CASE STUDY

for

Forced Internal Recirculation (FIR) Burner for Firetube Boiler Application

at

Fullerton College
Fullerton, CA

Prepared by

Gas Technology Institute
1700 South Mount Prospect Road
Des Plaines, IL 60018

December 2003

DISCLAIMER

Table of Contents

EXECUTIVE SUMMARY

Recently, Fullerton College upgraded its boiler room facility by installing a pair of Johnston firetube boilers that incorporate the GTI-developed forced internal recirculation (FIR) burner technology. The low-cost burner was selected to provide heat and hot water for several applications throughout the college, located in Fullerton, California. This report describes the development process of the FIR burner and the transition from a successfully tested prototype burner to a commercially available product. Results from previous field demonstrations are briefly mentioned and the results obtained at Fullerton College illustrate excellent performance for firetube boiler applications.

Until recently, external flue gas recirculation (FGR) approaches have dominated the 15 to 30 vppm NO_x retrofit market, and ultra-low-NO_x emissions performance (below 9 vppm) has been demonstrated with very high FGR levels. In most cases, the FGR requirement forces the fan size to be bigger and burner stability, fan horsepower, efficiency, and turndown are all compromised, leading to higher capital and operating costs.

As an alternative to this method, the FIR family of burners utilizes the distribution of a premixed or partially premixed flame around a metallic insert or "recirculation sleeve" that induces recirculation of combustion products back to the root of the flame. In this manner, the FIR burner technology combines the use of premixed combustion and internal FGR to reduce the bulk and peak flame temperature. The lower flame temperatures reduce the formation of thermal NO_x compounds. This recirculation sleeve controls the flue gas recirculation and anchors the flame over all the firing conditions. The recirculating sleeve also radiates to the cold furnace wall or a process heater wall, increasing heat transfer and helps to reduce the peak flame temperature. In doing so, NO_x emissions are drastically reduced without costly efficiency penalties incurred by external FGR, steam injection, or high excess air combustion.

The FIR burner has demonstrated low nitrogen oxide (NO_x) and carbon monoxide (CO) emissions from natural gas combustion, exceeding design targets of < 12 volumetric parts per million (vppm)* NO_x and < 50 vppm CO at design turndown, without any external flue gas recirculation. The burner can be used in a wide range of industrial and commercial boiler applications that produce paper, chemicals, petroleum products, food, and steel.

Development of the FIR burner technology was sponsored by: the U.S. Department of Energy — Office of Industrial Technologies; Gas Research Institute (a predecessor company of GTI); GTI's Sustaining Membership Program; and Southern California Gas Company. Installation of the boilers incorporating the FIR burner was sponsored by: Fullerton College, Southern California Gas Company, and GTI's Industrial Research Collaboration Programs.

* Emissions corrected to 3% O_2.

I. BURNER BACKGROUND AND DESCRIPTION

The demand for ultra-low-NO_x combustion technologies at industrial facilities is increasing. Current regulations by California's South Coast Air Quality Management District require NO_x levels below 30 volumetric parts per million* (vppm) for existing gas-fired units at or above 2 million Btu/h. New boilers in California and other parts of the U.S. are often limited to as low as 9 vppm NO_x. With expectations of even stricter NO_x emissions limits in the future, boiler owners need cost-effective, low-emissions burners for existing and new equipment.

The methods commonly used to achieve these low emissions include low-NO_x burners that utilize external flue gas recirculation (FGR), combustion at high excess air, steam or water injection, premixed fuel and air, flue gas diluted natural gas, or the use of a stack cleanup system such as selective catalytic reduction. All of these measures reduce energy efficiency, either by increasing stack gas losses or by increasing power requirements. Stack gas losses are incurred from increased flue gas volumetric flow exiting the boiler at elevated exit gas temperatures. Higher gas volumes leaving the boiler at higher temperatures reduce the overall boiler efficiency. In the case of steam injection, energy is taken from the steam side, introduced to the flue gas side and then exits the boiler stack taking its latent heat with it. Power required for additional or higher-capacity blowers, pumps, and other auxiliary equipment add to the energy costs of the boiler/burner system. Maintenance on this auxiliary equipment can also be high.

