Experience with Low Pressure Drop, High Efficiency, Low Emission Burners in Power Boilers

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Abstract

Two front fired power boilers, a 250 MW CE boiler with sixteen burners and a 75 MW Foster Wheeler boiler with six burners were retrofitted with new COEN burners developed for utility applications. The burners were engineered to meet low air pressure drop, low excess air and low NOx requirements. At the design stage a computational fluid dynamic models representing a portion of ductwork, the wind boxes and burners were set up to in order to evaluate the uniformity of air distribution between the burners. When firing natural gas the flame in both boilers was quite different compared with the original burners. Low flame emissivity - high transparency caused initial difficulties with high temperature in the super heater. In the 250 MW boiler with the burners arranged in a four by four array the problem was overcome with fuel biasing between the levels. At the same time low excess air operation, down to 0.3% O2 in the flue gas, with practically no carbon monoxide emissions and NOx emissions of 330 ppm, corr. to 3% O2 dry, at high fire were achieved. That also resulted in the increased overall efficiency of the system and power savings on the combustion air fans. In order to achieve low excess air, opacity and NOx when firing residual oil, a series of tests was conducted with different atomizer cap configurations. With the final components 12% opacity achieved, while firing with the excess oxygen level as low as 1.0%. NOx emissions at high fire were 320 ppm. Due to the low burner air pressure drop and high fuel pressure available, the burners could operate much higher the design capacity. Full boiler load could be easily carried by 14 burners. This, coupled with the ability to operate simultaneously on gas and oil, efficient individual burner air shut off dampers, and easiness of light off, greatly increased operational flexibility of the boiler.

The 75 MW boiler had only two levels of burners and the boiler depth was 25% more than the depth of the 250 MW unit, while the distance for mixing over the upper burner level was much shorter. With this geometry the ability to bias gas with overall low excess air was reduced, yet good overall performance was achieved The excess oxygen was well below 1.0% on both fuels and NOx emissions were 270 ppm (corr. to 3% O2 dry) on gas as well as on oil.

Introduction

In 1996 COEN company supplied 16 newly developed burners for a 250 MW front fired CE boiler. The burners were capable of firing natural gas and residual oil and were installed while the plant undergone overall retrofit.
The burners positioned in four rows of four with 8 ft spacing in vertical and horizontal directions. The depth of the radiant section was only 24 ft, the width was 45 ft and the and the height from the hopper to the nose was 40 ft. The combustion air is supplied by two individually controlled fans feeding the air into a symmetrically designed ducting that has a bypass section between the fans. The wind box is sectioned on four compartments with each supplying air to four burners - two over two. The boiler operates with positive furnace pressure without an induced draft fan. The air is preheated to about 480 deg F in two Lungstrom type air heaters. The boiler is also equipped with a flue gas recirculation (FGR) installed through the hopper.

The original burners had to be replaced due to corrosion damage, lack of performance and numerous other problems. With the old burners the operation had to be with a relatively high excess air, about 3% of oxygen in the stack when firing either gas or #6 Oil. High amount of water was also injected into the super heater. When firing #6 Oil fame was often impinging on the back wall creating concerns for the longevity of the water tubes. There were also problems with flame stability especially during the operation with FGR at reduced loads. The flow of FGR coming up through the openings in the hopper was interfering with the flames of low level burners. Difficulties with flame scanning, burner light off and inability to properly isolate the burners when putting them out of service created additional problems for the operational personnel. These problems were interfering with plant operation in light of frequent demands from the dispatcher to switch the fuels and modulate load.

In the process of retrofit the boiler was equipped with new state of the art controls, burner management system and a continuous emission monitoring (CEM) equipment. The CEM was showing instantaneous NOx and opacity in the stack and the excess oxygen upstream of the air heaters.

To reduce the impact of FGR on the lower burner flames the plant decided to equip the boiler with specially designed shields made out of a heat resistant alloy. The function of these shields at the hopper was to deflected the flow of FGR toward the rear wall of the boiler and away from the flames.

