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RECENT GAS AND OIL LOW NO_X RETROFIT EXPERIENCE

by

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ABSTRACT

Over the last several years, DB Riley has been involved in a number of gas and oil low NO_X retrofits for both utility and industrial boiler applications. The boilers retrofitted have included conventional, front wall, and opposed fired units, a cell fired unit, and Riley flat bottom TURBO® Furnace units. The Riley TURBO® Furnace applications featured modifications of the existing Directional Flame Burners while the other applications featured installation of DB Riley STS® (Swirl Tertiary Staged) Burners and Holman Boiler Works Environmentally Designed for Guaranteed Emissions (E.D.G.E.) low NO_X burners (LNB's). This paper provides a brief summary of the design, start up, and operating considerations as well as performance results. The following retrofit applications are featured:

Table 1 Summary of Retrofit Applications

Burner Type	Application	Unit Size or Capacity (MW or steam flow)	Firing Configuration	Fuels Fired
Circular	Utility A	670 MW	Wall	Oil and Nat. Gas
	Utility B/Unit #2	590 MW	Opposed	Oil and Nat. Gas
	Papermill A	300,000 lb/hr	Wall	Oil
	Papermill B	415,000 lb/hr	Wall	Natural Gas
Cell	Utility B/Unit #1	560 MW	Opposed	Oil
Directional Flame	Papermill C	600,000 lb/hr	TURBO®	Oil
	U.S. Refinery	500,000 lb/hr	TURBO®	Refinery Gas and Oil

NO_X guarantees met for the applications firing oil ranged from 0.28 - 0.40 lb/MMBtu while CO was less than 200 ppm by volume, dry basis, corrected to 3% O_2 (vdc). NO_X guarantees met for the applications firing gas ranged from 0.10 - 0.35 lb/MMBtu while CO was generally less than 100 ppm by volume, dry, corrected to 3% O_2 (vdc).

UTILITY A

Unit Description

Utility A was originally designed and manufactured by DB Riley, Inc. (formerly known as Riley Stoker Corporation) in the mid-1970's. The boiler is designed to operate at an MCR superheated steam flow of 4,650,000 lb/hr at 1980 psig and 955°F, and reheat steam flow rate of 4,625,000 lb/hr at 660 psig and 955°F. The nominal gross output at MCR is 670 MWe.

The unit was originally equipped with thirty Model 60, dual register, Riley Flare Type Burners rated at 236 MMBtu/hr each, designed for firing crude oil. The burners are arranged in three rows of ten burners each on the front wall as shown in Figure 1. The furnace is 80 feet wide x 40 feet deep.

