SOLID FUEL TO NATURAL GAS CONVERSIONS FOR EXISTING BOILER APPLICATIONS

William Gurski
Director Power Sales
Zeeco Inc.

John Guarco
Technical Director Boiler Burners
Zeeco Inc.

Nando Nunziante
Manager Power Controls
Zeeco Inc.

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Abstract

Recent discoveries of vast natural gas reserves in the United States have resulted in increased production of Natural Gas, resulting in lower prices. Petrochemical facilities are performing solid fuel conversions on their boilers to natural gas as a cost-effective and efficient fuel solution. Natural Gas is not only economically beneficial but also environmentally efficient with cheaper prices and reduced SO_2, NO_x, and CO_2 emissions. As more facilities consider boiler fuel conversions, it is important to understand all facets of the conversion, from the thermal evaluation of the boiler, to the complete design, supply and installation of the new firing system.

We will provide specific details and recommended practices from a recent Circulating Fluidized Bed (CFB) Boiler fuel conversion application designed for 1.4 billion Btu/hr of heat input for the maximum continuous steam rating. We will also review thermal performance results, design and supply of the complete new gas firing system, and installation conversion assistance for the boiler modifications and firing system installation details.

Introduction

Zeeco was contacted by a large industrial plant owner to assist them with the fuel changeover of a utility designed solid fuel CFB. Due to current contract requirements and the competitive nature of the industry, the plant owner will remain confidential.

The primary goals of the project are as follows:

- Full Conversion from Petcoke firing to Natural Gas
- Maintain boiler steam design capacity (~1200 kpph)
- Meet permitted NO_x requirements – 0.07 lbs/MMBtu
    - 25-100% heat input for NO_x emissions
- Minimal or no impact on the boiler waterside design

The owner provided the original boiler design information for Zeeco's review of potential boiler burner retrofitting options. This was the first of two boilers that would require retrofitting Two sister units were built/commissioned on solid fuels approximately three years previously. The units were originally designed with natural gas start-up burners and commissioned for main fuel support via the petcoke. The petcoke was to be fired and combusted via a circulating fluid bed system. Upon initial advisement from the plant owner, they noted that their petcoke fuel contract was no longer cost effective, as this fuel feedstock was significantly higher in price than originally estimated in the plant system's budget. The boilers were only in operation for less than two years when this decision to switch to natural gas was determined.

Zeeco will review the major facets of this boiler conversion—from the initial proposal phase to the commissioning and startup of the boiler and firing system. We will also discuss the combustion parameters of the technology behind the project's success–Zeeco's DT Ultra-Low NO_x Free-Jet Burner technology.

Combustion Parameters

In order to understand why the ZEECO® Free-Jet technology was chosen, formation of thermal NO_x emissions must first be examined. For gaseous fuels with no fuel-bound nitrogen (N_2), thermal NO_x is the primary contributor to overall NO_x production. Thermal NO_x is produced when flame temperatures reach a high enough level to "break" the covalent N_2 bond apart, allowing the "free" nitrogen atoms to bond with oxygen to form NO_x.

Stoichiometric Equation describing typical combustion in a natural gas fired burner:

Methane & Air with Excess Air

$$2CH_4 + 4\ (XA)\ O_2 + 15\ (XR)\ N_2 \dashrightarrow 2CO_2 + 4H_2O + (XA)\ 15N_2 + (XR)\ O_2$$

Natural air is comprised of 21% O_2 and 79% N_2. Combustion occurs when O_2 reacts and combines with fuel (typically hydrocarbon). However, the temperature of combustion is not normally high enough to break all of the N_2 bonds, so a majority of nitrogen in the air stream passes through the combustion process and remains diatomic nitrogen (N_2) in the inert combustion products. Very little N_2 is able to reach high enough temperatures in the high intensity regions of the flame to break apart and form "free" nitrogen. Once the covalent nitrogen bond is broken, the "free" nitrogen is available to bond with other atoms. Basic chemistry dictates that free nitrogen, or nitrogen radicals will react to other atoms or molecules that can accept them to create a more stable atom. Of the possible reactions with the products of combustion, free nitrogen will most likely bond with other free nitrogen to form N_2. However, if a free nitrogen atom is not available, the free nitrogen will react with the oxygen atoms to form thermal $NO_{x.}$ As the flame temperature increases, the stability of the N_2 covalent bond decreases, allowing the formation of free nitrogen and subsequently increasing thermal NO_x. Burner designers can reduce overall NO_x emissions by decreasing the peak flame temperature, which can reduce the formation of free nitrogen available to form thermal NO_x.