The requirements for the new burners included low excess, low NOx and low CO emissions. Another major requirement derived from the need to improve operational flexibility was the ability to maintain full load and performance with only 14 burners in service without any changes to the air supply system. To achieve this the burners had to be designed with a pressure drop below 125 mm of water column while firing on average 165 MMBtu/hr on Natural Gas and 157 MMBtu/hr on Oil. This was a challenge to the burner vendors as the maximum burner throat opening between the water tubes in the boiler front wall was limited to 32 inches. In other words, the hydraulic resistance of the burner needed to be about 10% lower than of an unobstructed opening of 32 inches in diameter.

An extensive combustion optimization work followed the completion of construction and was based on extensive data gathering at different operating conditions. It included Natural Gas firing with non uniformed fuel distribution between the burner levels (biased firing), #6 Oil firing with differently drilled oil gun caps, combination firing with some burners firing gas and others firing oil. The criteria for optimization were maximizing the overall system efficiency while meeting the emission requirements. When firing #6 Oil, the flame shape was also a limiting factor, as flame impingement onto the tube walls should be avoided. At each regime, the scope of data, besides those available from the control room, included traverse sampling of the boiler flue gas for oxygen, carbon monoxide and NOx at two locations: upstream of the economizer and downstream of the air heater.

Following a successful retrofit of the 250 MW boiler COEN received orders to supply the same type burners for two 75 MW Foster Wheeler boilers. Each boiler had 6 burners, three over three with 7 ft spacing vertically and 8 ft horizontally. The radiant section was 30 ft deep, 32 ft wide and 31 ft high. Air preheat was at 525 deg F. All burners had a common wind box. These boilers were not making the design capacity due to limitations of the forced and induced draft fans and some impingement on the back wall of the boiler when firing oil. The first boiler was commissioned in the end of 1998, the other will be commissioned this year.

Burner Design and Installation

The selected burners were newly developed venturi type utility burners of COEN Company. The burners had a single air flow zone with a low resistance spinner in the center retractable oil gun and six lance type gas spuds positioned around the spinner, Fig.1. The pattern of gas and oil fuel injection was contributing to the axial momentum of the combustion air flow, thus further reducing the hydraulic resistance of the burner. The nominal gas pressure at the burners was 14 psig . The steam atomized oil guns - COEN MV, were designed for oil pressure of 150 psig. Each burner was also equipped with an isolation sliding barrel damper, air flow metering device, retractable oil gun. There were six lance type gas spuds positioned around a spinner. The burner body and the damper were made out of 304 stainless steel, light weight design. For the most critical heat exposed burner components - the spinner and the gas spuds, 310 stainless steel was used. The burner body was attached only to the boiler water wall and the gas spuds and oil gun, protruding through the burner front plate, were designed with provisions for some displacement between the wind box front and the boiler water wall. With this design the stresses associated with the differential thermal expansions between the boiler and the wind box were practically eliminated.

For the 75 MW boilers the burners were substantially shortened as the wind box depth was only 42 inch. Other modifications were made to the sliding barrel damper to make the installation very forgiving to different kind of misalignment between the throat and wind box front openings without requiring any adjustments and maintaining the required tightness.

Air Distribution Between the Burners

Original problems with the air distribution between the burners, reduced hydraulic resistance of the new burners and the necessity to operate with minimum excess air raised concerns with the uniformity of air distribution within a wind box compartment. In order to address these concerns COEN company was asked to perform a computational study of the air flow through the wind box compartment and the burners and develop recommendation to air distribution improvement.

