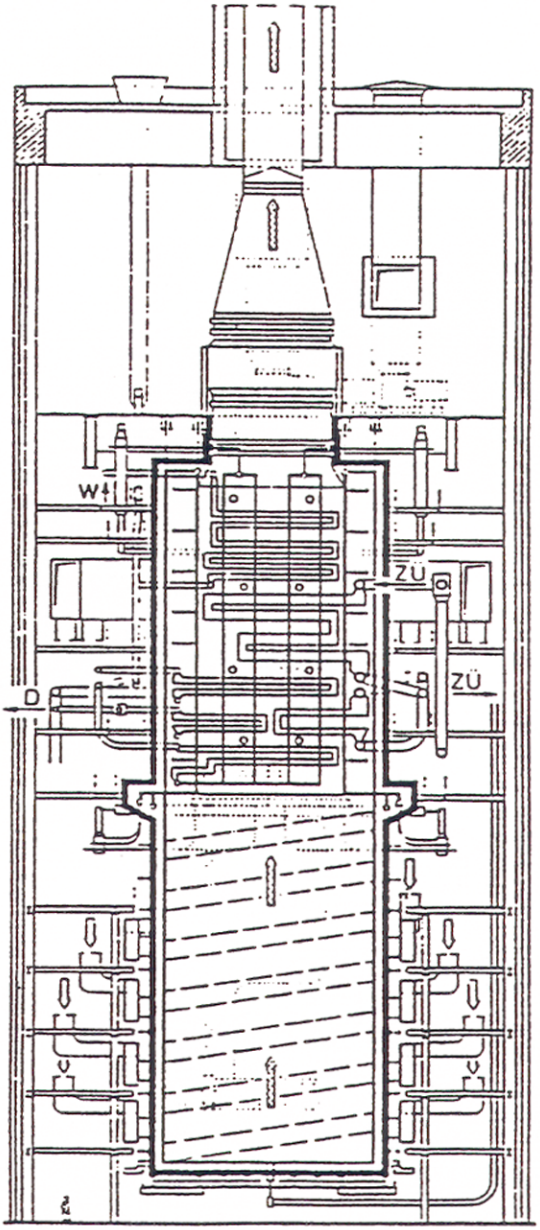
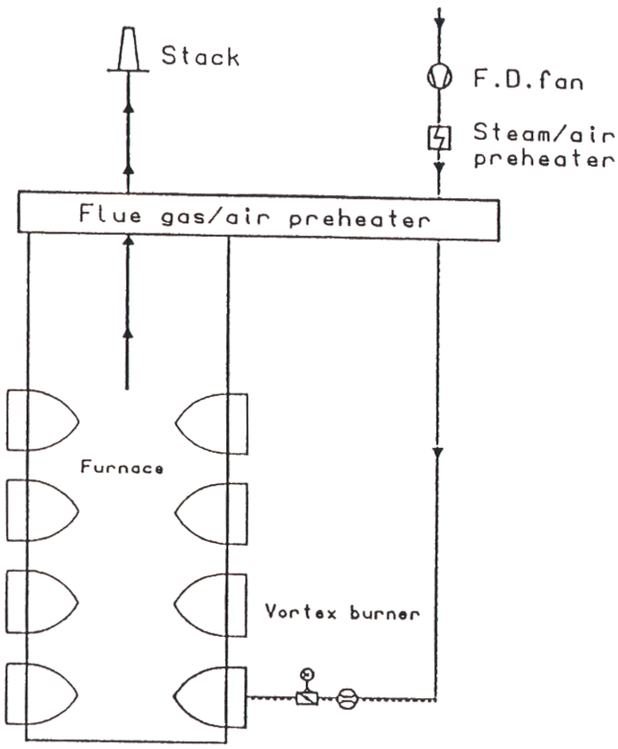
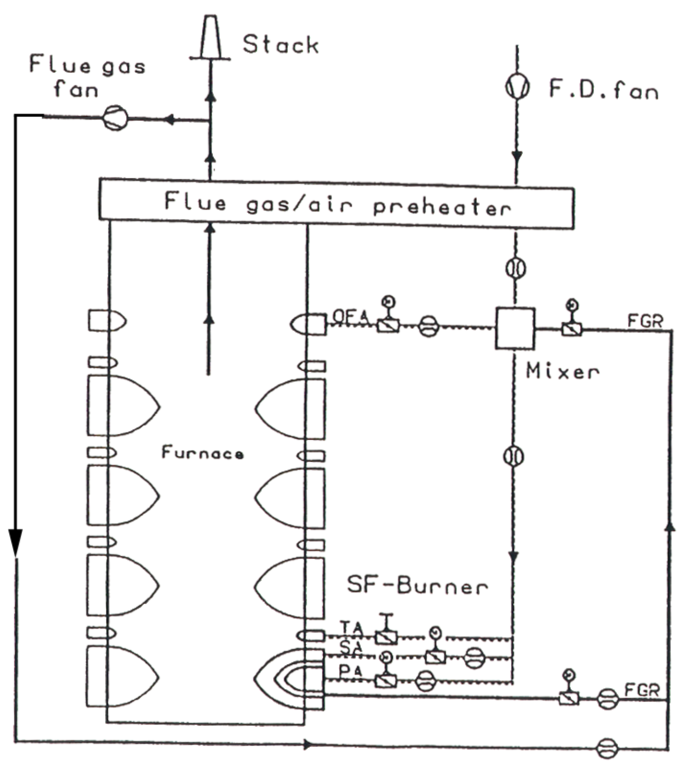


