Boiler Tuning with SPO: The Critical First Step in the NOx Compliance Strategy Of Central & South West Company

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INTRODUCTION

Across the United States, more and more utilities are focusing on cost effectiveness of boiler strategies to comply with the 1990 Clean Air Act Amendments (CAAA) NOx regulations in advance of the upcoming deregulation of the industry. When utilities are deregulated, they will be in a fully competitive environment. On the operations side, this means they must find ways to deliver services more efficiently without compromising environmental goals.

Boiler tuning is a logical first step in meeting both these challenges. It offers the best cost-benefit ratio and can determine if it is possible to avoid retrofits or repowering altogether. Many utilities are employing a tuning technology developed by Ultramax® Corporation and the Electric Power Research Institute (EPRI), based on Sequential Process Optimization (SPO)[1], as a cost-effective first-pass tool to gain emissions and performance improvements before consideration of capital expenditures. DO also enables these utilities to attain the right degree of compliance with current and future phases of CAAA[2]. It provides for a staged strategy for staying ahead of emissions regulations, but not so far ahead as to cause regret for taking actions that ultimately are not mandated or warranted.

This paper reports Central & South West (C&SW) Services' case study investigation of DO as a tool for both compliance and cost-action strategy. C&SW operates generating facilities in Oklahoma, Texas, Arkansas, and Louisiana. In Tailored Collaboration with EPRI, C&SW has applied DO to tune a single coal-fired unit as a test case for possible system-wide usage.

C&SW COMPLIANCE AND COST STRATEGY

C&SW's 14,200 MW generation mix includes nine solid fuel units that burn western coal and Texas lignite. All of these units are affected by Phase 2 NOx requirements of the CAAA. The thrust of C&SW's investigations centered around the early election option provision of the Title IV NOx rules of the CAAA. This provision would shelter Phase 2 units, such as C&SW's, under Phase 1 NOx limits until January 1, 2008. Early election would also defer any capital expenses until 2007, provide relief from any immediate restrictive Phase 2 limits that could be promulgated, and allow for application of new cost-effective technologies during the extension period.

Given the strategic advantages of the early election provision, C&SW began a search for an appropriate technology to drive NOx to its lowest level, in order to show the true capability of its units and the margins that would be available when the Phase II limits were prescribed by January 1997. C&SW required that the selected technology be least cost with minimal impact on performance and minimal downtime during implementation.

C&SW's preliminary analysis of plant NOx emissions suggested that combustion optimization would be an ideal solution at this initial stage of the strategy. The chief optimization approaches under consideration were parametric testing and the ULTRAMAX Method, a non-intrusive, DO-based technology co-developed by EPRI and Ultramax Corporation.

PARAMETRIC TESTING VS. DO

Detailed parametric testing is often used to quantify the effects on NOx emissions of changes in individual operating conditions. This involves the design of a relatively large set of runs to form a test matrix of all parameter combinations to be studied. During a test run, the control setting of only one parameter is adjusted with all others held constant. After all runs have been completed, the data are analyzed and best operating conditions identified.

Traditional parametric testing that follows this procedure of changing only one parameter at a time does not reflect the influence on performance of interactions between all parameters. Knowledge of these interactions is crucial in boiler applications, as optimum combustion conditions depend on a highly interrelated group of controlled parameters (such as airflows and burner tilts) and uncontrolled parameters (such as load and fuel quality) that can vary unpredictably.

As a consequence, parametric testing-based operating procedures are useful as general guidelines for NOx control and overall boiler performance, but they cannot identify conditions that balance emissions control and thermal performance. Plant operators thus rely on their knowledge to tune airflow and burner settings, but it is difficult for experience-based tuning to optimize performance because of the dynamics and increased complexity of boiler control, as well as individual operator preferences.

The ULTRAMAX Method of DO consists of procedures and computer software that utilizes data from the boiler unit acquired during normal operations at parameter settings under operator control. These settings, recommended by the software, take advantage of minor perturbations from standard settings in order to learn their effects on emissions and thermal performance[3]. The software then immediately analyzes the data after each test run to create statistical models and search for optimal combinations of settings.

The critical element of the DO is that each run is devised independently after detailed analysis of all data from previous runs. For each run, *all* control settings are purposefully and simultaneously adjusted; resultant performance effects are observed; models are created reflecting the influence of all input parameters; and new settings are advised for the next run, which is likely to obtain improved performance.