Thus far, external FGR approaches have dominated the 15 to 30 vppm NO_x retrofit market, and ultra-low-NO_x emissions performance (below 9 vppm) has been demonstrated with very high FGR levels. In most cases, the FGR requirement forces the fan size to be bigger and burner stability, fan horsepower, efficiency, and turndown are all compromised, leading to higher capital and operating costs.

As an alternative to these methods, the Gas Technology Institute (GTI) has developed the Forced Internal Recirculation (FIR) family of burners with funding support from the U.S. Department of Energy — Office of Industrial Technologies, Gas Research Institute (a predecessor company of GTI), GTI's Sustaining Membership Program, and Southern California Gas Company. The main feature of the FIR approach is the distribution of a premixed or partially premixed flame around a metallic insert or "recirculation sleeve" that induces recirculation of combustion products back to the root of the flame. In this manner, the FIR burner technology combines the use of premixed combustion and internal FGR to reduce the bulk and peak flame temperature. The lower flame temperatures reduce the formation of thermal NO_x compounds. This recirculation sleeve controls the flue gas recirculation and anchors the flame over all the firing conditions. The recirculating sleeve also radiates to the cold furnace wall or process heater walls, increasing heat transfer and helping to reduce the peak flame temperature. In doing so, NO_x emissions are drastically reduced without costly efficiency penalties incurred by external FGR, steam injection, or high excess air combustion.

---

* Emissions corrected to 3% O_2.

To maintain flame stability while supplying acceptable turndown levels, many of the early ultra low NO_x burners have employed moving parts to control the required flame/air velocities at strategic positions in the burner. The FIR burner design is much more simplistic and there are no moving parts. The amount of recirculated FGR and fuel mixing are controlled by the fluid dynamics and air pressure in the burner nozzles. No separate dampers, sliding sleeves, or complicated ducting are required. Once the burner is configured and tested, there is no adjustment that need be made to the burner, other than simply changing the fuel to air ratio through the standard fuel controls.

The burner controls required for the FIR burner are also very simple. Standard flame safeguard systems are employed without any special system configuration. All of the burners commercially tested on firetube boilers to date, have been set up with single point positioning systems. These jackshaft systems have been used on boilers for many years and have been time tested. Another advantage of the single point positioning system is that most boiler operators are very familiar with how they work and are accustomed to seeing them in burner applications. The single point positioning system allows a burner technician to adjust the air to fuel ratio by watching the flue gas oxygen concentration and adjusting the fuel input through the gas flow control valve. Once this has been completed through the entire operating range for the burner, the burner is set up and ready to operate in automatic regime. The boiler is then released to the burner management system and is controlled off of the system demand.

The FIR burner can be applied to a wide range of industrial and commercial boilers and process heaters including those used in the paper, chemical, petroleum, food, and steel industries. The FIR burner was originally conceived as an air-staged burner as shown in Figure 1, but the design has evolved for specific boiler requirements to include fuel-air staging designs and single-stage designs. The single-stage design has been successfully applied in firetube boiler designs. Extensive testing with these design iterations was performed at the GTI laboratories on firetube boiler simulators. The results were very promising with NO_x emissions measuring in the single digits. The work effort then focused on applying the FIR burner at various host sites during field demonstrations. The FIR burner was successfully applied to both watertube and firetube boilers, , and a down-fired vertical steam generator.

