SHB Power Plant Engineering

CFD Simulation of Recovery Boiler Combustion

Predictive Engineering Inc. has been working closely with SHB Power Plant Engineering to improve in-house capabilities for the modeling of bio-fuel power generation in STAR-CCM+. SHB is a local company in Portland OR that specializes in upgrading boilers to increase efficiency and reduce emissions. This has been a unique project that has involved software sale of Simcenter STAR-CCM+, engineering consulting services, and technology transfer so that SHB can run the models in house for further design exploration.

Combustion is one of the most challenging types of analysis to solve through CFD and the analysis requires a highly capable code with strong multiphysics capabilities. Predictive Engineering developed a model of a recovery boiler for SHB in support of on-going efforts to evaluate performance and identify areas of improvement. Recovery boilers are used in the paper-mill industry and are fueled by black liquor, which contains wood lignin from the pulping process. Although the black liquor is a highly viscous liquid, we utilized the coal combustion model in STAR-CCM+ to simulate the multistage combustion process of solid biomass fuel from drying, devolatilization, char burning, and reduction to ash/inert components. Combustion of the devolatilized gases within the lower furnace is handled by an eddy-break up model utilizing reversible reactions to provide a quick estimate of flame locations, energy release, and CO production. The model utilizes a built-in thermal NOx model utilizing the Zeldovich mechanisms to predict NOx formation from the combustion process. Radiation and conjugate heat transfer to the surrounding tube walls was modeled utilizing gray gas, participating media models.

One of the most challenging aspects to modeling black liquor combustion is to capture the unique swelling that occurs during combustion. As the injected black liquor droplets dry and devolatilize, the particles can swell 4 to 5 times the original size. This size expansion causes the lighter particles to lift up within the lower furnace. Once char burning commences, the particles shrink back in size and fall to the char bed below. To capture this effect, standard drag models were customized and tuned to meet the desired behavior.

