CFD Guides Design of Biomass Boiler Retrofit to Increase Capacity by 25% and Decrease Ash Carryover by 60%

Computational fluid dynamics (CFD) analysis supported the design optimization of a wood-fired furnace that was tested to operate with a 25% capacity increase with a 60% decrease in particulate emissions. The CFD modeling studies illustrated the potential operational improvements and increased the confidence levels of a successful set of boiler modifications. The combined use of CFD modeling with traditional boiler design methods were particularly effective for assessing the retrofit potential of an older stoker furnace. Proven retrofit design experience and a detailed baseline testing program that examined all aspects of the boiler equipment were key attributes to the award of a contract to ALSTOM Power Inc. (ALSTOM) for the modification of a 1975 vintage travelling grate stoker boiler located at a paper mill in Louisiana. When considering investing in upgrading an older boiler, the condition of the different components in the boiler system, combined with the fuel and mode of operation made it difficult to accurately quantify the performance to be gained by a retrofit. ALSTOM solved this problem by using CFD analysis to simulate the performance of the existing boiler, and then modeled the performance of

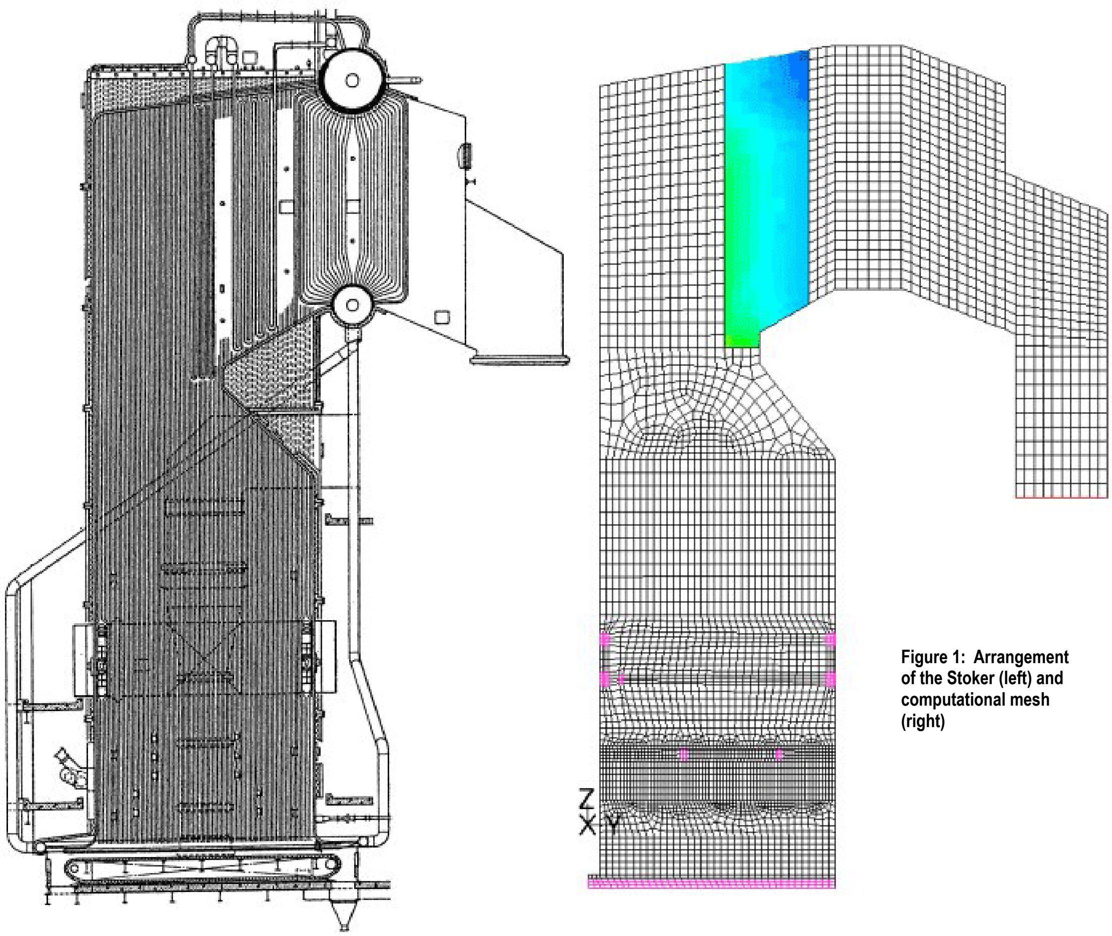

Figure 1: Arrangement of the Stoker (left) and computational mesh (right)

