Business from technology

Coupled operational model APROS/ FLUENT

FLEXe WP1
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Background

- During steep load changes in a boiler based power plant, the dynamic interaction between the steam side and the boiler furnace becomes important.
- Fuel inventory and the energy stored in solid materials (walls, pipes, fluidized bed, …), water and steam will affect the dynamics of the process and the instantaneous amount of heat transferred from the furnace to the water/steam side.
- The instantaneous conditions inside the boiler furnace determine the emissions of NOx, SO2, etc.
- Dynamic operation of the furnace and the steam side are coupled through control loops.
- Accurate boiler modeling, especially during load changes, thus requires that the furnace and the steam side are simulated in parallel and the links between the two regions are fully accounted for in the model.

Modeling of the boiler furnace

- Computational fluid dynamic simulation (CFD) methods are used to model the conditions inside boiler furnaces.
- Solution of the transport equations for mass, momentum, energy and chemical species produces 3D fields of velocities, chemical composition and temperature.
- The simulations can be carried out either in transient or steady state modes.
- Commercial (e.g. Ansys Fluent) and open source (e.g. OpenFOAM) codes are available for CFD modeling. At VTT, own submodels have been implemented in the codes to increase prediction accuracy.

Dynamic system modeling of a boiler

- Several modeling tools are available for dynamic system modeling of a boiler.
- At VTT, Apros process simulation software is developed (together with Fortum) and used for the purpose.
- Apros platform provides a realistic environment to study the dynamic behavior of processes and control approaches in a power plant.
- Modifications to Apros have recently been made to facilitate coupling Apros modeling to CFD simulation.
- Apros−CFD coupling was during winter 2015-2016 further developed in the COSIMU project by VTT and Fortum to facilitate the linking in boiler conditions that is required for the FLEXe project.

Goal for coupled simulation in FLEXe

- The goal in the present subtask in WP1 of the FLEXe project was to develop and demonstrate a procedure for coupling CFD simulation of a boiler furnace with dynamic system simulation of the entire boiler.
- Järvenpää BFB boiler was chosen as the demonstration case.
- The boiler furnace was simulated with VTT's BFB combustion models implemented on Ansys Fluent platform.
- Apros model for the boiler was obtained from Fortum and modified slightly to better describe the present operation mode of the boiler.
- Fortum delivered operation data from Järvenpää boiler and a situation at 50% fuel load was chosen as the initial condition for transient simulation.

CFD-Apros coupling (1/3)

In the following, the links between Apros and CFD are listed.

1. Evaporator on the membrane wall of the boiler
   - heat flux on the membrane wall transferred from CFD to Apros
   - temperature of the membrane wall transferred from Apros to CFD
   - two-way heat transfer coupling

2. Superheaters: heat transfer via plates
   - heat flux from CFD to Apros
   - surface temperature from Apros to CFD
   - two-way heat transfer coupling

3. Superheaters: volume heat sink
   - additional volume heat sink is needed for transferring correct amount of heat to superheaters (due to simplified modelling of the tube blocks)
   - total heat flux is transferred from the CFD model to Apros
   - the heat flux is distributed evenly per unit length of the Apros tubes for each tube row in the Apros model
   - two-way heat transfer coupling

CFD-Apros coupling (2/3)

4. Flue gas
   - mass flow rate and temperature transferred from CFD to Apros
   - molar fractions of O_2, CO_2, H_2O and N_2 transferred from CFD to Apros

5. Recirculation of flue gas
   - Apros controls the mass flow rate of recirculated flue gas by using the fuel and steam power and bed temperature
   - mass flow rate, temperature and concentrationsare transferred from Apros to CFD

6. Primary air
   - Apros determines the mass flow rate of primary air from the fuel and steam power and the amount of recirculated flue gas (i.e., bed temperature)
   - Apros calculates the temperature of primary air
   - Primary air data are transferred from Apros to CFD

CFD-Apros coupling (3/3)

