Proceedings of the 17th Annual North American Waste-to-Energy Conference
NAWTEC17
May 18-20, 2009, Chantilly, Virginia, USA

NAWTEC17-2373

ELEMENTS OF A SUCCESSFUL WASTE-TO-ENERGY BOILER UPGRADE

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ABSTRACT

Great River Energy operates a waste-to-energy plant in Elk River, Minnesota. The plant burns 850 tons per day of refuse derived fuel (RDF) in three boilers, and its three steam turbines can produce 32 MW of electricity. In the largest of the three units, the No. 3 Boiler, steam generation was restricted by carbon monoxide (CO) and nitrogen oxides (NO_x) emission limits. The plant had an interest in improving the combustion performance of the unit, thereby allowing higher average RDF firing rates while staying within emissions compliance.

The project was initiated by an engineering site visit and evaluation. The boiler had a history of unstable burning on the stoker grate, which required periodic natural gas co-firing to reduce CO levels. As an outcome to the evaluation, it was decided to install a new overfire air (OFA) system to improve burnout of combustible gases above the grate.

Current and new OFA arrangements were evaluated via Computational Fluid Dynamics (CFD) modeling. The results illustrated the limitations of the original OFA system (comprised of multiple rows of small OFA ports on the front and rear furnace walls), which generated inadequate mixing of air and combustible gases in the middle of the boiler. The modeling illustrated the advantages of large and fewer OFA nozzles placed on the side walls in an interlaced pattern, a configuration that has given excellent performance on over 45 biomass-fired boilers of similar design upgraded by Jansen Combustion and Boiler Technologies, Inc. (JANSEN).

Installation of the new OFA system was completed in April of 2008. Subsequent testing of the No. 3 Boiler showed that it could reliably meet the state emission levels for CO and NO_x (200 ppm and 250 ppm, respectively, corrected to 7% dry flue gas oxygen) while generating 24% more steam than a representative five month period prior to the upgrade.

This paper describes the elements that led to a successful project, including: data collection, engineering analyses, CFD modeling, system design, equipment supply, installation, operator training, and startup assistance.

1. INTRODUCTION

Great River Energy operates a late 1950s vintage Riley Stoker Boiler called the No. 3 Boiler at its waste-to-energy plant in Elk River, Minnesota. The boiler was designed to produce 215,000 lb/hr of steam at a temperature of 905°F and a pressure of 875 psig while firing pulverized coal. In 1989, the unit was converted to fire RDF on a traveling grate generating up to 173,600 lb/hr of steam at 750°F and 615 psig. A sectional side view of the boiler is shown in Figure 1.

The OFA system installed in 1989 was typical for OFA systems installed on stoker fired boilers during that time period. It consisted of several small circular ports (made from 4” and 2.5” pipe) arranged in three levels on the rear wall and two levels on the front wall. In this configuration, a booster OFA fan supplied hot combustion air to the OFA ports and to the fuel distributor spouts.

The No. 3 Boiler had operated without significant changes since its 1989 conversion to RDF firing. However, the unit was limited to a lower steaming rate (in the 135,000 lb/hr range), and periodically required auxiliary natural gas firing to achieve CO compliance.

In an effort to improve the burnout of CO and allow an increase in steaming and RDF firing rates, Great River Energy contracted JANSEN to evaluate the operation of the No. 3 Boiler with a focus on evaluating the OFA system. Specifically, the plant wanted to maintain emissions below permit levels while improving the unit's operating efficiency by:

1. Reducing the reliance on burning natural gas.
2. Reliably increasing steam generation from RDF firing.
3. Maintaining CO and NO_x emissions compliance at these higher RDF firing rates.
4. Reducing furnace slagging on the front wall.

2. FIELD EVALUATION

The first step in meeting the project objectives was to gather reliable information on the boiler operations. JANSEN engineers traveled to the plant site to make observations and collect data during a trial period. Data was collected while firing RDF with no natural gas, generating 144,000 lb/hr of steam with a flue gas oxygen at the generating bank of 9% (by volume, dry). Periodic spikes in CO emissions of up to 1,700 ppm (corrected to 7% oxygen) were observed throughout the test period. The boiler also exhibited a strong tendency to generate higher CO at lower flue gas oxygen concentrations.

Although the amount of OFA being delivered to the unit was close to the desired target level, the high CO emissions reflected the ineffectiveness of the air delivery arrangement and the absence of a modern combustion air control strategy. Also, the original OFA system design did not allow for increases in capacity.