Model Geometry and Mesh of Recovery Boiler

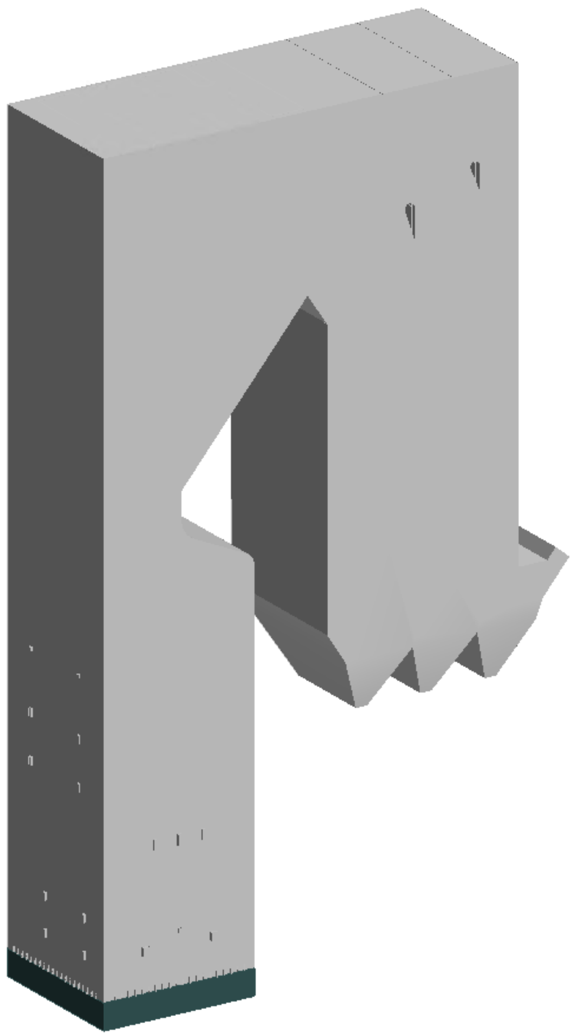
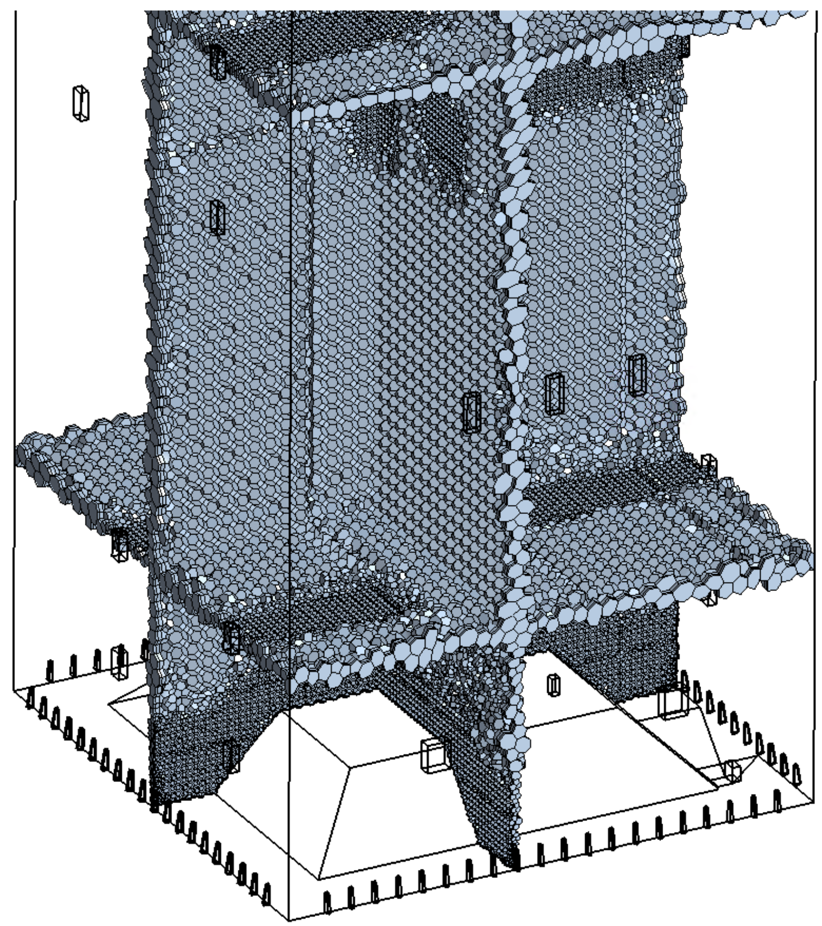
Full Geometry of Recovery Boiler	Polyhedral Mesh of Lower Furnace
	

Figure 1: Left: Full recovery boiler geometry. Right: View of polyhedral mesh, wall prism layers, and combustion air refinement in lower furnace of the boiler.

Flow Velocity Profile and Streamlines

As typical with recovery boilers, combustion air is fed into the lower furnace through a number of inlets, including primary, secondary, and tertiary air inlets, along with other air inlets.