The varied requirements of Power and Industrial plants entail the use of numerous types and configurations of burners. The method utilized to lower NO_x emissions can differ by application. However, thermal NO_x reduction is generally achieved by delaying the rate of combustion. Since the combustion process is a reaction between oxygen and fuel, the objective of delayed combustion is to reduce the rate at which the fuel and oxygen mix together and burn. The faster the oxygen and the fuel gas mix, the faster the rate of combustion and the higher the peak flame temperature.

Figure 1 plots Peak Flame Temperature against Thermal NO_x created. NO_x emissions increase as the adiabatic flame temperature increases. Slowing the combustion reaction reduces the flame temperature, which results in lower thermal NO_x emissions. The challenge in achieving lower thermal NO_x emissions is not the theory; however, it is in retrofitting the latest burner technologies into older existing boilers without adding expensive external components or processes.

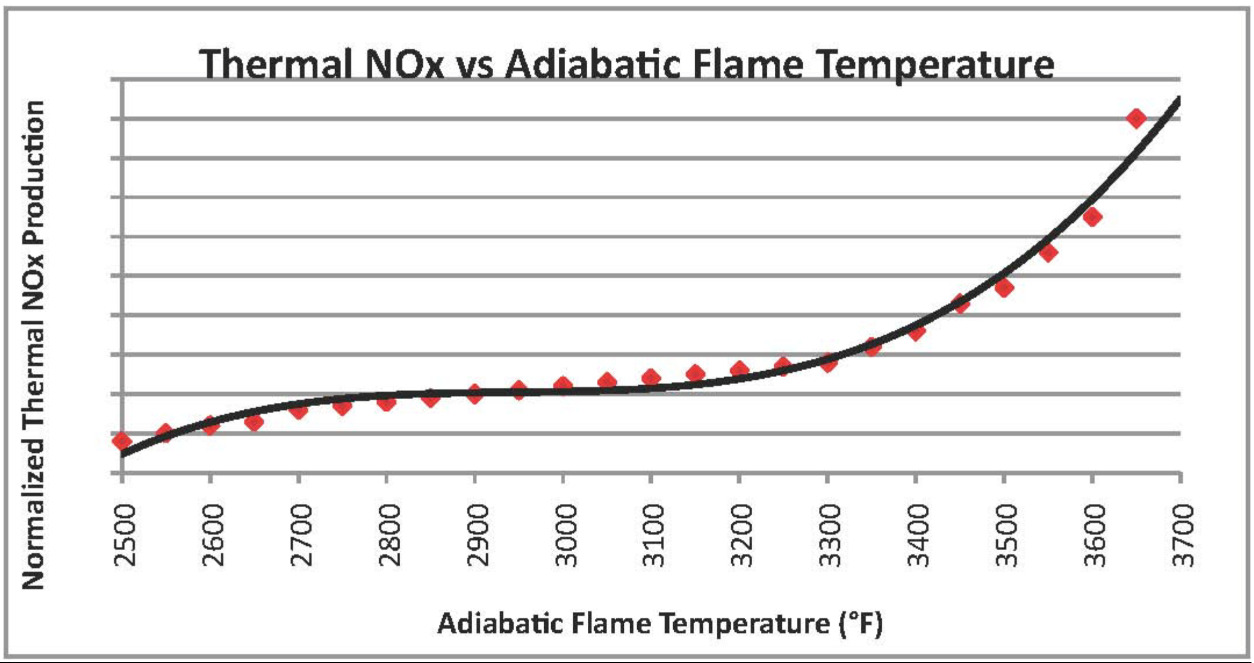

Figure 1: Calculated Peak Flame Temperature vs. Thermal NO_x Production

The industry's standard method to reduce thermal NO_x is to mix the fuel gas together with the inert products of combustion to recondition the fuel before combustion occurs. Since the reconditioned fuel is mainly comprised of inert components, the resulting composition burns at a lower peak temperature. To best utilize the inert products of combustion (flue gas) within the boiler, the fuel gas is introduced along the outside perimeter of the burner tile in an area where flue gas is present while the boiler is in operation. As the fuel gas passes through the inert products of combustion, mixing naturally occurs. This changes the composition of the fuel, and stabilization occurs at the tile exit. Since the reconditioned fuel mixture is 80 to 90% inert in most cases, the resulting flame burns at a lower peak temperature and generates less thermal NO_x.

