FPL.

Manatee Energy Center, 19050 State Road 62, Parrish, Fl 34219

October 29, 2008

Ms Trina Vielhauer -Chief
Bureau of Air Regulation
Department of Environmental Protection
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

RE: Manatee Plant Reburn Project Report

Dear Ms. Vielhauer:

FPL has conducted an 18 month program to evaluate nitrogen oxides emissions rates, boiler performance and Unit operation utilizing Reburn technology on Manatee Units 1 and 2. Enclosed please find the report summarizing the test program and its results.

Paragraph 7 of the Agreement for the Purpose of Ensuring Compliance with Ambient Air Quality Standards for Ozone, which is incorporated into Air Construction Permit No. 0810010-010-AC states:

Following the receipt of the report, FDEP and FPL shall meet to discuss whether further change in the applicable nitrogen oxides emissions limit for Manatee Units 1 and 2 is possible. If FDEP and FPL mutually agree on a change in the nitrogen oxides limit for Manatee Units 1 and 2, FPL shall submit a Title V application for the Manatee Plant's Title V permit to incorporate the new, agreed-upon limit. If FDEP and FPL do not agree on any new nitrogen oxides limit for Manatee 1 and 2, the limit established in Paragraph 6 shall remain applicable.

If you have any questions or need any additional information, please contact me at (941)-776-5211.
Sincerely,

Paul Plotkin
Plant General Manager

Paul Plotkin

Enclosure:
cc: A.A.Linero, P.E. Administrator New Source Review Section, DEP

REPORT SUMMARIZING THE RESULTS OF THE REBURN PROJECT AT FPL'S MANATEE UNITS 1&2

Prepared For
Florida Department of Environmental Protection

October 2008

I. Introduction

The project goal for Reburn was to "*reduce emissions of nitrogen oxides from an existing electrical generating facility for the exclusive purpose of ensuring compliance with the ambient air quality standards for ozone, as provided by Section 366.8255(1)(d)7, Florida Statutes (2002)*"[1]. To that end, FPL installed Reburn on the fossil steam boilers 1&2 at the Manatee Plant (PMT) and agreed to a reduced emission rate of 0.25 Lb/MBtu for NOx on a 30-day rolling average. In addition, a further project goal was to potentially identify and implement the lowest emissions rate possible for Manatee Units 1&2 following an 18-month optimization period.

This report will summarize the results of the program and address whether any further change in the applicable nitrogen oxide limit is possible under tested and other alternative operating scenarios.

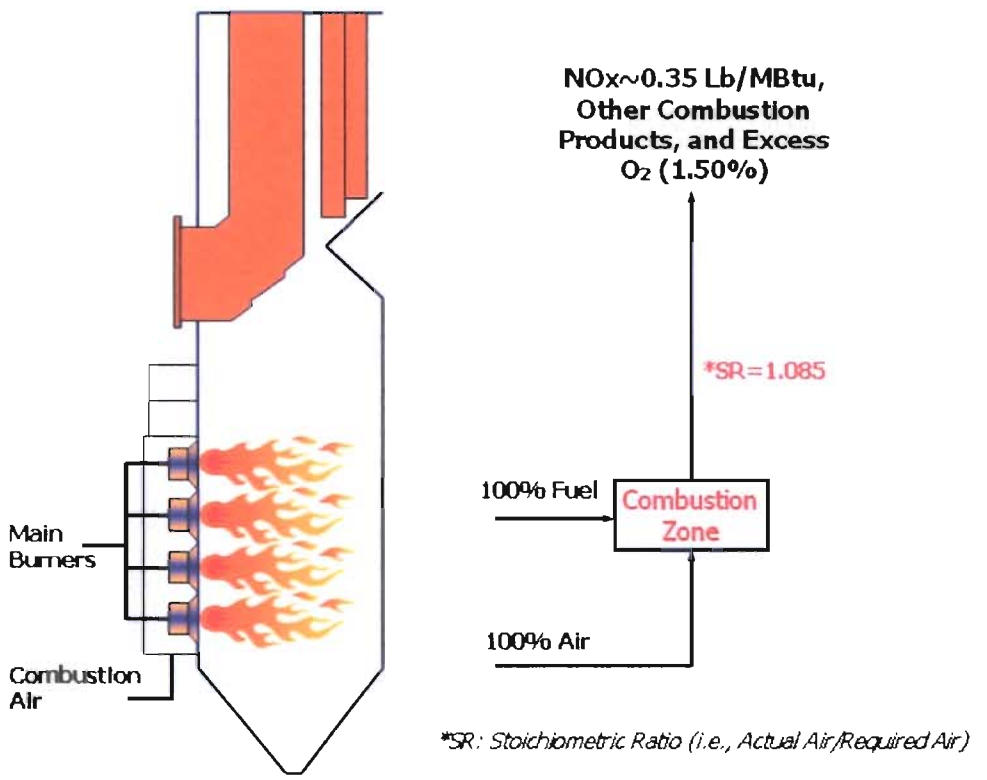
[1] "Agreement For The Purpose Of Ensuring Compliance with Ambient Air Quality Standards for Ozone, Sept. 2002"

II. Technology and Upgrades Description

Reburn is a technology which lowers the emissions of oxides of nitrogen (NOx) by inhibiting their formation, and by the chemical reduction of already formed NOx. Reburn reduces the quantity of primary fuel in the furnace, alters the primary combustion stoichiometry, injects the reburn fuel into a fuel-rich secondary zone above the primary combustion zone, and completes the oxidation of the reburn fuel with overfire air (OFA). Reburn fuel may be the same as the primary fuel, or it may be a different type of fuel. Reburn technology has many applications globally, particularly with coal-fired boilers, in which case the reburn fuel may be coal, oil, or gas. The Manatee Plant Reburn installation is the first demonstration of the technology on a large, oil-fired utility boiler.

Prior to the Reburn upgrades, PMT combustion process was optimized by controlling fuel and air delivered to the furnace (see Fig.1). For perfect combustion, the supplied air must be equal to the air theoretically required by the fuel. The ratio of actual to required air is commonly known as stoichiometric ratio (SR). Due to several process & equipment inherent inefficiencies (e.g., flame mixing, interaction between burners, localized air-fuel imbalances, etc.) optimum burning of fuels is carried out at SR greater than 1.0 in conventional combustion processes. SR is directly controlled by Excess O_2. For example, SR of 1.085 equates to the PMT targeted Excess O_2 of 1.5%Vol. at full load.

Fig.1 - Pre-Reburn Upgrade Configuration



To retrofit Reburn on Manatee Units 1&2, significant modifications of the boilers were necessary. For example, the 32 fuel main burners of the primary combustion zone were reduced to 24 burners, as shown in Figs. 2 & 3.