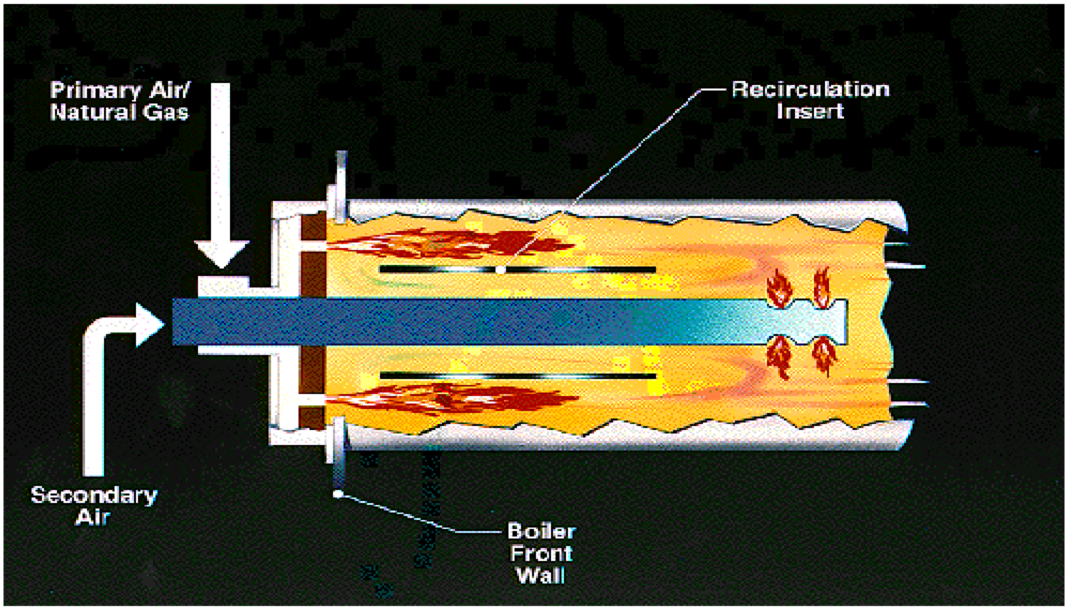

Figure 1. FIR Burner Concept

One of the first field demonstrations was at Vandenberg Air Force Base (AFB) on a firetube boiler. This application was the result of an initiative by the federal government entitled *Reinventing Environmental Regulation*, which proposed 10 principles of regulatory reform and directed the U.S. Environmental Protection Agency to implement 25 high priority actions. One of these was aimed at achieving regulatory reform within the Department of Defense through a program called ENVVEST (Environmental Investment). A framework was established for developing pilot programs at several selected Department of Defense facilities. Vandenberg AFB was selected as the prototype facility to pilot the ENVVEST program, thereby implementing a common sense and cost-effective environmental protection program to meet regulatory requirements. The first phase of the ENVVEST program at Vandenberg AFB focused on emissions reductions from boilers, furnaces, and process heaters.

As part of Vandenberg's air quality initiative, GTI and Detroit Stoker Company (DSC) teamed together and demonstrated the FIR burner on the Existing firetube boiler at theBase. The results of the field demonstration show that the 2.5 million Btu/h FIR burner achieves very-low emissions at low excess air without the use of external FGR, water or steam injection, all of which either reduce boiler efficiency or are expensive. Extensive short- and long-term evaluation of the commercial prototype burner demonstrated the performance capabilities of the FIR burner concept. NO_x emissions were demonstrated over the range tested from 9.8 vppm at 0.5 million Btu/h to 17.2 vppm at 2.0 million Btu/h. The excess oxygen content measured in the stack ranged from 4.5% O_2 at 0.5 million Btu/h and 2.3% O_2 at 2.0 million Btu/h. CO emissions were stable at less than 15 vppm across the load range. These values represent a 75% reduction compared to baseline NO_x levels. At baseline conditions with the original burner NO_x emissions ranged from 45 to 80 vppm.

Another application of the FIR burner was a watertube boiler at DSC manufacturing facility in Monroe, Michigan. The boiler is used to generate process steam and for heating the 400,000-square-foot facility during the winter months. The 20 million Btu/h host boiler was a watertube design originally a stoker that was converted to natural gas firing before the beginning of this demonstration. The existing burner controls were interfaced with the FIR prototype burner for testing. Water-cooled panels were installed over the refractory floor at the beginning of the demonstration to determine the effect of cooling surface on emissions.