Recommendations were made to alleviate these problems and allow an increase in steaming and RDF firing rates by installing a new OFA system similar to that previously described in the literature [1]. The OFA system design included CFD modeling to evaluate alternatives. The primary purpose of the modeling was to quantify flue gas flow patterns, O_2 and CO levels, turbulence, temperatures, etc., for different OFA delivery strategies in order to validate the number, size, and location of OFA nozzles, and to illustrate the advantage of an upgraded OFA system over the original OFA system.

3. COMPUTATIONAL FLUID DYNAMICS MODELING

The base for the JANSEN boiler modeling is a commercial CFD software package called FLUENT. FLUENT incorporates aspects such as fluid flow (three-dimensional velocities and pressures), general combustion and gas component concentrations, and energy balance calculations. Using this framework, solid fuel boiler-specific processes such as RDF drying, volatile release, combustion in suspension and on the grate, and carryover of ash and burning particles are added.

To date, JANSEN has modeled approximately 50 industrial boilers burning a variety of solid fuels. These models have been used to identify combustion improvements and other operating problems [2]. For the No. 3 Boiler, the model was customized to handle RDF composition and size distribution profiles. The model calculation results included profiles of O_2, CO, and flue gas temperature throughout the furnace, which were used to compare the effectiveness of alternative means of air delivery.

Combustion air was delivered from under the grate, through the overfire ports or nozzles, through the fuel spouts, and through the front wall burners. It should be noted that even when natural gas was not being fired, a small fraction of combustion air was used for cooling of the burner air registers.

The distribution of combustion air with the original OFA system and the upgraded system is shown in Table 1.

JANSEN's approach is to use relatively few (six to eight) nozzles located on the side walls of sufficient size to provide 35% to 50% of the combustion air at less than 15 in. wg of pressure. In this case, the low pressure characteristics of the OFA nozzles meant that the system design could be implemented without an upgrade to the existing OFA fan, although a new separate ambient fuel distributor air fan was installed to reduce fan motor horse power usage. Additionally, installing the nozzles on the side walls was less expensive as there were fewer interferences.

The CFD modeling work was carried out to optimize the placement of the nozzles on the side walls and ensure superior combustion performance. A layout of the modeled furnace showing the original and the new OFA system arrangement is show in Figure 2.

In the upgrade cases modeled, the OFA nozzles were approximately 50 sq. in., located at an elevation approximately 9 feet above the grate. The low nozzle inlet velocity and convergent design allows the nozzles to operate at low operating air pressures while still providing a high OFA jet velocity (approximately 270 ft/s) for adequate penetration and turbulent mixing with the volatiles being released from the grate. An illustration of the JANSEN High Energy Combustion Air Nozzle^{TM} is shown in Figure 3.

3.1 Results of CFD Modeling

Figure 4 shows a modeling plot to compare jet penetration profiles of the original OFA and the upgraded OFA system. Presented in the figure are regions of the furnace with a velocity higher than 40 ft/s colored by the localized temperature. As seen from the figure, the original OFA system with numerous smaller ports provided insufficient low jet momentum for the OFA to penetrate very far into the furnace. Whereas the upgraded OFA system, with nozzles located on the side walls in an interlaced pattern, provides significantly deeper penetration and aggressive mixing of the OFA with the volatiles.

Figure 5 shows a comparison of the temperature profiles within the furnace. The plots indicate that a more effective OFA system improves the burnout of volatiles and in-flight fuel particles in the lower furnace, leading to hotter lower furnace temperatures and relatively cooler furnace exit temperatures. Additionally, a hotter lower furnace helps the fuel drying process and minimizes fuel piling and ash clinkering on the grate.

Figure 6 shows relative improvements in the burnout of the in-flight fuel particles by improved air delivery. The plots show particle traces of the in-flight fuel particles and are colored by the particles' stage in the combustion process. The green particle traces represent drying, yellow represents volatiles burning, red represents unburned char, and teal represents fly ash. The model with the upgraded OFA arrangement predicted more than 50% reduction in carryover of in-flight char particles leaving the furnace.

Table 2 presents predicted average flue gas conditions at the furnace exit plane. The original OFA delivery case resulted in higher concentrations of CO at the furnace outlet. Modeling of the new OFA system predicted significant improvements in CO burnout (~85% reduction) and lower FEGT (by 100°F) at the same excess air level.

