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NO_x REDUCTION EXPERIENCE ON NATURAL GAS FIRED TURBO® FURNACES

by

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ABSTRACT

The unique TURBO® Furnace and its associated Directional Flame (DF) burners developed by DB Riley, Inc. in the 1960's provide NOx reduction challenges not typically encountered with conventional wall and opposed-fired applications featuring circular burners. An overview of the low NO_X retrofit systems and test results is presented for two natural gas fired utility boilers with TURBO® Furnaces. The units are rated for 210 MWg and 360 MWg. A NOx level < 0.10 lb/10^6 Btu and reductions up to 64% from pre-retrofit levels were demonstrated using a combination of advanced overfire air (OFA), flue gas recirculation (FGR), and DF burner modifications.

INTRODUCTION

The TURBO® firing concept was first used in the 1940's as a means to reliably burn petroleum coke, a low volatile fuel requiring high furnace retention time to ensure complete combustion. The TURBO® Furnace design is characterized by a venturi cross section with opposed fired, downward tilted burners located at a single elevation. Units designed for gas and oil firing typically feature a flat furnace bottom covered with refractory.

TURBO® Furnaces are equipped with Directional Flame (DF) burners. Each DF burner consists of a series of vertical slots through which fuel and air are introduced into the furnace. As shown in Figure 1, DF burners for gas and oil firing typically feature five slots with three main fuel guns. Since DF burners are not swirl stabilized like most wall fired circular type burners, they exhibit more of a diffusion burning characteristic, yielding lower peak flame temperatures and thermal NO_X levels than comparable wall fired applications with pre-NSPS circular burners. Without swirl flame stabilization, however, DF burners can be prone to flame detachment, which tends to increase NO_X due to inadequate control of fuel/air mixing. DF burners also feature adjustable directional vanes located in the air slots above and below the main fuel guns. The directional vanes are linked together such that the upper and lower vanes can be adjusted separately through a range of approximately ±30 degrees, providing flexibility to control steam temperature and to a lesser degree fuel/air mixing and NO_X. Each DF burner has a compartmentalized windbox and separate multiple bladed air damper assembly with a single pneumatic operator.

This paper presents the findings from two low NO_X retrofit systems applied to natural gas fired TURBO® Furnaces. Unit A features advanced OFA, DF burner modifications and conventional flue gas recirculation, while Unit B features advanced OFA, DF burner modifications and induced FGR (IFGR).

