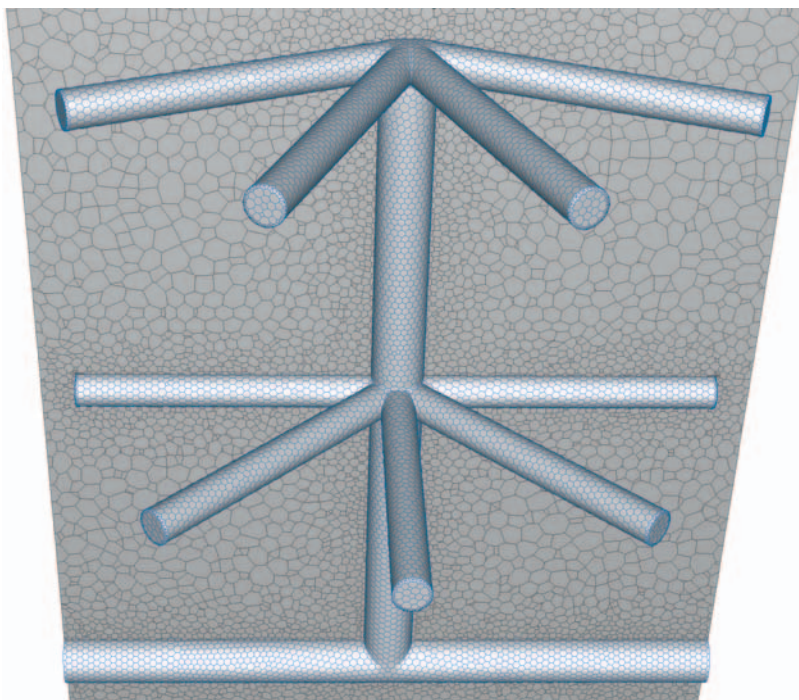


The mesh structure

# Scrubbers for Flue Gas Cleanup

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Mesh in the spray bank zone

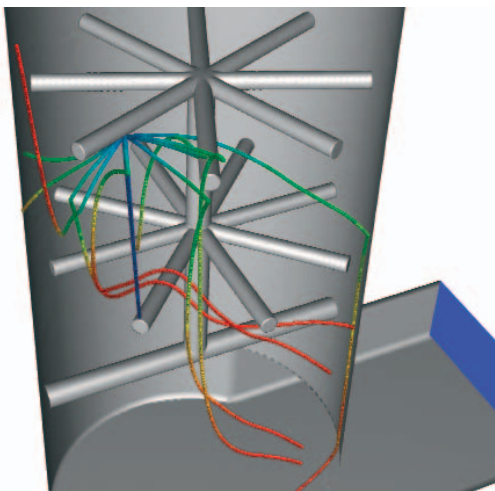
WITH TODAY'S INCREASINGLY RESTRICTIVE environmental regulations, there is an ongoing need for state-of-the-art modeling of pollutant formation and removal in industrial processing units. A particularly important issue is the sulphur dioxide ( $\text{SO}_2$ ) content in the flue gases of power plants. A typical approach for removing this hazardous component is through absorption by limestone slurry droplets in so-called flue gas scrubbers. Scrubbers consist of large towers in which up to several thousands of nozzles provide a homogenous distribution of droplets within the gas flow. This leads to the highest possible absorption rate for a given slurry mass flow. To optimize the nozzle configurations for scrubbers, CFD simulation is one of the best tools to use.

The absorption of  $\text{SO}_2$  is a complex process with several mechanisms to be considered. The continuous phase (gas) and discrete phase (droplets) have to be calculated as well as the interaction between them. The momentum and temperature of the droplets affect the gas flow and vice versa. Additionally, mass transfer between the droplet and gas phases has to be taken into account. Depending on the difference in the partial pressure of water vapor in the two phases, there might be evaporation from the droplets or condensation onto the droplet surfaces. Rapid changes in temperature cause both evaporation and condensation to have a significant influence on the  $\text{SO}_2$  absorption rate, which itself is governed by a complex ion chemistry mechanism within the droplets. The heat and mass transfer rates are dependent on the droplet surface area, which changes during evaporation or condensation, or whenever there is splashing at the walls. To account for the latter, an appropriate wall interaction model also has to be part of the CFD simulation. With FLUENT's user-defined function (UDF) capability, a set of models addressing these issues has been implemented, and a test case with typical scrubber conditions has been created to illustrate the capabilities.