the new system. The results helped identify limitations of the baseline system and how the modifications would improve the performance. "With CFD, ALSTOM was able to illustrate to the mill that the new design represented a significant improvement and was a wise investment. When both the customer and the supplier team up to gather all the CFD model inputs, everyone benefits. Things that people assumed might be happening suddenly become more tangible. The goal was to satisfy the customer and help them to be able to operate their equipment more efficiently," noted Paul Chapman of ALSTOM's Power Plant Laboratories.

ALSTOM's parent is a global specialist in energy and transport infrastructure. It serves the energy market through its activities in the field of power generation, and the transport market through its activities in rail and marine. In fiscal year 2002/2003, it had annual sales in excess of 20 billion Euros and employed approximately 100,000 people in more than 70 countries. It has supplied almost 20 percent of the world's total installed capacity in power generation equipment.

Upgrading wood and biomass-fueled boilers

There are hundreds of wood and wood waste boilers in operation in the US that serve the important role of providing process steam by burning low-grade wood wastes associated with wood and paper processing. These boilers are required to burn a changing mix of wood, wood wastes, hog fuel, and other various solid and gaseous waste streams. With the rising cost of energy, and the desire to reduce gaseous and solid emissions, previously overlooked power boilers are receiving more attention. Many of these older units are now potential candidates for revitalization. Modernization can provide many benefits, including increased steam capacity, higher boiler efficiency, lower gas and solids emissions, and decreased operating and maintenance costs. While these objectives are clear, the task of quantifying a significant renovation that often involves modification of pressure components boils down to economic justification. Given the range of different style boilers and the unique conditions at each site, prediction of performance and calculation of investment payback remains difficult.

