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Multi-Pollutant Emissions Control - Ashworth Combustor Retrofit to AEG Hutsonville Unit #4

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INTRODUCTION

ClearStack Combustion Corporation's multi-pollutant reduction Ashworth Combustor is a three-stage combustion technique that reduces the major air pollutants (NO_X, SO_2, Hg, other metal air toxics and particulate) associated with coal combustion. Limestone is added with the coal to capture sulfur and mercury in the slag and fly ash produced.

ClearStack, in association with PROMECON USA, Alstom Power, Sargent & Lundy, and United Conveyor completed an engineering assessment of retrofitting the Ashworth Combustor to the 85 MWe Ameren Energy Generating (AEG) Hutsonville Boiler #6, Unit #4. The purpose of the engineering assessment was to determine if the Ashworth Combustion technique could be physically retrofit to the boiler and if so what boiler performance impacts would result. The Illinois Clean Coal Review Board and ClearStack funded this study, and AEG internally is assessing environmental permitting issues. In 2003, a 40 million Btu/hr unit was successfully tested [1] in Lincoln, Illinois. NO_X emissions were reduced to 0.095 lb/million Btu of coal fired and SO_2 emissions were reduced by 72% using a Ca/S ratio of 0.85. Mercury capture of 93 to 100-wt% was achieved and 80 to 100-wt% of the other air metal toxics were captured. Slag and fly ash leachate tests showed 0 mg Hg/liter. Further, 26-wt % of the fluorine and 14-wt% of the chlorine were captured. This combustion technique is a low cost retrofit technique for multi-pollutant emissions control.

RETROFIT APPLICATION

Hutsonville Boiler #6 (Unit #4) is a Combustion Engineering (nominally 85 MWe) tangentially fired boiler, producing 1500 psig/1005 ^{o}F superheated steam with a gross heat rate of 10,000 Btu/kWhr. It is a natural circulation boiler that has both superheat and reheat. The boiler feeds a GE steam turbine generator. It uses once through service water from the Wabash River for the steam turbine condenser. Bottom ash is water quenched in the bottom of the furnace and is periodically sluiced to the ash-retaining pond. Boiler #6 has three Raymond 593 coal pulverizers and the pulverized coal is air swept to three burner levels located on all four corners of the boiler furnace.

It has a Westinghouse Distributive Control System (DCS) that can be modified to run the three-stage combustion system. Each unit has a Continuous Emissions Monitoring system (CEMS). It also has a sulfur trioxide (SO_3) flue gas conditioning system to reduce fly ash resistivity.

Physical Retrofit For the retrofit, the right rear corner of the boiler furnace was very congested and it was decided to evaluate three-corner firing with the Ashworth gasifiers, see Figure 1. Alstom completed Computational Fluid Dynamic (CFD) modeling based on three-corner firing and found that the tangential swirl, although skewed somewhat was still established in the furnace and would yield a viable firing configuration.