7. Secondary, tertiary and other air feeds
   - Apros determines the mass flow rates from the fuel and steam power, bed temperature and the O2 monitor of flue gas
   - Apros determines the air temperature
   - Apros transfers the data to CFD

8. BFB bed model
   - user defined BFB bed model implemented in CFD code (proprietary model at VTT)
   - bed model obtains data from Apros (mass flow rate, temperature and species concentrations of primary air and recirculated flue gas)

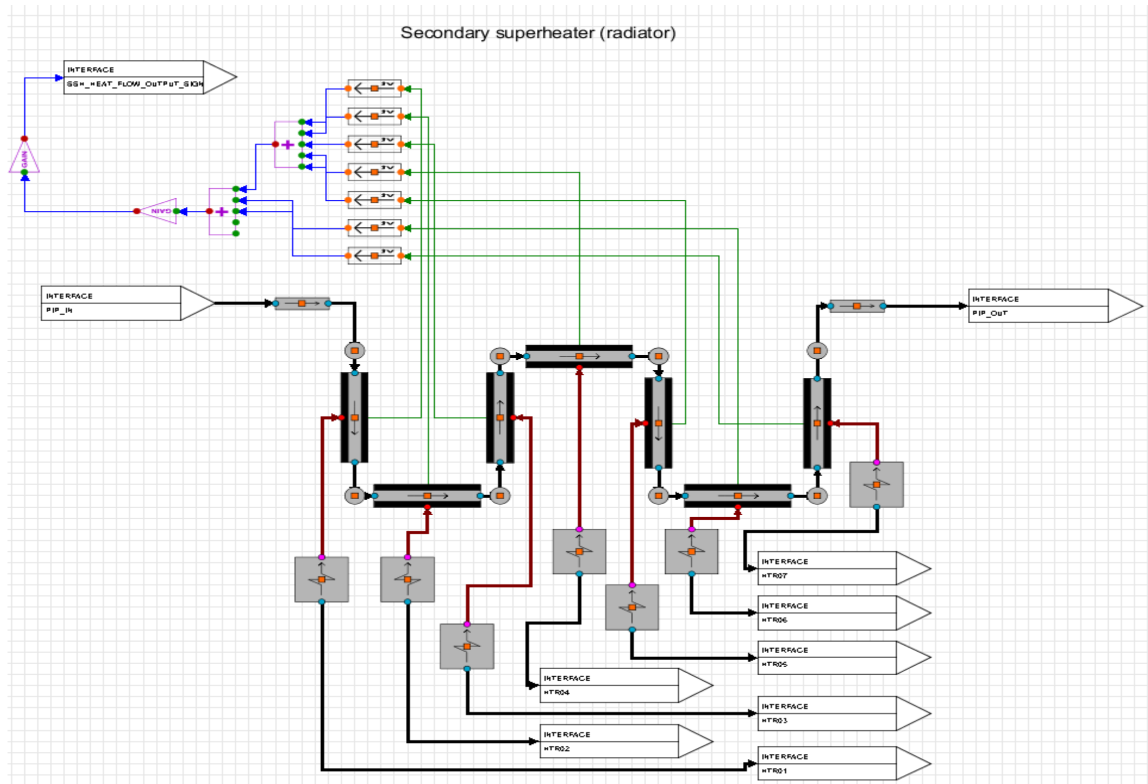
9. Fuel injections
   - fuel properties and temperature are defined in the CFD model
   - mass flow rate of fuel is calculated in Apros and transferred to CFD