Because data analysis and model refinement occur after each run, settings that may harm performance can be immediately identified and eliminated from consideration, which facilitates continuous improvement along a course toward optimum operations. This characteristic makes ULTRAMAX DO suitable for normal operating environments, unlike parametric testing. In addition, the cause-and-effect relations captured in ULTRAMAX models allow immediate, intelligent response to changes in uncontrolled variables, such as load, fuel quality, and seasonal temperature. Other noteworthy features of DO utilization are conditioned simulations, what-if tests, and sensitivity analysis.

After initial optimization and modeling, the next stage is to establish an on-line operator advisory capability by linking the models and software to the distributed control system[4]. This enables the operator to maintain optimal performance dynamically under changing fuel, operational, environmental and business conditions.

OPTIMIZATION WITH DO

After weighing the advantages and disadvantages of these two approaches, C&SW chose to test the value of DO by optimizing Unit 1 at Oklaunion Power Station, a plant in Vernon, Texas, operated by West Texas Utilities. Unit 1 is a Foster-Wheeler opposed-wall boiler fueled by pulverized coal and rated at 666 MW net. The project was undertaken through a Tailored Collaboration with EPRI and managed by a team composed of staff from C&SW, Oklaunion Power Station, and Ultramax Corporation.

Optimization of Unit 1 took place in 1995, from September 25 through September 29, and October 9 through October 13. In addition to reducing NOx to its lowest level, goals for the project were to maintain CO, LOI, and opacity limits. These objectives were to be achieved under acceptable operating conditions and without violating any operating constraints. Also, C&SW wished to evaluate the ease of applying the technology and the demands on plant personnel.

Using the ULTRAMAX Method of DO for boiler optimization requires three distinct steps as shown in Figure 1: process formulation, sequential optimization and engineering analysis, followed by linking to a data acquisition system. To develop the process formulation, the knowledge of plant operators, engineers, and others familiar with the boiler and control system was pooled to identify and categorize key input and output parameters, operating constraints, and optimization goals.

The initial choices and subsequent refinements resulted in the formulation shown in Figure 2. The abbreviated names are defined in Table 1. The following controlled inputs were included in the eventual formulation: O_2 bias; upper, middle, and lower hood position (see Figure 3); feeder bias F and D; and air bias F, E, B, and A. Outputs were FEGT, heat rate, CO, economizer outlet temperature, LOI, opacity, superheat and reheat temperatures, superheat and reheat spray, average O_2, and windbox pressure. NOx was the minimizing variable.

Historical baseline performance for Unit 1 was established from data obtained on September 25 under normal operating conditions and automatic control complemented by normal operator adjustments. The average of five test runs was used as the Unit 1 baseline for full load. The baseline NOx value was 0.49 lb/MBtu, heat rate was 9833 Btu/kWh, and LOI was 1.1 percent.

Using the baseline as a starting point, an iterative, run-by-run procedure was followed as new settings were recommended by the ULTRAMAX software after it analyzed the results obtained from previous runs. These were operator controllable settings and did not involve loop changes for gain, reset, etc. The parameter adjustments were accomplished in a matter of minutes.

A test run started with advised new settings from ULTRAMAX for each of up to 10 key controlling parameters. After a critical review, the operator implemented these settings, or some modified ones, since it is not necessary to follow the advice. After a 15-20 minute period to allow for unit stability, measurements of each output parameter were recorded including NOx, LOI, CO and steam temperatures. These were averaged for 15 minutes in order to dampen system noise. A run was completed in about an hour when this data was entered into ULTRAMAX which updated its models, revised its optimum estimates and offered a new advice. In this way, learning took place after each run and this new knowledge was used by the software in advising the next set of adjustments. This enabled the sequential development of models that reflected the current behavior of the boiler and discovered a path toward true optimization.

The DO approach is intended to blend with standard daily operating procedures, so most results data were available directly from the Westinghouse DCS. An exception was LOI that required a laboratory test usually performed off-site. Because LOI values were needed on an hourly basis, a HOT FOIL® LOI Instrument developed by Fossil Energy Research Corp. and EPRI was used. With this instrument, the analysis of an ash sample took about 15 minutes, a satisfactory time-frame for sequential optimization.

IMPROVEMENTS OBTAINED

The total of 80 runs were conducted during the project under advice provided by the ULTRAMAX DO software. At the completion of sequential testing, the best runs for the specified goal were examined and tested again on a three-hour verification run to confirm the validity of the settings. These were then recommended for a new baseline.