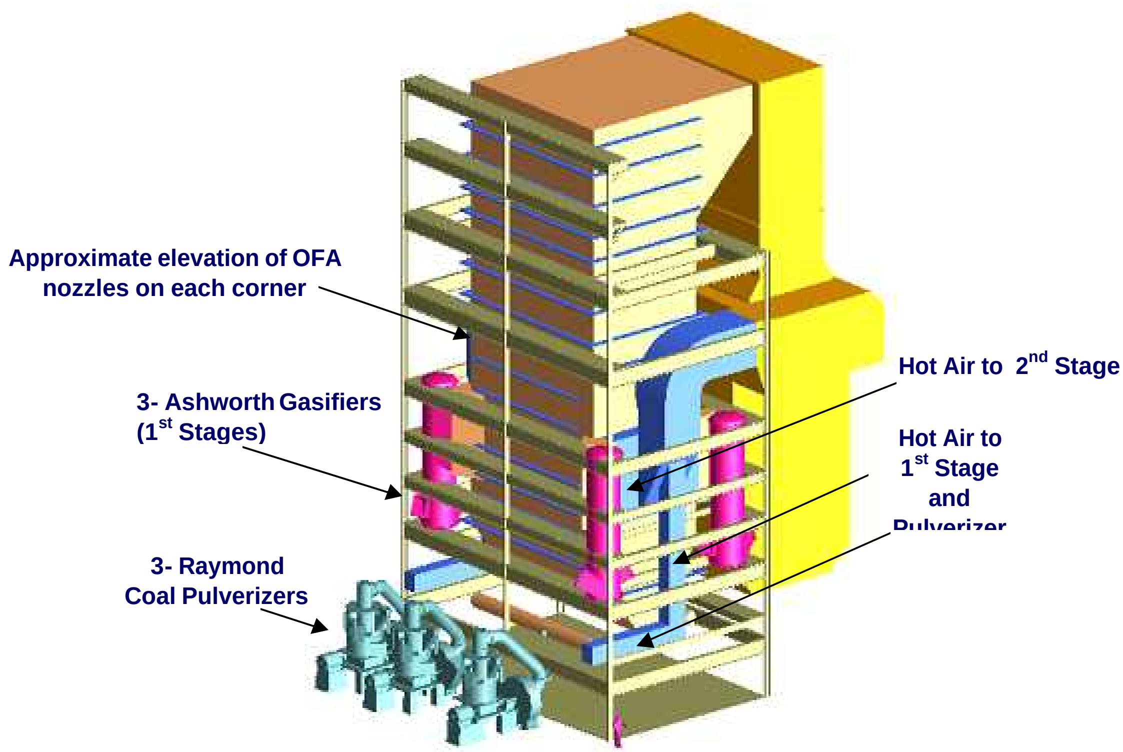


Figure 1. Three corner Ashworth gasifier firing.

Temperatures The temperatures in the furnace are a little different. Since the combustors are water-cooled and remove heat external to the boiler, the flue gas entering the convective passes reduces by 65-70 ^{o}F below the baseline modeling case, see Figure 2. However, if the 2nd and 3rd stage air entries of the Ashworth combustor are designed to be tiltable the fireball could be raised up to increase the exit temperature.

Heat Flux Several differences are noted between the base case and the gasifier condition. The lower section of the furnace (the hopper) has significantly less heat flux. This is primarily due to the location of the gasifiers shifted upward relative the current windbox. The coal particles in the base case circulate in the hopper and burn with combustion air, while for the gasifier, the particles leaving the gasifier are essentially free of carbon. The gasifier, compared to the baseline case, indicates higher flux in the firing zone where the hot gases enter the furnace cavity. However, the heat absorption per wall is similar, see Figure 3.

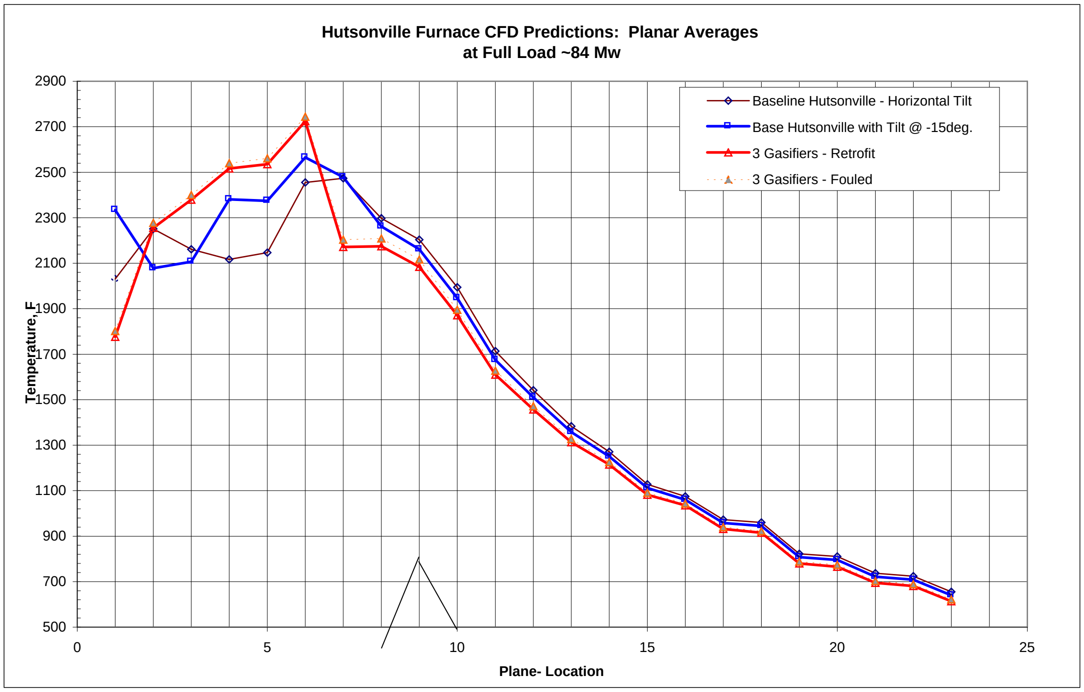


Figure 2. Temperature distribution comparison.