The mixing of the fuel gas with flue gas prior to combustion is called Internal Flue Gas Recirculation (IFGR). When IFGR is too aggressive, it can result in an increased blower power usage, decreased burner turndown, and increased flame destabilization. Through Free-Jet Theory, maximizing IFGR while maintaining flame stability and flame length can become a challenge.

Flame Stabilization

In order to fully utilize the Free-Jet Theory, Zeeco devised a method to stabilize the burner flame with a highly inert fuel gas/flue gas mixture. This type of combustion is achieved when the flame is stabilized in a low-pressure area created on a series of specially designed hot refractory ledges. As combustion occurs, the refractory ledge retains heat and flame stability is enhanced. Thus, to achieve improved stability and extreme Thermal NO_x reduction, the Free-Jet Technology:

1. Mixes inert flue gas through free-jet methods with all of the fuel gas before combustion occurs, lowering flame temperature.
2. Stabilizes the flame on a refractory ledge, improving flame characteristics

Before combustion is initiated, a furnace is typically filled with normal air, which contains 21% oxygen. Once the burner is ignited, the oxygen content inside the furnace decreases until the burner achieves maximum duty. At this point, the oxygen content in the furnace is normally 2 to 3%. To keep the burner stable throughout the transition from start-up with 21% oxygen to maximum duty with 2 to 3% oxygen, Zeeco developed a series of stabilization ledges as shown in **Figure 2**. These ledges are a design feature of the Zeeco® Free-Jet Burner chosen for the boiler retrofit.

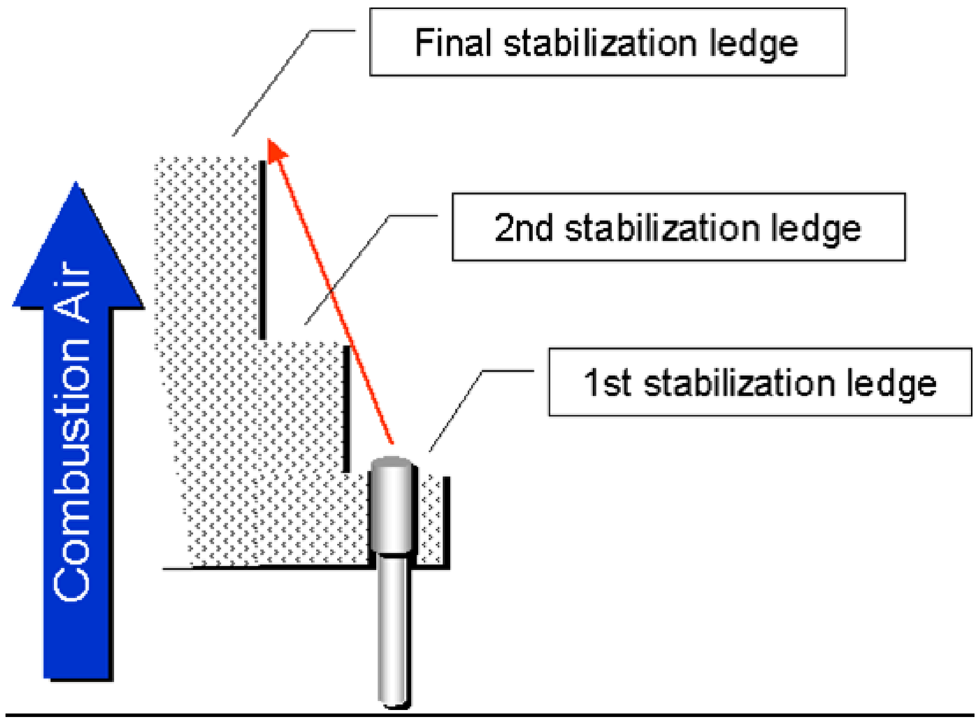

Figure 2: Free-Jet Flame Stabilization Method Illustration

Burner Technology Description

Introduction to Free-Jet Technology

The Zeeco Free-Jet burner series was designed with the specific purpose of maximizing the amount of IFGR to reduce thermal NO_x emissions without sacrificing burner performance with respect to flame length, turndown, and stability. The maximization of IFGR means many of the problems associated with using high levels of EFGR to achieve low emissions can be reduced or eliminated. Specifically, Zeeco's Free-Jet design dramatically reduces or eliminates the need for EFGR by reducing blower power usage, increasing turndown, reducing maintenance and improving flame quality.