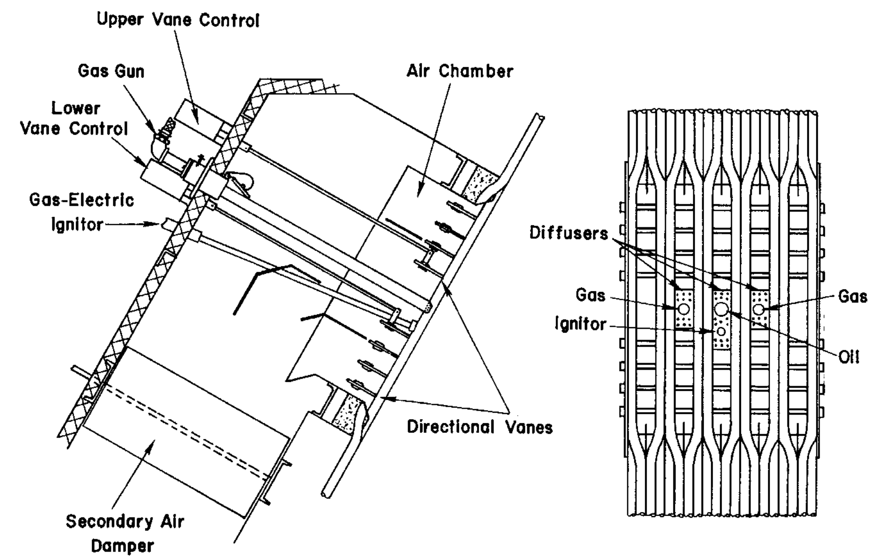

Figure 1 Typical Directional Flame Burner for Gas and Oil Firing

UNIT A

Unit Description

Unit A is a 210 MWg, natural circulation boiler that went into initial operation in the early 1960's. The boiler is designed for a maximum continuous rating of 1,505,163 lb/hr of main steam flow at 1,850 psig and 1003°F, and reheat steam flow of 1,331,339 lb/hr at 520 psig and 1003°F. The unit features a pressurized furnace design with two forced draft (FD) fans and Ljungstrom air heaters. The TURBO® Furnace was originally furnished with fourteen Directional Flame burners rated for 148 x 10^6 Btu/hr (MCR), each with two gas guns and a single oil gun designed to fire natural gas with heavy oil as a back up fuel. The boiler configuration is shown in Figure 2.

Previous Modifications

Unit A was retrofitted by DB Riley with OFA and FGR systems in the early 1970's to reduce NO_X emissions below 175 ppm, volume, dry, corrected to 3% O_2 (vdc) for gas firing. The original OFA system consisted of fourteen over-burner ports each having three slotted water wall openings on the upper slope of the TURBO® Furnace arch. The OFA ports were fed by takeoff ducts on the top of each DF burner windbox and furnished with modulating flow control dampers. Figure 3 shows a schematic illustration of the original OFA port configuration. The FGR system consisted of one double width/double inlet fan with a bifurcated discharge which recirculated "hot" flue gas from the gas inlet of each air heater to mixing devices located in each of the hot air ducts that supply combustion air to the DF burner windboxes. The FGR system also featured inlet and outlet flow control dampers on the fan as well as separate balancing dampers and venturis on each fan discharge section. In conjunction with the FGR system, reheater surface was removed and the original bare tube economizer was replaced with a finned tube economizer.