Demonstration of the approach

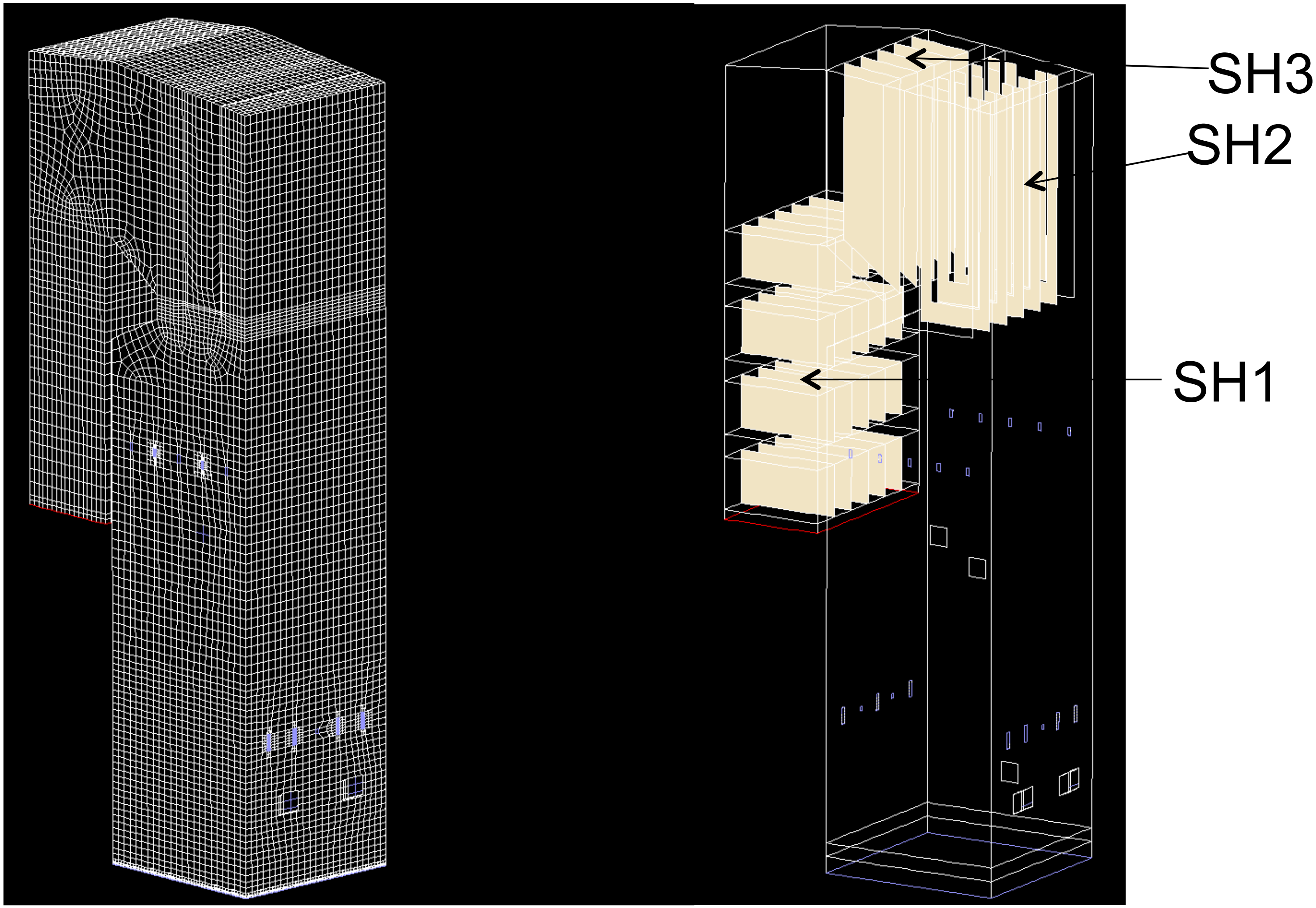
- The descriptions of heat exchangers in the CFD model geometry and in the Apros model for Järvenpää BFB boiler were modified to match each other.
- The same coordinate system was used in CFD and Apros to facilitate the physical links.
- Before simulation of a steep load increase, a linked Apros-CFD simulation was carried out for the steady state conditions.
- Arriving at steady state proved to take a long time.
- Transient linked CFD-Apros simulation progresses also fairly slowly. About 2 minutes of real time can be simulated in a day.
- The method is thus best suited for studying steep transients.