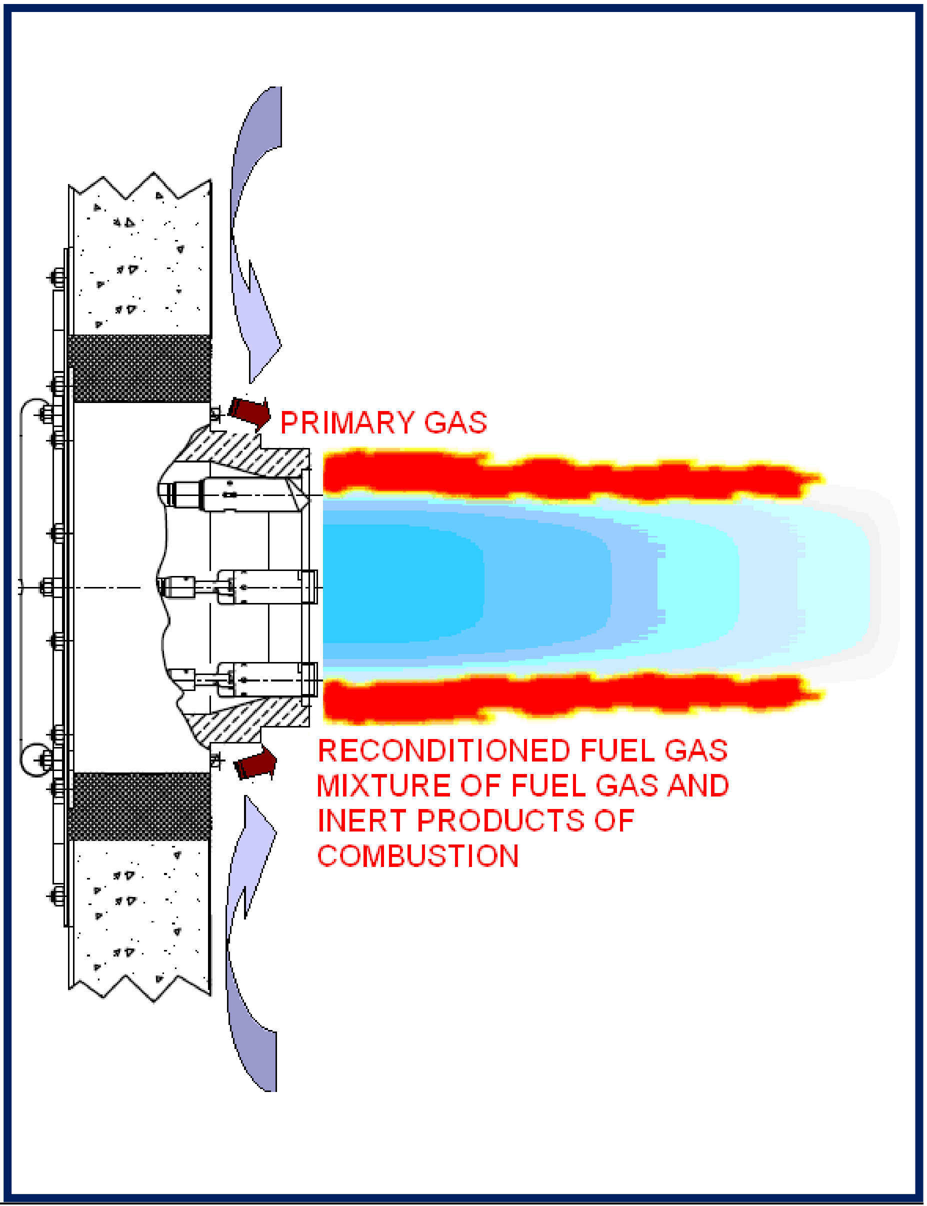

Figure 3: Inert Products of Combustion (Flue Gas)

Pre-Award Engineering

Since the boiler was only in operation for a short period of time, the plant needed assistance with the selection of the new gas firing system and options that would allow them to operate the boiler at the same steam flow capacity and pressure as originally designed for petcoke firing. Zeeco designed three possible boiler conversion options for the operator to consider. Every option required removing the existing start-up burners and closing off the tube openings or retrofitting with new larger burners:

1) Remove the fluid bed bottom and vertically fire the boiler. This option was feasible for a full 100% conversion as the entire fluid bed and nozzle/air system would be removed in favor of six new burners with a corresponding windbox and air system (1500 MMBtu/hr).
2) Removing the four start-up burners and increasing the firing capacity to the necessary levels for full load steam conditions (1500 MMBtu/hr).
3.) Removing the four start-up burners with new burners, plus adding a second level of four burners above to achieve the necessary heat input for full load steam conditions (1500 MMbtu/hr).