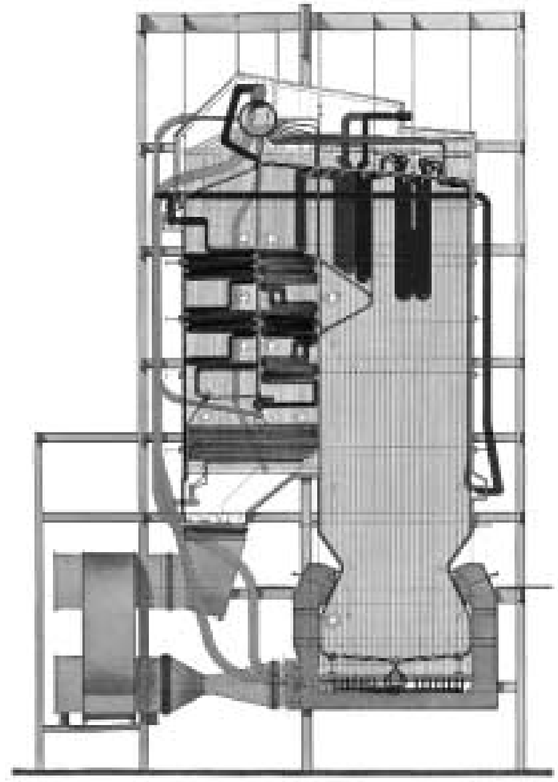

Figure 2 Unit A Boiler Schematic

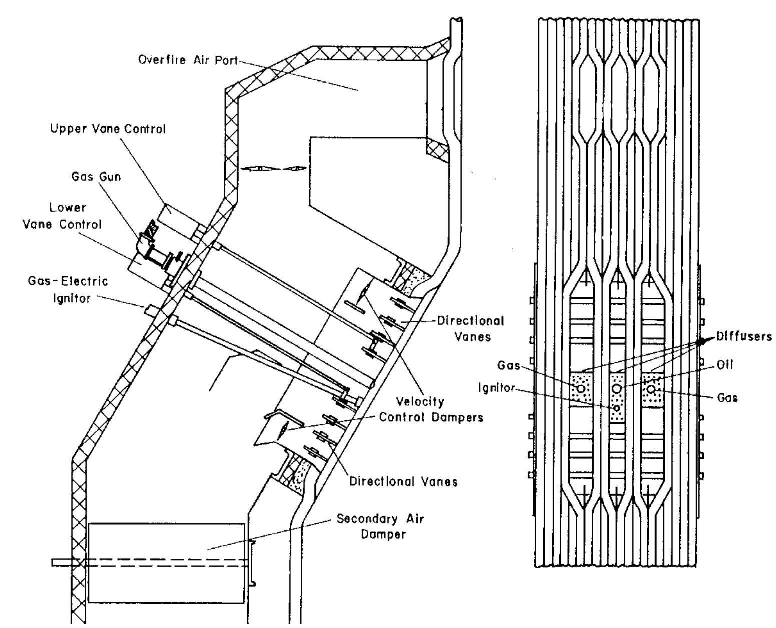

Figure 3 Unit A Original OFA Configuration

Unit A underwent additional modifications by the customer during the 1980's and 1990's. Refractory was added to the DF burner throats to improve air flow distribution and to the OFA ports to increase furnace penetration. Burner and furnace flow studies were performed in 1995 using a 1/6 scale plexiglass model. OFA flow was determined to be approximately 40%. As a result of the flow study, additional burner throat modifications were made and the FGR mixing devices were modified to improve distribution.

Latest Retrofit

In response to increasingly stringent emissions limits promulgated by the local air quality district, the customer teamed with DB Riley in January 1998 to develop and implement a compliance strategy for Unit A. A two-phased approach was used. The first phase consisted of an engineering study to review pre-retrofit test data and determine the modifications required to lower NO_X emissions, control CO emissions, and maintain boiler performance. The NO_X reduction design was developed using the pre-retrofit test data and DB Riley's in-house NO_X data base. Computational Fluid Dynamic (CFD) modeling was conducted using the commercially-available FLUENT CFD code. A 3-D furnace combustion model was constructed to evaluate the OFA design in terms of furnace mixing, CO burn out, and impact on furnace exit gas temperature profiles. Additional boiler performance impacts were evaluated using in-house mathematical and thermal models calibrated with the pre-retrofit data.

The second phase of the project involved implementation of the engineering study recommendations which included:

- installation of rotor tipping kit for existing FGR fan,
- replacement of the existing OFA system with an advanced OFA system consisting of fourteen over-burner and four wing OFA ports,
- addition of burner windbox partition plates,
- installation of twenty-eight fuel staged gas gun tips,
- removal of existing primary superheater surface, and
- installation of additional finned-tube economizer surface.

The FGR fan OEM predicted that rotor tipping would provide a 7% flow increase, 15% static pressure increase and 25% HP increase. The existing FGR fan motor was determined to be sufficient for the predicted operating conditions. The predicted FGR flow requirement was 10% for the target NO_X value of 0.091 lb/10^6 Btu (75 ppm vdc).

An advanced OFA system with 1/3 - 2/3 dampers and oval-shaped ports was furnished to provide proper furnace penetration and velocity for NO_X and CO control throughout the boiler load range. Wing OFA ports were added to address the chronic problem of high CO in the corners of the furnace. The OFA system was designed to maintain the 40% OFA flow predicted by the physical flow model study.

Burner windbox partitions were added to de-couple the OFA from the DF burner air. This separation of OFA and burner air allows desired burner zone stoichiometry to be achieved for NO_X control while simultaneously being able to balance air flow burner to burner for CO control. A schematic of the windbox partitioning is shown in Figure 4.