The most successful run, at a unit load of 666 MW, produced the following results:

- NOx was lowered from 0.49 lb/MBtu at baseline to 0.40 lbs/MBtu, a reduction of 18 percent.
- Heat rate decreased from 9833 Btu/kWh to 9812 Btu/kWh, a reduction of 0.3 percent.
- LOI decreased from 1.10 percent to 0.16 percent, a reduction of 85 percent.
- All other performance and emission constraints were satisfied.

A comparison of the results of the best run with baseline results is shown in Table 2. Also, a comparison of the optimized settings which produced these results versus the baseline settings is shown in Table 3.

These results were achieved over a two-week period during normal work hours, with the boiler in normal dispatch and no testing interruptions. NOx was reduced run-by-run as better combinations of parameter settings were "discovered" based on advice from the models (see Figure 4).

In addition, optimization with DO identified the relative influence of each input variable on each output variable. For example, the Oklaunion Power Station staff has learned that the greatest influence on NOx is the D feeder bias, followed by the O_2 bias, the lower hood position, and the F feeder bias. Air bias E, B and A had little or no effect on NOx, either individually or in interaction with another variable.

CONCLUSIONS

C&SW has determined that DO can serve as a least-cost means of reducing NOx emissions while improving thermal performance, thus allowing the utility to stage its strategies and stay ahead of emission regulations and the demands of the future competitive power market. Indeed, NOx reduction from Unit 1 far exceeded expectations. As a result, C&SW is considering DO for use in all its fossil-fired plants, as the first step in implementing its NOx compliance and cost-action strategy. After initial optimization and modeling, a possible next stage is to establish an on-line operator advisory capability by linking the models and software to the distributed control system. This enables the operator to maintain optimal performance dynamically under changing fuel, operational, environmental and business conditions.[4]

REFERENCES

1. C. W. Moreno and S. B. Yunker, "ULTRAMAX: Continuous Process Improvement Through Sequential Optimization", paper presented at EPRI, Palo Alto, Calif., 1992.

2. P. D. Patterson, R. J. Boyle, J. W. Pech, "TVA exceeds CAAA NOx requirements", Power Engineering. 99(8): 3 (1995).

3. C. W. Moreno and S. B. Yunker, "Reducing NOx Emissions and Improving Boiler Efficiency Using Synthetic Intelligence", presented at Conference On Expert System Applications for the Electric Power Industry, Phoenix, 1993.

4. M. S. Krueger and P. D. Patterson, "Illinois Power's Operator Advisory System to Reduce Heat Rate and Control NOx Based on Sequential Optimization", in Conference Papers of Power-Gen '95 Americas,

Volume D3-4, Power-Gen '95 Americas, Anaheim, 1995, pp 10-22.

Bias	A method of balancing the effects of two or more similar devices such as forced draft fans, coal feeders, etc. Used to obtain better control by allowing the operator to favor one device slightly more than the other. • Air Bias A - Air flow to burner A compared to a reference value. • Air Bias B - Air flow to burner B compared to a reference value. • Air Bias E - Air flow to burner E compared to a reference value. • Air Bias F - Air flow to burner F compared to a reference value. • Feeder Bias D - Coal through coal feeder D compared to a reference value • Feeder Bias F - Coal through coal feeder F compared to a reference value. • O_2 Bias - The comparative air flows resulting from favoring one forced draft fan over another.
BOOS	Burners Out Of Service.
Deslag	Refers to the removal of slag from the interior of the boiler.

	Accomplished with "soot blowing" or by manual means. Slag occurs when combustion con-ditions are unfavorable, ash fusion conditions change, a cold spot occurs, etc.
FEGT	Furnace Exit Gas Temperature.
Hood positions	Sleeve damper position for each tier of burners.
LOI	Loss On Ignition; a measurement of unburned carbon found in flyash. Serves as an indicator of the efficiency of the combustion process.
RH Temp	Reheat steam temperature. N and S represent positions North and South.
SH Temp	Superheat steam temperature. N and S represent positions North and South.
Spray Flows	Water sprays used to control temperatures of superheat and reheat steam.

Table 1. Explanation of boiler terms and abbreviations that appear in tables, figures and text.