Fig.2 - Pre-Reburn Upgrade Configuration

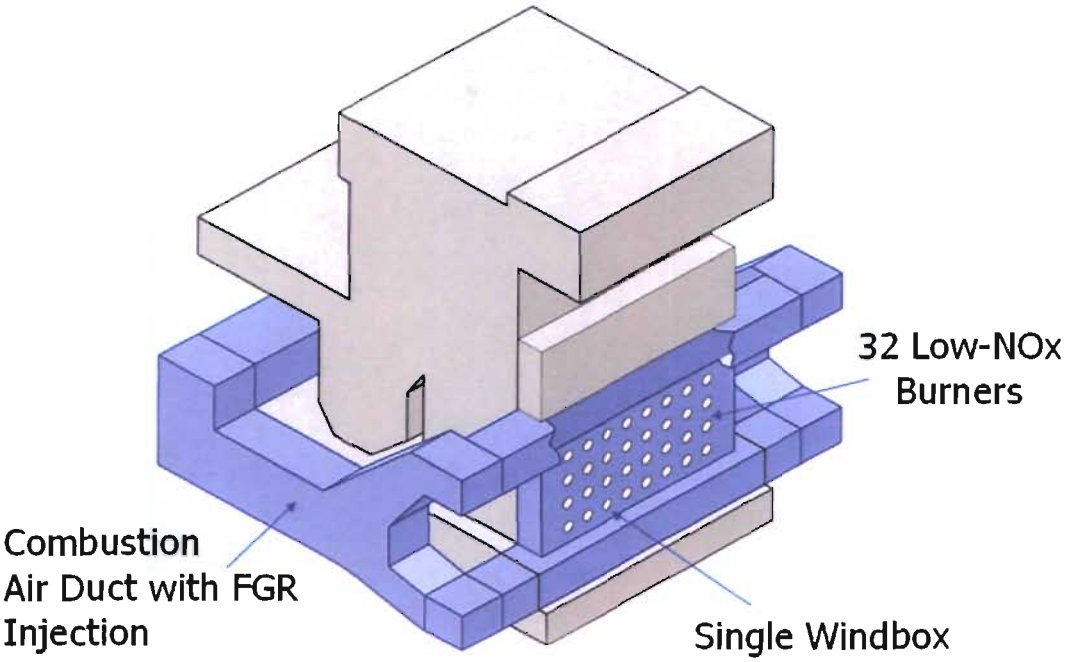
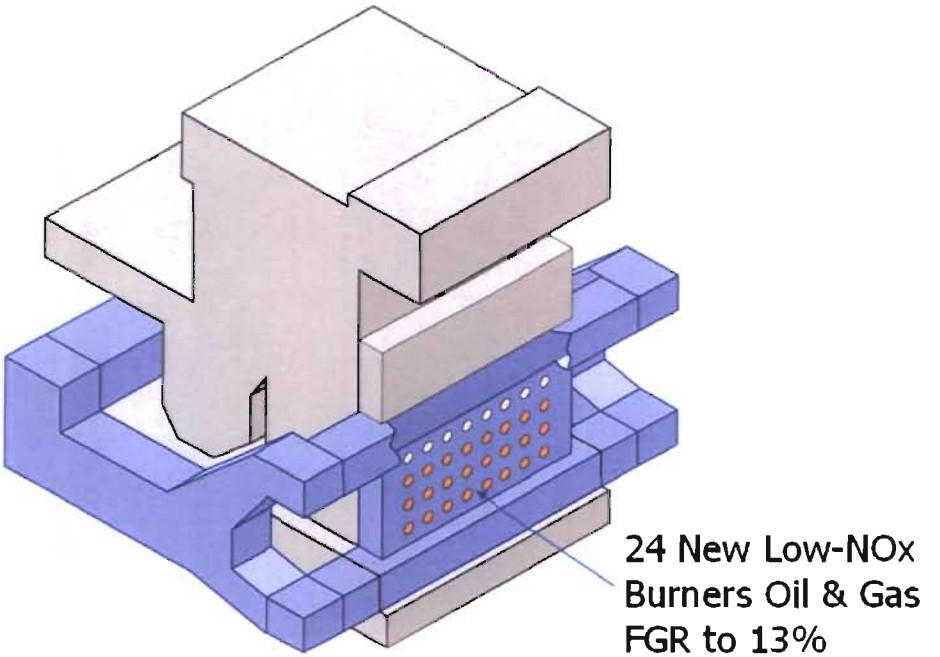
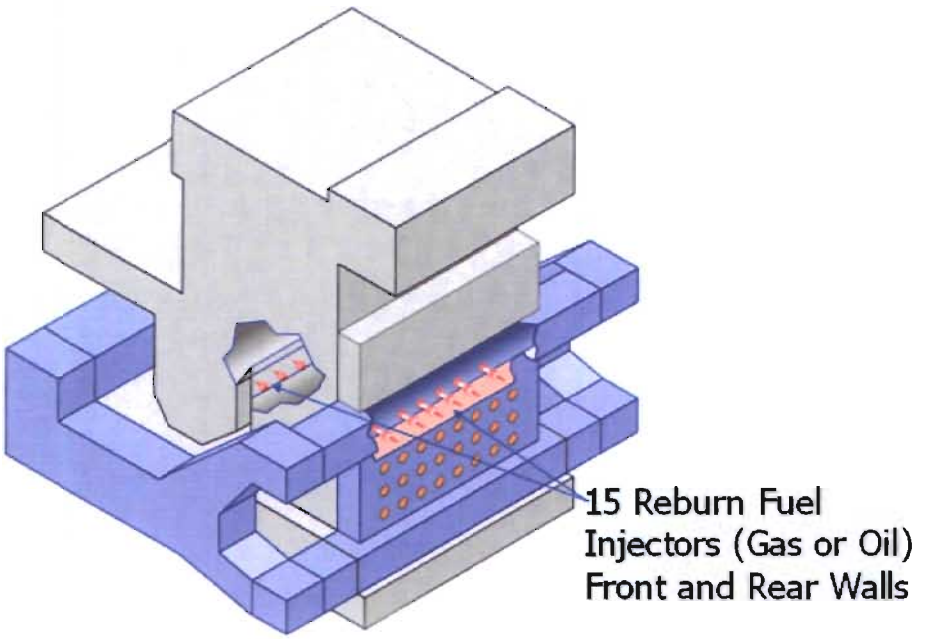


Fig.3 - Post-Reburn Upgrade (Combustion Zone)



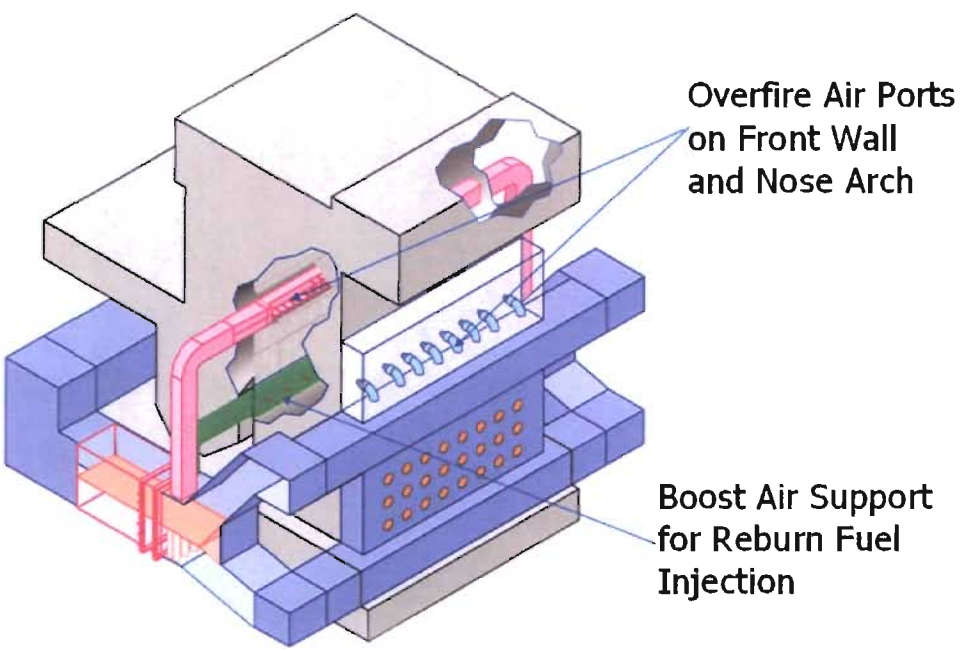
Fifteen reburn fuel injectors were added to the furnace front and rear walls [Fig. 4].

Fig.4 - Post-Reburn Upgrade (Reburn Zone)



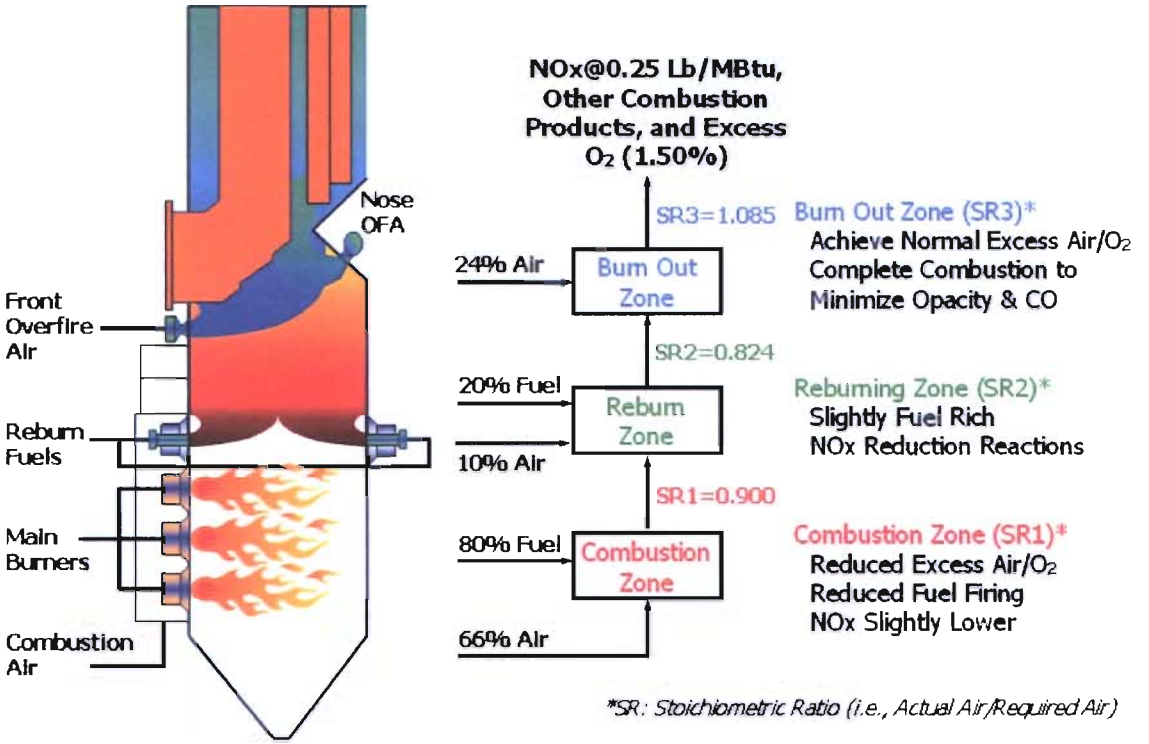
Boost air for the reburn fuel injection and OFA ports were also added to the boilers [Fig. 5].