Option One was not selected, as it would have required an entire new lower section of the boiler, plus major reconstruction of the fluid bed in order return to solid fuel firing. Option Two was not selected, as the heat release/absorption area within the boiler would have been too great for the water/steam production side.

Option Three was selected, as the owner determined that they wanted the flexibility to return to petcoke firing should the price for natural gas rise to a level higher than petcoke fuel. This allows ~80% of the system's equipment to remain available for future petcoke firing. This solution also offered the least cost to retrofit back to solid fuel firing. The plant owner also had the challenge of the water/steam side of the project, as the boiler system would now be required to operate on 100% natural gas firing instead of a high pressure recirculating fluid bed system. Zeeco assisted the plant owner and the boiler's Original Equipment Manufacturer (OEM) with the system design and selection. Several iterations were submitted by the Boiler OEM on the redesign, and Zeeco worked as a team with the three parties to select the best option for firing the boiler.

The challenge with the boiler redesign interactions was to ensure that the following conditions were met, as required by the plant owner:

- Maintain main steam flow per original design
- NO_x emissions at permit levels
- Boiler able to follow steam needs per electrical generation requirements
- Ability to ramp per the original design conditions
- Turndown of 10-1
- No design impact or changes on existing water or steam circuit metallurgy (tube material changes)

Two design challenges were discovered throughout the Pre-Award Engineering Phase. The first included the air system redesign due to the fluid bed operating on primary and secondary air systems. This is further detailed in the Contract Execution Section below. Another challenge was the integration of the natural gas firing Burner Management System (BMS) and controls into the existing Distributed Control System (DCS). This is also further explained in the Contract Execution Section.

Project Engineering

Once awarded, Zeeco immediately began the burner and BMS systems design. The plant owner required less than 26-week delivery for all components, as the need to fire natural gas was critical to the financial status of the project.

Zeeco began the contract with a full-site visit with the entire team, including the plant owner and boiler OEM. The technical requirements and time schedule were reviewed to ensure all those involved were informed of the critical nature of the project. The technical details of the project varied, as the unit was being fully converted from a solid fuel CFB to a natural gas fired utility boiler. Many items required detailed analysis during the contract phase, including:

- Burner integration into the existing waterwall and boiler structure
- Addition of one new elevation of burners and effects of flame in this furnace region
- Complete redesign of the burner combustion air system and air heater outlet to a single pressure and delivery system to the new burners
- Integration of the new BMS panel and controls logic into the existing DCS system
- Design and location of all new gas fired fuel valving and rack systems, plus local termination cabinets
- Refractory removal and modification to support new natural gas firing (lower boiler refractory was no longer needed due to the elimination of petcoke and recirculating solids from the cyclone)
- Structural modifications to support all equipment and ancillaries for the natural gas firing (combustion air ducting, burner supports, valve racks, etc.)

Burner integration posed several challenges. The new burners were required to fit into the existing waterwall opening and modified from a downfired arrangement to a horizontal firing arrangement. Zeeco advised the plant owner that the new Zeeco Free-Jet DT burner would be able to fit within the existing opening, and would allow the exact tube opening design to be used for the new upper burner elevations. Zeeco also assisted with the design of the support systems and relocation of all structural steel for the new burner locations (maintenance platforms, etc.).