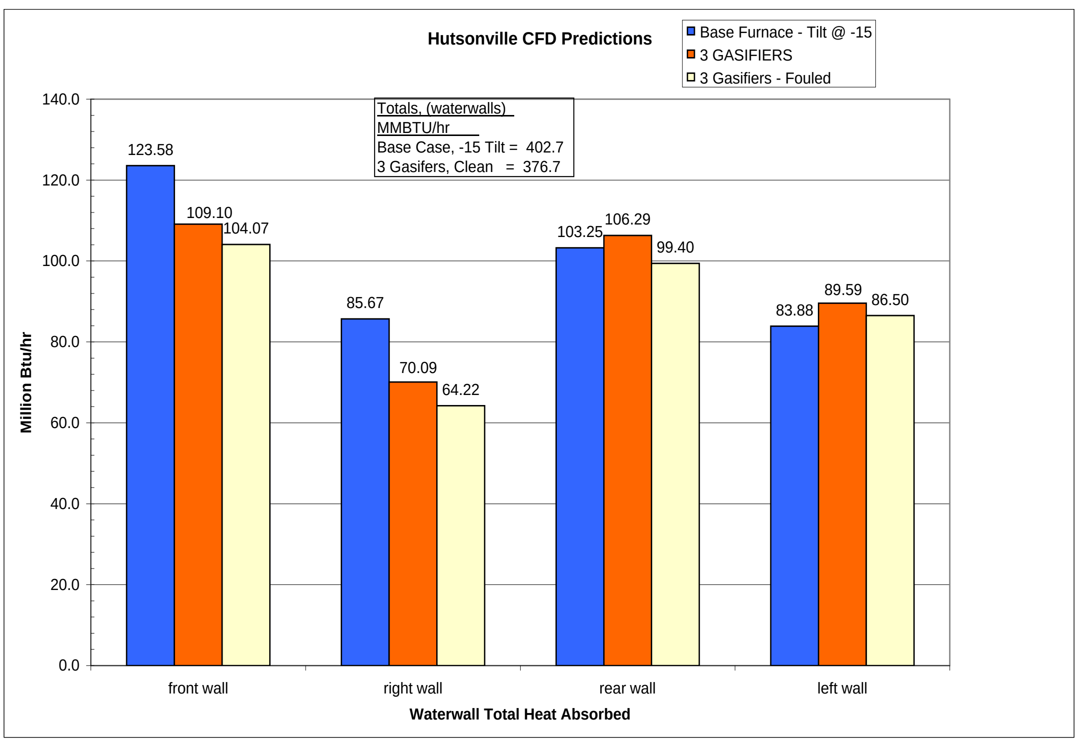


Figure 3. Heat absorption comparison.

Gasifier-Boiler Integration Two simple solutions were found for integrating the gasifier cooling water into the boiler water circulation system. One is to by-pass the last extraction steam BFW heater and use the heat from the gasifier to heat up the water. This extraction steam, by going through the steam turbine and not the BFW heater would increase power out, raising the capacity of Unit #4 from 85 to 88.5 MWe; the heat rate however would increase by around 120 Btu/kWhr. The other method would be to take the water from the economizer outlet and pass that water through the gasifier waterwalls before going into the steam drum. With this case there would be little change in capacity or heat rate.

Swirl Vortex Despite only three gasifiers being located on three corners of the furnace, not four, the flow vortex characteristic of the tangential firing is established, as shown by the contours of velocity magnitude shown in Figure 4. The velocity of the jets entering the furnace for the baseline case is near the 200 ft/s level, while the gasifier case has velocities above that level. The separated overfire air (SOFA) jets for the gasifier case are also clearly shown in the velocity contour plot. The SOFA jets provide a useful centering action to the flow.