Figure 2. Arzberg Power Plant Unit NO. 6



a. Original System



b. Low-NO_x Retrofit System

Figure 3. Low-NO_x Combustion System at Arzberg Power Station

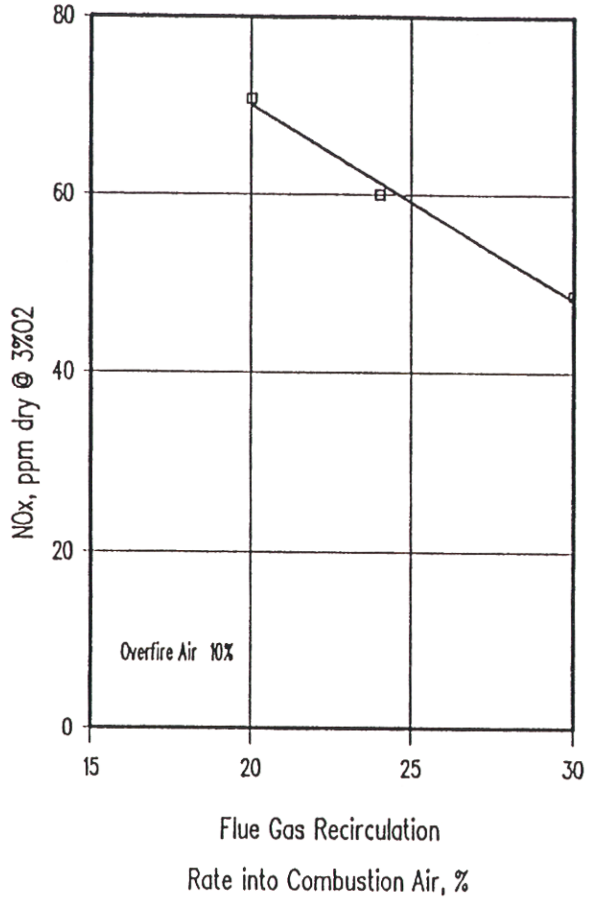


Figure 4. NO_x as a Function of FGR into the Combustion Air - Natural Gas Operation