Outputs	**Units**	**Baseline**	**Optimized**
FEGT	° F	2203	2303
Heat Rate	Btu/kWh	9833	9803
CO	ppm	52	6
Economizer Out Temp..	° F	839	825
LOI	%	1.1	0.16
SH Temp N.	° F	1004	1001
SH Temp S.	° F	1004	1001

RH Temp N.	° F	1001	1001
RH Temp S.	° F	1004	1001
SH Sec. Spray	Kgal/hr.	11.8	55
RH Spray	Kgal/hr.	97.4	150
Avg. O_2 N.	%	2.9	2.2
Avg. O_2 S.	%	2.8	2.2
O_2 Distribution	%	-0.1	0
RH Distribution	° F	-0.003	0
Windbox Pres.	in H_2O	3.6	2.75
NOx	lb/MBtu	0.49	0.40

Table 2. Comparison of Baseline Vs. Optimized, Oklaunion Unit 1.

Inputs	**Units**	**Baseline**	**Optimized**
O_2 Bias	%	0.25	-0.34
Upper Hood Position	holes	4.5	5.8
Middle Hood Position	holes	3.5	3.8
Lower Hood Position	holes	2.5	2.8
BOOS Position	scale	0	0
Feeder Bias F	%	0	-16

Feeder Bias D	%	0	-14
Air Bias F	%	0.980	0.948
Air Bias E	%	0.988	0.976
Air Bias B	%	0.980	1.000
Air Bias A	%	0.980	0.972
Time Since Last Deslag	hrs.	145	42

Table 3. Comparison of Baseline Vs. Optimized, Oklaunion Unit 1.