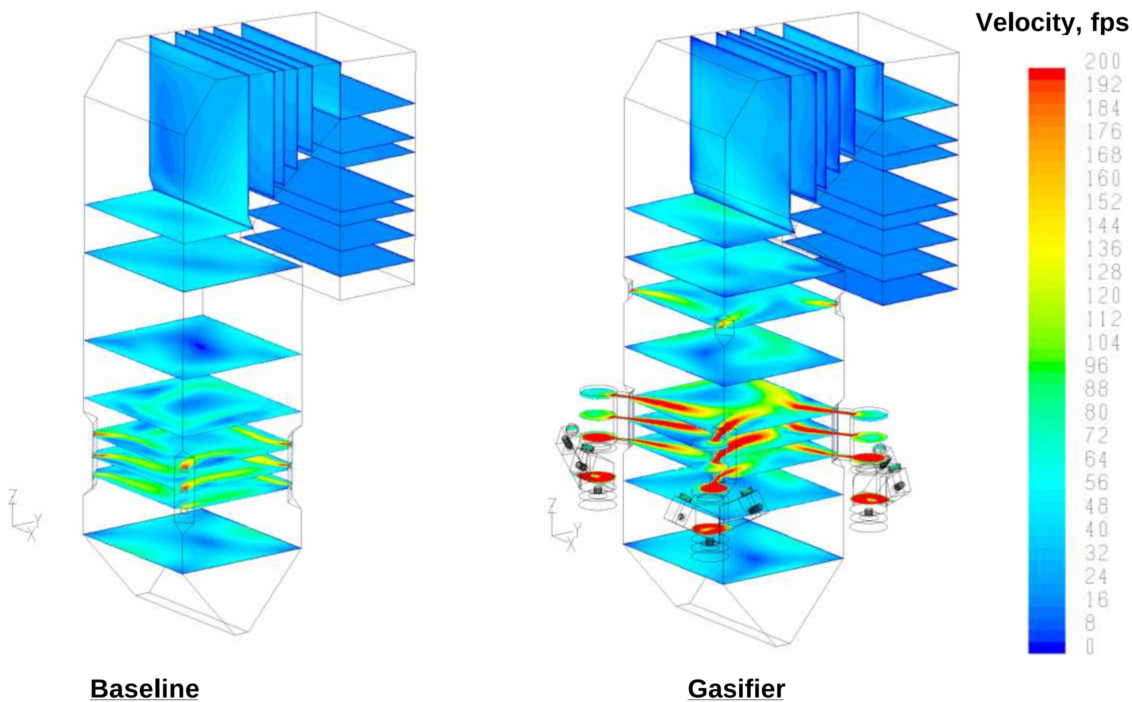
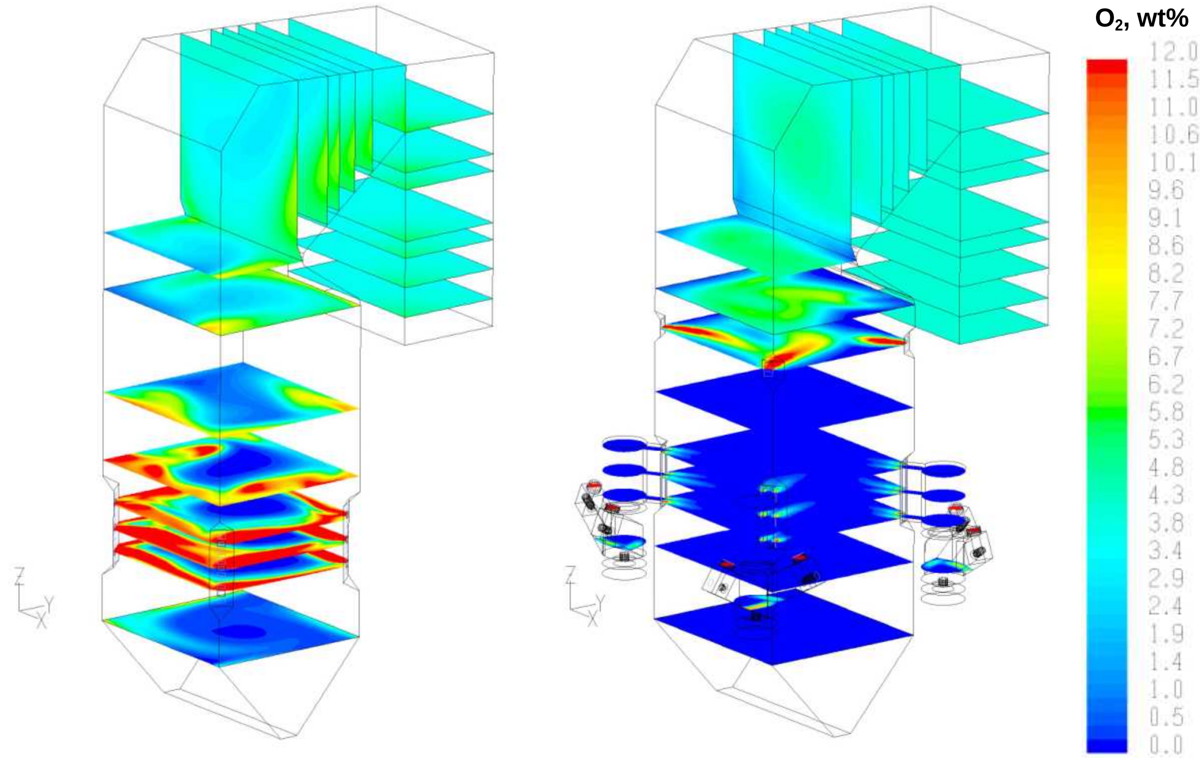