Fig.5 - Post-Reburn Upgrade (Boost Air & OFA):



To reduce NOx generating reactions, Reburn divides the combustion process into three interacting zones, as mentioned earlier. The combustion, reburn, and burnout zones, each with its own SR, are shown in the following simplified process diagram (Fig. 6). Note fuel and air are staged at different furnace elevations to lower the peak flame temperature where maximum conversion of N_2 into NOx occurs.

Fig.6 - Post-Reburn Upgrade Configuration

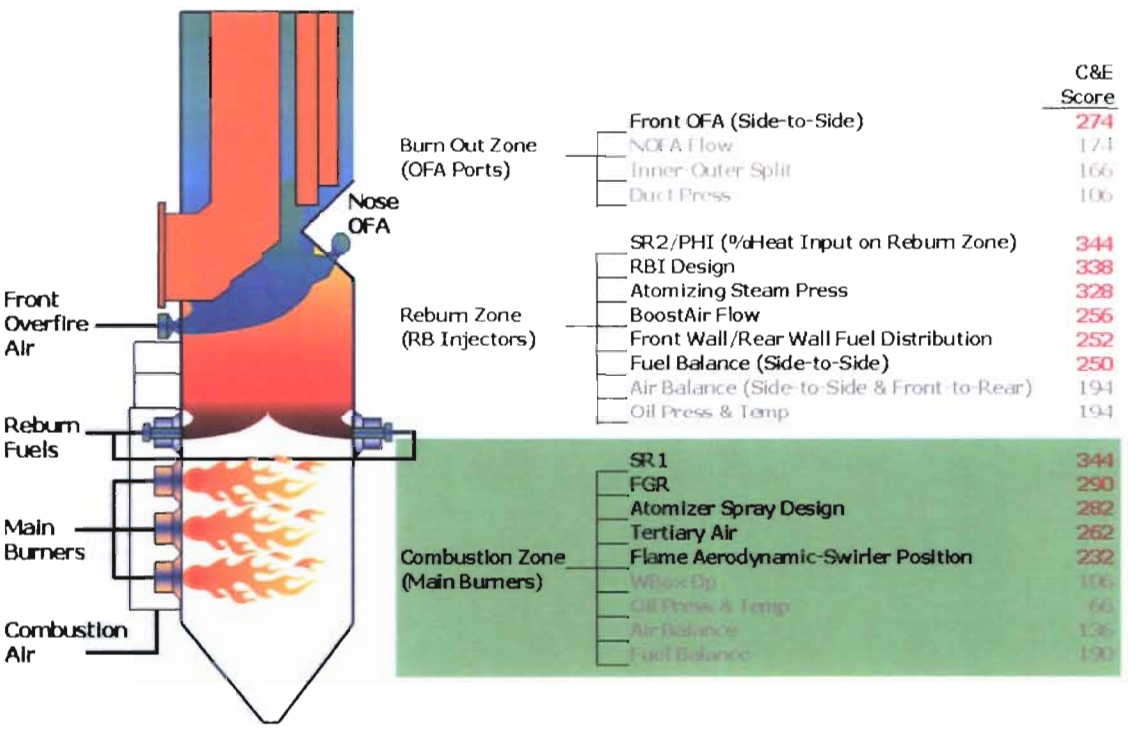


III. Optimization Process

The optimization process focused on activities in the three major boiler zones (i.e., combustion, reburn, and burn-out zones). With over twenty variables potentially affecting the Reburn process, brainstorming sessions were conducted to streamline the list. As a result, these variables were graded and ranked using a cause & effect (C&E) matrix based on their potential reduction of NOx, Opacity, Combustibles, and Excess O_2. Only those scoring high (i.e., above 200) were deemed critical variables and kept for further evaluation and optimization.

As shown in Fig. 7, the combustion zone optimization addressed five variables: stoichiometric ratio, flue gas recirculation, atomizer spray design, tertiary air, and flame aerodynamics/swirler position. As the different variables were tested, it was important to evaluate each variable's impact on the overall unit operation. While each variable could potentially be tested to its extreme end-point, unit operation could not be compromised in the short term nor sustain long term adverse effects.

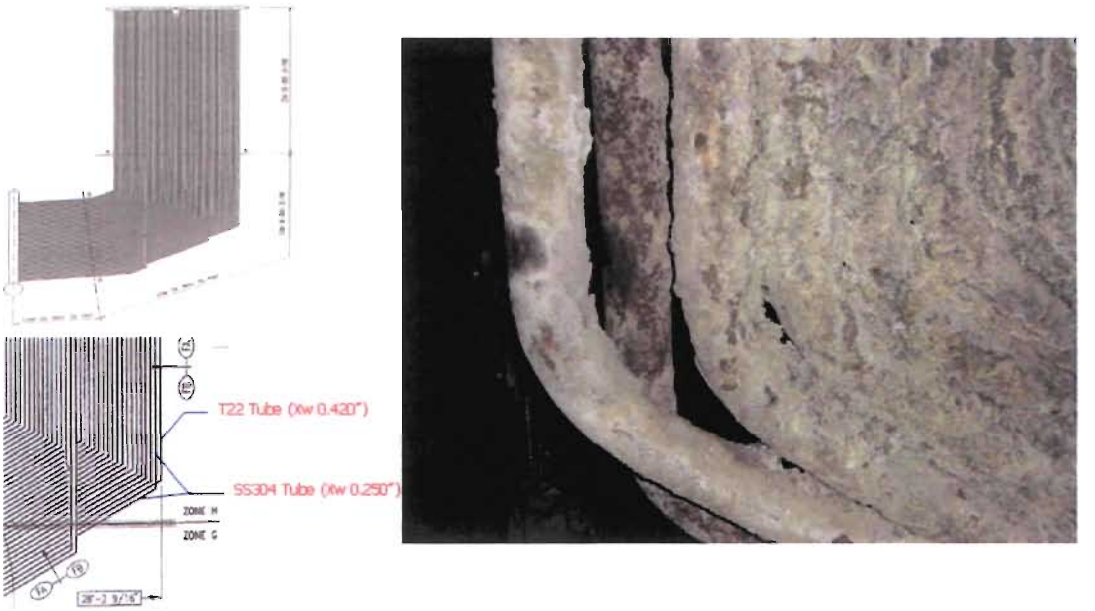
Fig.7 - PMT Reburn Combustion Zone Optimization



Combustion Zone Stoichiometric Ratio:

Performance was tested at various stoichiometric ratios. Operating the furnace at low stoichiometric ratios can cause rapid loss of boiler tube material due to strong localized reducing atmospheres in the burner zone. Heat transfer tube wastage was monitored for 10 months of Reburn operation. Results showed that the furnace waterwall tubes did not experience elevated levels of wastage. The radiant superheater showed a small degree of wastage on the carbon steel tubes, while the stainless steel leading edge tubes showed potential for early excessive wastage [Fig. 8].

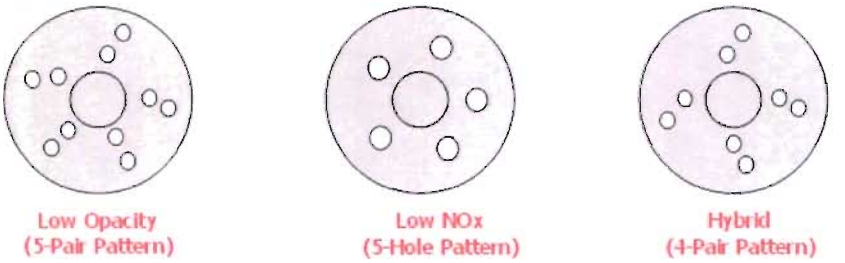
Fig.8 – PMT1 Furnace Tube Wastage: Rad SH Tube Panel



Main Burner Atomizer Spray Design:

Fig.9 - Comb Zone Opt. – Atomizer Impact on Emissions

OEM (Todd-John Zink) proposed the following three spray plate atomizer configurations for performance evaluation:

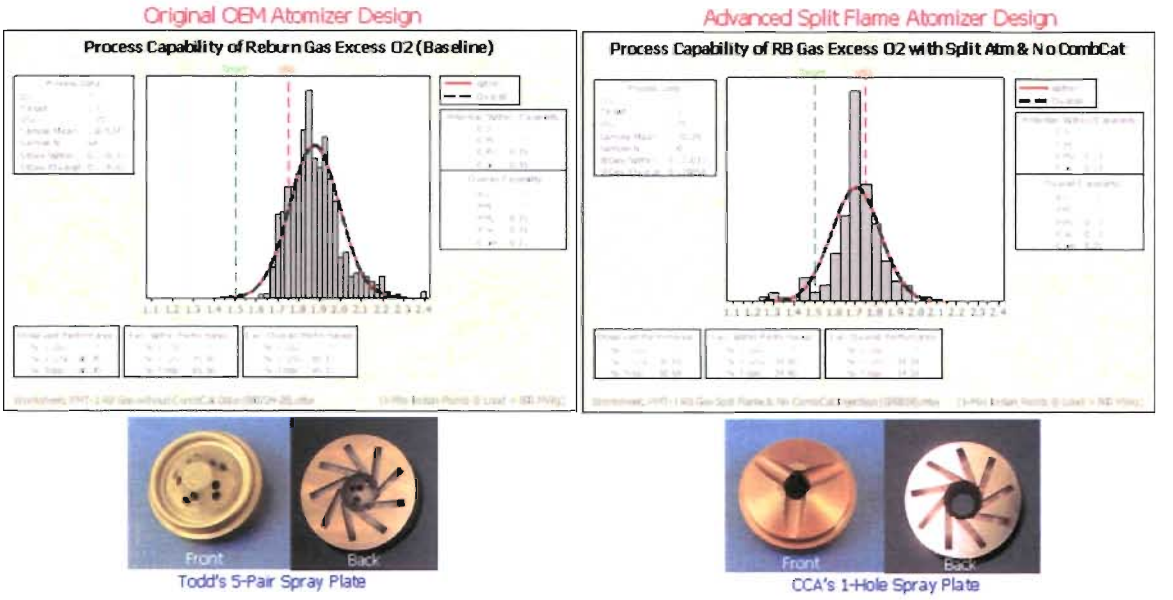


The 5-pair spray plate exhibited severe wear after only 500 hours of oil firing service [Fig.10]. The ligament between the paired holes was too thin. Poor performance of the atomizers resulted in higher NOx and Opacity.

Fig.10 - Comb Zone – Burner Atomizer Performance

Changing the oil atomizers from Todd's original 5-pair holes to Combustion Component Associates' (CCA's) single-hole split flame pattern reduced air demand & improved Excess O_2 process capability by nearly 0.5 point (i.e., -0.35 to 0.13).

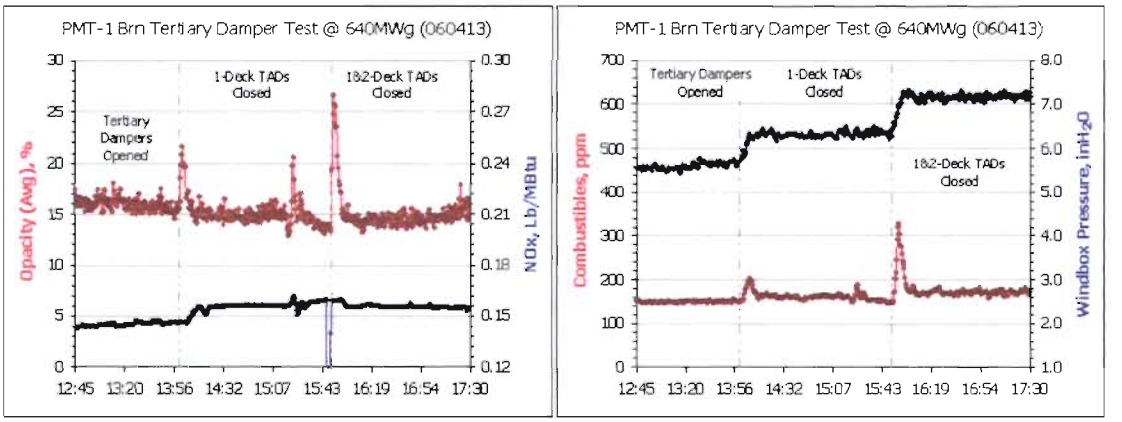
Fig.11 - Comb Zone – Burner Atomizer Perf. (Cont'd)



Tertiary Air Damper:

Fig.12 - Combustion Zone Opt. – Burner Tertiary Air Damper

Tertiary Air Dampers (TADs) were tested to quantify the impact on Opacity:

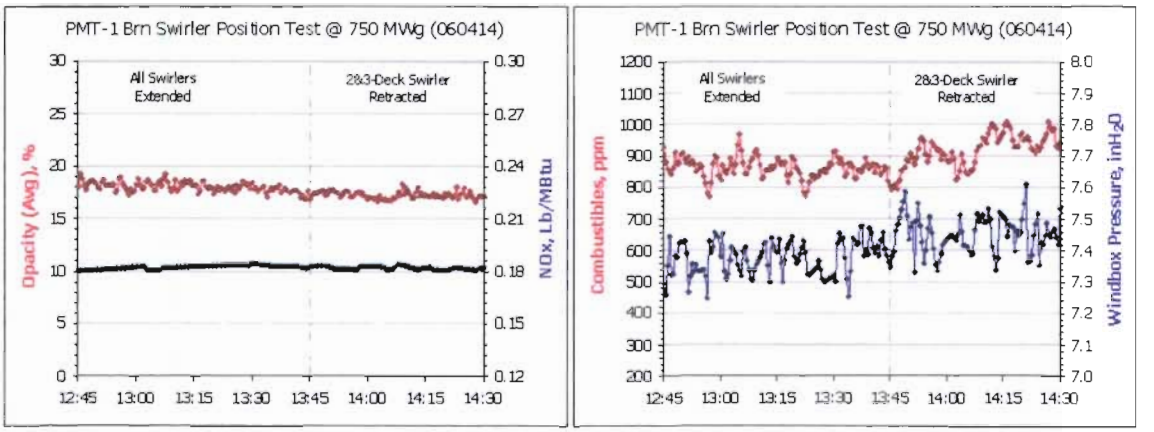


- Conclusion: Burner TADs had negligible impact on Opacity and Combustibles with slight increase on NOx. However, windbox pressure increased by 1.25 inH_2O, resulting in higher FD Fan aux power consumption. Keep TADs fully opened.

Burner Swirler Position:

Fig.13 - Combustion Zone Opt. – Burner Swirler Position

Burner Swirlers were adjusted to quantify the impact on Opacity:

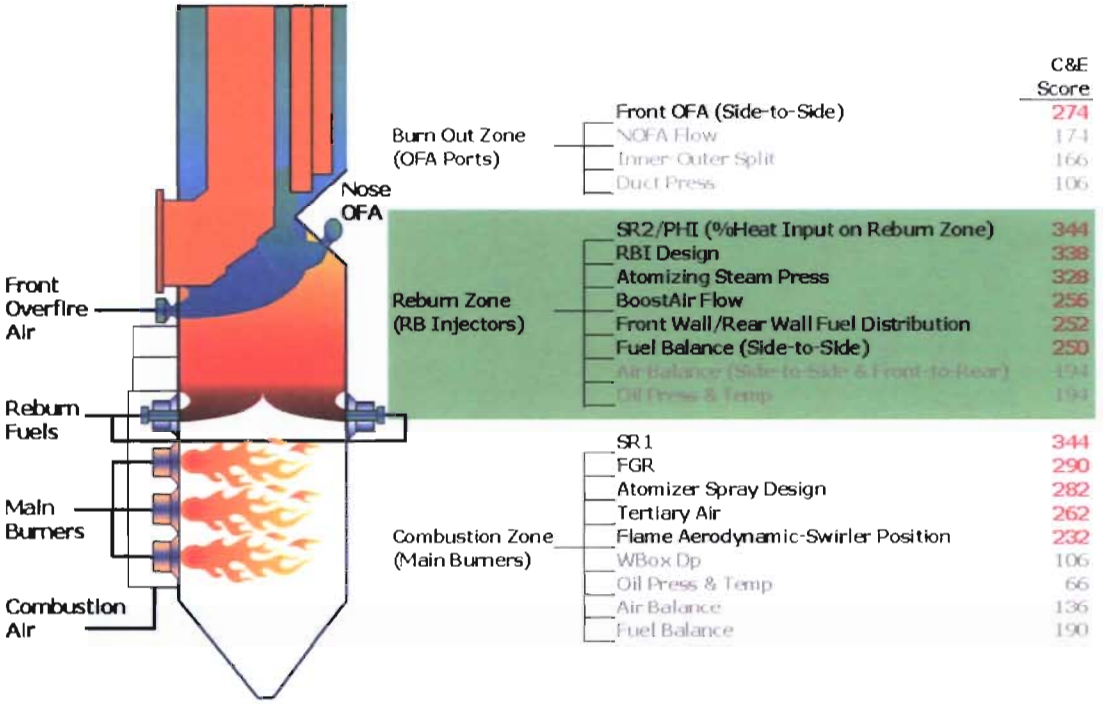


➢ Conclusion: Burner swirler positioning had negligible impact on Opacity and NOx but increased Windbox pressure and combustibles. Swirlers should be operated fully extended.