4. IMPLEMENTATION OF THE NEW OFA SYSTEM

Following a review of the process and CFD evaluation of the No. 3 Boiler, Great River Energy initiated the design and equipment supply for the recommended OFA system changes. This phase of the project included visits to the plant to collect equipment information, drawings, and take field measurements. As part of the project, the following new equipment was supplied:

- Eight high energy combustion air nozzles
- OFA ducting to both sides of the boiler
- OFA flow balance dampers in the OFA supply ducting
- Fabric expansion joints
- A new OFA fan inlet control damper and actuator
- Tube bends for the new OFA air nozzles
- A new ambient air fuel distributor air fan and outlet damper
- Air ducting from the fuel distributor air fan to the existing fuel distributor air spouts

The equipment was installed during the Spring 2008 outage. A photo of the new OFA nozzle arrangement on the left hand side wall is shown in Photo 1.

In addition to the mechanical work, the boiler controls were upgraded by Novaspect, Inc. to improve the combustion air controls and allow for an O_2 trim implementation. Prior to the OFA upgrade, the quantity of combustion air was set by the operator via a set point. As a result, the unit experienced significant swings in flue gas oxygen as the fuel piles on the grate built up, dried and burned down. The CO emissions from the unit were more pronounced at lower oxygen concentration. Maintaining the flue gas oxygen at an acceptable and steady level was an important element in lowering CO emissions from the unit. These upgrades, in addition to the OFA modifications, improved the boiler's ability to run in automatic mode, achieve a higher RDF firing rate, and maintain CO and NO_x compliance.

5. OPERATING EXPERIENCE

The boiler was started up with assistance from JANSEN engineers during the last week of April 2008. After the boiler operators gained more experience with operating the new air system, JANSEN engineers returned in June of 2008 for a formal performance test to confirm the design and operation of the upgrade.

Efforts were undertaken to optimize air and fuel delivery prior to the performance test. Resulting operating conditions are shown in Table 3, along with the pre-upgrade and the OFA upgrade design conditions for comparison purposes.

During the June 2008 performance testing, the unit was operated at a steaming rate within 2.5% of the upgrade design target and 24% higher than a representative five month pre-upgrade operating period. Higher OFA flows and lower excess air than was specified in the design conditions were delivered to the unit as a result of less tramp air infiltration following the annual boiler outage. The CO emissions averaged 159 ppm (corrected to 7% oxygen) and the NO_x emissions averaged 184 ppm (corrected to 7% oxygen). Both emissions levels met the performance guarantee provided to Great River Energy by JANSEN.

A comparison of pre-upgrade emission trends to the post-upgrade emission trends are shown in Figure 7. The figure shows that although the unit is now operating at a higher steaming rate than pre-upgrade, the frequency and magnitude of CO spikes for the same oxygen concentration have been reduced. Also, the new OFA system allows the unit to be operated at lower flue gas oxygen levels without exceeding CO emission permit levels, which simultaneously lowers NO_x emissions.

6. CONCLUSIONS

As waste-to-energy plants are faced with meeting more stringent emission requirements from RDF/MSW fired boilers, the importance of uniform delivery of the fuel on the grate and an effective OFA system is becoming paramount. It is important that the design of the air system meet the emission requirements and that the system can be easily operated and controlled. Also, the installation should be as simple as possible to reduce the overall cost and downtime required for the project.

Prior to embarking on the design for a project of this type, the engineers should have a good grasp of the problems and the required solution, including site visit data collection and detailed process analysis. CFD modeling is a useful tool for evaluating different OFA arrangements and operating strategies, providing information that is not available by any other means.

Successful implementation requires close communication by all parties involved. While a proper OFA system is required, attention must also be given to the control system. Along with other basic boiler control functions such as steam load following and furnace draft control, it must also be able to provide the correct amount of undergrate and OFA at the right pressure, and have the capability to offer oxygen trim control.

ACKNOWLEDGEMENT

We would like to thank Tim Steinbeck - Plant Manager, Gary Kleis - Operations Supervisor, Great River Energy boiler operators and Mike Cerkoney of Novaspect Inc. for their assistance, valuable editorial review, and comments.

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2. Walsh, A. R., Dayton, C. R., Averett, J. A., *Elements of a Successful Bark Boiler Upgrade*, TAPPI Engineering Conference, Atlanta, Georgia, 2000.