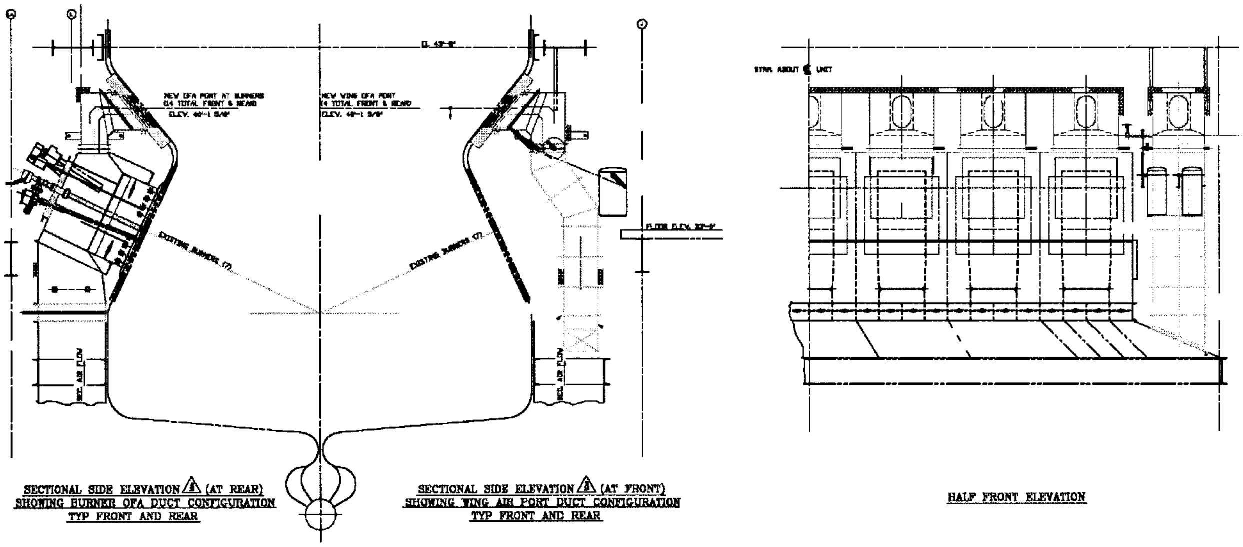

Figure 4 Windbox Partitioning Applied to Unit A

Test Results

Post-retrofit testing was conducted in June of 1999. The DF burner directional vanes were successfully used to tune convective pass metal temperatures below alarm levels. Burner air supply damper settings were varied to improve O_2 and CO distribution at the economizer outlet gas sampling grid as well as to achieve sufficient furnace air staging. Figure 5 shows a comparison of initial and final economizer outlet O_2 and CO readings. Burner air flow probe readings were found to be unreliable due to close proximity of burner air supply dampers to the probes. Flame scanner signal strength at minimum boiler load was improved by operating with the 1/3 OFA dampers open, which decreased burner air velocity and increased flame attachment.