Reburn Zone Optimization:

As shown in Fig. 14, the reburn zone optimization focused on evaluating six variables: SR2/%Reburn heat input, reburn injector (RBI) design, oil atomizing steam pressure, boost air flow, reburn fuel front-rear wall distribution, and side-to-side reburn fuel balance.

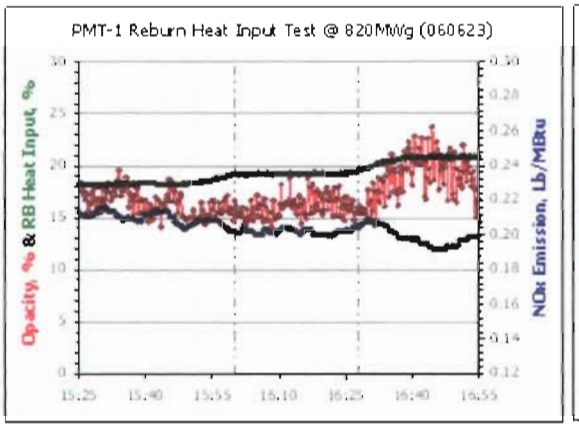
Fig.14 - PMT Reburn Reburn Zone Optimization

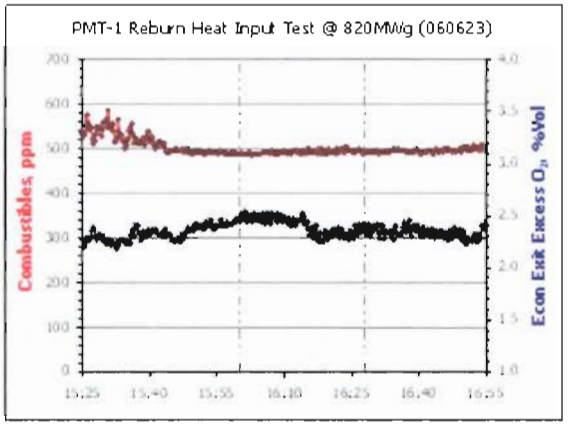


Reburn %Heat Input:

Fig.15 - Reburn Zone Heat Input Evaluation

Heat input to the Reburn zone and its impact on emissions were assessed at various loads. Here is the typical oil response at full load:





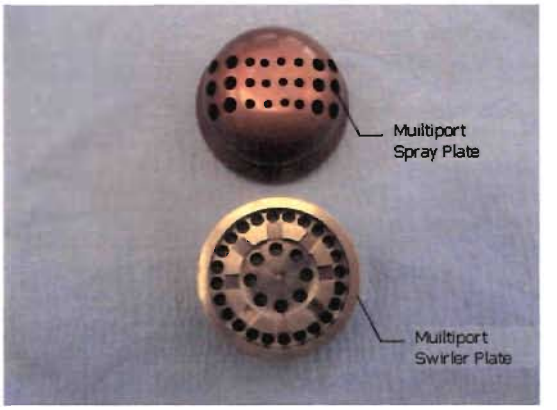
➢ Conclusion: NOx emissions were reduced with increasing RB heat input. Opacity increased above 20% heat input.

Reburn Oil Injector Design:

OEM proposed two oil injectors for performance evaluation [Fig. 16].

Fig.16 - Reburn Zone Opt. – Oil Injector Designs

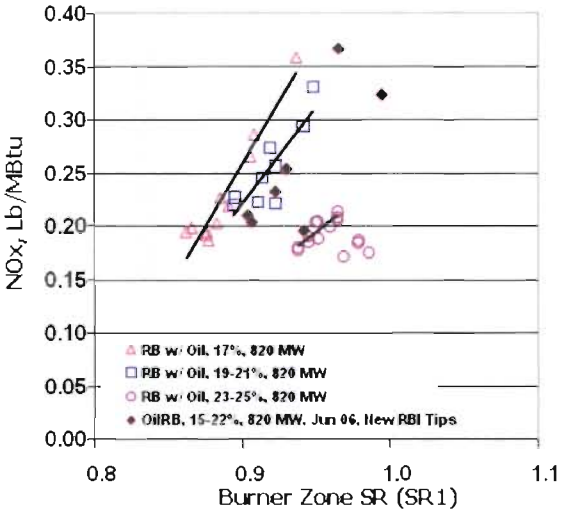
Original Slot Design

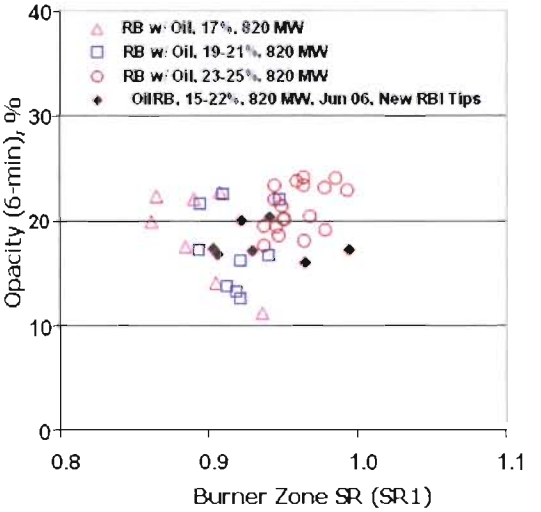


New Multiport Design

Fig.17 - Reburn Zone Oil Injector Design

These atomizer designs were tested to quantify their reburn oil injection capabilities and their NOx and Opacity responses:



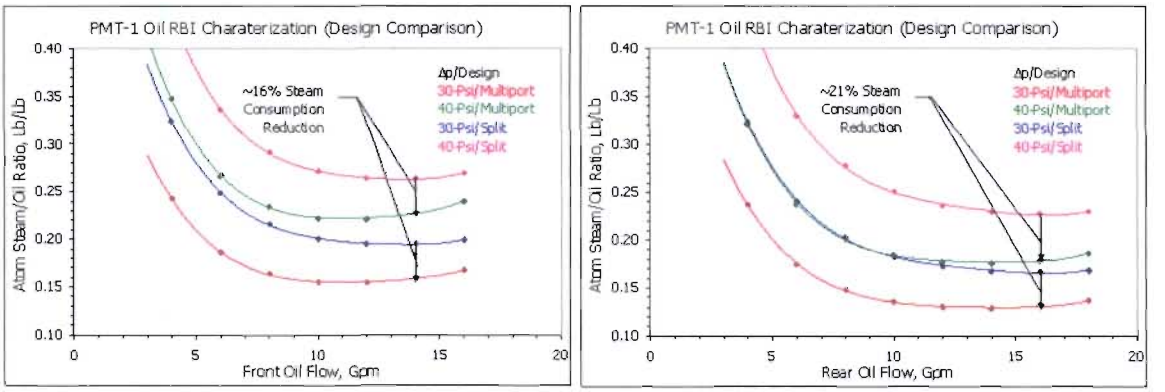


➢ Conclusion: New multiport Reburn injector oil atomizers had similar emission performance as the original slot tips.

Oil Injector Atomizing Steam:

Operating the reburn atomizers at higher than design steam pressure improved emissions, but nearly doubled the water consumption. In addition, the split-port injectors resulted in 15%-20% reduction in atomizing steam consumption compared to the original multi-port design with no significant degradation in emissions [Fig. 18].

Fig.18- Reburn Zone Oil Injector Atomizing Steam

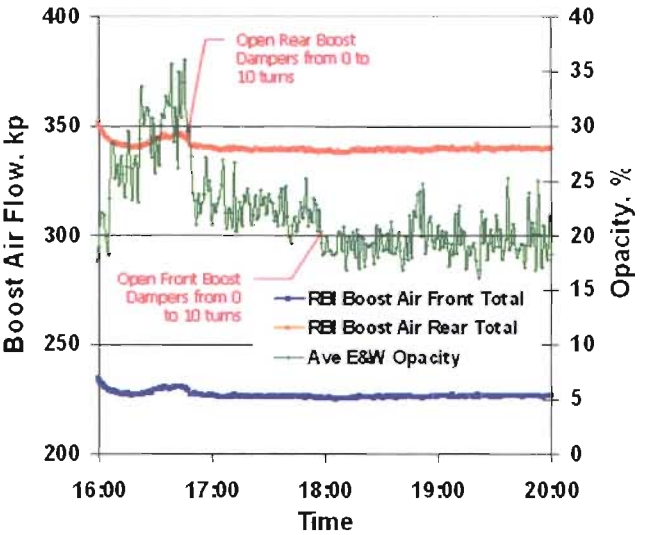


➢ Conclusion: Use the split-port option for the front and rear reburn oil injection at high atom steam pressure to minimize Opacity emission with minimum water consumption.