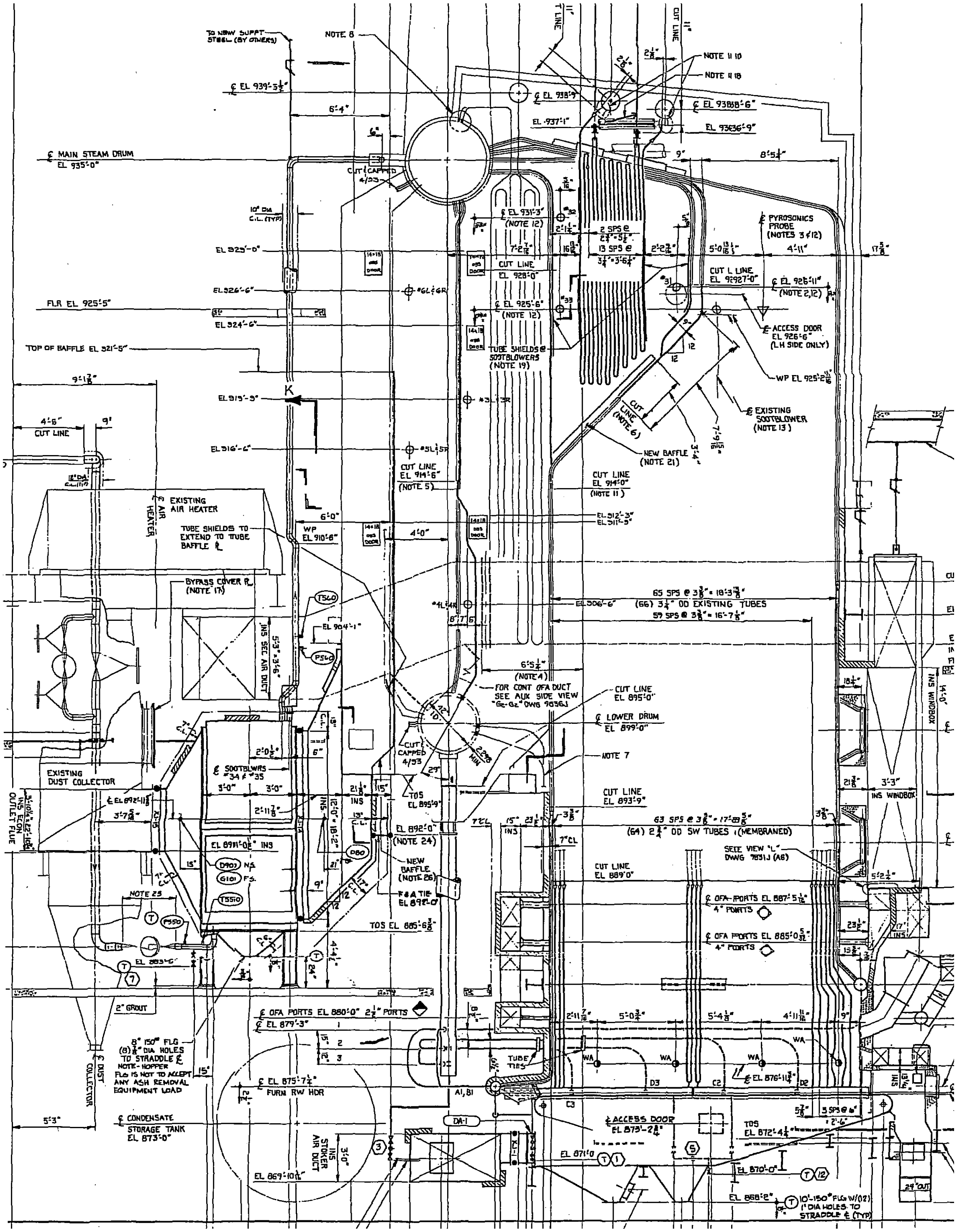
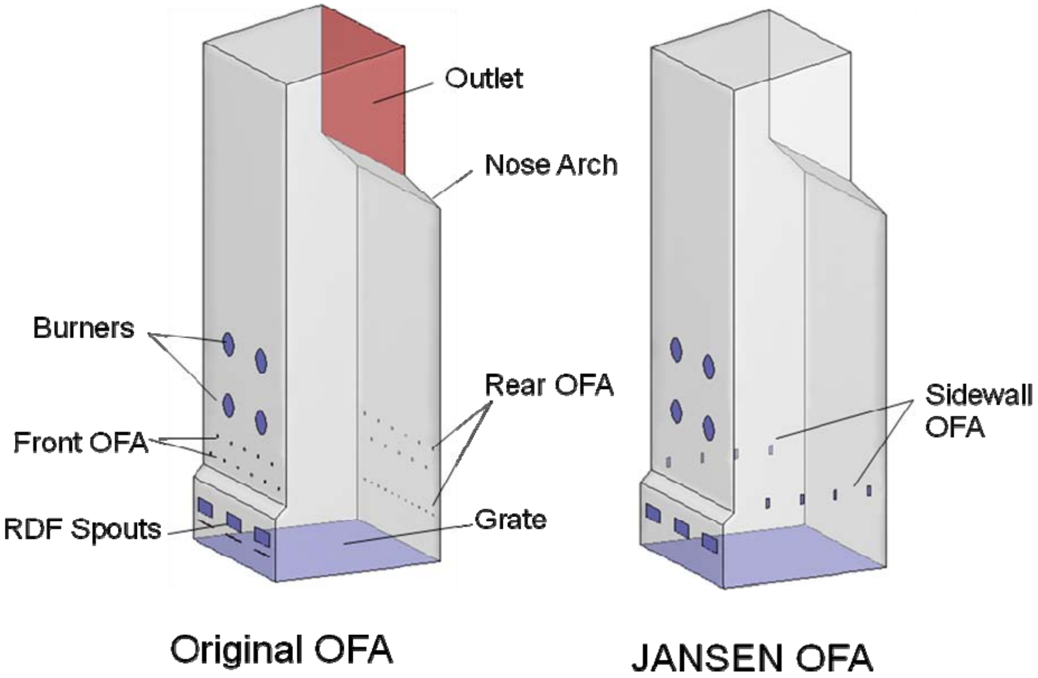