Velocity Vector Plot	Streamlines Through Lower Furnace

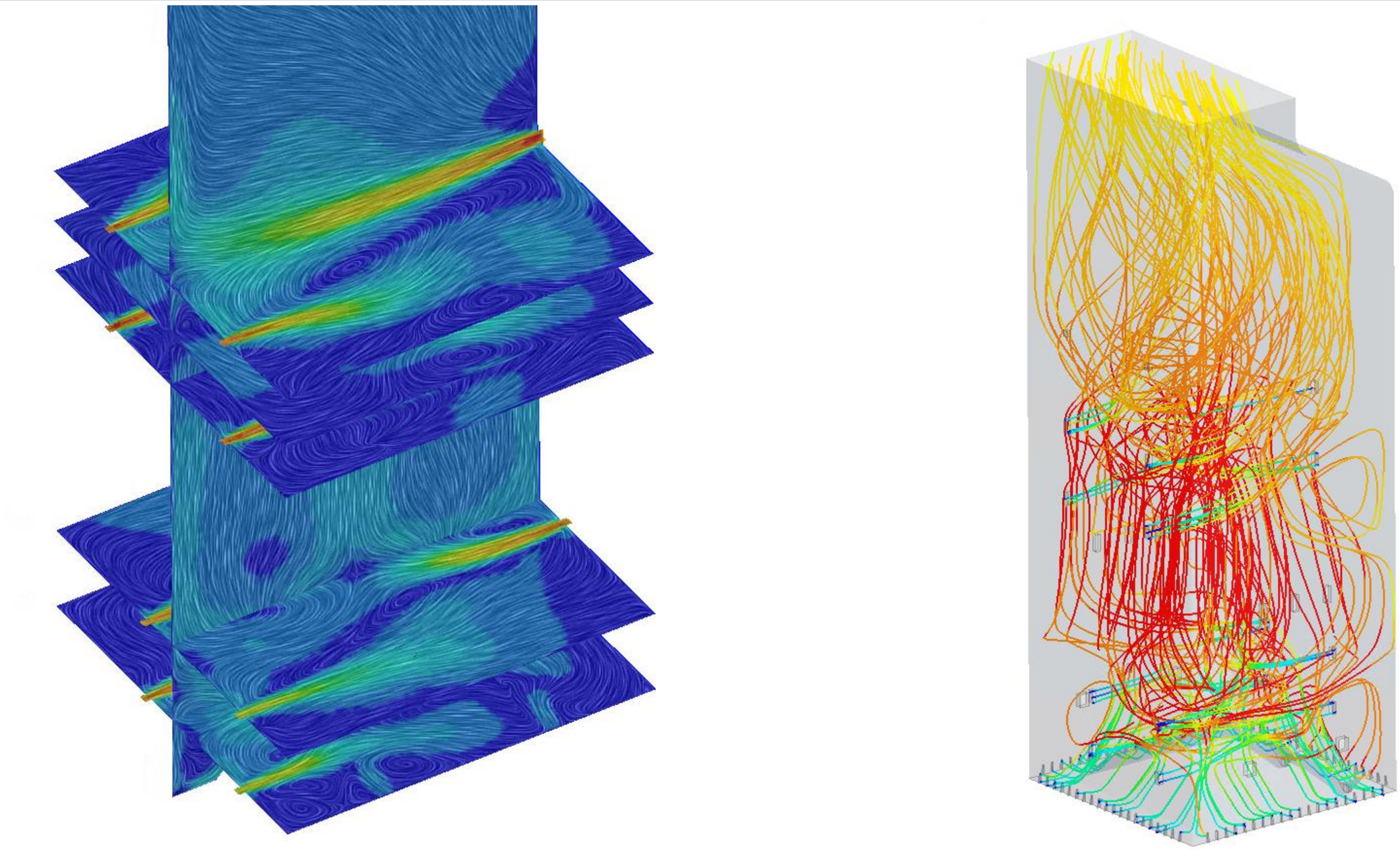


Figure 2: Left: Velocity vector plot (line integrated) of airflow from secondary and tertiary air inlets. Right: Velocity streamlines from main air inlets plotted against air temperatures.

Fuel Injection and Combustion

Figure 3 shows the fuel particle paths (left) and the resulting combustion temperatures. The black liquor droplets are modeled as Lagrangian multiphase particles using the coal combustion model to handle reactions for water evaporation, devolatilization, and char burning.