Figure 4. Horizontal plane velocities comparison.

Oxygen Distribution Oxygen distribution in the furnace is shown for the range between 0 and 12% dry in Figure 5. The base case has zones about the perimeter exceeding 12%, while the gasifier case has essentially no O_2 in the mid-furnace zone, except for the slot air adjacent to the sides of the rectangular gasifier outlets. The coverage by the SOFA level is captured for the gasifier case, where these jets mix very well with the furnace gases and result in very uniform O_2 levels at the economizer outlet. In fact, O_2 distribution is more uniform for the gasifier than the baseline case, where remnants of the radial stratification remain in the backpass.



Baseline **Gasifier**

Figure 5. O_2 distribution comparison.

Carbon Monoxide Carbon monoxide distributions are shown in Figure 6 to accentuate different zones. A consequence of staged combustion is abundant CO in the zone below the SOFA (Reburn zone condition). In the upper furnace at the SOFA level, the CO levels drop rapidly from the mixing of excess air and final burnout for the gasifier case. By comparison, the baseline case at left shows bands of CO at the burner levels.

CO levels in the backpass for the gasifier condition are significantly lower than the baseline case in part because particulate char combustion is diminished relative to the baseline case. Particles from the gasifier entering the furnace have very little combustible carbon. By contrast the baseline case has some portion of the remaining entrained carbon still burning at the nose and higher. This is supported by the fact that the baseline horizontal tilt case has higher CO than the down-tilt case. For the baseline case the CO off-gas from the coal particles in the upper furnace contributes to higher CO levels in the backpass. Note the CO pockets at both sides near the roof, just above the nose. This is due to the segregation of particulate in this zone, contributing to the CO sources. The gas mixing in this area due to swirl is diminished and insufficient to burn out the CO for the baseline case. The gasifier case shows CO levels in the single digit range (7-8 ppmw) that is unusually low but may be correct. Low CO levels (15 to 30 ppmvd @ 3% O_2) were also shown in the Lincoln demonstration even though there was excessive air leakage into the furnace (10-11% O_2 with combustion air addition only to yield 3% O_2 in the flue gas) that reduced furnace temperatures.