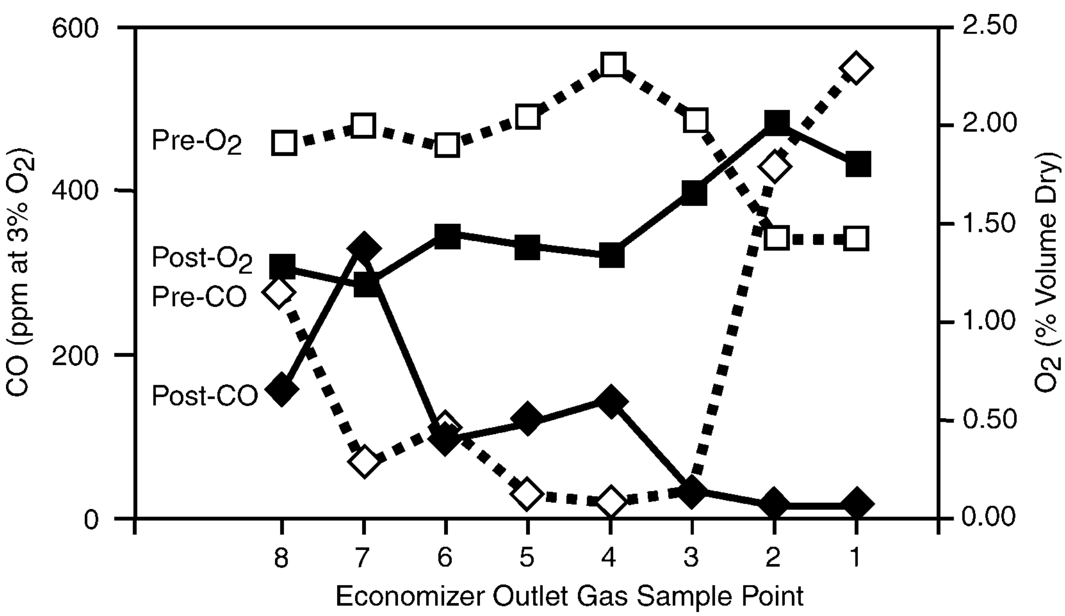

Figure 5 Comparison of Pre- and Post-retrofit Economizer Outlet CO and O_2 Profiles

A comparison of the pre- and post-retrofit performance at full load for the optimized burner settings is shown in Table 1. These results demonstrate that a NO_X level of 0.091 lb/10^6 Btu was achieved without burner replacement, and without significantly impacting boiler performance. The higher than predicted FGR flow requirement is believed to be a result of higher than design furnace stoichiometry resulting from lower than design OFA flow.

Table 1 Comparison of Pre- and Post-Retrofit Performance for Unit A at 210 MWg

	Pre-retrofit	Predicted	Post-retrofit OFA and FGR
Boiler Data			
SH Gas Damper, % Open	95	—	100
RH Gas Damper, % Open	60	—	27
SH Temperature, °F	1006	1002	999
RH Temperature, °F	1007	1002	1007
SH Spray Flow, klb/hr	190	162	162
RH Spray Flow, klb/hr	86	55	52
AH Gas Inlet Temperature, °F	719	746	746
FGR System Data			
Motor Current, amps (FLA=97)	47	—	90
Inlet Damper, % Open	35	—	75
Balance Damper, % Open	24	—	29
Firing Systems Data			
NO_X, lb10^6 Btu	0.146	≤0.091	0.091
NO_X Reduction, %	—	—	38
CO, ppm vdc	191	≤400	112
Excess Air, %	9	7	7.1
FGR, %	1.7	10	12.5
W/F dp, iwc	1.25	4	5.2

UNIT B

Unit Description

Unit B also went into initial operation in the early 1960's. It is a cycling unit featuring natural circulation and a nominal rating of 360 MWg at peak load. The boiler is designed for a peak load of 2,630,000 lb/hr of main steam flow at 2,550 psig and 955°F, and reheat steam flow of 2,310,000 lb/hr at 582 psig and 955°F. The unit features a pressurized furnace design with two forced draft fans with double inlets and variable speed drives, as well as two Ljungstrom air heaters. The TURBO® Furnace was originally furnished with sixteen Directional Flame burners rated for 220 x 10^6 Btu/hr (peak), each with three natural gas guns and a single light oil gun. The boiler configuration is shown in Figure 6.

Retrofit Scope

In May 1999, the customer contracted DB Riley to design and furnish a low NO_X retrofit system capable of reducing NO_X emissions to below 0.19 lb/10^6 Btu in order to meet state mandates for the metropolitan corridor within which the plant is located. Unlike Unit A, Unit B was in its original design configuration with no NO_X reduction equipment or techniques applied. A NO_X control philosophy similar to Unit A was used for Unit B and featured FGR, advanced OFA consisting of sixteen over-burner ports and four wing ports with 1/3 - 2/3 dampers and oval-shaped tube openings, burner windbox partitions for separate control of burner air and OFA, and forty-eight fuel staged gas guns. In addition, the existing 2-bladed DF burner air damper assemblies were replaced with 4-bladed assemblies to accommodate the windbox partitions for separate burner air and OFA flow control. The design flow basis for the OFA and FGR systems was 40% and 5% respectively.