Boost Air Evaluation:

Fig.19 - Reburn Zone Boost Air Evaluation

Boost air to the reburn injection system (front & rear) was assessed and its impact on Opacity was quantified:

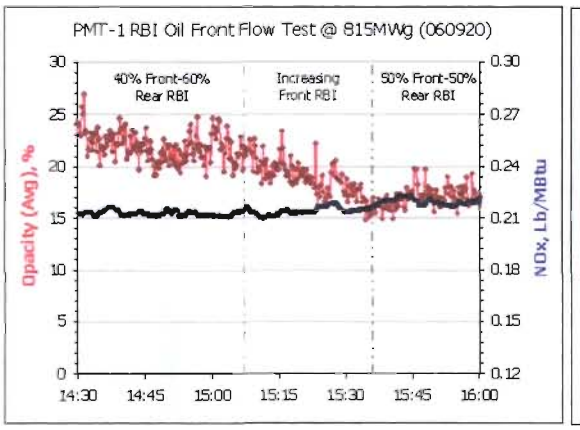


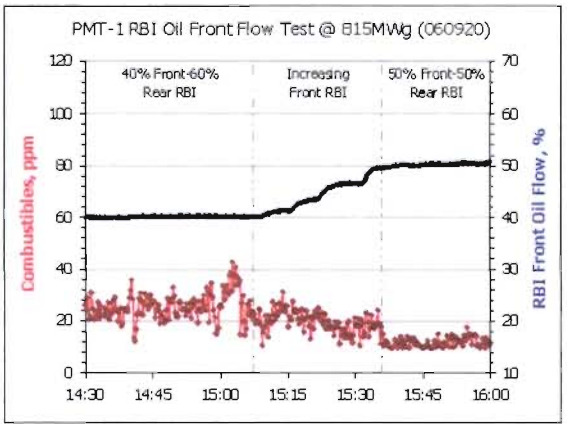
➢Conclusion: Boost air had a positive effect on Opacity. Keep front & rear air dampers fully opened.

Reburn Zone Fuel Front-Rear Balance Evaluation:

Fig.20 - Reburn Zone Fuel Front-Rear Balance Evaluation

Fuel balance between the front and rear wall injectors was assessed with the following emission performance results:





➢Conclusion: Increasing front wall fuel injection rate had a positive effect on Opacity and Combustibles. Use a minimum ratio of 50/50% Front/Rear fuel distribution.

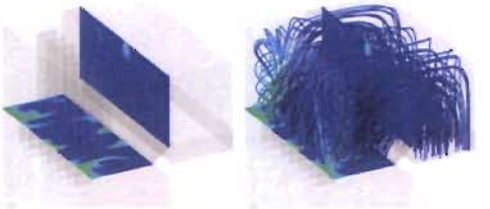
Reburn Zone Fuel-Side to Side Evaluation:

Fig.21 - Reburn Zone Fuel Side-to-Side Balance Evaluation

Fuel balance across the reburn injection system (side-to-side) was assessed from its impact on Opacity, as follows:

Unit No.1	Test No.	304	312	313	314	315	316
	GE Tst						
Test Date		19-Sep-06	20-Sep-06	20-Sep-06	20-Sep-06	20-Sep-06	20-Sep-06
Test Time	Start	12:30	13:50	14:50	15:45	16:45	17:20
	End	13:00	14:00	15:00	16:00	17:15	17:30
Test Condition		All RBIs w/throttled 50% RBI#7 (Baseline)	Adjusted RW Boost Dmprs w/throttled 50% RBI#7	All RBIs 100% Open	Reduced Rear RB Oil Flow	Increase FGR & Lower BrnO	Throttled RBI#6 & 15 50%
Gross Load	MWg	818.2	815.9	817.6	817.5	817.2	817.2
Net Generation	MWn	783.6	781.5	783.1	783.2	782.9	782.8
Reburn Heat Input	%	19.6	19.0	19.1	18.9	19.1	19.0
Econ Out O2 Avg	%	2.02	2.19	2.18	2.27	2.16	2.17
%FGR (Uncorr)	%	14.1	10.2		11.0	14.4	
Emissions							
Opacity E	%	32.4	26.6	23.7	19.1	22.4	16.3
Opacity W	%	26.3	20.4	19.3	15.6	17.4	12.9
Opacity Avg (Instan)	%	29.4	23.5	21.5	17.3	19.9	14.6
Opacity 6-Min Avg	%	30.0	28.4	22.2	17.8	21.3	17.4
Combustibles E (Servo)	ppm	61	92	42	16	42	19
Combustibles E (Ametek)	ppm	41	60	56	55	54	52
Combustibles W (Ametek)	ppm	7	7	7	7	3	7
Combustibles W (Servo)	ppm	9	9	9	9	9	9
Combustibles Avg (Servo)	ppm	30	42	28	22	28	22
APH-In Comb E (Ametek)	ppm	2	2	1	0	25	1
APH-In Comb W (Ametek)	ppm	6	7	7	7	7	6
APH-In Comb Avg (Ametek)	ppm	4	5	4	4	16	3
NOx (Ovation)	Lb/MBtu	0.173	0.207	0.213	0.218	0.200	0.200
NOx (CEM)	Lb/MBtu	0.172	0.207	0.211	0.217	0.198	0.200
	ppm	118	141	144	148	136	130
Comments:		Baseline w/RBI#7 Throttled 50%	Adjusted BoostAir Damper	Set RBI#7 @ 100% Open	Biased RB Oil toward Front by 7%	FGR from 11 to 14% & adjusted O2 to baseline	Throttled RBI#6 & 15 by 50%

CFD Predictions with RBI#7&15 Out



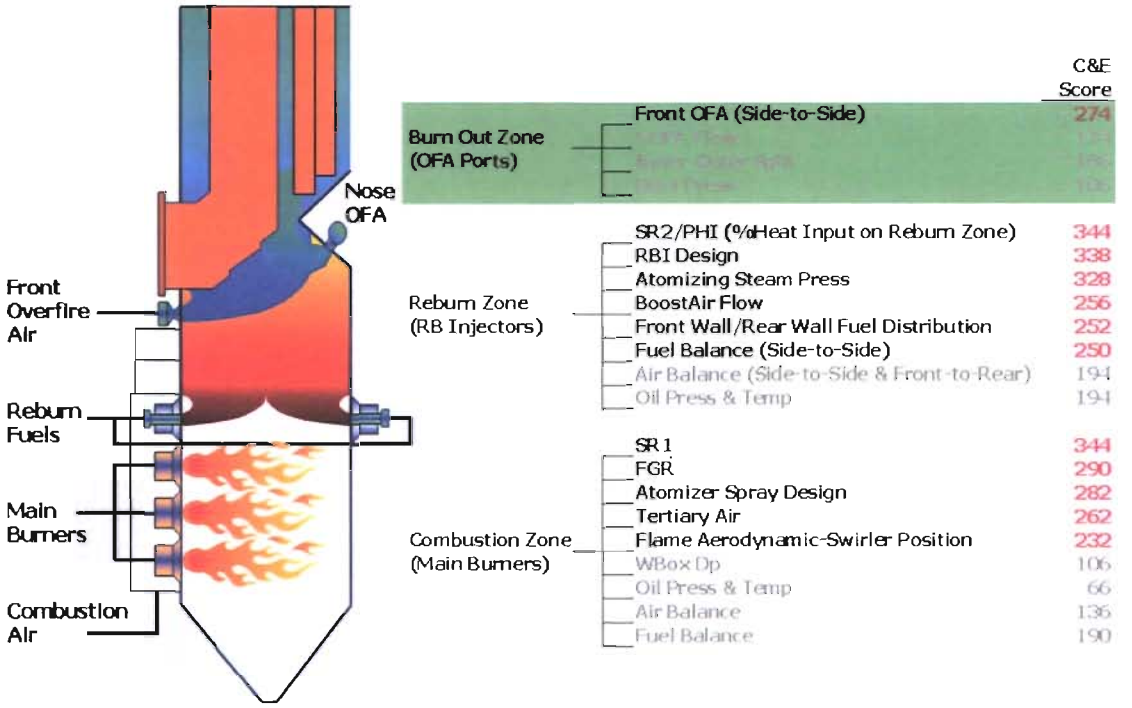
Soot Precursors Pathline Tracking

➢ Conclusion: Lowering wing fuel injection rate had a positive effect on Opacity (e.g., 19.9 went to 14.6% Opacity in above case). Use smaller atomizers at Wing RBI#1,6, 7, and 15.

Burn Out Zone Optimization:

Side-to-side balance of front OFA was evaluated as part of the burn out zone optimization, as shown in Fig. 22.