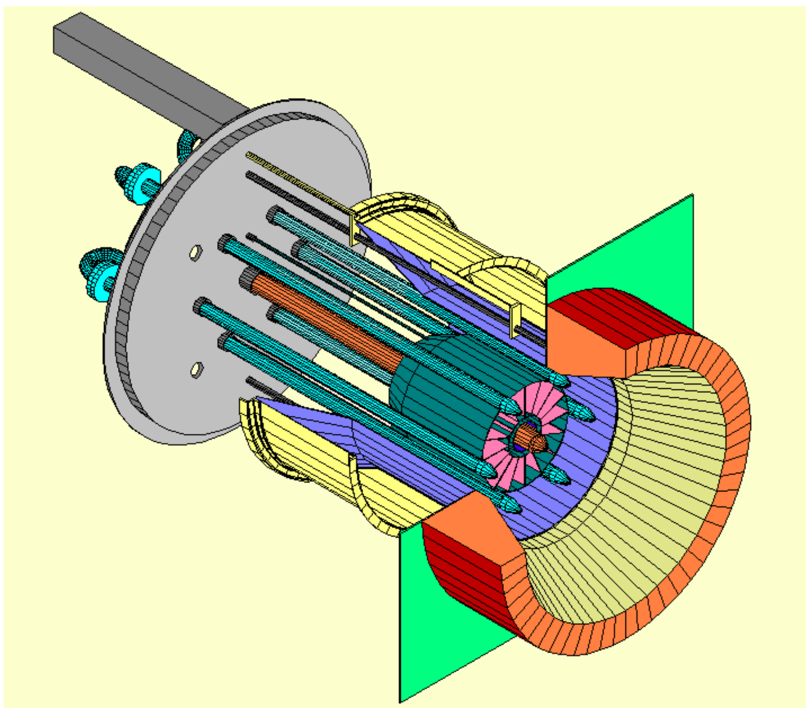

Fig.1 Schematic of the Burner

The computational study was performed by using a computational fluid dynamic software package FLUENT TM. The numerical model represented a compartment with four burners, as mainly the distribution of air within a wind box compartment was in question. The model adequately replicated geometry of the burner body. The spinner was substituted with the equivalent blockage, Fig.2. The effects of the gas spuds and oil gun were omitted as not essential for the purpose of the study. The modeling results illustrated by Fig. 3, showing a four burner wind box compartment of the 250 MW boiler. The expected uniformity of the air distribution between the four burners within each compartment was closely maintained within +/- 2%, thus establishing a good design basis for low excess air operation. The readings from the air flow measuring devices in

each burner, however, deviated within +/- 4,..,5% without any specific pattern between the symmetrical compartments. Thus, it was concluded that the discrepancy was due to a limited accuracy of the flow metering devices of the burners.
In the following projects for 75 MW boilers the manufacturing tolerances were changed and accuracy of the flow meters was improved. Air distribution measured by flow metering devices built into the burners was as predicted by the model: the middle upper burner was getting 3% less air than the burners from the left and right and the lower burners were getting 3% more flow than the upper burners at the average.