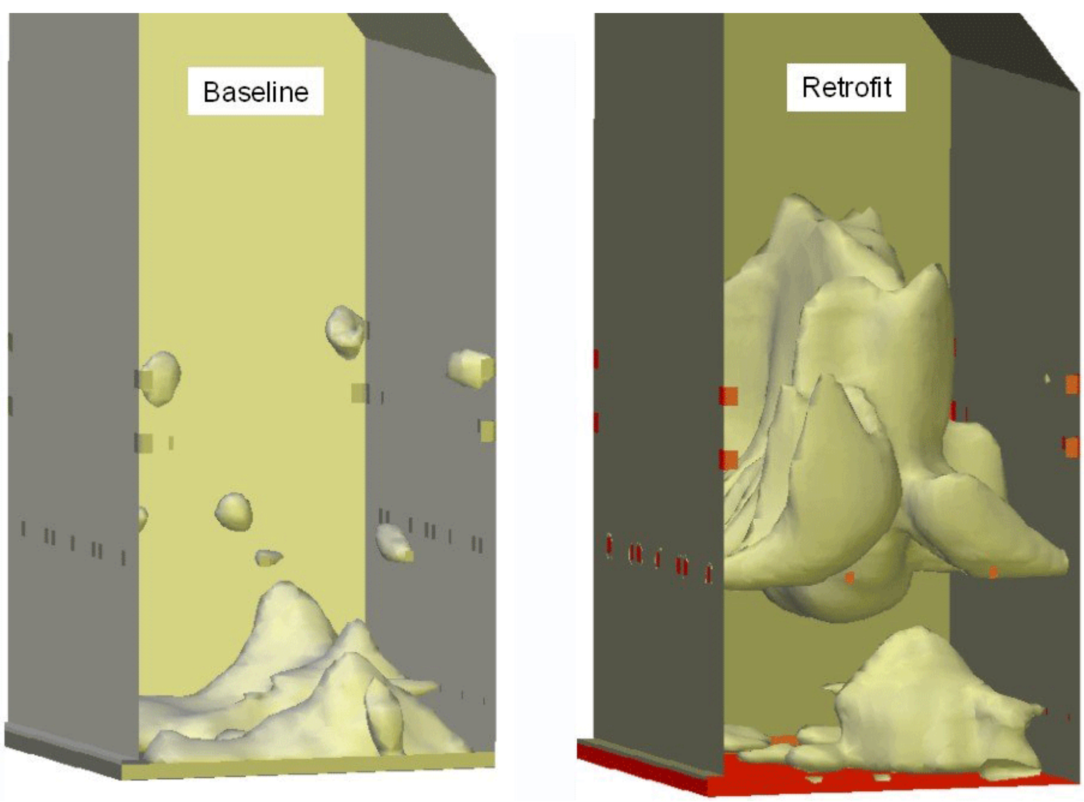

Figure 2: Iso-surfaces of turbulence levels for the original and retrofit firing conditions

"In the initial phases, an engineering assessment is made to develop a proposal," according to Dave Gadai, director of pulp and paper engineering for ALSTOM's Windsor, CT. operations. "While the upgrade usually involves a modification of the boiler's combustion air system, it is actually a total combustion system upgrade. Because each retrofit is different, all of the subsystems - furnace geometry, air system equipment, fuel properties and handling equipment, and the combustion grate system- must be studied. We can make some estimation of the impact of these factors on the performance of the boiler, but using CFD helps us better predict the combined impact of all suggested modifications," says Gadai. Adds Chapman, "In generating a stoker boiler model, we work with engineering to quantify the inputs needed to generate a reasonable CFD representation. Some details and various flows are not readily available. That poses a challenge. Older units are particularly troublesome because they lack good flow measurement devices and monitoring equipment."

ALSTOM was asked to upgrade a 1975 vintage VU-40 stoker boiler that occasionally experienced opacity problems when firing 100 percent hog fuel. It also had a pattern of erosion-related tube leaks when operating at higher loads, and carbon loss with high excess air. Carbon monoxide levels were estimated to be quite high at this unit.

When management at this mill asked for a study that would document performance improvements after a retrofit, ALSTOM decided to present a more precise evaluation by running 'before' and 'after' CFD simulations. The CFD model of the boiler produced velocity, temperature, species concentrations, and other variables throughout the solution domain for a specific set of input boundary conditions. As part of the analysis, a designer could change the geometry of the furnace or the boundary conditions and study the effect on the gas flow patterns or temperature distributions. CFD also can provide relative trends on variables such as particulate carryover or emissions.