FIGURE 1. SIDE VIEW OF THE NO. 3 BOILER (PRE-UPGRADE Configuration)



Original OFA

JANSEN OFA

FIGURE 2. CFD MODEL OF THE BOILER FURNACE SHOWING PRE- and POST-UPGRADE OFA ARRANGEMENTS

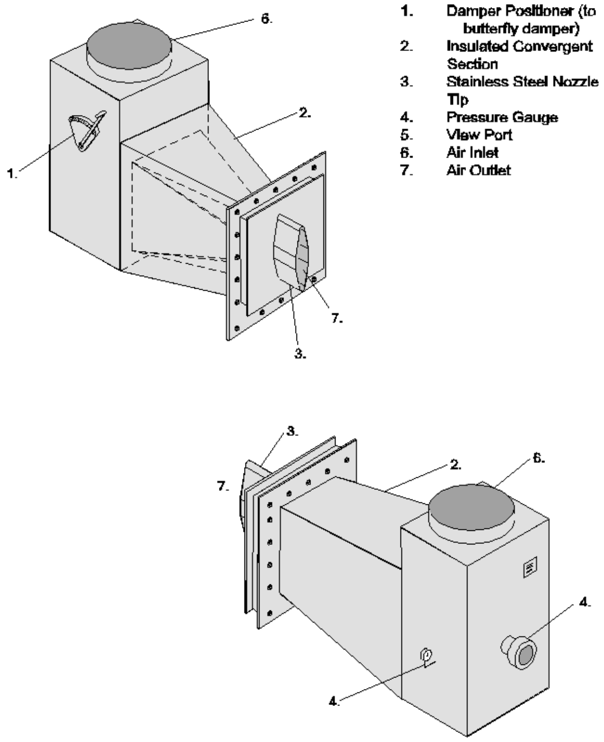
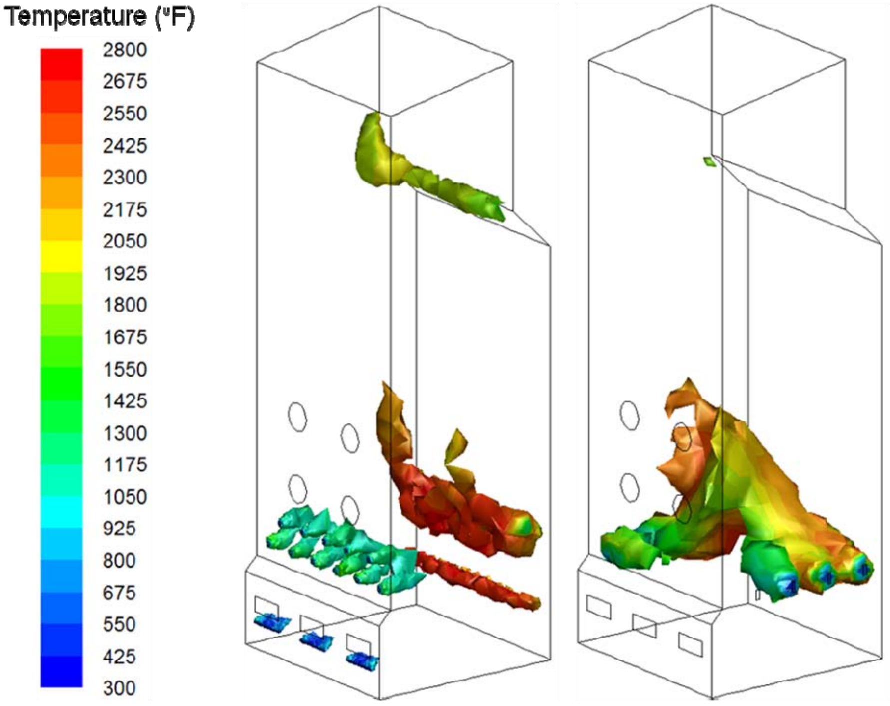