With the water-cooled floor, NO_x concentrations ranged from 6.7 vppm at 11 million Btu/h to 8.3 vppm at 5 million Btu/h. The excess oxygen measured in the stack ranged from 3.0 to 2.5% O_2 and the maximum CO emissions were 40 vppm, measured at 25% load. Additional tests were performed which included automatic start-up and operation, load swinging from 20 to 100% at regular and increased speed, and boiler shutdown.

After removing the water-cooled panels exposing the refractory floor, NO_x concentrations ranged from 8.0 vppm at 11 million Btu/h to a high of 9.9 vppm at 15 million Btu/h, but with a slightly lower value at maximum fire. It was not possible to test at lower loads because steam was required for heating and manufacturing use. The excess oxygen content measured in the stack ranged from 3.0 to 2.1% O_2 and CO emissions were consistently below 25 vppm. As before, additional tests were performed which included automatic start-up and operation, load swinging from 55 to 100% at regular and increased speed, and boiler shutdown. The DSC FIR burner was in operation for over four years on the unattended watertube boiler and logged over 10,000 hours. Overall, the burner has experienced high reliability with no deterioration of performance.

At another host site, a 60 million Btu/h commercial prototype FIR burner was designed and built for demonstration at a brewery in Southern California. The boiler house operates four boilers to provide steam to the brewery, two of which are generally in operation to handle normal load swings. All four boilers were previously fitted with low-NO_x (30 vppm) natural gas burners that utilized external FGR to comply with regional regulations. The boilers are also equipped with individual continuous emissions monitors for monitoring NO_x, CO, and stack oxygen.

The 60 million Btu/h commercial prototype FIR burner is a fuel-staged burner that was configured to use the host site's existing combustion controls. The burner package includes a blower and fuel control valve, and initially used the existing FGR controls for secondary air trim. The boiler at the host site is an E. Keeler D-type watertube boiler. Performance targets for NO_x and CO emissions were met at 18 to 60 million Btu/h, although CO emissions at the lowest load (15 million Btu/h) continued to be slightly above the 30 vppm target. NO_x concentrations varied from 7.0 to 9 vppm across the boiler range; while, CO emissions were consistently single-digit above 18 million Btu/h. The excess oxygen content measured in the stack ranged from 4.5 to 5.7% O_2 to control NO_x emissions at levels under 10 vppm. This performance represents a 65% NO_x reduction and a 96% CO reduction compared to the previous (baseline) burner. Because external FGR is not used with the FIR burner, the total flue gas volumetric flow rate was reduced in comparison with the previous (baseline) burner. After comparing stack temperatures and fan power demand, and accounting for the slightly elevated excess air requirement for optimal FIR operation, the net energy efficiency improvement was about 1.0%.

Based on the success of the FIR burner at various field demonstrations the FIR burner technology was licensed to Johnston Boiler Company (firetube boiler applications); Coen Company Incorporated (package watertube boiler applications); and Peabody Engineering Corporation (field-erected boilers in the steel industry).

II. HOST SITE

Fullerton College is located in the city of Fullerton, and is the oldest community college in continuous operation in California. The college was established as a department of the Fullerton Union High School on April 25, 1913, and was reorganized as a district junior college on March 31, 1922. In the spring of 1964 the residents of the Anaheim Union High School District, the Brea-Olinda Unified School District, and the Placentia Unified District elected to form an interim junior college district to be merged with the existing Fullerton College District to form a larger organization. Subsequently, an election was held and the North Orange County Community College District came into existence, encompassing an area of 150 square miles. Cypress College, in the city of Cypress, opened its doors in September 1966, as the second college in the district. A portion of Garden Grove was annexed to North Orange County Community College District, effective July 1, 1976.

The boiler room at Fullerton College had two existing firetube, water-back boilers each rated at 8 million Btu/h. The boilers had the capability to provide heat and hot water for several applications at the college, including dormitory, classroom, and library use. However, with expansion of the college underway, the need for increased capacity and compliance with California emissions requirements dictated that the boilers be upgraded. Fullerton College elected to replace its current system with two new Johnston Boiler Company boilers (Johnston Boiler Company is GTI’s licensee for FIR burner technology in firetube boilers). For this application, Fullerton College required less than 12 vppm NO_x with greater than 85% combustion efficiency.