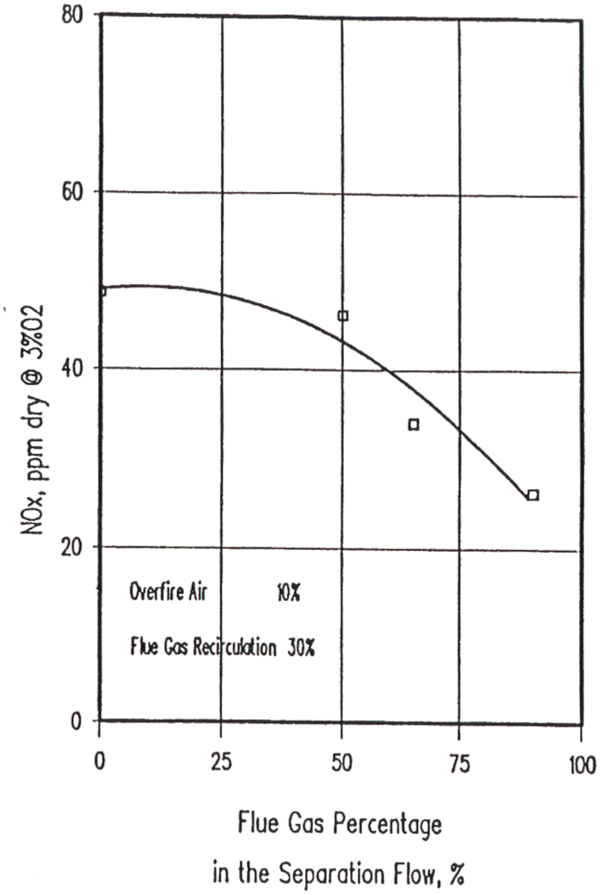


Figure 5. No_x as a Function of FGR into the Annulus - Natural Gas Operation

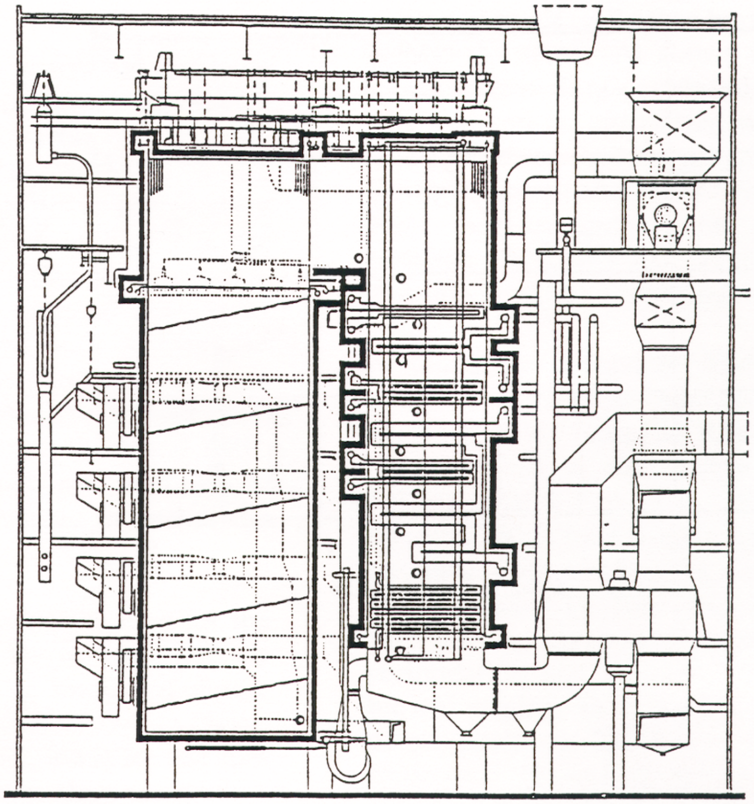


Figure 6. Värtan Power Station