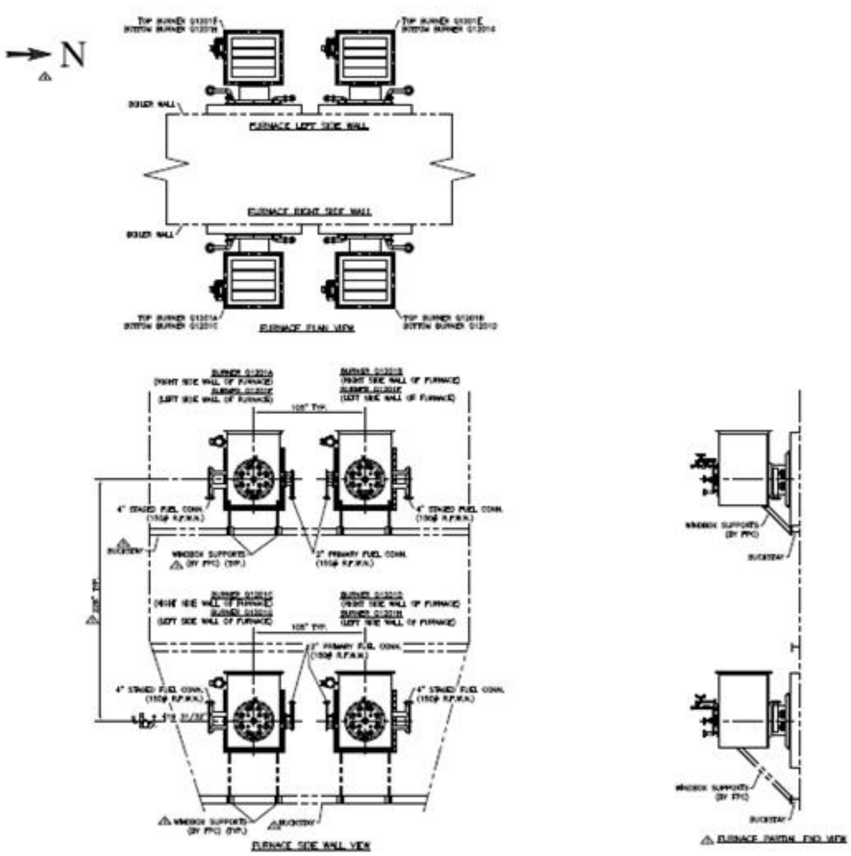

Figure 4: Boiler Design Diagram

It was important to ensure the new upper burner elevation had a proper flame fit within the boiler furnace and would not adversely affect heat transfer to the waterwalls or radiant furnace super heat. An elevation of ~19 feet was selected for the new burners above the existing burners as the ideal location, for not only proper flame fit but also ease the installation of the burners without major boiler structural modifications.

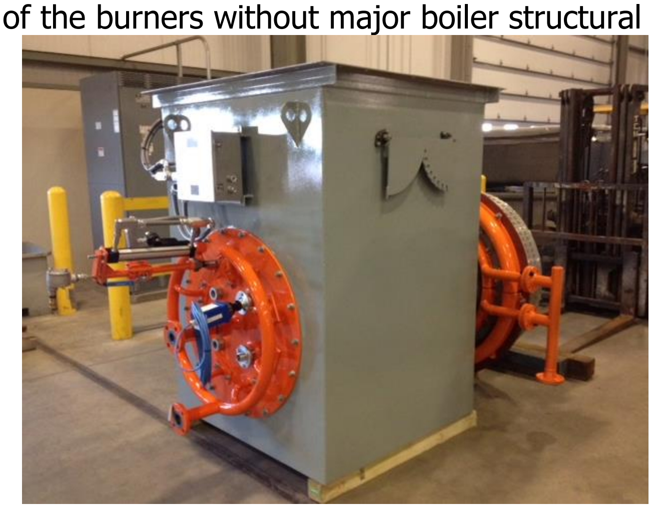

Figure 5: Zeeco's DT Free-Jet Burner

The combustion air system was completely redesigned from a two-system design (primary for the fluid bed nozzles and secondary air system for bed support), to a single pressure design. Zeeco was contracted to assist the plant owner with the entire system redesign, as well as routing to the new burner elevations. Zeeco also assisted with a new design for the air heater outlet and fan control due to the single pressure design needed for the new burners. Zeeco's Model Simulation Engineering Team spent significant time on-site with the Plant Owner's personnel designing the new system. Zeeco's engineers designed and constructed a scaled Plexiglas model of the entire combustion system and ran the Physical Flow Simulation model in our Connecticut facility. The completed model ensured +/- 3% distribution to each burner with less than 10% peripheral distribution around each burner's air entry.