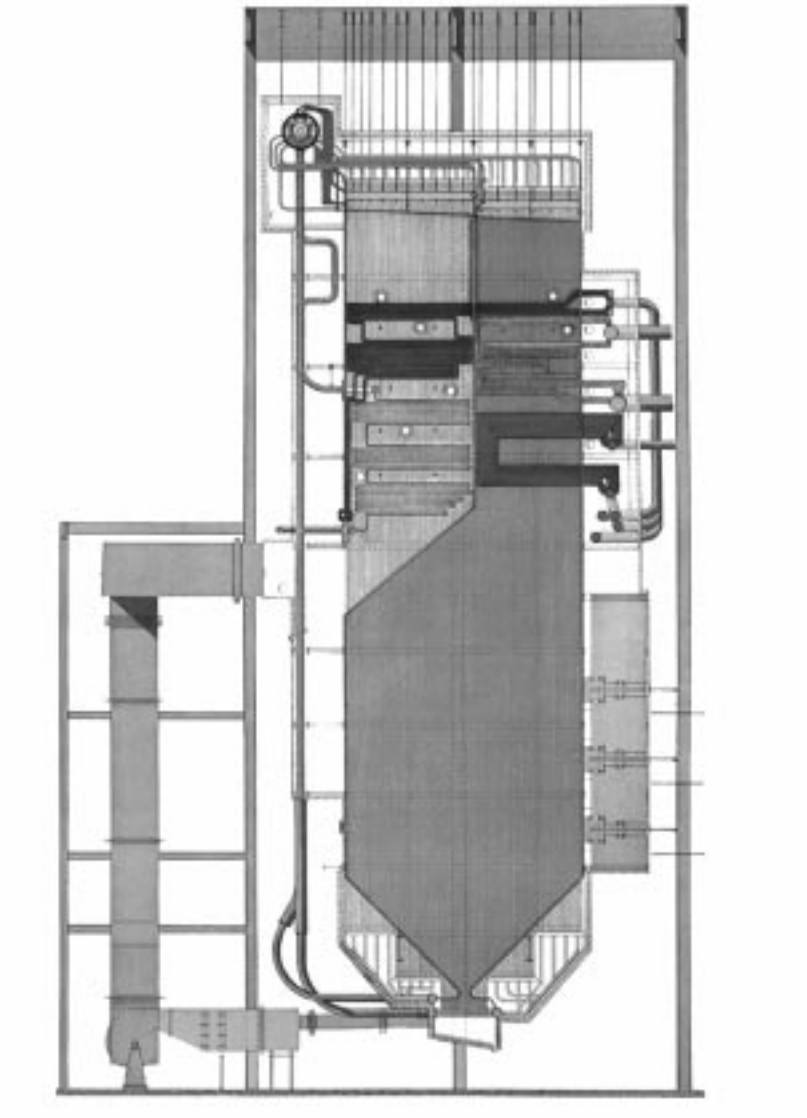

Figure 1 Utility A Boiler Configuration

Low NO_X Retrofit / Gas Conversion

Utility A contracted Riley in July 1992 to perform a burners only (no overfire air) low NO_X retrofit and gas conversion of the unit. The original burners were replaced with thirty Riley STS® (Swirl Tertiary Staged) Burners suitable for firing oil, using Y-jet steam atomizers. Additionally, only twenty of the burners were designed with natural gas firing capability due to a main gas supply limitation to the plant. The standard, dual fuel STS® Burner, as shown in Figure 2 features separate automatic primary and secondary air flow control shrouds which can be used to balance windbox air flow to individual burners. They also control the degree of internal air staging required for NO_X control and overall combustion performance. The secondary air also passes through a separate, multi-blade register which imparts a high degree of swirl to the secondary air, thereby controlling fuel/air mixing. The ability to independently control air flow and swirl provides maximum flame shaping capability. The STS® Burner was introduced to the market in 1991[1] and pilot scale test results have been previously documented[2].

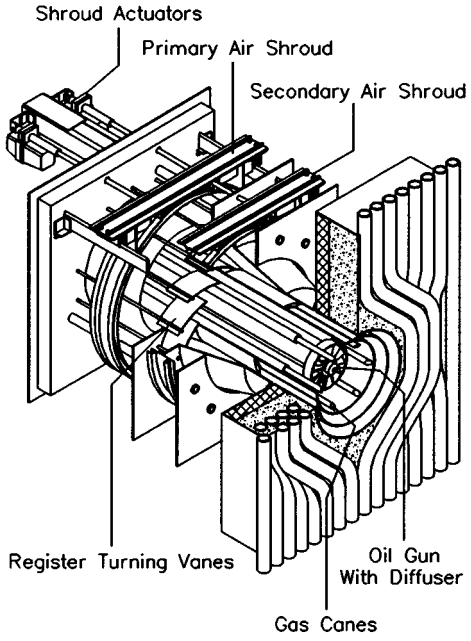

Figure 2 Standard STS® (Swirl Tertiary Staged) Burner

Since the original burners already had air staging capability, oil atomizer design played a crucial role in the overall NO_X reduction strategy for the only retrofit of this burner. Numerous atomizer spray plate designs featuring alternating fuel rich and fuel lean zones were tested. The optimum atomizer design yielded a NO_X reduction of 35% from pre-retrofit levels while maintaining acceptable levels of CO and opacity.

Significant combustion-induced vibration was encountered during initial gas firing, but was eliminated by “tuning” the adjustable gas canes on the STS® Burners. The gas canes are designed so that the axial and rotational position of the gas tips can be changed while the burner is in operation. The final gas cane configuration was the same for all burners. Combination firing of natural gas and oil (separate burners) was also conducted during the test program. A summary of the results for oil, gas and oil/gas combination firing is presented in Table 2.

Table 2 Utility A Summary of Results

	Pre-retrofit	Post-retrofit	Post-retrofit	Post-retrofit
Fuel(s) type	#6 Oil	#6 Oil	Natural Gas	Combination #6 Oil and Nat. Gas
Boiler load, %MCR	100	100	50	97
Gross generation, MW	667	665	337	650
Burners in service firing #6 Oil Nat. Gas	 30 –	 30 –	 – 20	 13 17
% of total heat input, oil/gas	100/0	100/0	0/100	55/45
NOx, lb/MMBtu	0.59	0.38	0.27	0.38
CO, ppm, vdc	–	13	89	31
Opacity, percent	–	10	1	–
Excess air, percent	15	6	17	5

UTILITY B / UNIT #2

Unit Description

Utility B Unit #2 was designed and manufactured by the Babcock & Wilcox Company (B&W), and was placed in service in 1976. The unit is a balanced draft, sub-critical, natural circulation boiler designed for firing #6 fuel oil. The boiler is designed for an MCR superheated steam flow of 4,002,000 lb/hr at a temperature of 1005°F and pressure of 2500 psig. MCR reheat steam flow is 3,700,000 lb/hr at 1005°F and 600 psig. The boiler has cycling capability and utilizes a sliding pressure operating mode. The nominal output is 590 MWe.

The unit, as shown in Figure 3, is opposed fired and was originally equipped with thirty-two OEM burners designed to fire #6 oil (4 x 4 matrix front and rear). Also featured in the original design were eight over burner column overfire air (OFA) ports, and a flue gas recirculation (FGR) system capable of delivering flue gas to the windbox and lower furnace for emissions and steam temperature control.

Low NO_X/Low CO Retrofit/Gas Conversion

With the original equipment installed, the unit demonstrated the ability to operate at the required NO_X level of 0.28 lb/MMBtu at loads greater than 500 MW while firing #6 oil. However, CO emissions typically ranged from 2,000 - 10,000 ppm under these conditions. Superheater metal temperatures frequently exceeded alarm limits when FGR was used at these loads. When NO_X was permitted to vary up to 0.50 lb/MMBtu, CO levels dropped, but remained generally in excess of 200 ppm. The goals of the retrofit were to add gas firing

capability to unit #2 and simultaneously meet NO_X and CO emission limits of 0.28 lb/MMBtu and 200 ppm, respectively, for both natural gas and #6 oil firing. Maximum operating limits of 90% MCR on oil and 60% MCR on gas were stipulated in the customer's retrofit specification. The 60% MCR limit for gas firing was a result of temperature limitations imposed by the existing convective pass tube metallurgy.