III. FIELD RESULTS

Fullerton College decided to replace both boilers Installation of the packaged boilers at Fullerton College occurred in stages to allow for continued usage of steam and hot water. Removal of the existing Boiler No. 2 was initiated in early February and final testing of the new packaged boiler was completed on February 24th. The new boiler with its FIR burner system was placed in continuous operation and operated for a ten-day period without incident. This trouble free operation provided enough confidence to initiate the removal of the existing Boiler No. 1 in early March. Final testing was completed with the new packaged boiler on March 26th. After a ten-day period of trouble free operation the packaged boiler was accepted by the college and placed online for continuous operation. The boiler room at Fullerton College is shown in Figure 2, Boiler No. 1 is pictured on the left. Combustion was stable and quiet through the entire range and the FIR burner flame is shown in Figure 3.

Figure 2. Fullerton College Boiler Room

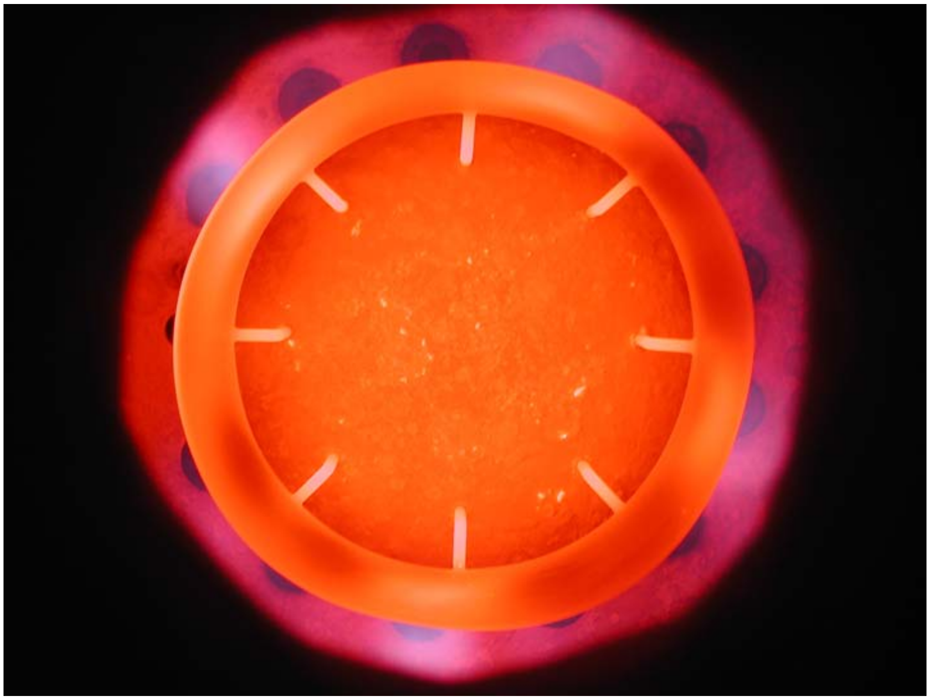

Figure 3. FIR Burner Flame

The set up of the burner was comparable to a conventional burner and easier than a burner equipped with external FGR. Both of the packaged boilers installed at Fullerton College surpassed the performance goals established for NO_x emissions and combustion efficiency. Baseline emissions with the existing firetube boilers ranged from 78 vppm at low fire to 86 vppm at high fire. NO_x emissions from the FIR-equipped packaged Boiler Nos. 1 and 2 were below 10 vppm from low to high fire, see Figure 4. and CO emissions although not shown on the plot were consistently below 15 vppm through the entire firing range. This represents an average 88% reduction in NO_x emissions compared to baseline data. The FIR burners combined with the Johnston four pass boilers were also more efficient than the existing boiler package. At the lower firing ranges, the FIR burners could run at lower excess oxygen levels and this enhanced efficiency. In fact the FIR burners could operate at the same excess oxygen through the entire firing range, see Figure 5. The new packaged boilers/burners were more efficient through the entire firing range by more than one and a half percentage points, see Figure 6.