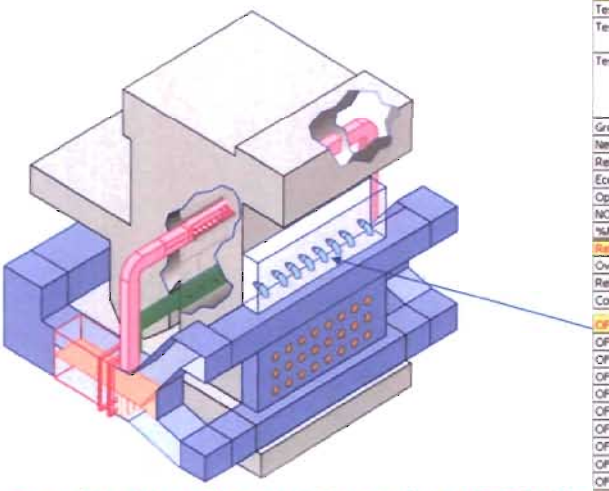
Fig.22 - PMT Reburn Burn Out Zone Optimization



Air Side-to-Side Balance Evaluation:

Fig.23 - Burn Out Zone Air Side-to-Side Balance Evaluation

Air balance across the over fire air system (side-to-side) was assessed from its impact on Opacity, as follows:



Unit No.2	Test No.	64	65	66
Test Date		18-Jan-07	18-Jan-07	18-Jan-07
Test Time	Start	16:50	18:15	19:30
	End	17:05	18:30	19:45
Test Condition		Increased PHI from 18 to 20	Increased FGR at Settled O & OFA PIDs	Reduced Overall O & Adjusted OFA Ports
Gross Load	MWg	808.8	810.5	810.6
Net Generation	MWn	773.9	775.2	776.4
Reburn Heat Input	%	19.4	20.0	20.0
Econ Out O Avg	%	2.39	2.35	1.95
Opacity (Avg)	%	17.9	17.2	18.8
NOx (Ovation)	Lb/MBtu	0.194	0.184	0.181
%FGR (Uncorr)	%	16.9	18.0	18.4
Reburn Stoichiometrics				
Overall (SR3)	Ratio	1.212	1.198	1.172
Reburn Zone (SR2)	Ratio	0.835	0.829	0.831
Combustion Zone (SR1)	Ratio	0.907	0.907	0.907
OFA Ports				
OFA 1 (West)	%	41.5	44.3	44.2
OFA 2	%	31.4	34.3	29.2
OFA 3	%	31.4	34.3	26.1
OFA 4	%	32.0	34.8	24.7
OFA 5	%	31.8	34.6	24.6
OFA 6	%	31.3	34.0	26.3
OFA 7	%	31.3	34.2	29.1
OFA 8 (East)	%	41.4	44.5	43.8
OFA Damper (Avg)	%	34.0	36.9	31.0

➢ Conclusion: Increasing wing OFA flow had a positive effect on reducing Excess O_2. Use smiling-face configuration (i.e., more open toward the wing ports).

IV. Summary, Results, and Conclusion

1. NOx from the Combustion Zone had a strong correlation with Flue Gas Recirculation and SR1. High flue gas recirculation and low SR1 result in low NOx. Excess O_2 has no effect on main burner NOx generation.

2. Assessment of furnace and radiant panel tubes showed little corrosion. Visual inspections found that wastage was most marked on Radiant Panels #6 & 7.

3. Based on the industry experience for low stoichiometric ratios of 0.8, new Manatee Plant limits were defined for sustained long operating performance. Combustion SR1 should be limited to 0.9 so that Reburn SR2 is maintained at or above 0.8 in order to avoid long term degradation of furnace waterwalls.

4. Todd's Low-NOx (5 pair-hole spray) and Hybrid atomizers produced similar Opacity but higher NOx than the Low-Opacity style. However, Low-NOx design exhibited severe wear after 500 hours of service.

5. Combustion Components Associates' single hole split flame atomizer was significantly more wear resistant and capable of operating up to 5,000 hours. This new atomizer reduced the NOx emission spread but did not shift the mean.

6. Burner tertiary air had negligible impact on Opacity and Combustibles with a slight increase in NOx. However windbox pressure increased by 1.25 inH_2O. Burner tertiary air dampers should be kept fully open.

7. Burner swirler positioning had negligible impact on Opacity and NOx but increased windbox pressure and combustibles. The swirlers should remain fully extended.

8. NOx emissions were reduced with increasing Reburn heat input. Opacity increased above 20% heat input.

9. New multi-port reburn injector oil atomizers had similar emission performance as the old slot tips.

10. Increasing reburn injector atomizing steam-oil differential pressure has a positive effect on Opacity while maintaining NOx. However it significantly increased the water consumption of the reburn system. Use the split-port option for the front and rear reburn oil injection at high atomizing steam pressure to minimize NOx and Opacity emissions and reduce water consumption by more than 15%.

11. Reburn boost air had a positive effect on Opacity. Keep front and rear air dampers full opened.

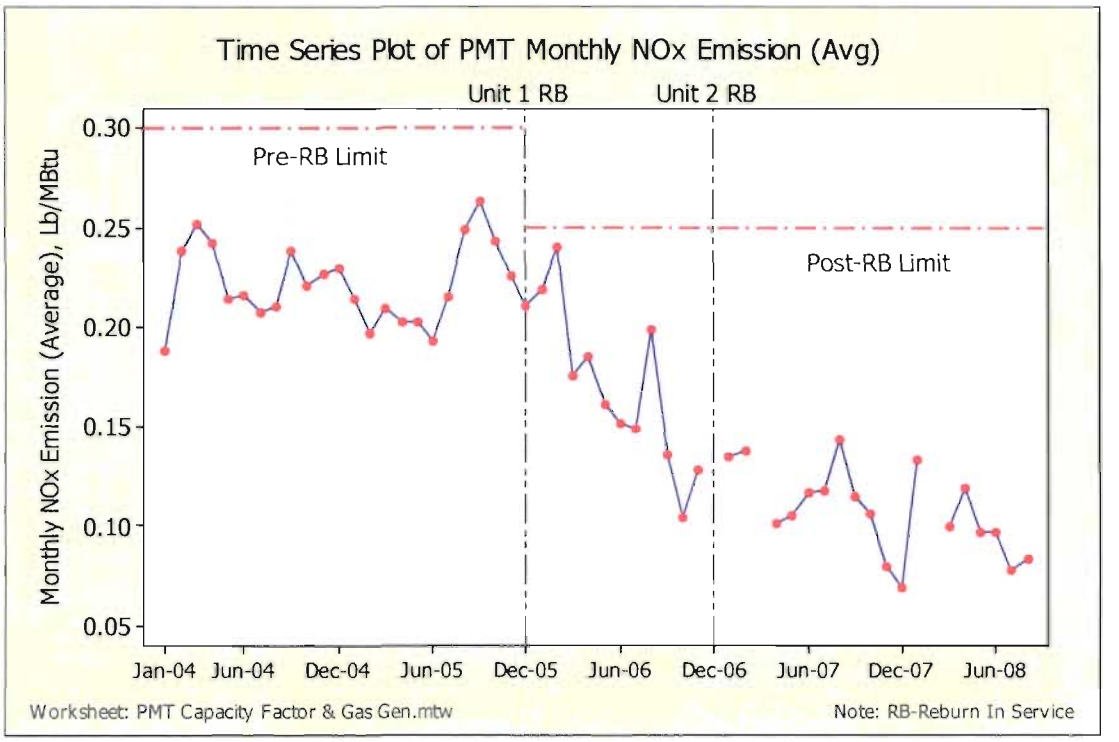
12. Increasing front wall fuel injection flow had a positive effect on Opacity and Combustibles emissions. Use a minimum reburn injector fuel ratio of 50/50%, front to rear.

13. Lowering wing fuel injection rate had a positive effect on Opacity. Use smaller RBI atomizers at Wing Ports #1, 6, 7, & 15.

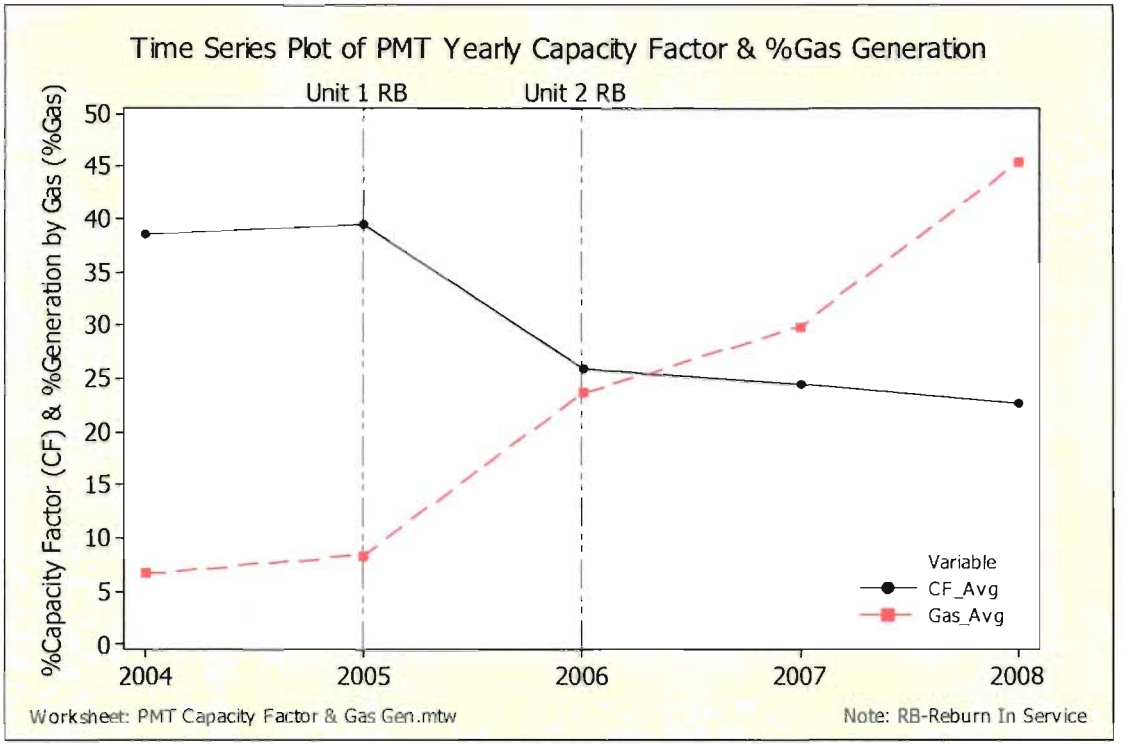
14. Increasing wing Over-fire-air flow had a positive effect on Excess O_2. Use "smiling-face" configuration (i.e., more open toward the wing ports).