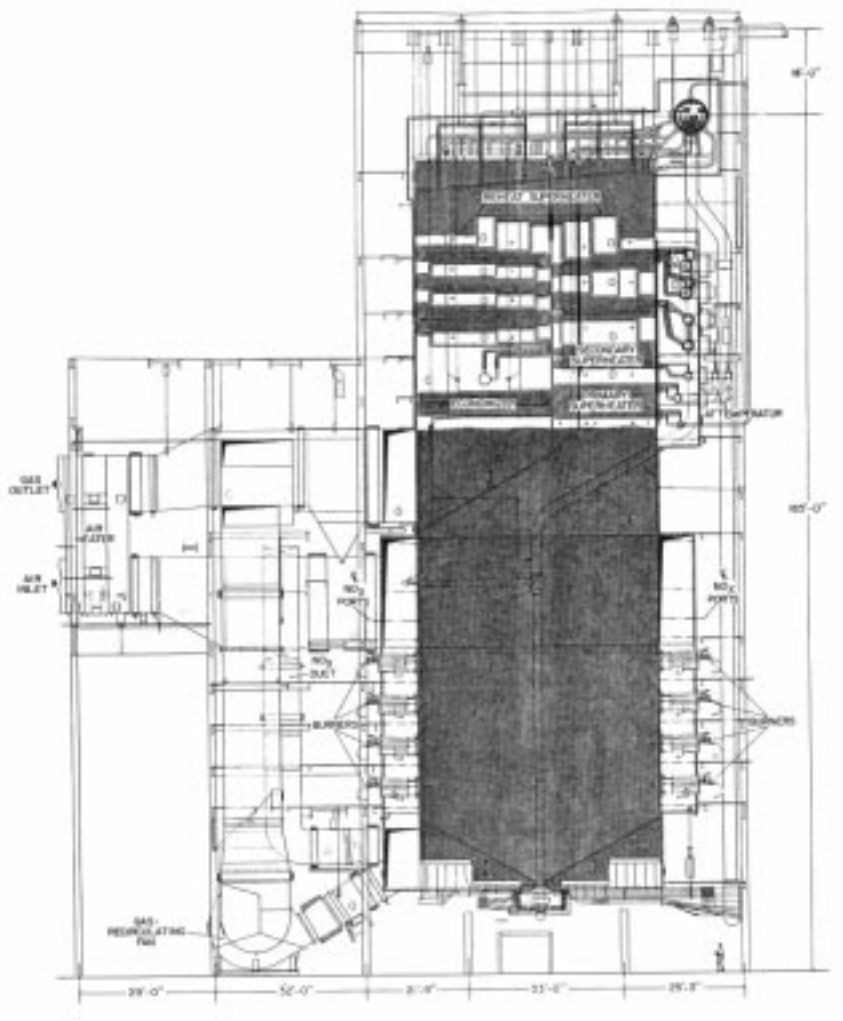

Figure 3 Utility B

Utility B contracted DB Riley in November 1995 to furnish a retrofit system consisting of thirty-two standard, dual fuel STS® burners and twelve OFA ports. The measures taken to reduce CO emissions included installation of the dual register STS® burners for improved fuel/air mixing, replacement of the original steam assisted mechanical atomizers with steam atomized, internal mix, low NO_X atomizers, and installation of an enhanced OFA system including "wing" OFA ports in addition to the over-burner column ports. The burners were designed for 100% MCR operation on either fuel which is equivalent to a per burner capacity of 186 MMBtu/hr on oil and 193 MMBtu/hr on natural gas. The post-retrofit test results are shown in Table 3 and confirm that the project objectives were met.

Table 3 Utility B Unit #2 Summary of Results

	Pre-retrofit	Post-retrofit	Pre-retrofit	Post-retrofit
Fuel Type	#6 Oil	#6 Oil	Natural Gas	Natural Gas
Boiler Load, %MCR	106	90	N/A	60
Gross Generation, MW	592	507	N/A	354
NO_X, lb/MMBtu	0.32	0.27	N/A	0.24
CO, ppm, vdc	5527	159	N/A	62
Particulate, lb/MMBtu	—	0.0505	N/A	—
Excess Air, Percent	7	12	N/A	12

PAPERMILL A

Unit Description

The unit at Papermill A is a Riley OD-1 industrial boiler with a pressurized furnace, designed to fire #6 fuel oil. The boiler is rated for a maximum steam flow of 300,000 lb/hr at 975 psig and 900°F. The furnace is 19 feet wide x 18 feet deep and was originally fitted with six Riley Series #82 burners rated for 65 MMBtu/hr each and arranged in two rows of three burners on the front wall as shown in Figure 4.