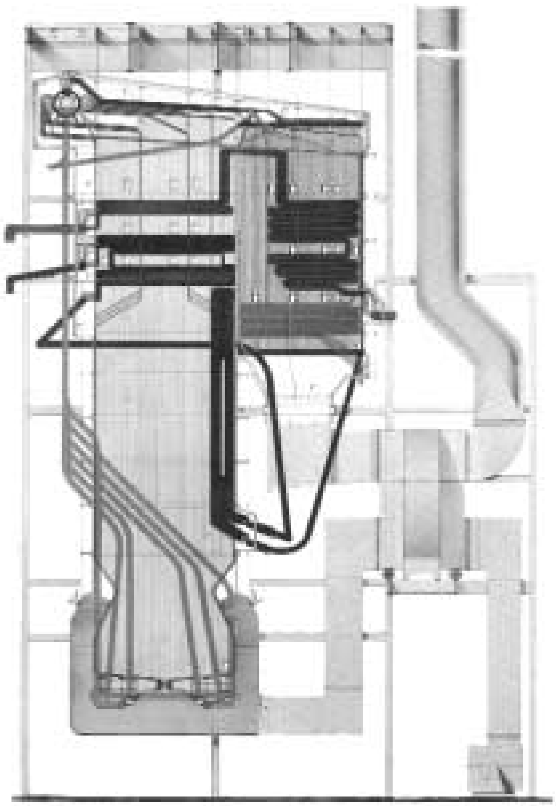

Figure 6 Unit B Boiler Schematic

The major difference in the NO_x control philosophy for Unit B was the use of Induced Flue Gas Recirculation (IFGR) rather than a conventional system with separate FGR fan. The IFGR system on Unit B is designed to recirculate "cold" flue gases from the air heater gas outlet to the FD fan inlets using the pressure differential between the breeching and FD fan inlet. The IFGR system includes an automatic isolation valve, flow indicating probes, expansion joints and 3-sided fan inlet boxes for each FD fan inlet as shown in Figure 7. An analysis of the boiler and FD fans, based on 1998 data provided by the customer, suggested that no boiler or FD fan modifications were required to accommodate 5% IFGR at peak load operation.

Field Results

Optimization testing on Unit B began in January of 2000. Initial tests were conducted with OFA only (IFGR dampers closed) to determine the required burner air supply damper settings for balancing economizer outlet O_2 and CO profiles. Immediately it was discovered that these profiles were extremely sensitive to both burner air and OFA supply damper position. In fact, burner air damper adjustments and changes in the economizer outlet gas profiles frequently did not correspond to one another, making burner tuning efforts extremely difficult. Table 2 shows the non-optimized performance achieved with advanced OFA and DF burner modifications only. A NO_X reduction at peak load of 46% from 1998 levels was demonstrated using advanced OFA and DF burner modifications.