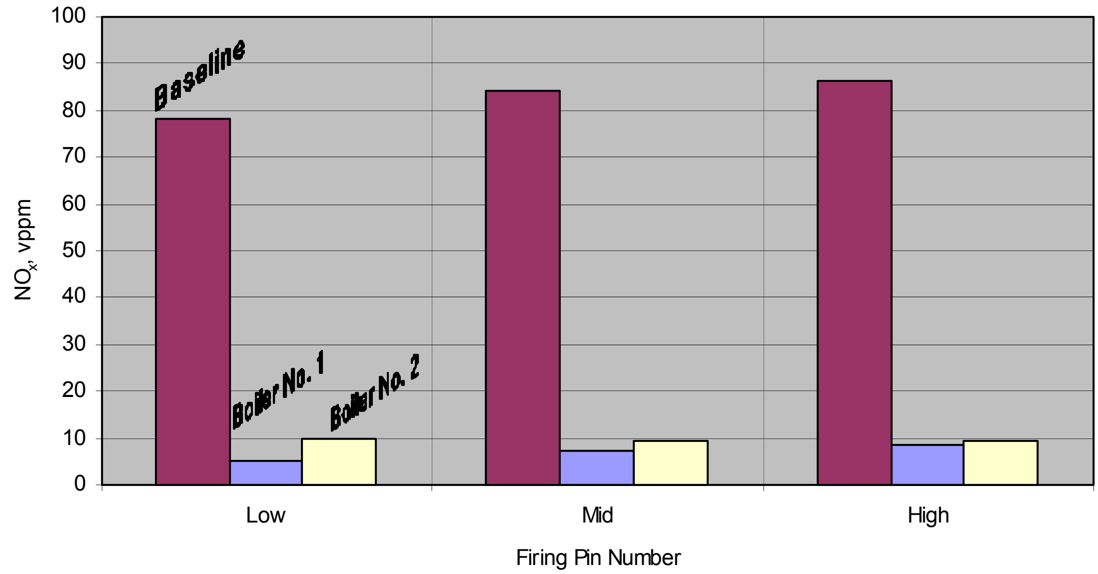

Figure 4. NO_x Emissions Over the Firing Range

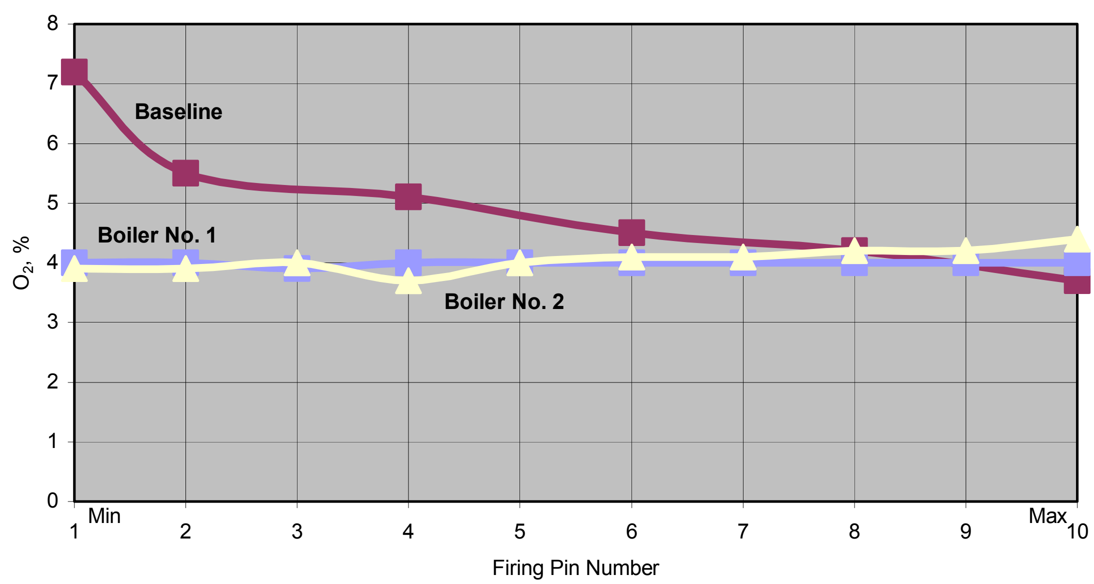

Figure 5. Excess Oxygen Over the Firing Range

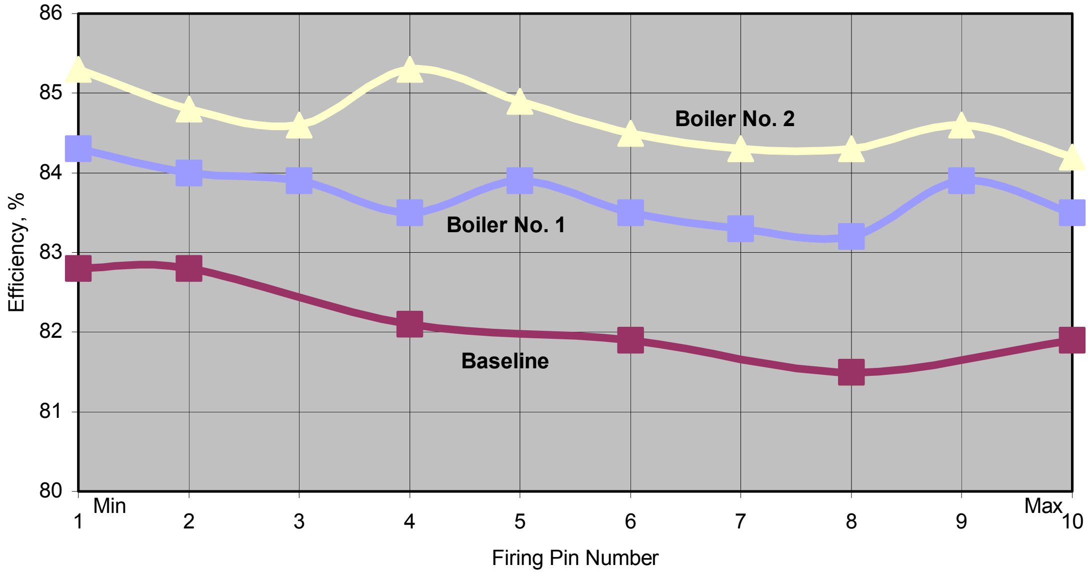

Figure 6. Combustion Efficiency Over the Firing Range

IV. CONCLUSIONS

The FIR burner and boiler package(s) were able to surpass the stringent emissions performance required at Fullerton College. NO_x emissions were consistently below 10 vppm across the firing range while CO emissions were consistently below 15 vppm. This represents an average 88% reduction in NO_x emissions when compared to baseline data. Combustion was stable and quiet through the entire firing range. These results were achieved without the use of external FGR or other diluent injection. Since there is no external FGR or steam injection to control for NO_x abatement, the FIR burners are significantly easier to set up than other burners. FIR burner controls are via a simple and time-proven jackshaft and linkage concept. No sophisticated controllers, flame scanners, or oxygen trim is necessary. The single-stage approach is both simple and effective. Testing has showed that the combustion efficiency of these packaged boilers surpassed that of the conventional boilers that were originally installed.

Attachments

Contacts

Program Manager	Mr. Steve Sikirica Gas Technology Institute 1700 South Mt. Prospect Road Des Plaines, IL 60018 Tel: (847) 768-0859 Fax: (847) 768-0600 E-mail: steve.sikirica@gastechnology.org
Gas Supplier	Southern California Gas Company
Host Site	Fullerton College 321 E. Chapman Avenue Fullerton, CA 92832
Johnston Boiler Company	Mr. David Thornock Johnston Boiler Company 300 Pine Street Ferrysburg, MI 49409 Tel: (616) 842-5050 Fax: (616) 846-6380 E-mail: davidthornock@johnstonboiler.com