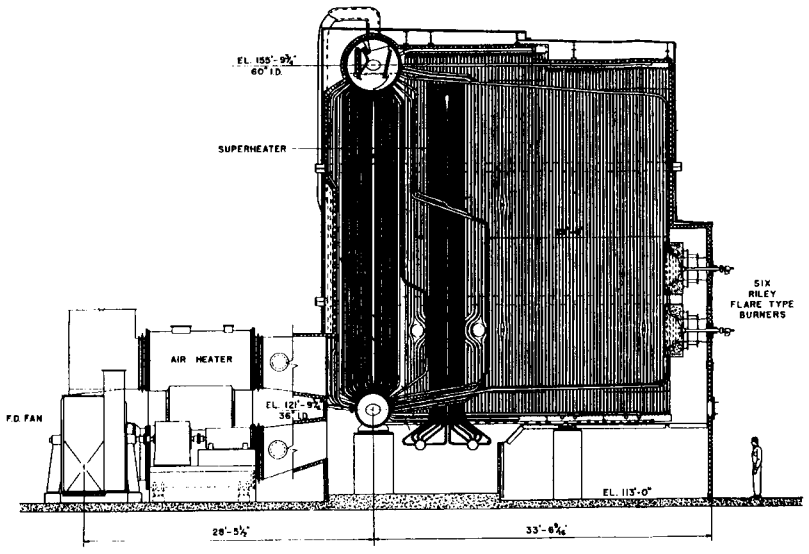

Figure 4 Papermill A

Low NO_X Retrofit

Baseline testing prior to the retrofit confirmed that the unit was limited to 95% MCR. The retrofit consisted of six standard DB Riley STS® Burners with low NO_X type, steam atomized, Y-jet atomizers. A NO_X reduction of approximately 20% was achieved with CO < 50 ppm vdc and opacity < 15%. Results are summarized in Table 4.

Table 4 Papermill A Summary of Results

	Pre-retrofit	Post-retrofit
Burner load, %MCR	95	97
Steam flow, lb/hr	285,000	290,000
NO_X, lb/MMBtu	0.47	0.38
CO, ppm, vdc	8	37
Opacity, percent	11.5	14.5
Excess air, percent	8	9

PAPERMILL B

Unit Description

The boiler at Papermill B is a B&W PFI industrial boiler originally designed to operate at 415,000 lb/hr steam flow at 875 psig and 825°F. Installed in the early 1970's, the unit has a pressurized furnace and was designed to fire natural gas with preheated combustion air. The original air heater is no longer in service, and the boiler is currently operated with ambient combustion air.

The furnace was originally equipped with five OEM circular gas burners rated at 83 MMBtu/hr each, arranged on the front wall in a "three over two" pattern. An OFA system consisting of two opposing wall ports and one front wall port was provided with the original equipment. The furnace is 24 feet wide x 21 feet deep.

Low NO_X Retrofit

DB Riley was contracted in January1996 to supply LNB's for Boiler #2 at Papermill B. As part of this customer's retrofit specification, the unit was derated to 300,000 lb/hr steam flow. The E.D.G.E. low NO_X gas burner, developed by Holman Boiler Works, Inc. and shown in Figure 5, was selected for this application. The standard E.D.G.E. burner utilizes a combination of fuel and air staging within the burner as well as fuel induced recirculation (FIR) of the products of combustion. FIR differs from conventional external flue gas recirculation (FGR) in that flue gas is recirculated from the boiler back pass exit using the pressure energy of the fuel (i.e., no external FGR fans are required) and then intimately mixed with the fuel rather than the combustion air. This FIR technique has been proven to be approximately five times more effective at reducing NO_X than conventional FGR. The design principles and NO_X reduction capability of the E.D.G.E. burner have been documented for single burner applications with NO_X levels < 20 ppm (0.024 lb/MMBtu) achieved.[3]

The project requirements for NO_X and CO emissions were 0.10 lb/MMBtu and 400 ppm, vdc, respectively. The relatively liberal NO_X requirement allowed windbox air to be substituted for flue gas in the FIR nozzles, thus eliminating the need to install flue gas ducting from the boiler back pass exit to each burner.

DB Riley and Holman Boiler Works partnered on this project to develop an E.D.G.E. low NO_X gas burner suitable for multiple burner applications. Unique to this application is the combination of the E.D.G.E. burner with a total air shroud which is used to balance air flow to the individual burners and for isolating out-of-service burners. Each burner was furnished with a single pneumatic cylinder and two sets of internal limit switches to control the position of the total air shroud.

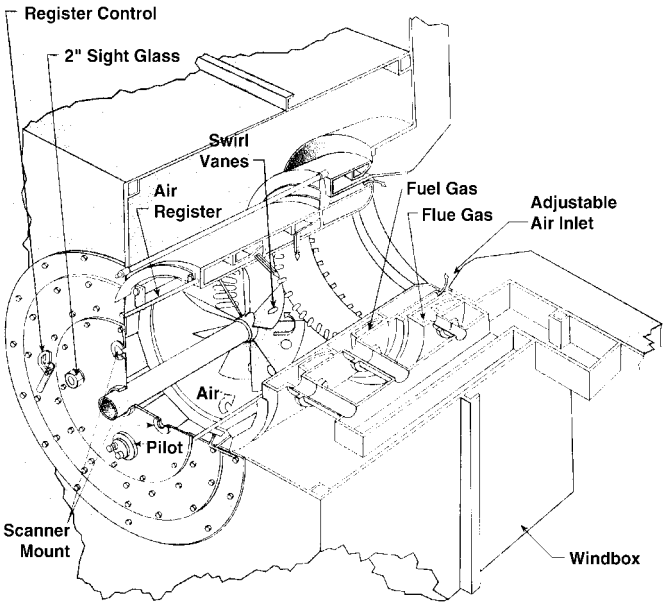

Figure 5 Typical E.D.G.E. Low NO_X Burner

Results of post-retrofit testing are shown in table 5. NO_X levels 20-35% below the required level were demonstrated over the operating range of the boiler. This performance was achieved by using the existing burner throat openings and permitted the elimination of the existing OFA system. Use of flue gas in the FIR nozzle could provide additional NO_X reduction.