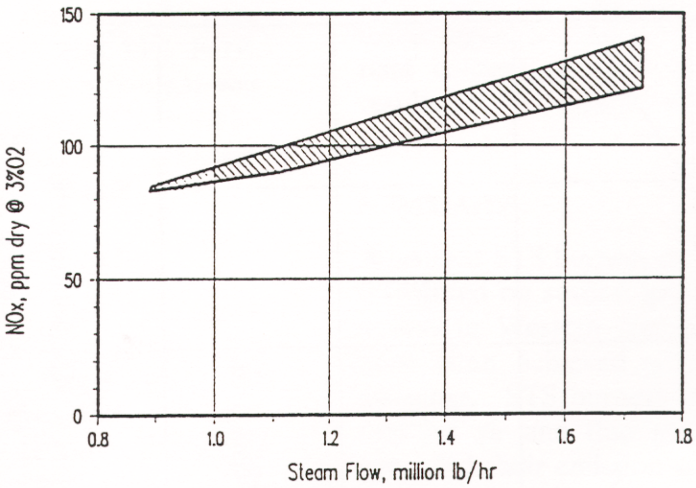


Figure 7. NO_X Versus Boiler Load Post-Retrofit Heavy Oil Firing

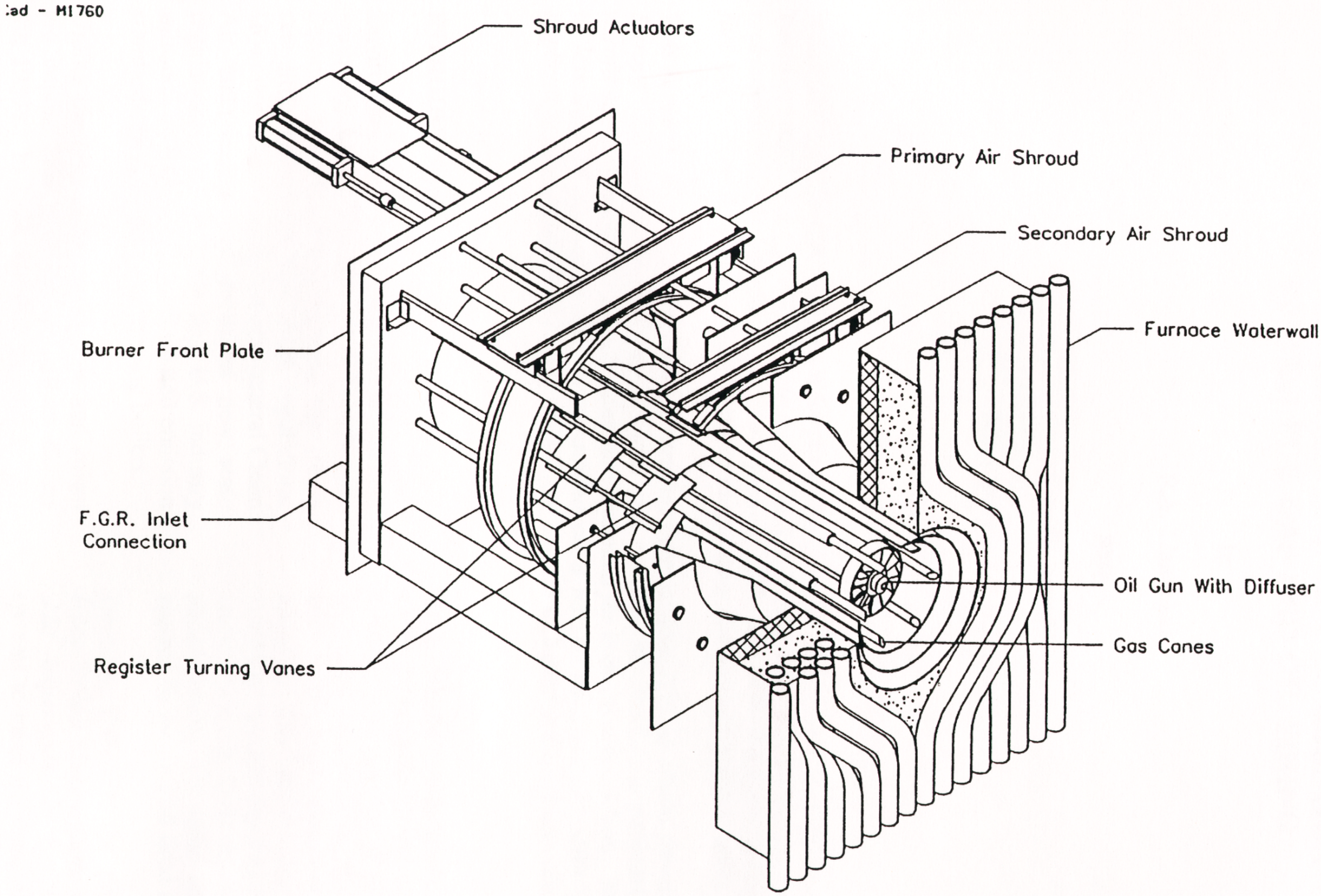


Figure 8. Riley Low-NO_x STS Burner (Model 90) for Windbox Burner Arrangements