Example of Apros modeling of heat transfer surfaces - Secondary Superheater (SSH)

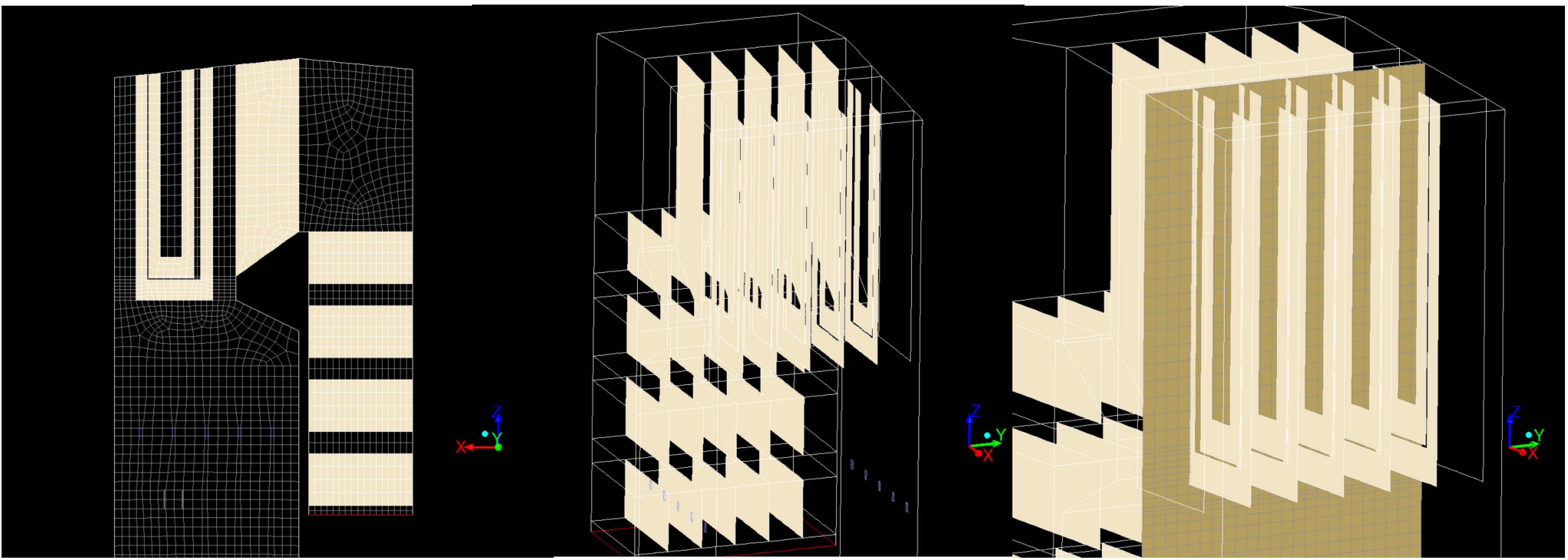
- 7 tubes containing 106 nodes for each CFD model plate.
- Positions (x,y,z coordinates) set to match the plates of the CFD model



CFD modeling of Järvenpää BFB-boiler
- Surface mesh of the boiler furnace & Super-heater plates