Table 5 Papermill B Summary of Results

	Guarantees	Post-retrofit Results			
Boiler Load, %MCR	100	101	81	69	48
Steam Flow, lb/hr	300,000	304,000	243,000	208,000	145,000
Windbox/Furnace Differential Pressure, iwc	—	5.8	4.0	3.0	1.5
NO_X, lb/MMBtu	0.10	.066	.077	.074	.080
CO, ppm, vdc	400	108	0	0	0
Excess Air, percent	–	15	22	22	30

UTILITY B / UNIT #1

Unit Description

Utility B Unit #1 was designed and manufactured by B&W. It is a 560 MW once through, supercritical, double reheat boiler with pressurized furnace that went into commercial operation in 1968. The boiler is designed to operate on #6 fuel oil at a maximum continuous rating of 3,720,000 lb/hr of superheated steam flow at 3825 psig and 1007F. The reheat stage I steam flow is 3,172,000 lb/hr at 1074 psig and 1001°F while the reheat stage II steam flow is 2,896,000 lb/hr at 330 psig and 1000°F.

As shown in Figure 6, the unit was originally equipped with forty-eight opposed fired original equipment manufacturer (OEM) cell burners with a nominal rating of 100 MMBtu/hr each. The burners were arranged in sixteen cells of three burners each - two elevations of burners on each firing wall. The furnace is 54 feet wide x 39 feet deep.

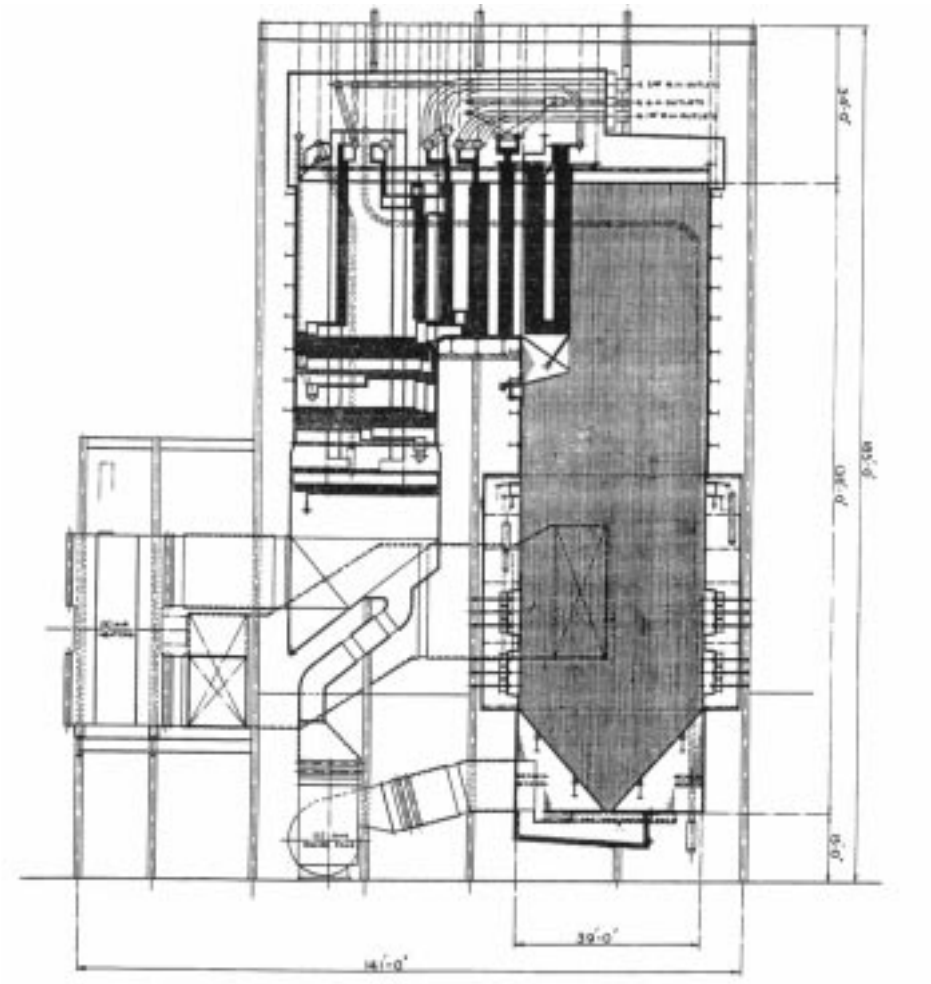

Figure 6 Utility B/Unit #1

Low NO_X Retrofit

In July 1994, Utility B contracted DB Riley to provide a low NO_X retrofit system consisting of low NOx burners, OFA and an FGR system. The original forty-eight OEM cell burners were replaced with forty modified DB Riley STS® burners rated for 120 MMBtu/hr each and utilizing low NO_X type oil guns. This arrangement eliminated the need for burner

respacing. Twelve OFA ports - eight close coupled OFA ports in the uppermost burner openings and four new "wing" OFA ports - were also added. Pressure part modifications were limited to the four new "wing" OFA ports, because the existing upper burner openings were modified for OFA service.