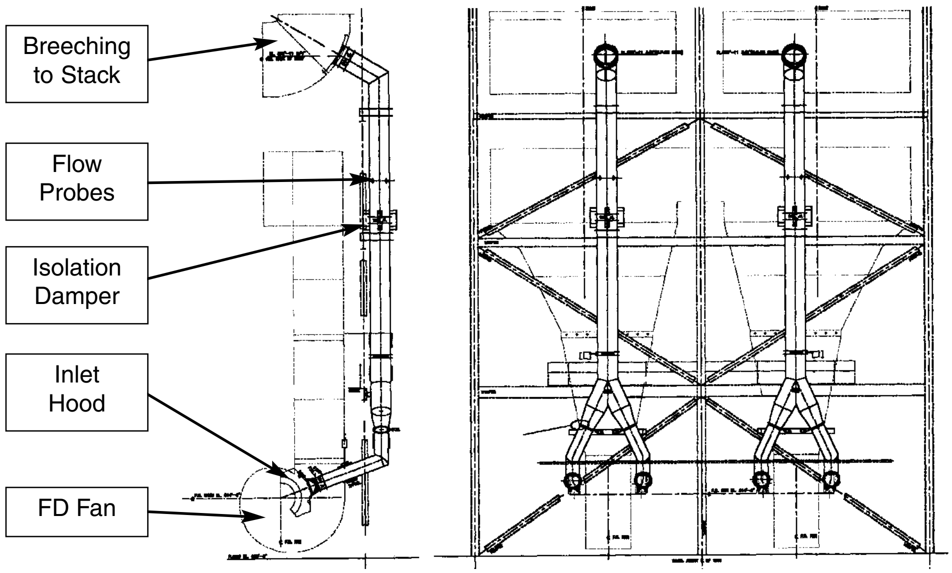

Figure 7 IFGR System Applied to Unit B

Table 2 Comparison of Pre- and Post-Retrofit Performance for Unit B

	Pre-retrofit	Post-retrofit OFA Only	Post-retrofit OFA and FGR
Boiler Data			
Boiler Load, % Peak	103	99	104
Main Pass Damper, % Open	30	30	70
Bypass Damper, % Open	100	100	100
SH Temperature, °F	969	976	962
RH Temperature, °F	990	983	969
SH Spray Flow, klb/hr	8.8	149.2	253.9
RH Spray Valve, % Open	N/A	45	65
AH Gas Outlet Temperature, °F	293	296	299
AH Leakage, %	5.6	10.4	8.8
FD Fan Data			
Static Discharge Pressure, iwg	27.8	27.0	27.7
Ambient Temperature, °F	95	64	68
Motor Current, amps	293	309	322
Fan Speed, rpm (1150 Design)	N/A	1061	1143
Damper Position, % Open	N/A	100	100
Firing Systems Data			
NO_X, lb/10^6 Btu	0.491	0.264	0.175
NO_X Reduction, %	—	46	64
CO, ppm vdc	106	94	33
Excess Air, %	5.5	4.3	4.6
IFGR, %	—	0	4.9
W/F dp, iwc	4.7	4.9	9.2

When the IFGR system was put in service, Unit B became fan limited. After further investigation, it was surmised that the following factors could be contributing to the fan limitation:

- use of > 5% IFGR for NO_X control
- abnormally high system pressure drop from main pass gas dampers being operated at only 30% open
- reduction in FD fan suction pressure due to pressure drop across inlet hoods
- increase in air heater leakage from approximately 5% to 10% since June 1998
- deterioration of the non-OEM FD fan rotor and inlet cones since June 1998

Additional optimization tests were conducted with increased OFA flow and main pass gas dampers opened from 30% to 70%. These changes resulted in an IFGR flow reduction to the design value of 5% and allowed the boiler to achieve peak load steam flow with an ambient air temperature of 68°F, however at the expense of significantly higher superheat spray flow (≈10%). A comparison of these results with pre-retrofit data is provided in Table 2. A NO_X reduction of 64% was demonstrated using advanced OFA, DF burner modifications, and IFGR. Boiler capacity is seasonally limited by the FD fan when IFGR is used for NO_X control. The customer is currently operating Unit B with OFA only, which will allow them to achieve NO_X compliance for the remainder of 2000. The customer is also working with fan consultants to explore options for performance enhancements to the FD fan.

SUMMARY

DB Riley has demonstrated that NO_X levels below 0.1 lb/10^6 Btu are achievable for natural gas fired TURBO® Furnaces without replacing the existing Directional Flame burners. NO_X reductions of up to 64% are achievable on natural gas fired TURBO® units using a combination of advanced OFA, DF burner modifications and FGR or IFGR. FD fan performance impacts must be carefully evaluated when the use of an IFGR system is being considered. Pre-retrofit FD fan performance testing and system draft loss analysis is strongly recommended in such cases.