Figure 6: Free-Jet Physical Flow Simulation

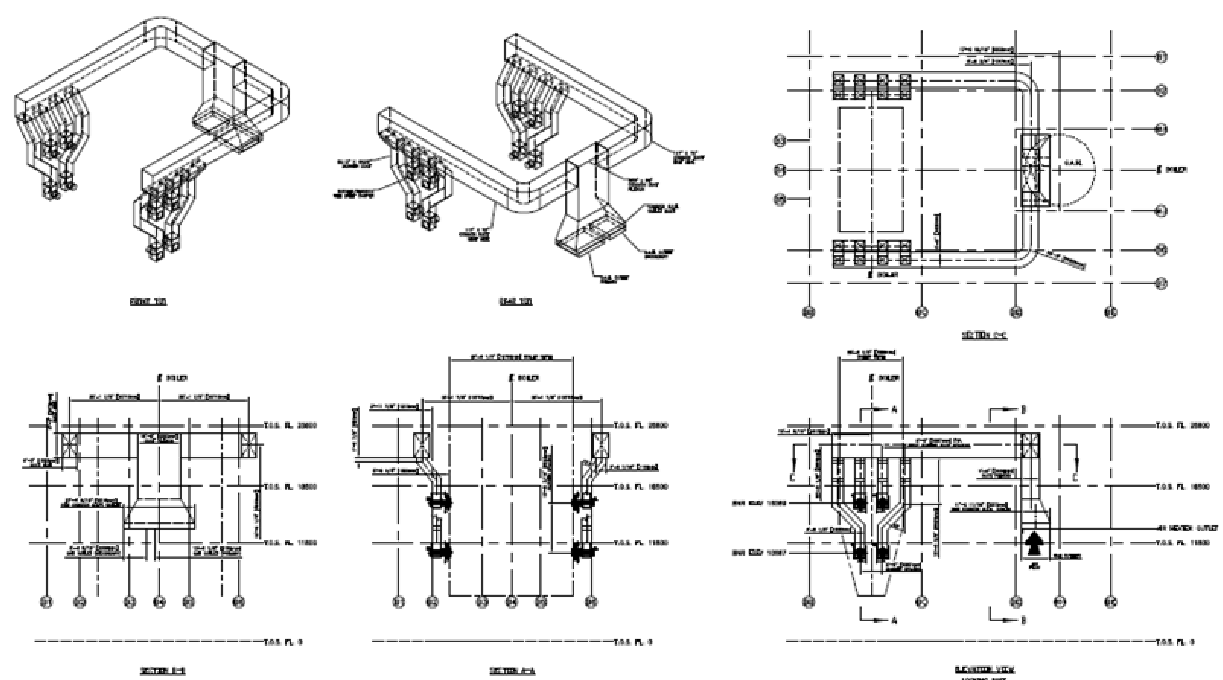

Figure 7: Zeeco's New Design Combustion Air System

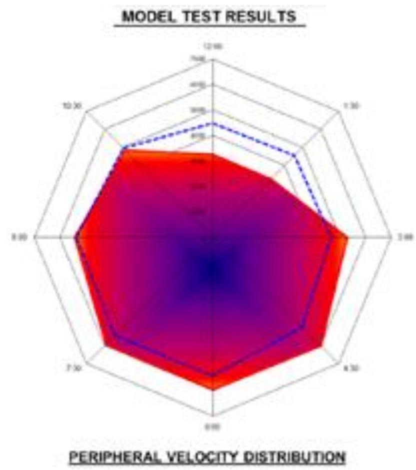

Figure 8: Example of Model Study Peripheral Distribution Chart

Due to the boiler's original controls and Burner Management System's design for main fuel petcoke firing and natural gas start up burners, they were not designed for full load natural gas firing. During the initial design proposal phase, it was agreed that a separate Redundant PLC BMS system would be necessary to integrate into the main DCS system. This would allow the main system to remain "as-is" in the event the unit was to return to petcoke firing in the future. Essentially, it would be a "fuel selector" switch to return the boiler's operation back to petcoke firing. This system was designed in working with the plant owner's original DCS and BMS supplier to ensure a smooth integration into the DCS system.