FIGURE 3. JANSEN HIGH ENERGY COMBUSTION AIR NOZZLE^{TM} FOR WASTE-TO-ENERGY BOILERS



Original OFA **JANSEN OFA**

FIGURE 4. OFA VELOCITY CONTOURS (>40 ft/s) COLORED BY LOCALIZED TEMPERATURE

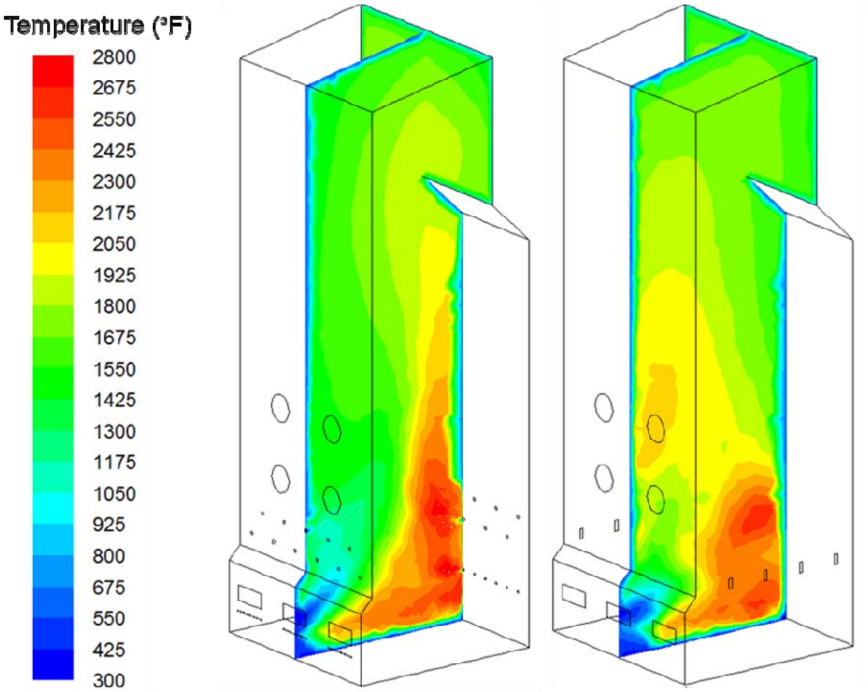


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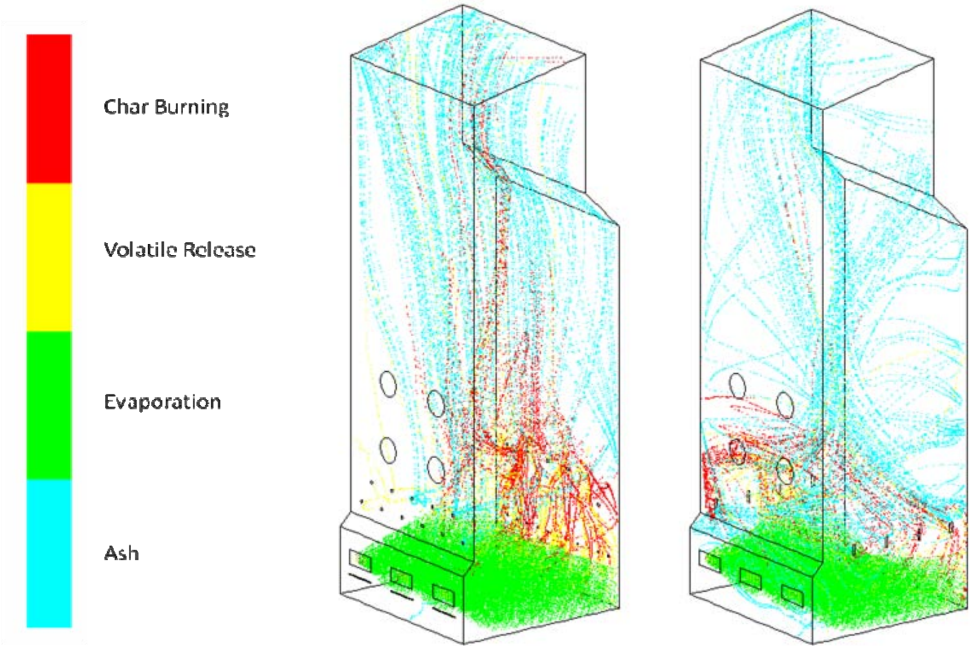
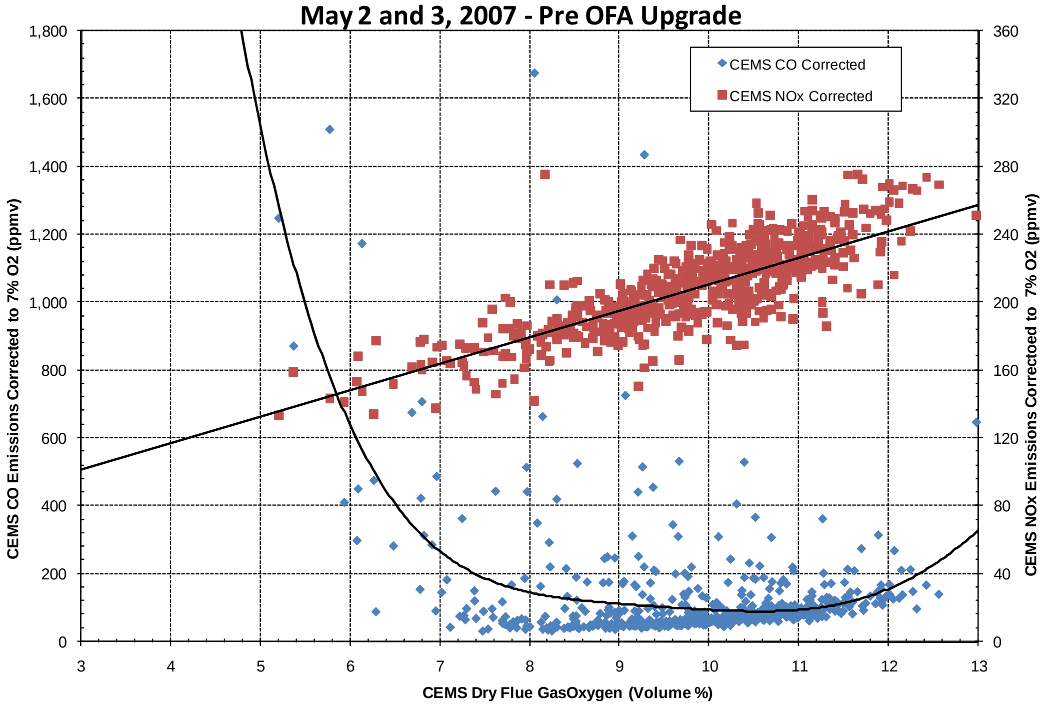
FIGURE 5. FURNACE TEMPERATURE PROFILES