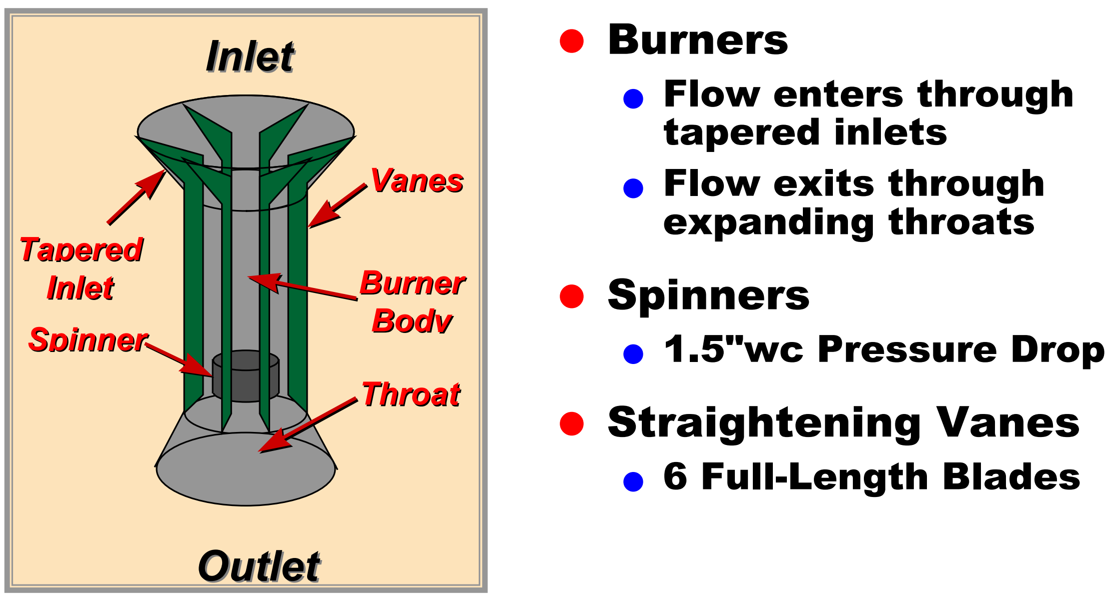

Figure 2. Burner features included in model

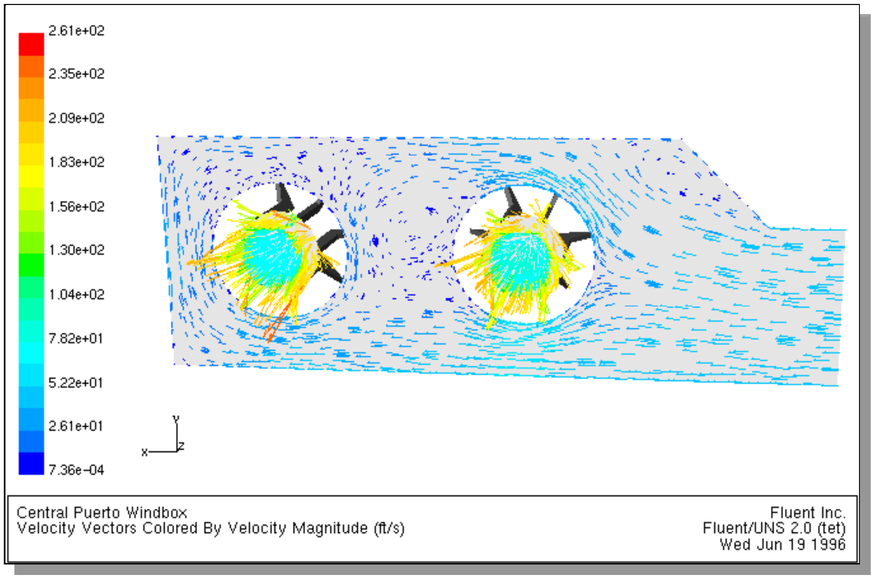

Figure 3. Velocity Vectors at Burner Exit

The air distribution system of the 250 MW boiler was equipped with the air flow metering devices continuously measuring the air flows going to each wind box compartment with four burners. The readings from these devices showed good uniformity of air distribution between the upper and lower compartments. With some of the burners in the compartment out of service, the air flow to the compartment, however, was not reduced according to the number of the burners remaining in service. With one burner in the compartment down the flow through each remaining burner was increasing by 10% compared with the other compartment with four burners. With two burners off the effect was even stronger. The leakage of air through the isolated burner were measured at the level of about 20% compared with the burners in service.

These findings were important for developing the recommendations for the efficient operation of the boiler with different number of burners out of service.

Boiler operation on Natural Gas. 250 MW Boiler

The initial experience with gas firing showed drastic differences in the flame appearance compared with the old burners. The flame was so transparent that the whole volume of the boiler radiant section looked uniformly glowing. There was no visible flame shape. The low emissivity of the flame resulted in the reduction of the radiation heat transfer to the walls and increased temperature in the super heater. The immediate result was increased amount of water injection for attemperation even with low excess air. With the boiler at maximum load the attemperation system was at maximum capacity of 60 ton per hour and there was reduction in the overall efficiency of the plant due to significant water injection in the reheater.

The solution to the problem was found in redistributing the fuel between the levels. The manual gas shut off valves in the lines supplying gas to all but the lowest level of burners were throttled down to create fuel lean firing of upper burners and fuel rich firing of lower burners. The degree of fuel redistribution was increased in steps, while monitoring the CO emissions. When the difference in firing rates between the lower and upper burners reached 20% the amount of water injection in the super heater was reduced by 47% to 32 ton per hour. Heavier biasing of fuel to the lower burners was not giving further reduction in the water injection. This additional biasing was, however, was very effective for the reduction of NOx emissions.