Particle Tracks and States of Fuel	Combustion Flame Temperatures

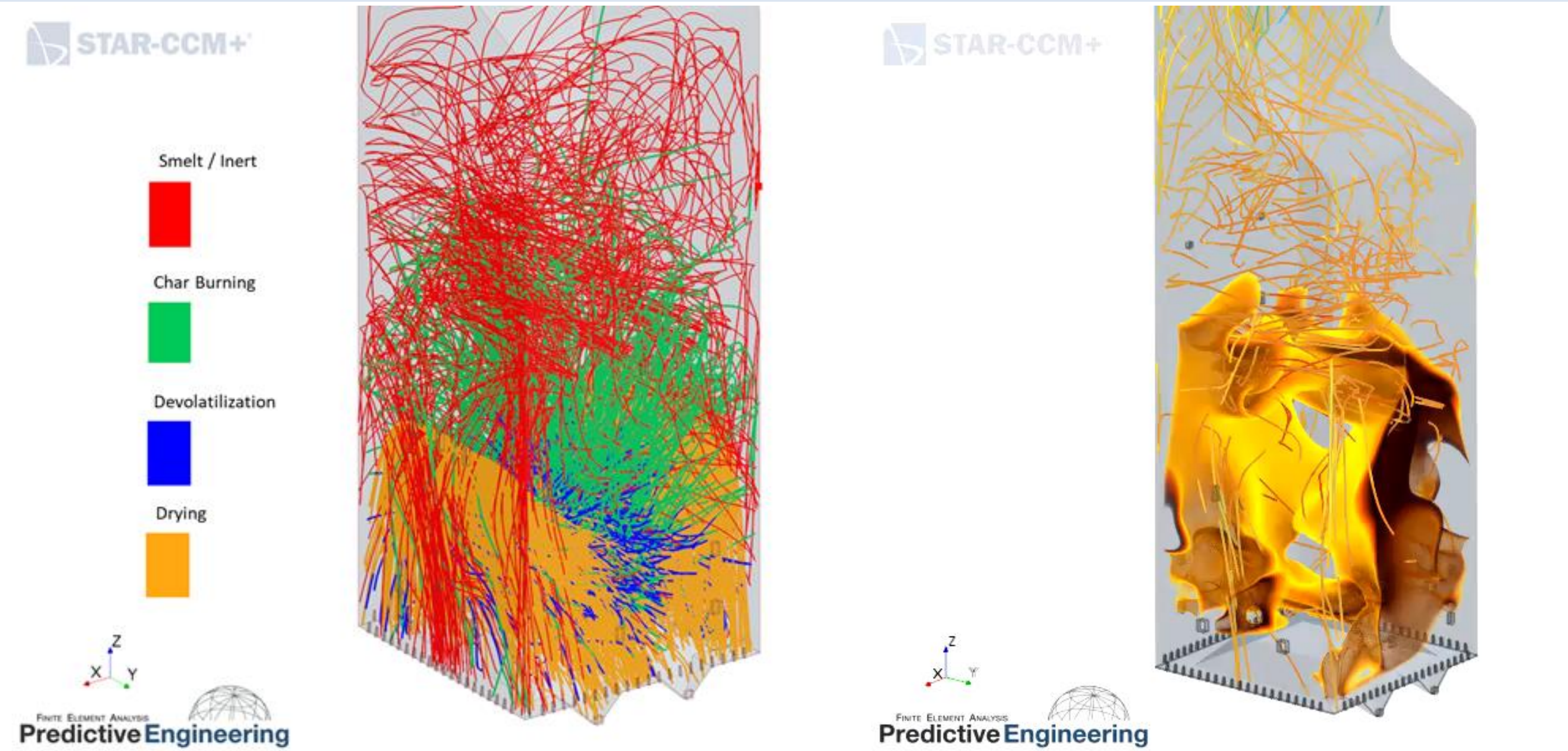


Figure 3: Left: Particle paths and states for black liquor injection. Right: Peak temperatures from fuel combustion near main inlet air inlets.

Emissions Prediction

The primary emission outputs from the model are levels for CO and NOx. Figure 4 displays relative contour plots of these emission levels within the lower furnace of the recovery boiler.