For this application, the standard STS® Burner design had to be modified in order to reuse the existing burner throat openings. The burners have a very close vertical spacing of 3'-10" centerline to centerline. An automatic register with manual total air and primary/secondary biasing shrouds was utilized in lieu of the automated primary and secondary air shrouds and manual secondary air register on the standard STS® Burner. This resulted in a more compact register design which was suitable for the 3'-10" vertical burner spacing. The modified STS® burner utilized for this application is shown in Figure 7.

NO_X reduction in excess of 70% from pre-retrofit levels was achieved with CO < 100 ppm and particulates < 0.06 lb/MMBtu while firing #6 oil having a fuel nitrogen content of 0.48% by weight. This information is summarized in Table 6.

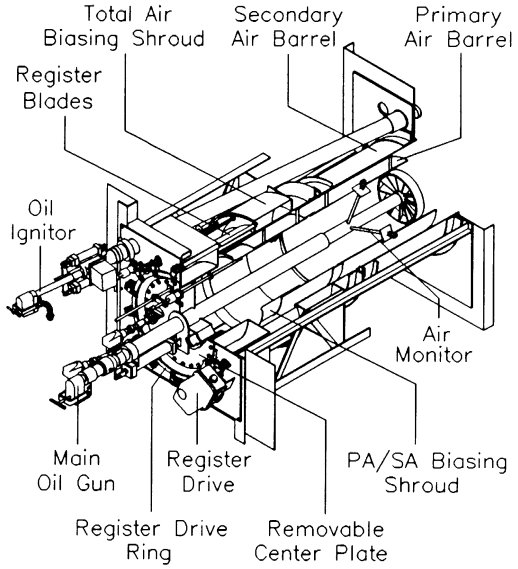

Figure 7 Modified STS® (Swirl Tertiary Staged) Burner

Table 6 Utility B/Unit #1 Summary of Results

	Pre-retrofit	Post-retrofit
Boiler load, %MCR	103	98
Gross generation, MW	579	581
NO_X, lb/MMBtu	0.96	0.26
CO, ppm, vdc	78	60
Particulate, lb/MMBtu	0.1	0.06
Excess air, percent	4.5	7

Shortly after completion of the acceptance testing it was discovered that furnace exit gas temperature (FEGT) and NO_X steadily increased over time. This required derating of the unit to maintain NO_X compliance. Subsequent investigation revealed that the characteristics of the furnace water wall slag deposits from the magnesium oxide (MgO) additive in the fuel oil had changed from a dark coating to a very light, reflective coating which reduced furnace heat transfer, driving up FEGT and NO_X. Full load firing capability and emissions compliance were restored by reducing the MgO concentration in the fuel oil. This change produced a self-limiting, readily shedding furnace water wall deposit and resulted in steady FEGT and NO_X values over time.

PAPERMILL C

Unit Description

The boiler for Papermill C was originally designed and manufactured by Riley Stoker Corporation in the early 1970's. The unit has a Riley flat bottom TURBO® Furnace designed for balanced draft operation and is equipped to fire #6 oil. The boiler is designed for a main steam flow of 600,000 lb/hr at 1300 psig and 855°F. The furnace is opposed fired and was originally furnished with four Riley Directional Flame burners rated for 180 MMBtu/hr each. Each burner was furnished with two steam atomized oil guns. The furnace plan area is approximately 25 feet wide x 23 feet deep. A typical TURBO® Furnace and a typical gas/oil fired Directional Flame Burner are shown in Figures 8 and 9.