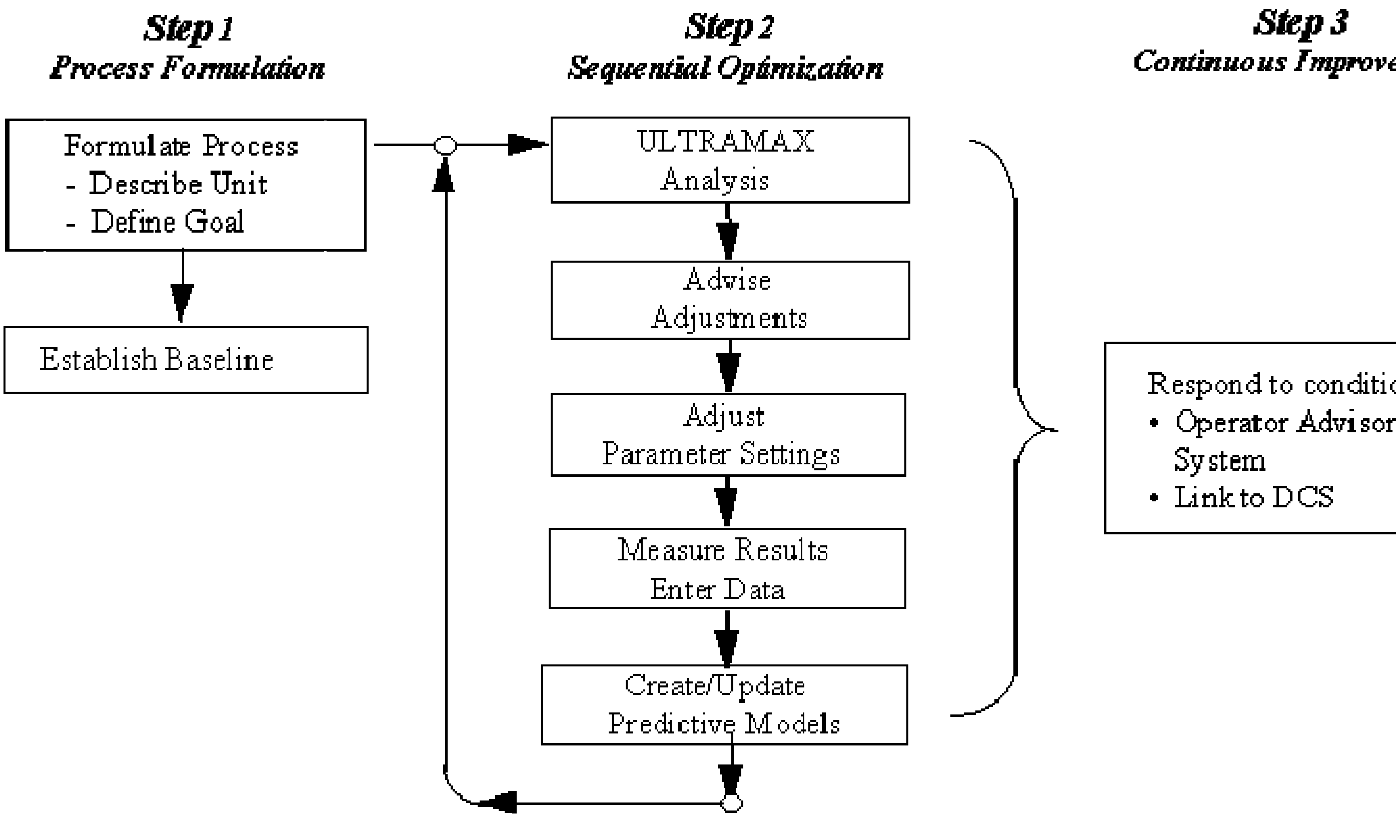

Figure 1 - Flow Diagram showing the steps in implementing ULTRAMAX DO.

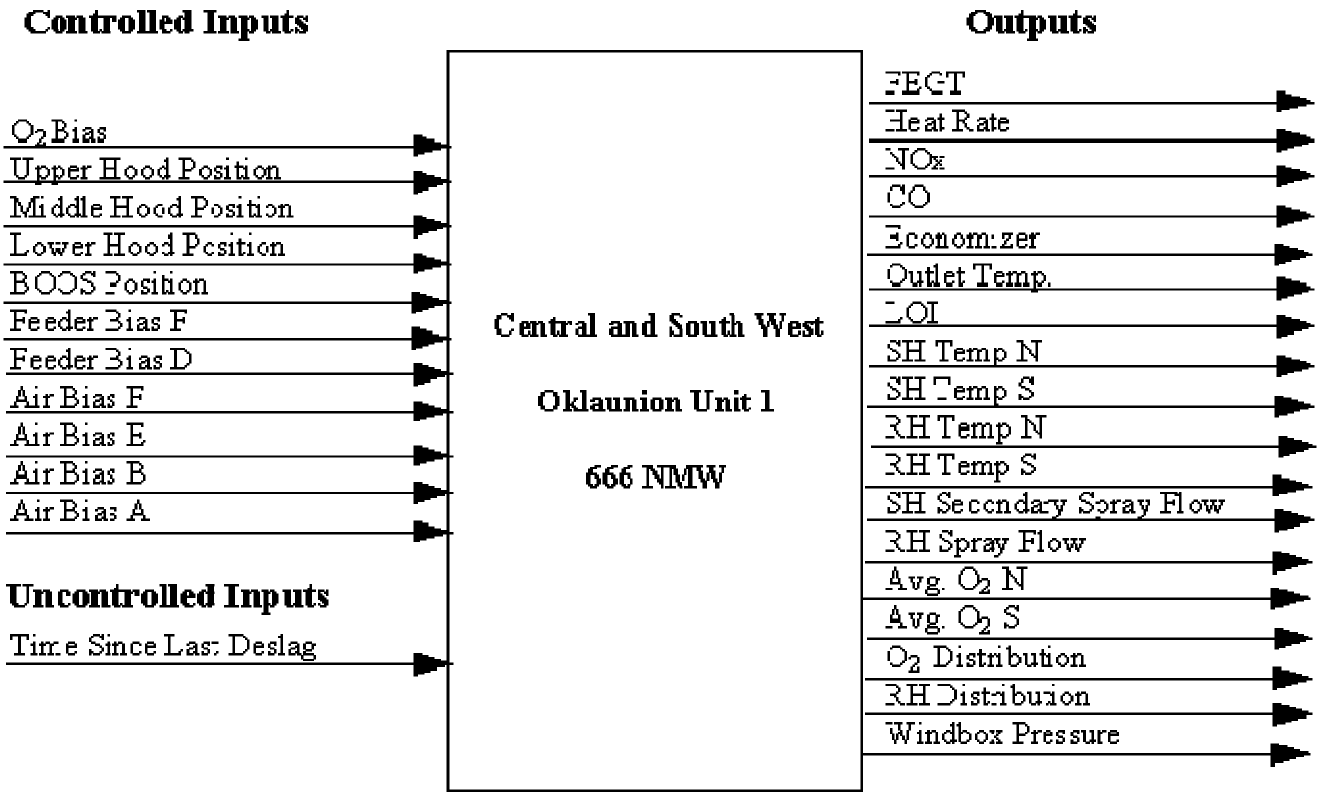

Figure 2. ULTRAMAX Decision Diagram with adjusted input parameters and measured outputs.