Final Considerations:

PMT monthly average NOx emissions are shown below. Note the consistent downward trend since the first unit was upgraded with Reburn in December 2005.

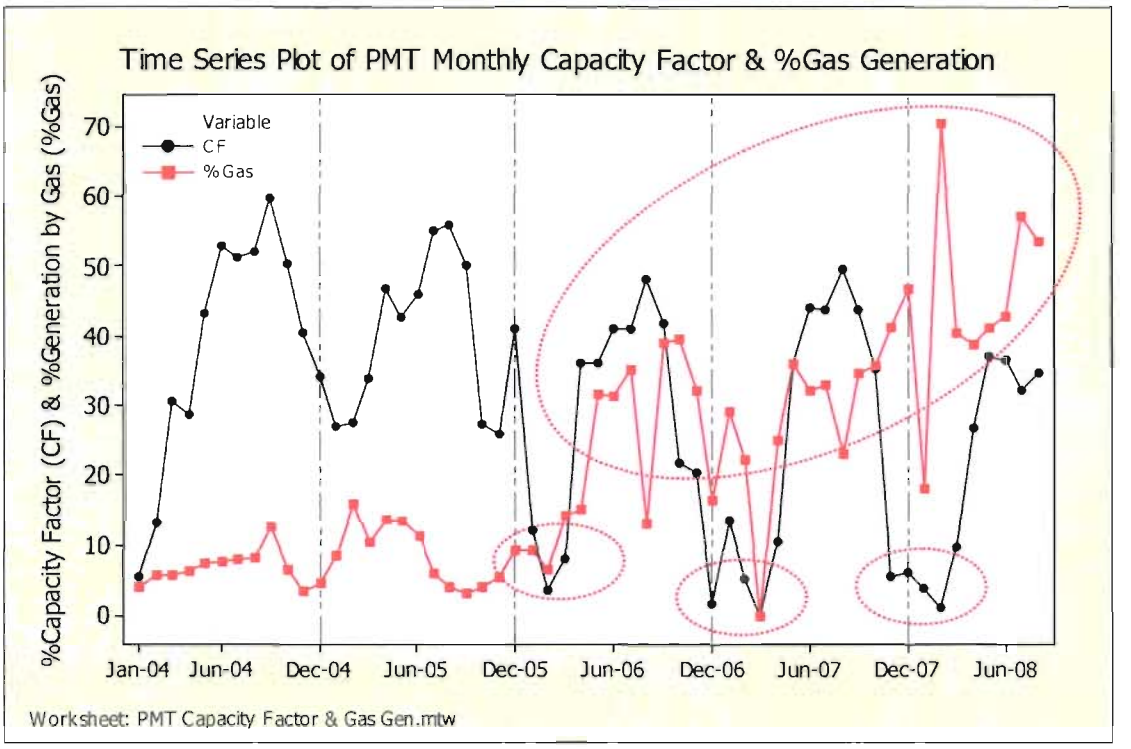


To validate this performance, unit dispatching and fuel mix were further examined. Manatee Plant average capacity factor and percent of generation from natural gas (since 2004) are shown below. Note the changes coinciding with Reburn upgrade implementation:



- Conclusions: Gas firing has steadily increased, from 7% to 45% since the first Reburn upgrade in 2005. In addition, average capacity factor has dropped from 39% to 23% over the last 3 years.

In order to better understand the variability, PMT monthly capacity factor and % gas generation were trended. Note the large variations in gas firing during the last 3 years, along with the frequent periods of low capacity factors.

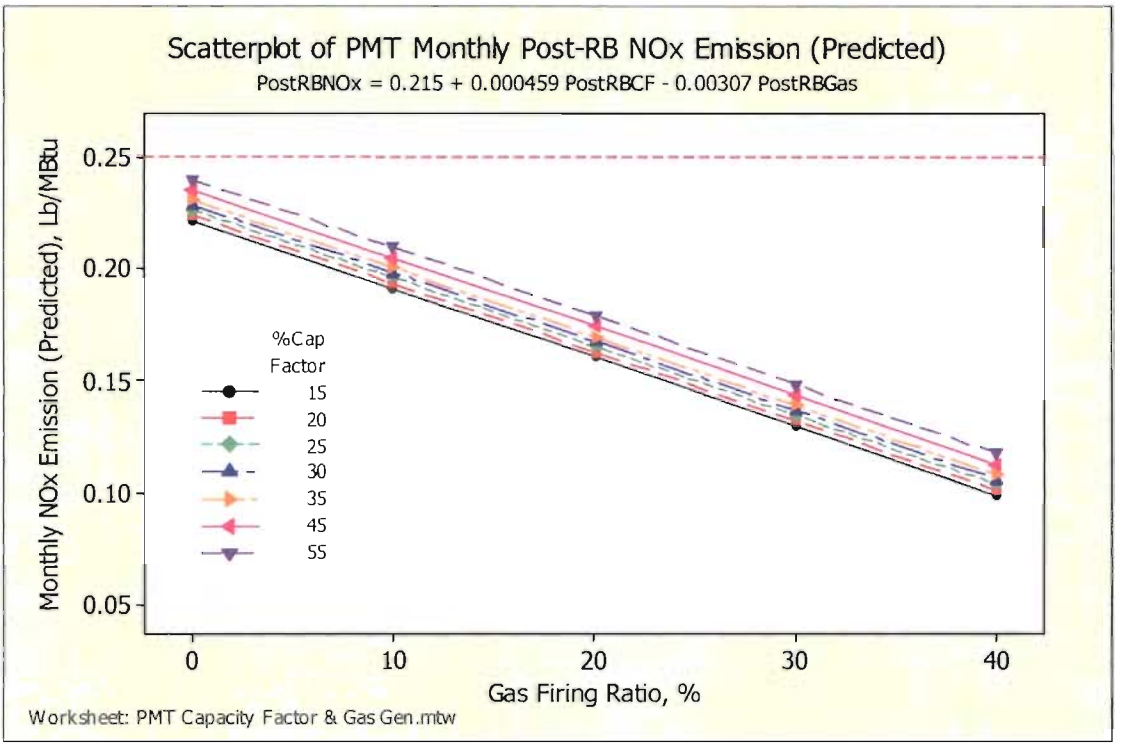


In order to normalize NOx emissions by unit dispatching differences before and after the Reburn upgrades, post-Reburn monthly NOx was correlated as a function of capacity factor and gas firing:

```
The regression equation is:

PostRBNOx = 0.215 + 0.000459 PostRBCF - 0.00307 PostRBGas

Predictor        Coef     SE Coef      T      P
Constant      0.21515     0.01109  19.41  0.000
PostRBCF    0.0004592   0.0002459   1.87  0.073
PostRBGas  -0.0030677   0.0003069  -9.99  0.000

S = 0.0199285   R-Sq = 79.4%   R-Sq(adj) = 77.8%

Analysis of Variance
Source          DF        SS        MS      F      P
Regression       2  0.039742  0.019871  50.03  0.000
Residual Error  26  0.010326  0.000397
Total           28  0.050068
```

- Conclusion: Unit capacity factor and gas firing explained nearly 80% of the Manatee Plant post-Reburn NOx variability ($R^2 = 0.794$).

Using this correlation to normalize NOx emissions, post-Reburn NOx emissions were calculated at various capacity factors and gas firing ratios, as shown here:



Note that as the gas firing ratio is reduced, NOx emissions increase rapidly.

- Final Conclusion: Data shows that Manatee Plant's Reburn NOx monthly average emissions are highly dependant on gas firing ratio and unit capacity factors. Further change in the applicable nitrogen oxide limit is not possible under alternative operating scenarios.

- Final Recommendation: Manatee Plant's NOx operating limit should be kept at its current level of 0.25 Lb/MBtu (30-day rolling average) to allow flexibility in responding to system load demands and gas pricing/availability issues.