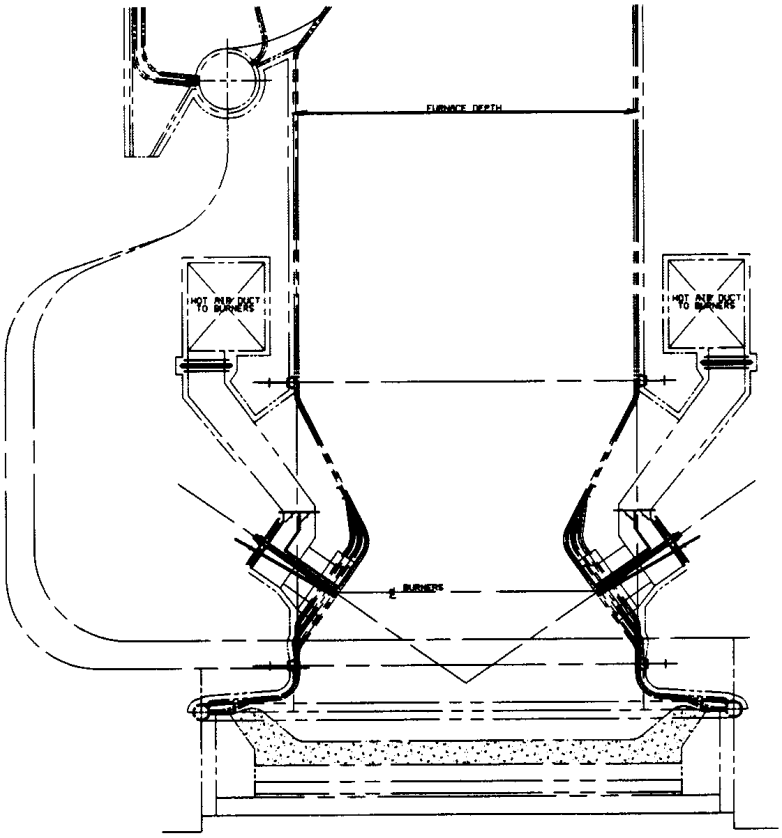

Figure 8 Typical Flat Bottom TURBO® Furnace

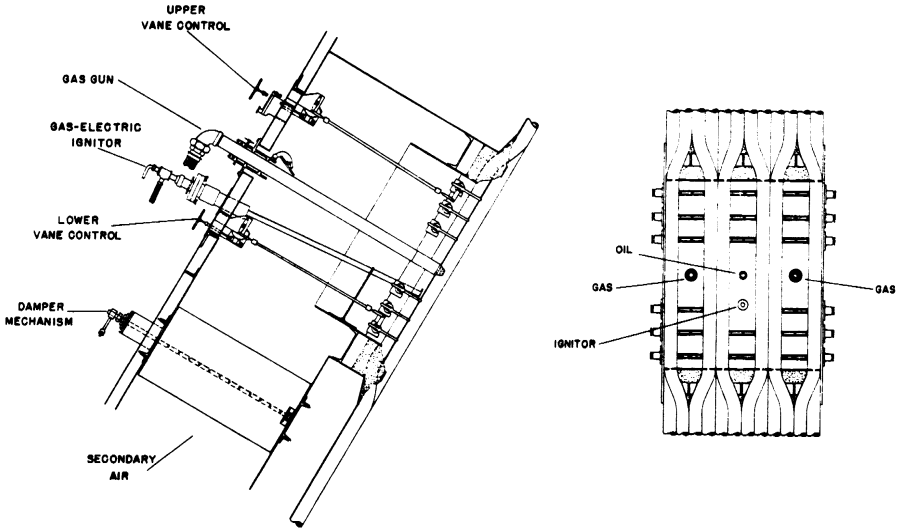

Figure 9 Typical Gas/Oil Directional Flame Burner

Low NO_X Retrofit

The retrofit consisted of Directional Flame Burner modifications only. The original axial flow Directional Flame Burners were retained. The individual burner windboxes were partitioned and furnished with separate air dampers and drives, thus providing air staging capability within the burner. The burner windbox partitioning coupled with the burner directional vanes and unique design of the TURBO® Furnace produces a pseudo-OFA effect. An outline drawing of the retrofit system is shown in Figure 10. Also furnished as part of the retrofit were eight low NO_X type, Y-jet oil atomizers and combustion air swirlers and diffusers.

The boiler was derated by the customer to 500,000 lb/hr. Post retrofit testing yielded a NO_X reduction in excess of 35% from the baseline level firing #6 oil. CO and opacity remained low. Pre- and post-retrofit test results are summarized in Table 7.

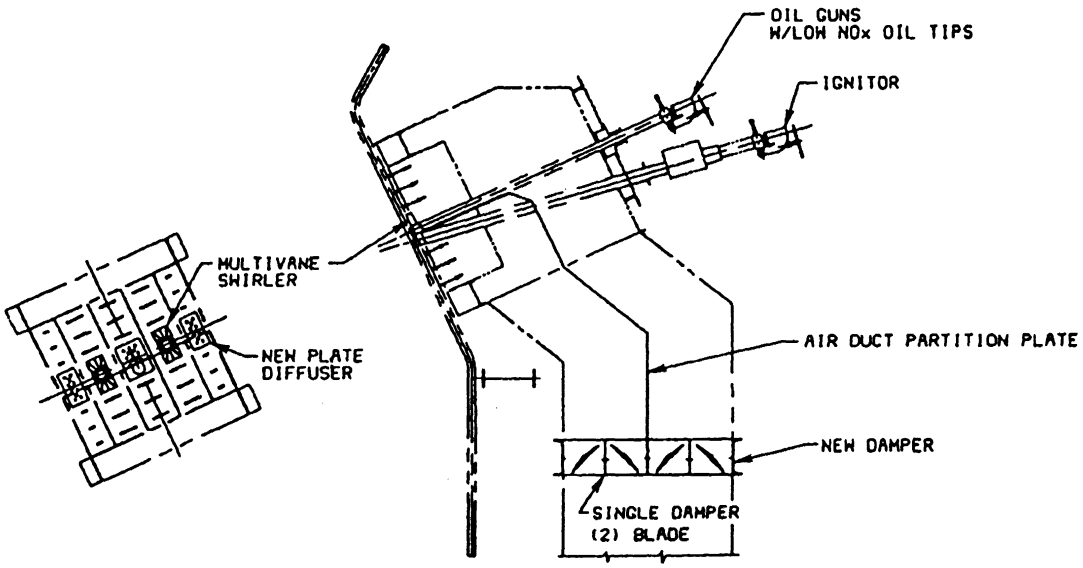

Figure 10 Papermill C Burner Modifications

Table 7 Papermill C Summary of Results

	Pre-retrofit	Post-retrofit
Boiler load, %MCR	83	85
Steam flow, lb/hr	500,000	507,000
NO_X, lb/MMBtu	0.51	0.36
CO, ppm, vdc	0	0
Opacity, percent	4	5.8
Excess air, percent	13	17

U.S. REFINERY

Unit Description

The boiler installed at this U.S. Refinery was originally designed and manufactured by Riley Stoker Corporation in the late 1950's. It featured a Riley flat bottom TURBO® Furnace designed for balanced draft operation. The unit was originally equipped to fire petroleum coke, refinery gas, and/or oil. The boiler is designed for a maximum superheated steam flow of 500,000 lb/hr and is operated at 600 psig and 750°F.