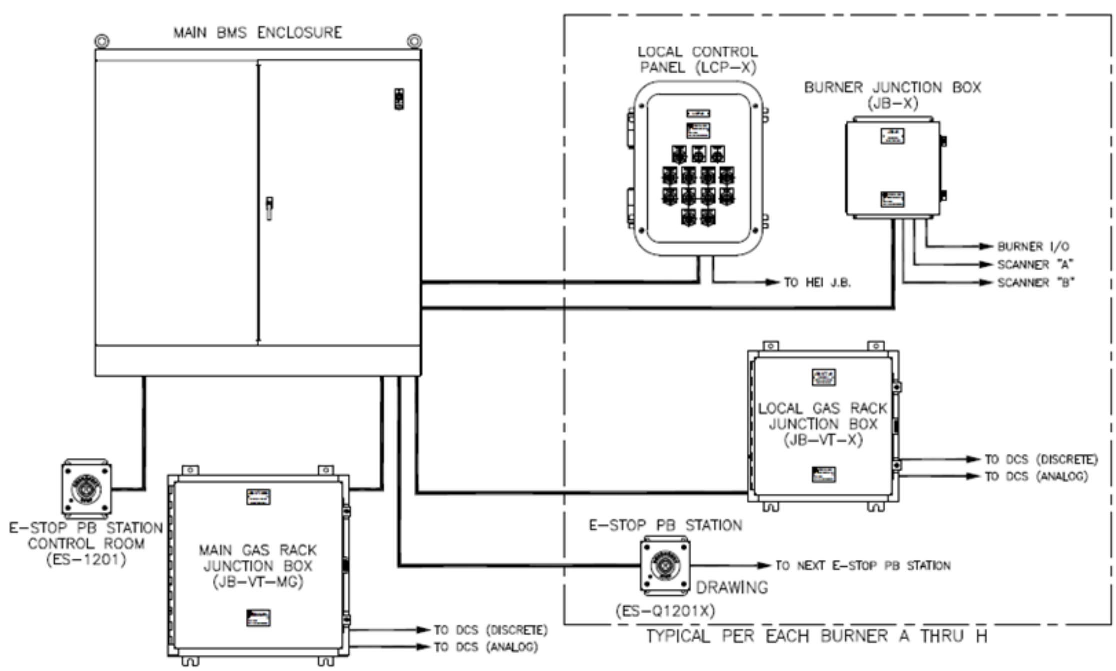

Figure 9: Boiler's Burner Management System

In order for the new burner system to be modified to fire on natural gas, several modifications were required for successful full load natural gas firing, including:

- Removal of furnace's lower slope refractory- During petcoke firing, the turbulent nature of the fluid bed, including the solids return from the cyclone, required the lower slope tubing to be fully protected from potential erosion. When the solid fuel is removed, this lower slope no longer required the refractory coverage to protect the tubing from solids within the cyclone, promoting further heat absorption in the furnace for natural gas firing, and to assist with lower emissions.

- As noted above, the cyclone design in a CFB is to remove solids from the furnace exit flue gas and return them to the fluid bed to promote high efficiency firing and lower carbon loss. With petcoke firing removed, the cyclone was no longer needed for this operation. The inlet to the cyclone plated off, effectively "closing" the inlet so no flue gas would pass through the cyclone. The loop seal exit was "plugged" with refractory to protect it from furnace gasses. This sealing can be deemed 'temporary", as the plate and refractory plug can be removed in the event petcoke firing is deemed cost effective over natural gas firing.

- All back-end clean up equipment are placed out of service due to natural gas firing.

Upon all final design "freeze" and plant owner approvals, fabrication and procurement proceeded and all equipment was delivered to the site by the end of March 2013. Due to the critical schedule, the plant owner was required to take the boiler out of service in late January 2013 to begin the modification process for the natural gas firing. The equipment, upon on-site arrival, was immediately transported to the boiler and the installation process began.

Due to the diligence of the entire engineering team, the integration and installation of the burners, valving and BMS proceeded very smoothly throughout the outage. All the upfront engineering and time ensured the design was cost effective and the outage was completed on time.

Commissioning and Startup

The plant owner also contracted Zeeco's Service Engineers to provide full commissioning and installation assistance, to ensure that all mechanical and electrical equipment was installed per Zeeco's requirements. Zeeco's Service Engineering team was on-site to review and check out the electrical/mechanical/BMS/DCS installation. This proceeded very smoothly during checkout, and all minor issues were addressed in the time allotted for commissioning. Actual equipment start-up proceeded immediately after the final commissioning. Burner performance and full steam boiler operation was achieved in less than two weeks.

Final Conditions are as noted:

- Final emissions performance met the contract and permit requirements of 0.07lbs/MMBtu
- Full load steam boiler requirements were met within the two week timeframe

Conclusion

Boiler steam load and emissions were met in a very timely fashion, and the plant owner was able to generate plant power within less than a month after the initial boiler start-up. The plant owner operated the boiler and turbine/generator near design capacity for over three months after final commissioning. The effort placed on the entire project, pre and post-award, led to the overall success of the boiler's conversion. The integration by the plant owner and the three primary engineering parties led to a fully integrated design that was reviewed by all to ensure the timely success of the project. Based upon the success of the first boiler, Zeeco was awarded the contract for the second CFB boiler conversion, and will begin with installation and commissioning to be in mid-2014.