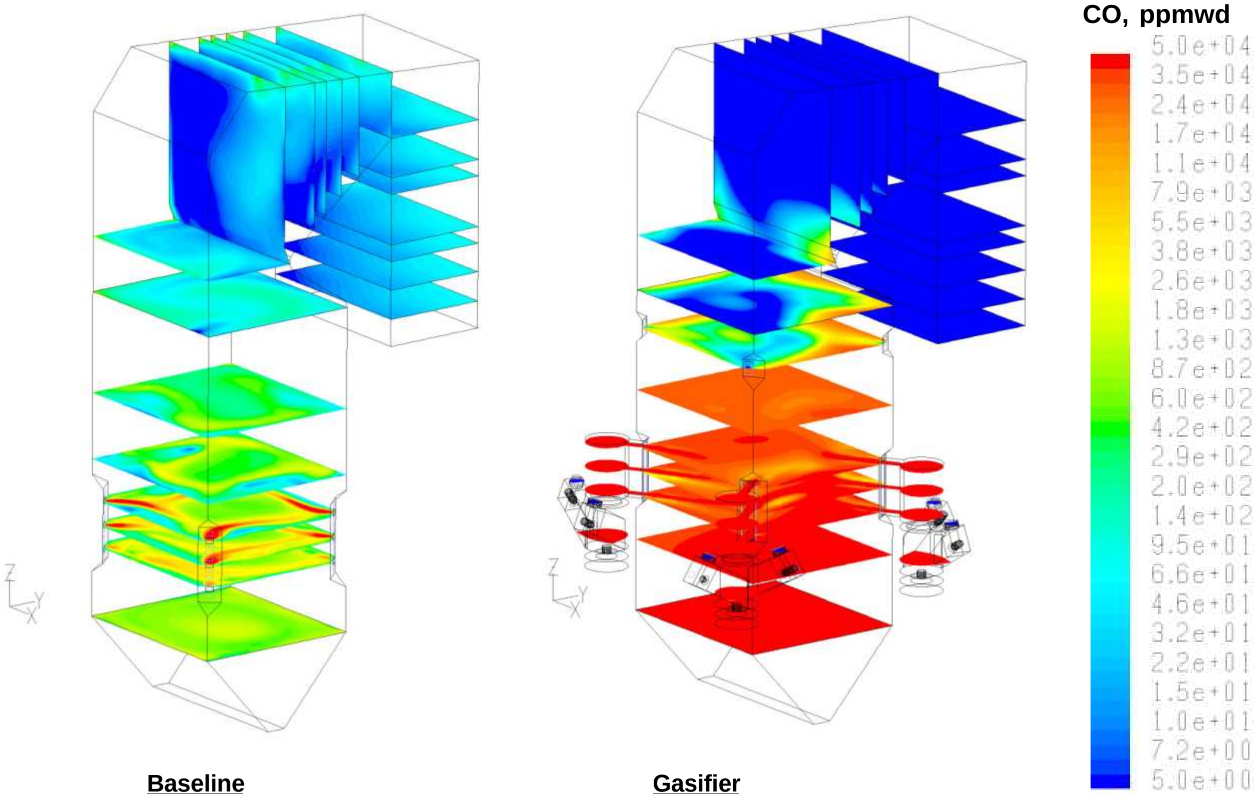


Figure 6. CO distribution comparison.

NO_X Emissions An important aspect of this retrofit project will be the emissions. Using the NO_X prediction tools in Fluent, NO_X emissions for the baseline case and gasifier case were generated. The physical models enable prediction of NO_X from thermal, prompt and fuel mechanisms. NO_X predictions with Fluent are usually performed as a post-processing activity, once the flows, chemical reactions and thermal environment is converged. The baseline NO_X calculations were based on a 20% excess air level and were tuned to the actual levels before Hutsonville went to the close-coupled OFA approach by adjusting the fraction of nitrogen in the fuel evolved with the volatiles and char fractions. From the fuel analysis, the nitrogen content is 1.27% (1.5% on a dry-basis). For these NO_X calculations, it was assumed that nitrogen was evolved proportionally in the devolatilization and char combustion phases.

The baseline NO_X predictions were tuned to the actual level by biasing the destination ratio of the volatile N and Char N fractions. For the baseline case, it was found that a reasonable match to the data was obtained with 80% of the volatile N evolved as HCN with the remaining 20% as NO. For the char N, a ratio of 55% HCN and 45% NO was used. For the gasifier, the NO_X model settings were identical to the baseline. Under these conditions, the gasifier case produced 86 ppmvd of NO (0.095lb $NO_X/10^6$ Btu) on a volume-dry basis. This compares to 481 ppmvd or 0.53 lb $NO_X/10^6$ Btu for the base case. The vertical centerline and horizontal plane NO_X concentrations comparison for the base case and gasifier case is shown in Figure 7.