The original twelve Riley Directional Flame burners - six front and six rear - were furnished with three coke nozzles, two gas guns and one steam atomized oil gun each. The burners are rated for 58 MMBtu/hr each. A generic sketch of the original Directional Flame Burner is shown in Figure 11. The plan area of the furnace is 29 feet wide x 21 feet deep. The furnace was retrofitted by others with gas ducts to the lower furnace to allow burning of a low BTU offgas stream from the refinery. The "offgas ducts" were also fitted with a

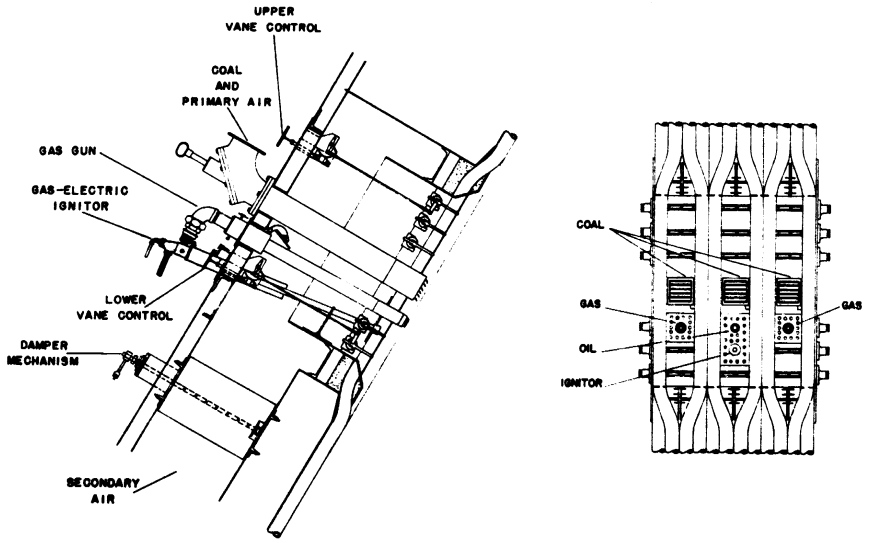

Figure 11 Original Directional Flame Burner

"purge gas" system which utilized flue gas to cool the ducts when not in use. Prior to the low NO_X retrofit, this purge gas system was utilized as a makeshift FGR system to reduce NO_X emissions.

Burner Retrofit

The goal of the retrofit was to modify the existing burners to eliminate coke firing and provide enhanced air control for combustion optimization while firing refinery gas as the primary fuel. The scope of the Directional Flame Burner modifications included:

1. removal of the coke nozzles,
2. relocation of the oil and gas guns,
3. installation of flame stabilizers,
4. installation of individual burner windbox partition plates,
5. modification of the existing burner combustion air dampers to provide air staging within the burner using manual damper operators with position indicators, and
6. replacement of burner directional vanes and tube clamp assemblies.

Several problems were encountered during the refurbishment of the 40-year-old burners. Many of the lead tubes on the burner throat openings had moved as much as 3" into the furnace over time. Several of the burner housing panels were also observed to be warped. These problems made alignment of the directional vane assemblies very difficult and ultimately lead to difficult or restricted range of travel on the adjustable directional vanes. The mis-aligned furnace tubes also necessitated modifications to the refinery gas guns and air diffuser plate installation. An inspection of the upper furnace revealed several large sections of the rear furnace wall seals and boiler nose arch area were in very poor condition allowing hot furnace gases to bypass part of the upper furnace and initial sections of the convective pass. These furnace leaks are believed to be partially responsible for the excessively high air heater air outlet temperatures (> 700°F) measured during baseline testing.

A significant portion of time was spent optimizing the burner settings and balancing combustion air flow to the Directional Flame Burners. Optimization test data shows the burner modifications yielded NO_X reduction of approximately 60% both with and without the makeshift FGR system compared with the pre retrofit data. A combination of burner optimization and fan damper, furnace, and boiler feedwater pump repairs also restored full load firing capability to the boiler. The test results are summarized in Table 8.

Table 8 U.S. Refinery Summary of Results

	Pre-retrofit w/o FGR	Pre-retrofit w/ FGR	Post-retrofit w/o FGR	Post-retrofit w/ FGR	Post-retrofit w/ FGR
Boiler load, %MCR	78	80	78	78	96
Steam flow, lb/hr	390,000	400,000	390,000	390,000	480,000
NO_X, lb/MMBtu	0.34	0.25	0.14	0.10	0.16
CO, ppm	120	–	20	10	5
Opacity, percent	–	–	10	7	1
Excess air, percent	10	10	10	10	11

SUMMARY

DB Riley has successfully retrofitted several gas and oil fired utility and industrial boilers including wall, cell, and TURBO® Furnaces with low NO_X firing equipment. The scope of these projects has varied from modification of existing burners, to installation of LNB's only, and installation of LNB's coupled with OFA and FGR systems. LNB's that have been retrofitted include the DB Riley STS® burner as well as the Holman E.D.G.E. burner. No pressure part modifications to the existing burner throats were required for installation of the LNB's; minor pressure part modifications were required for installation of the OFA systems. NO_X reductions in excess of 70% for #6 oil and 60% for gas firing have been achieved while maintaining acceptable CO and opacity levels.

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