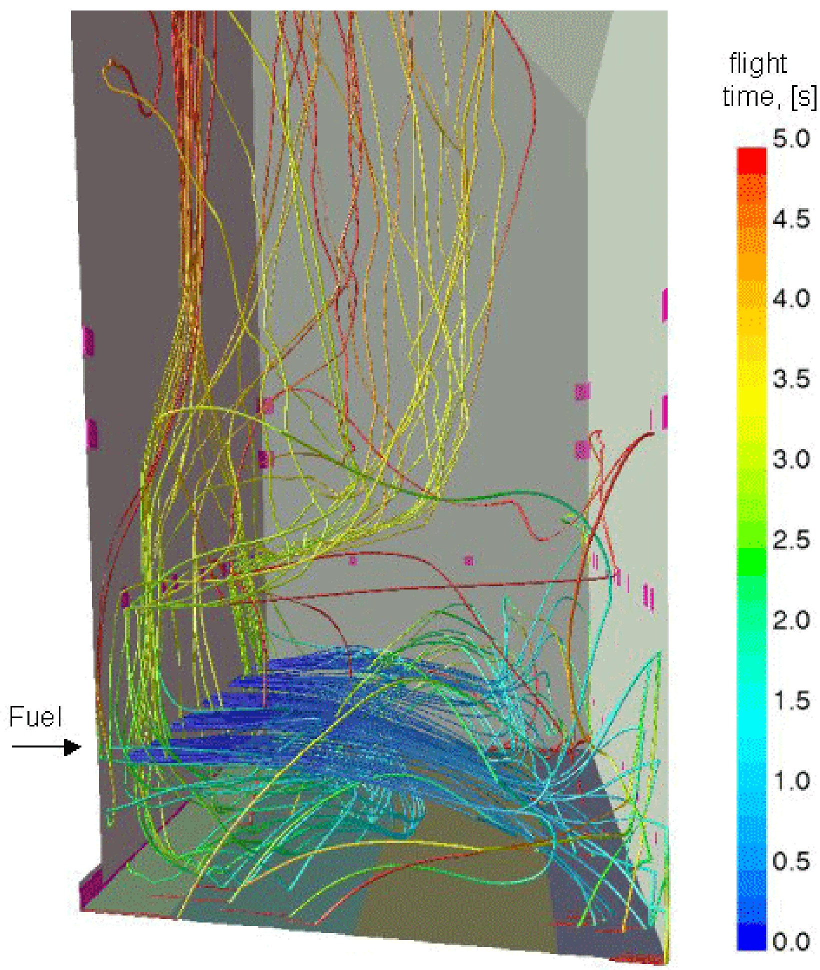

Figure 3: Wood particle tracks colored by residence time for the retrofit case

Fluent Inc., which is located in Lebanon, New Hampshire, licenses a complete set of tools for analyzing fluid flow, heat transfer and combustion. ALSTOM's Power Plant Labs, which is an R&D center supporting the many different power generation businesses globally, has performed an extensive collection of combustion and heat transfer simulations to study and improve the power generation systems and components that ALSTOM supplies. In addition, for many years ALSTOM has collaborated with Fluent to suggest improved submodels and capabilities for the FLUENT software. Because of the diverse range of fuels that are fired in different modes, Fluent's standard code needed to be modified to more accurately describe pulverized coal and other fuels. The CFD modeling experts at ALSTOM often encounter situations that require the development of custom code in the form of User Defined Functions (UDFs) that are connected to the solver. Fluent's suite of software tools, including mesh generation, parallel solver capabilities and efficient post-processing are fully utilized at Power Plant Labs.

The successful retrofit of this particular stoker boiler started with a CFD analysis of the existing boiler, shown with the computational mesh in Figure 1. CFD meshes were developed for both the baseline and retrofit system designs. The baseline system had a series of small ports on the two sidewalls to inject air above the grate where wood particles burn on a traveling grate stoker. In addition to the sidewall air injection, two separate ducts fed corner tangential windbox assemblies for additional overfire air and support fuel. A separate fan was used to recycle cinders collected in hoppers on the back end of the boiler, injecting them through nozzles in the rear wall into the lower combustion zone. Bark was injected at the front of the boiler by five mechanical distributors spaced across the front wall. A relatively coarse unstructured grid of 220,000 cells was used, consisting of all hexahedral elements. The cells were smaller near the overfire air injection nozzles to provide additional detail of the mixing process. The upper furnace was represented with larger cells. If required, the mesh could be adapted with FLUENT's solution-based adaption tools.

Inputs for the CFD model

After creating the furnace geometry for the CFD analysis of the boiler, specific inputs needed to be determined. A sample of the fuel was screened and analyzed to determine the heating value and chemical composition. With the bark firing rate known by the plant, the chemical reaction and combustion model settings could be prescribed. For the fuel injection representation in the CFD model, eight particle size groups were defined and prescribed at each of the five distributors, with mass distribution to the different distributors weighted according to the actual feeder speeds used during the baseline test conditions. In addition to the bark, the char recycle flow rates were estimated. This pneumatically injected char and ash was divided uniformly to the eight injection nozzles. These feeds were assigned particle size distribution and composition that was determined from laboratory analysis.

Estimating and prescribing the air entering the boiler is important, but often difficult to do. Many of the different air inputs are not monitored during operation. For example, the total air to the stoker might be measured with a flow orifice, but the distribution of air to the various sections of the stoker is not readily apparent. To generate a more accurate representation of the baseline operating conditions, measurements and observations were recorded and discussed before running the baseline case. Some of the air distribution was determined using pitot tubes to measure air flows in supply ductwork. At the outlet of the furnace, sample grids measured gas composition on both sides of the air heater. During the testing phase, some additional mechanical degradation was found, allowing ambient air to leak into the furnace. These flows were estimated and also included as part of the total combustion air in the CFD model. The efforts expended on accurately configuring the model inputs increase the overall cost of the modeling effort, but improve the accuracy of the model, and can provide ALSTOM with the opportunity to fix other problems that might be missed by the initial assessment.