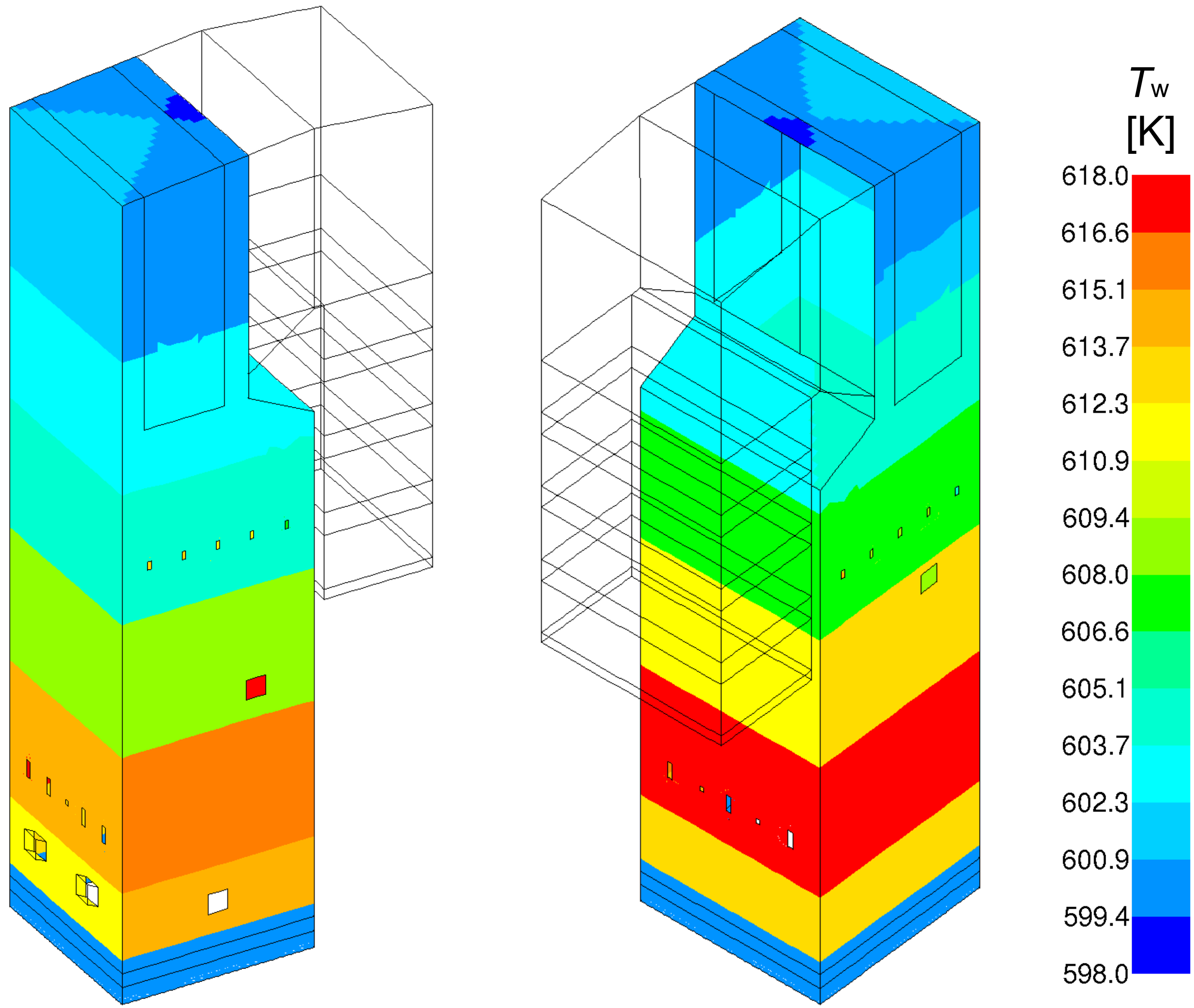


CFD modeling of Järvenpää BFB-boiler
- Super-heater plates & grid spacing



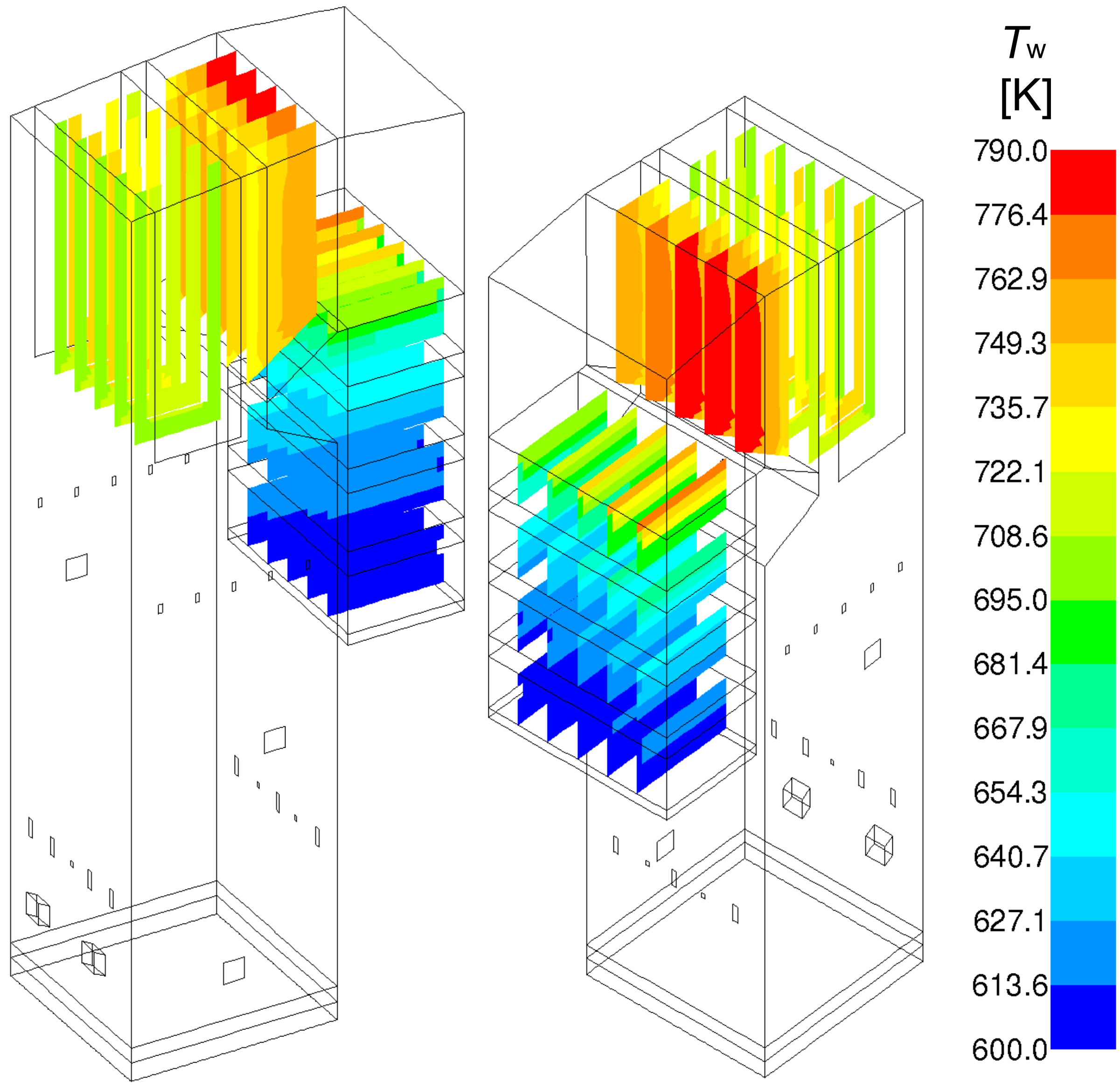
Results: Temperature distribution at the evaporator surfaces

- Slightly asymmetrical surface temperature distribution (furnace side)
- Each wall connects to its own Apros components
- Vertical division of the Apros components is clearlyvisible (transferring heat to each Apros node instead of tube section)
- The temperature differences are minor, since boiling water on the “steam side” is in saturation temperature



Results: Temperature distribution at the superheater surfaces

- Slightly asymmetrical surface temperature distribution (furnace / back pass side)
- Each superheater plate connects to its own Apros components
- Several superheater elements represented by each plate



Conclusions

- Coupled CFD-Apros simuation approach was successfully developed and demonstrated.
- The simulations are slow and thus the method is best suited for analysis of steep transients.
- Potential applications
  - Testing of control strategies/methods
  - Analysis of effects on emissions
  - Analysis of local temperature changes during transient operation
  - Analysis of local conditions during load changes to evaluate risks of corrosion
  - etc.

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