The final setting was with the gas pressure at the upper burners reduced to 55% of the pressure at the low level. With this heavy biasing the flame inside the boiler was still clear of soot even with very low excess air. The NOx was reduced by 30%, compared to the operation with no biasing, Fig.4. Fig. 5 shows final NOx in relation to the load. There were practically no carbon monoxide emissions. The average traverse readings at the economizer section of the boiler were 15 ppm of CO at 0.35% of O2 and 60 ppm at 0.2% of O2. However, fluctuations in the air flow within +/- 1% limited the practical minimum setting of O2 to 0.35%.

These good results can be explained by a strong stirring effect created by the burners in the upper part of the boiler radiant section. Due to a very high conversion rate of the burner differential air pressure to the momentum of the flow discharging from the burner throats, the jet coming out of the throat was capable of penetrating all across the boiler. The intense mixing of gas and air provided by the burner on one hand resulted in a low flame emissivity, that was undesirable. On the other hand that prevented formation of soot anywhere in the boiler, even though two lower levels of burners were firing at substoichimetric conditions.

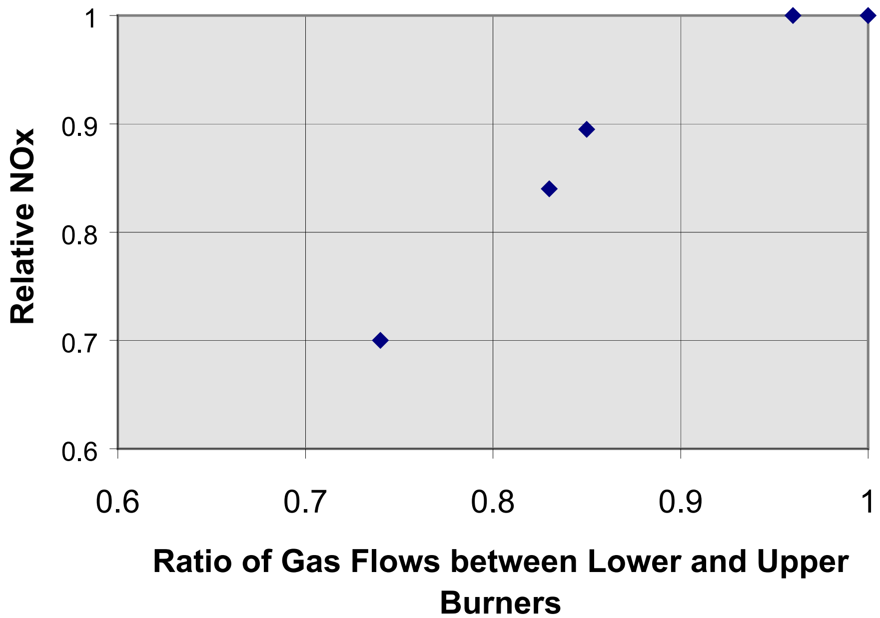

Fig.4 Effect of Gas Fuel Biasing on NOx

When firing gas, the burner differential pressure was very low. With all the burners in service at 250 MW output the burner differential pressure was only 65 mm w.c. With fourteen burners carrying full load the pressure drop was 85 mm. The low pressure drop resulted in substantial power savings, as the air flow rate was controlled by fan inlet vortex dampers.

Boiler operation on #6 Oil

Initial firings with #6 Oil showed problems with maintaining low excess air due to increased opacity and flame impingement on the rear water tube wall. The opacity in the stack was approaching the limit of 12% with about 3% oxygen concentration in the stack. In this case, high momentum of the discharging air flow and relatively weak swirling motion generated by the burner spinner were making the flame longer than anticipated.