Original OFA

JANSEN OFA

FIGURE 6: PARTICLE TRACES OF FUEL, CHAR AND FLY ASH



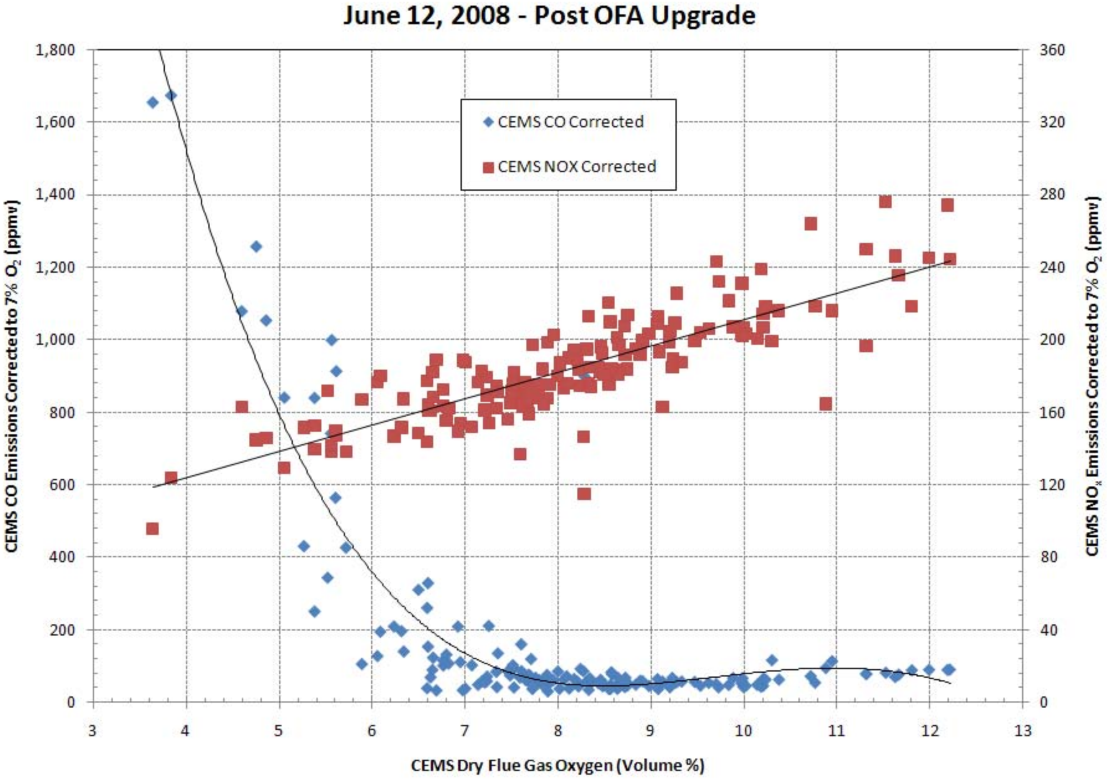


FIGURE 7: PRE- AND POST-UPGRADE EMISSION TRENDS

TABLE 1. COMBUSTION AIR DISTRIBUTION

	Units	Pre-upgrade OFA	Post-upgrade OFA
Undergrate air	mass % of combustion air	46.4	42.1
Overfire air	mass % of combustion air	32.8	34.4
Burners	mass % of combustion air	2.5	2.9
Fuel Spouts	mass % of combustion air	18.3	20.6

TABLE 2. CFD PREDICTED FLUE GAS CONDITIONS AT THE FURNACE EXIT PLANE

Case	O_2 (volume %)	CO (ppm)	Furnace Exit Temperature (°F)
Original OFA	5.9	340	1,715
New OFA	5.9	<50	1,615

TABLE 3. COMPARISON OF OPERATING CONDITIONS

Parameter	Units	Pre-Upgrade Site Visit	OFA System Design	Post-Upgrade (June 2008)
Steam and Feedwater				
Steam Flow	1,000 lb/hr	144	166	162
Final Steam Pressure	psig	747	747	736
Final Steam Temperature	°F	700	691	721
Feedwater Temperature to Unit	°F	264	264	279
Fuel				
RDF Firing Rate	1,000 lb/hr	46.3	51.9	50.7
Natural Gas Firing Rate	scfm	0	0	0
Combustion Air				
Total Combustion Air Flow	1,000 lb/hr	323	320	299
Undergrate Air Flow	1,000 lb/hr	150	139	135
Overfire Air	1,000 lb/hr	106	112	134
Burner Air	1,000 lb/hr	8	8	7
Fuel Distributor Air	1,000 lb/hr	16	20	18
Other (Furnace In-leakage)	1,000 lb/hr	43	41	5
Excess Air	%	70	50	45
Combustion Air Temperature	°F	365	372	395
Flue Gas				
Flue Gas Oxygen at Generating Bank Outlet	%	7.5	6.0	4.1
CO corrected to 7% Oxygen (by volume, dry)	ppm	127	<200	159
NO_x corrected to 7% Oxygen (by volume, dry)	ppm	209	195	184
Air Flow Splits (% of total combustion air flow)				
Undergrate Air	%	46	43	45
Overfire Air	%	33	35	45
Burner Windbox Air	%	3	3	2
Fuel Distributor Air	%	5	6	6
Other (Furnace In-leakage)	%	13	13	2

PHOTO 1. POST-UPGRADE OFA NOZZLES ON THE LEFT SIDE WALL