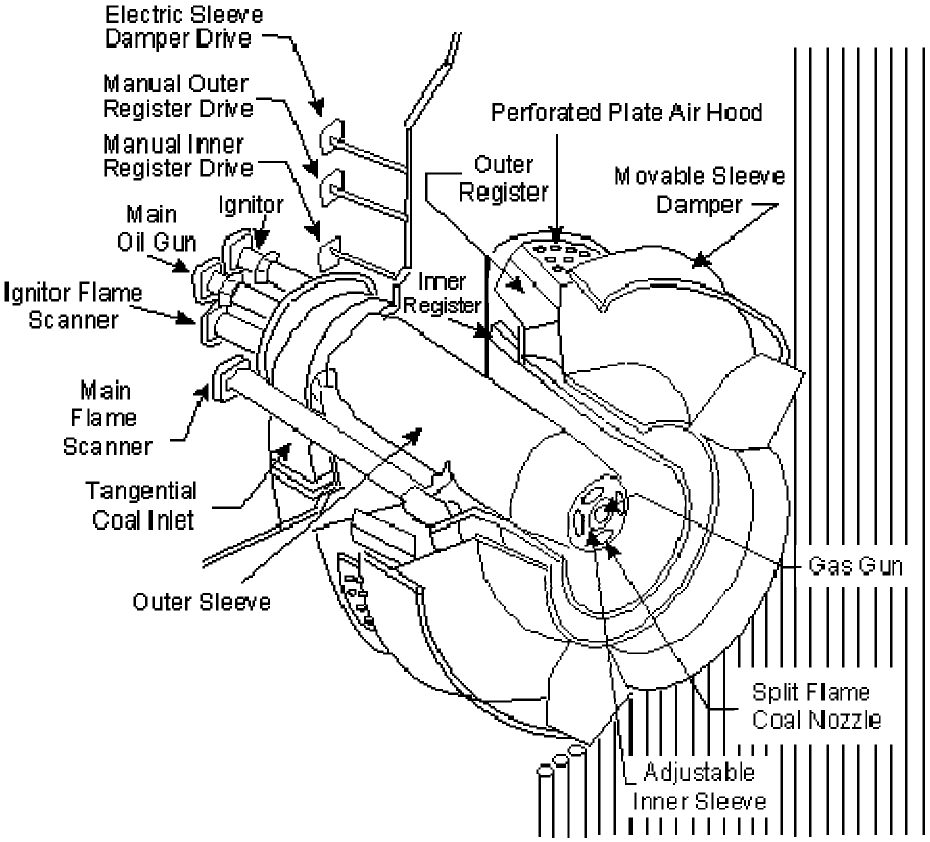

Figure 3. Cutaway of low NOx burner showing sleeve damper (hood).

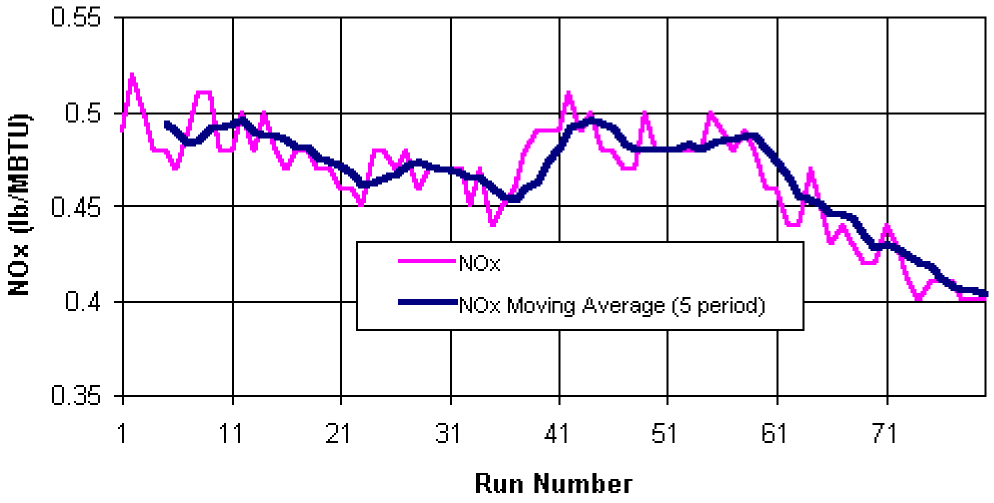

Figure 4. Run-by-Run NOx Profile for Oklaunion Unit 1.