The distribution of oil and atomizing steam between the burner levels was also uneven due to not fully compensated hydrostatic oil pressure difference between the burner levels. The atomizers were designed for constant differential pressure between steam and oil. However, this differential was about 7 psi (0.5 bar) lower at the low level of burners than at the upper level, creating detrimental fuel biasing and atomizing steam deficiency to the lower level. Another significant factor, responsible for a longer flame at the low level of burners, was absence of upcoming flow from the burners of lower levels that would bend the flame upward.

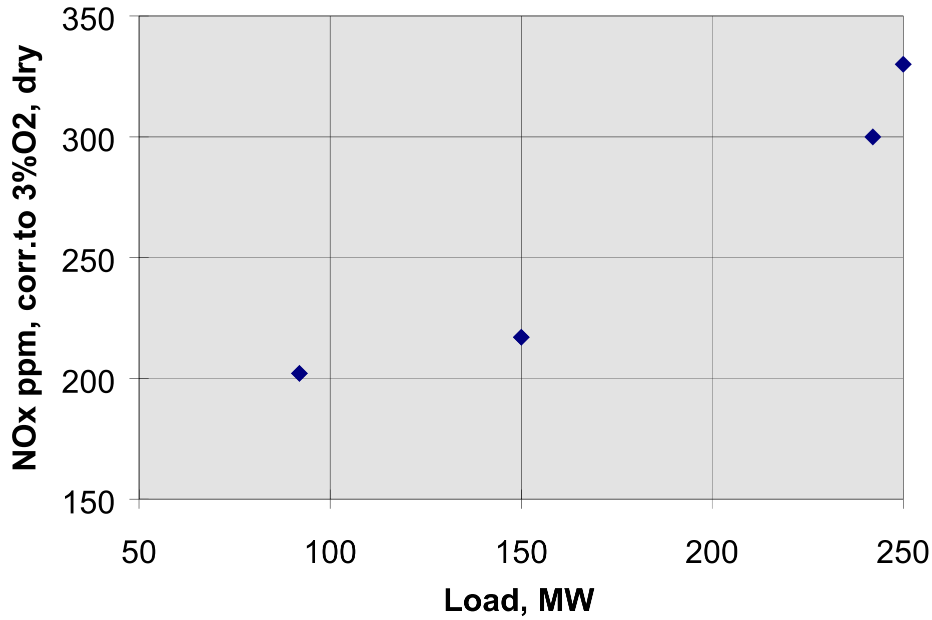

Fig.5 NOx Emissions on Natural Gas

In order to compensate for these effects the overall atomizing steam flow was slightly increased. At the same time the atomizing steam flow to the burners of two upper levels was throttled down. This allowed to reduce the excess air and operate at full load with 2% O2, as measured at the economizer section of the boiler, with the opacity at the stack of about 10,..,12%. The NOx emissions were 270 ppm (corr. to 3% O2, dry), that was well below the required level of 340 ppm. However, the problem with flame impingement at the burner low level was not yet completely resolved. So, the next step was modification of the atomizers.

With the modified atomizers the flame was shortened, and the excess air was reduced to 1.5% O2. There was, however, increase in NOx emissions by about 15% to 310,..,320 ppm. Due to continuous high load demand during the period when boiler was firing oil we were not able to record the data at loads below 90%, at witch point the NOx was 20% lower than at high fire. When firing #6 Oil there were no detectable carbon monoxide emissions.

With 14 burners firing #6 Oil with power output of 250 MW the burner differential pressure was 5.4 inches w.c.

Simultaneous Firing of Gas and Oil. Firing at low loads

The difference in the burner hydraulic resistance for Gas and Oil firing created some difficulties for simultaneous firing of two fuels. The old practice for simultaneous firing was to maintain equal heat inputs on burners firing either fuel. With the new burners this became unacceptable, as the oil fired burners were running with insufficient air. The new rule was to maintain an average per burner heat input from oil at 80% of the average heat input on gas. This ratio was accounting for the difference in the air flows of the burners firing oil and gas and also for the difference of about 7% between the optimum excess air on gas and oil. Following this rule on some regimes led to situations when burners firing gas had to operate up to 120% of the original maximum rating. The example of such a regime is the boiler at high fire, one to three burners firing gas and two burners out of service and the remaining burners firing gas. This, however, was not a problem as there was a substantial margin in the gas pressure at the burners and the burners demonstrated excellent stability even when fired much higher the original capacity.