For the superheaters, boiler bank, and economizer sections, bulk heat extraction rates were determined from ALSTOM’s performance measurements and calculations. Waterwall heat transfer coefficients and water side temperatures were prescribed in conjunction with wall emissivities. Gas radiation properties were calculated based on composition particulate concentrations. With the model inputs well established, the baseline configuration was run and converged. At this point the retrofit air system nozzle arrangements were compared to the baseline case.

The baseline results indicated a flow maldistribution with a stream of fuel rising up the rear wall without effective interaction with the overfire air jets. This plume at the rear wall remained segregated in the upper furnace and was low in oxygen. Char particles were elutriated from the stoker bed and not fully burned in the lower furnace. The sidewall jets had only a minor impact on mixing. The tangential nozzles imparted some swirl to the rising gases, however their elevation was too high in the furnace for optimal combustion. The analysis of particle burning patterns was corroborated by visual inspections through ports in the upper furnace and in-furnace flame cameras. Fuel particles along the back wall were lifted up and floated out of the boiler without being completely burned.

Results

After establishing a baseline CFD model, different retrofit arrangements were modeled and examined by comparing velocity distribution, gas composition, temperatures, and particle trajectories and residence times. “It was clear that we needed to increase the overfire mixing effectiveness,” says Chapman. “So one of the first things we looked at was adopting the HMZ™ design.” This air system has a partially interlaced configuration consisting of offset pairs of large versus small nozzles to control the penetration distance and establish high turbulence levels in the center zone. Analysis of the model with the HMZ™ system showed a much more uniform O_2 distribution and penetration of the jets to the center, with more intense combustion in the lower furnace to increase the bark drying rates on the stoker. Instead of a rising plume of fuel against the rear wall, the channel was centralized, allowing the gases to mix thoroughly. With the representation of the stoker fabric seal and modified air distribution, entrainment levels from the stoker were reduced. This kept the fuel particles on the grate longer, increasing the residence time and particulate concentration in the upper furnace. The combination of the high performance overfire air design with the stoker fabric seal represented a very significant improvement potential compared to the baseline. Figure 2 shows a comparison of the turbulence levels for the baseline and final design. All of the modeling results suggested that the boiler performance would be quite dramatic.

On the basis of these predictions, plant management decided to proceed with the retrofit and the new air system and fabric stoker seal were installed. An illustration of the wood particle trajectories for the final design appears in Figure 4. After the modifications, performance tests confirmed a significant increase in boiler capacity on biomass firing. Prior to the upgrade, the boiler was capable of only 280,000 lb/hr steam, firing a high moisture level fuel. When the moisture level dropped, the capacity achievable increased to 350,000 lb/hr. At this load, the boiler suffered from high erosion and the boiler operation could not be maintained without tube failures. After the upgrade, the boiler biomass firing capability increased to 350,000 lb/hr for high moisture fuel and up to 480,000 lb/hr for low moisture fuel, representing a 25 percent minimum capacity increase. Carbon monoxide levels after the retrofit were reduced from over 1000 ppm to 260 ppm. A net reduction of 60 percent in the pre-retrofit flyash disposal rates, measured in truckloads, was also observed.

Summary

CFD modeling was an important element of this project and allowed the retrofit performance of this unit to be predicted with reasonable accuracy. The combination of CFD modeling with extensive boiler designs and retrofit experience increased customer confidence to modify this particular unit. Feedback from the customer confirmed these impressions. The customer said that the boiler now performs far better than before the retrofit. While the emissions were lowered and the bark firing capacity increased, the customer found other economic and operational benefits to justify the retrofit. In particular, the boiler can handle more wet bark without support fuel - an additional savings. Overall, the customer said the complete retrofit project was very satisfactory.