Mass Fraction of CO in Lower Furnace	NOx mass Fraction in Lower Furnace

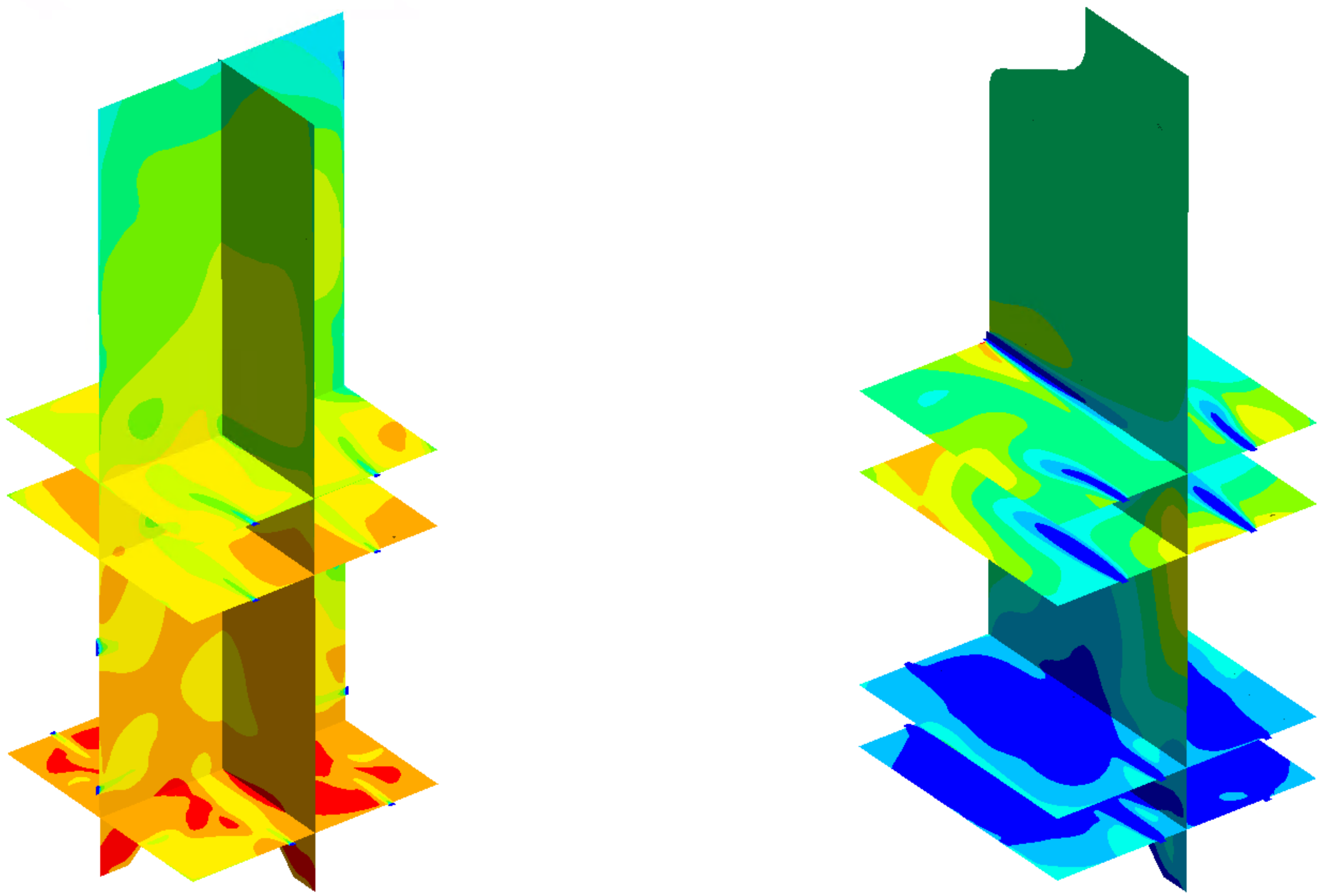


Figure 4: Left: Mass fraction of CO in lower furnace. Right: NOx mass fraction in lower furnace.

Wall Heat Flux

The primary function of the recovery boiler is steam generation for power generation in the Kraft recovery process. The left side of Figure 5 shows the heat flux from convective and radiative transfer on the tube walls. The right side of Figure 5 shows temperature contour plots in selected planes of the lower furnace. The cooler inlet combustion air rapidly heats up through the surrounding combustion reactions.