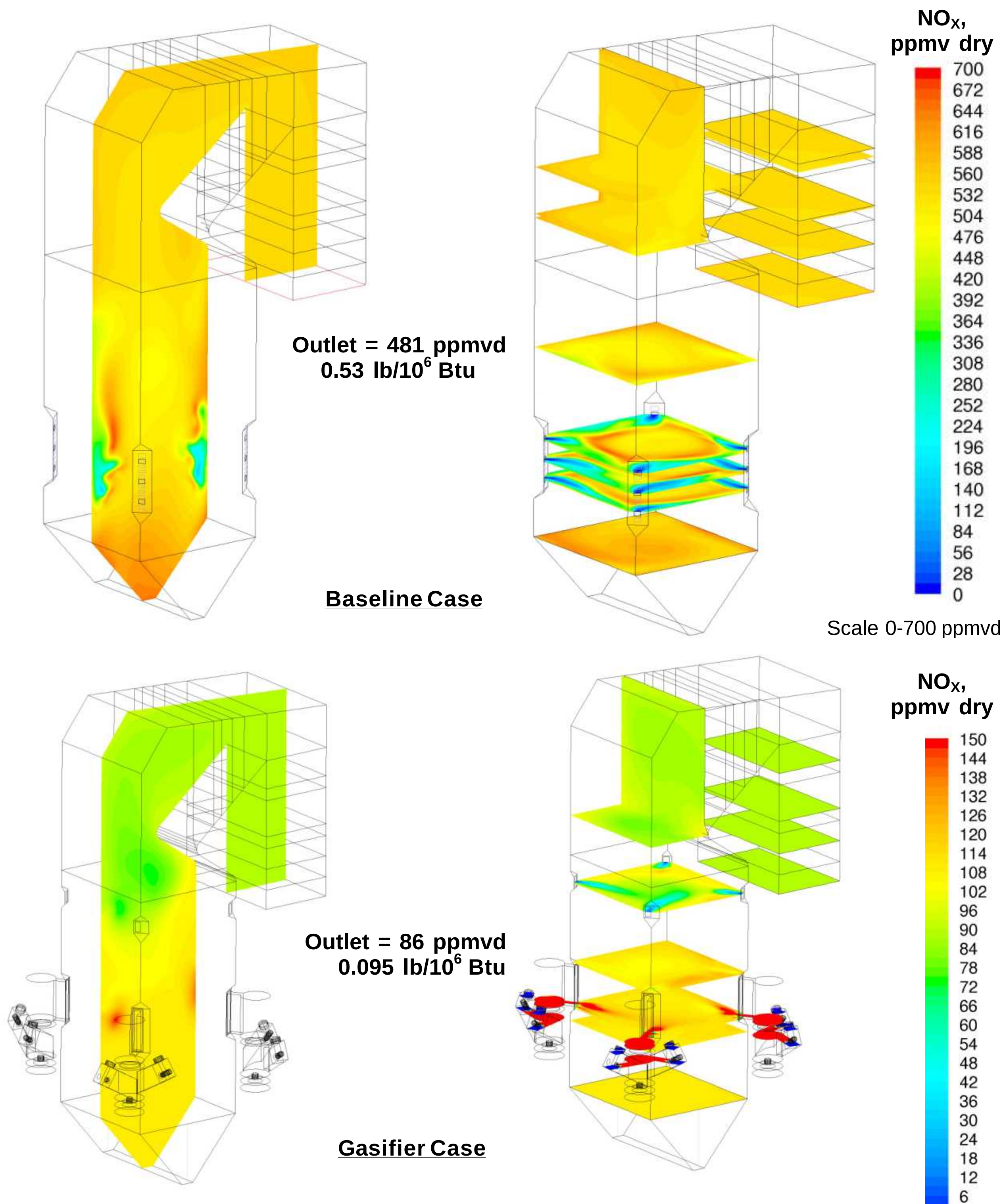


Figure 7. Nitrogen oxide emissions comparison.

The NO_X levels build for the baseline case away from the nozzles in the center of the firing zone. By contrast, the CFD model shows NO being produced in the gasifier, and then diminishes in the main furnace zone. This is really not the case. The 0.60 SR in the gasifier produces a condition that completely or near completely converts all fuel bound nitrogen to diatomic nitrogen (N_2). Figure 8 shows the University of Stuttgart results[2] for a varying SR based on firing coal at three seconds residence time at 2372 °F (1300°C). For these tests, coal N to NO when using a SR of 0.60 was about 4%.

The first stage (gasifier) is operated at higher temperatures than that tested by the University of Stuttgart, so reaction rates are faster and less residence time is required. The thermochemical equilibria analysis[3] at 2600°F also shows that no NH_3, HCN (NO precursors) or NO should be formed when gasifying coal at an SR of 0.55 to 0.65. This was seen in earlier two-stage gasifier tests. This information was relayed to Alstom but at the time they had no way to alter the model to reflect this. Nonetheless, the modeling predicted very low NO_X emissions (0.095 lb/10^6 Btu) to the atmosphere.