Other rules for simultaneous burner firing and firing with burners out of service included maintaining some symmetry between the left and right wind box compartments with respect to the number of burners in service and type of fuel. If a deviation from these rules was necessary, it could be compensated by slightly higher excess air.

At partial load the FGR fan was automatically engaging as the steam temperature was dropping. When firing oil, the threshold for the FGR engagement was at 200 MW. When firing gas the need for FGR was below 120 MW.

During one of the boiler shut downs after several months of operation the inside of boiler radiant section was inspected. It was found that all the FGR deflectors in the hopper were burned down. Nevertheless, the new burners never showed any flame stability problems even at low loads (about 90 MW), so the deflectors appeared to be unnecessary.

Operation of the 75 MW Boiler

Due to the limitations of the existing forced and induced draft fans the maximum capacity of the boiler with the old burners was limited to 65-67 MW depending on the weather conditions. With the new burners 75 MW was achieved just at the limit of the induced draft fan and with 1,..,2% margin on the forced draft fan.
The NOx emissions on oil and gas at high fire were 270 ppm (corr. to 3% O2, dry). The CO emissions were insignificant with O2 at the back of the exhaust down to 0.9% on Natural Gas and 1.1,..,1.2% O2 on oil. The opacity was not measured, but visually the exhaust stayed clean down to 1.2,..,1.3 % O2 when firing oil.
Overall operation of the burners was very reliable on both fuels.
A short study was performed on the effect of fuel and fuel and air biasing between the levels when firing natural gas. Contrary to the 250 MW boiler, fuel biasing between the levels in this boiler was found ineffective for the reduction of attemperation water in the super heater of the boiler. It did not help to reduce the NOx either, while requiring some

increase in the overall excess air. Actually the NOx was even 5% higher. Shifting both gas and air in the same proportion to the lower level only marginally decreased amount of attemperation in the super heater, increased NOx and created additional difficulties for the operation.
When firing gas at high fire one test was performed with steam injection through the oil guns. This small addition of steam reduced NOx emissions by 20% without impact on the flame stability.

Conclusion

The overall experience with the new burners was very successful. The burners demonstrated good stability, easiness of light off, reliable flame scanning. Within minutes the boiler could be switched from firing one fuel to another and taking fast load swings was not a problem. The efficiency of the operation was improved in both boilers due to low excess air operation with practically no carbon monoxide emissions.
Low pressure drop design of the burners proved itself in the 250 MW boiler with power savings on the forced draft fans and with additional operational flexibility: full load could be easily maintained on either fuel with only 14 burners in service. In the 75 MW boiler low excess air and low pressure drop design solved significant capacity problems.
Biasing of Natural Gas toward the lower levels in the tall boiler with four levels of burners was found to be an extremely powerful tool for intensifying the heat transfer in the radiant section of the boiler and reducing the amount of water injection in the super heater and reheater by 28 ton per hour. The biased firing also allowed to reduce the NOx emissions by 30%. When firing Natural Gas, the NOx emissions at full load were below 330 ppm, corr. to 3% O2 (dry). When firing #6 Oil the excess air had to be maintained not lower than 8% (1.6% O2), as at this level the opacity was climbing to the maximum allowable level of 12%. NOx emissions of 310,…,320 ppm (corr. to 3% O2, dry) were well below the guaranteed level of 340 ppm. Due to biased firing techniques and the differences in burner hydraulic resistance with respect to the type of fuel, proper personnel training was very important for the boiler operation with maximum efficiency.
Gas biasing was found ineffective for improving the operation of the 75 MW boiler with two rows of burners. NOx emissions at high fire were 270 ppm (corr. to 3% O2, dry) with insignificant CO with stack O2 down to 0.9% on Natural Gas. When firing oil the opacity was not measured, but visually the exhaust stayed clean and CO emissions low down to 1.1,..,1.2 % O2.