Heat Absorption on Lower Tube Walls	Temperature Contour Plots of Lower Furnace

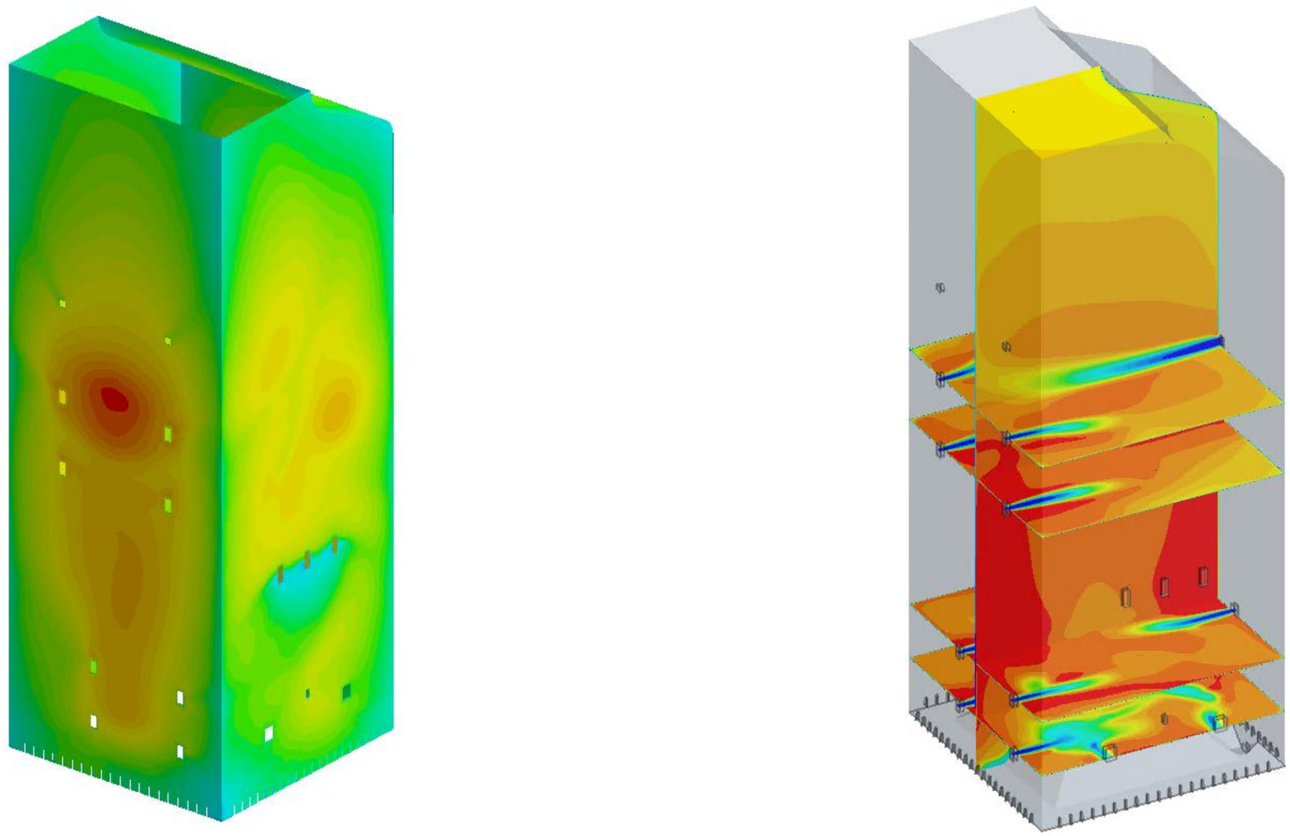


Figure 5: Left: Contour plot of heat absorption on the recovery boiler tube walls. Right: Temperature contours of selected planes in lower furnace