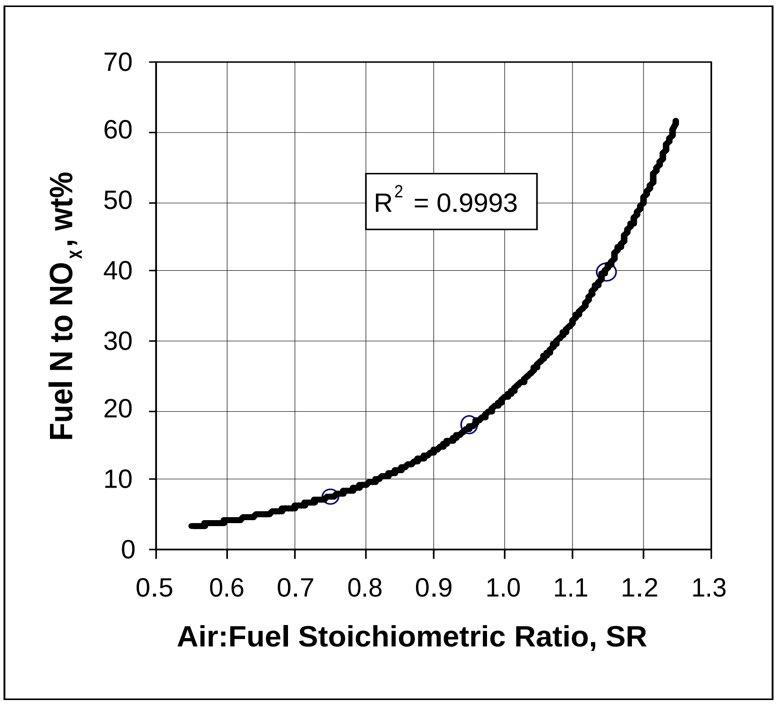


Figure 8. Gasifier SR versus Coal N to NO results.

Particulate Capture Although particulate capture was not included in the Alstom report, while at Alstom's offices we asked the CFD programmers if they could give us an estimate of the amount of slag that would be captured with the gasifier design for Hutsonville. Under the assumption that the particles hitting the slag covered walls will stick to them, the capture would be, according to their model, some 65%.

SO_2 and Hg Capture Sulfur dioxide (SO_2) and mercury emissions (Hg) were not modeled here because this cutting edge technology is not in the current modeling database. Based on the Lincoln Demonstration, it is expected that some 70% of the sulfur will report to the slag and fly ash with some 90+ % Hg reporting to these two streams as well. In the Lincoln Demonstration, as reported by DTE laboratories, similar reduction levels for the other 15 air metal toxics occurred through capture in the slag and fly ash.

Conclusions Although not at liberty yet to discuss costs, retrofit of pollution control devices to a power plant normally increases the cost of operating the plant. With the Ashworth Combustor, significant operating savings occur because it is a multi-pollutant device that can take credits for the reduction of three major air pollutants (NO_X, SO_2 and Hg), not just one as with most technologies. It is an advanced technology that also removes 80 to 100% of the other 15 air metal toxics. So in the future if any other of these air metal toxics, such as nickel for example, are regulated, no additonal technology will be required. In addition, for this application there is a potential to also receive $15 million in refined coal tax credits[4] and this is true for any other unit installed before the end of 2009.

The technology is initially earmarked for the retrofit of coal-fired power plants having capacities of 200 MWe and less due to the unfavorable economics of adding Selective Catalytic Reduction, Wet Scrubbers, and Activated Carbon Injection followed by a Baghouse to comply with current and future EPA emission limits for NO_X, SO_2 and Hg emissions.

References:

1. Ashworth, R., Kakaley, R., and Widenman, T., *Ashworth Combustor Demonstration*, Coal-Gen 2003 Greater Columbus Ohio Convention Center, Columbus, Ohio Aust 6-8, 2003.
2. Kluger, Frank, et. al, *Comparison of Coals and Air Stage Combustion with Respect to NO_X Emissions*, 23rd International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, FL, March 9-13, 1998.
3. Ashworth, R., McClure, S.,and Woodring, M*., Ashworth Combustor Demonstration Test Results,* 27th international Technical Conference on Coal Utilizations and Fuel Systems*,* Sheraton Sand Key, Clearwater, FL March 4-7, 2002.
4. Federal bill - *American Jobs Creation Act of 2004*, passed into law October 2004.