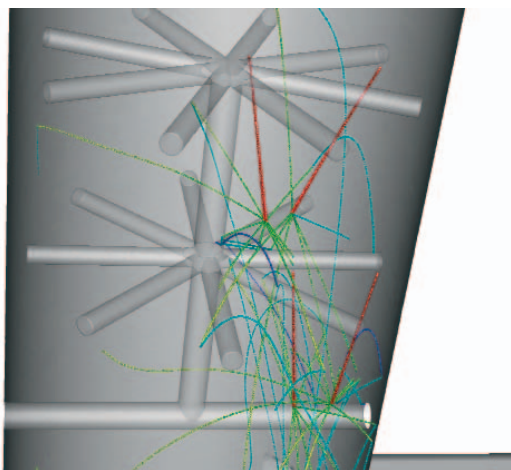
A cylindrical scrubber with two sets of eight radial spray bars was considered. The grid was built using the polyhedral mesh

capability of FLUENT 6.3. The original mesh consisted of a total of 1.25 million cells, which were reduced to 250,000 cells after the tetrahedral elements were converted to polyhedra. Using sizing functions, a sufficient grid resolution in the near wall regions of the spray bank was ensured. A flue gas mass flow rate of 65kg/s was set at an inlet at the bottom of the unit with SO<sub>2</sub> and water vapor mass fractions of 0.0024 and 0.12 respectively, and the remainder consisting of air. Sixty-six full cone nozzles were distributed in a circular pattern on the sixteen radial pipes for a total slurry mass flow rate of 330kg/s. Both the gas flow and the droplets started with an initial temperature of 316K. For the droplets, the dispersed phase model (DPM) was used with a large number of trajectories, whose interaction with the gas phase was evaluated separately. The RNG k-ε model and the stochastic tracking method were used to incorporate the effects of turbulent fluctuations on both phases in the simulation.

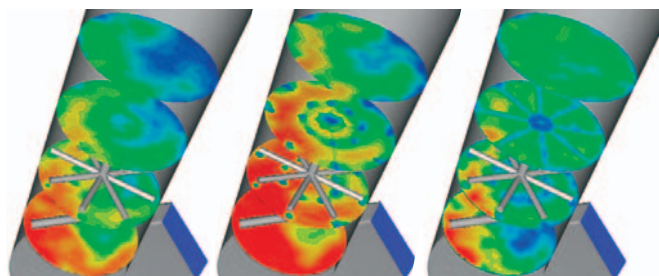
In a surrounding air flow at ambient temperature, a water droplet is subject to a coupled heat and mass transfer process. With increasing velocity difference between the two phases the transfer is enhanced and can be calculated with the Ranz-Marshall law, which can be used for SO<sub>2</sub> absorption as well as vaporization and condensation [1]. Since the latent heat of water



Droplet temperature evolution along some of the droplet trajectories



Droplet splashing and breakup at the walls; the droplet trajectories are colored by particle diameter, so the red trajectories occur before splashing and breakup occur

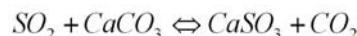


Contours of water vapor content (left), SO<sub>2</sub> mass fraction (middle), and vertical velocity (right) on four slices within the scrubber; the flow in the unit is from bottom to top

is quite high, the droplet temperature change along its trajectory cannot be neglected, since a temperature change of 10K can significantly affect the SO<sub>2</sub> partial pressure at the droplet surface.

When droplets hit the wall there are several possibilities of what can occur. Under certain conditions a droplet can become part of the liquid film on the wall and in other instances there may be splashing and breakup of the droplets. The latter results in an increased number of droplets with a larger total surface area, a change that again significantly affects the momentum, heat and mass transfer rates. For this application, it was assumed that the wall interaction behavior was governed by dimensionless Weber and Reynolds numbers [2] and a model was developed accordingly.

The removal of SO<sub>2</sub> in the droplets is governed by a reaction with limestone, which can be described by the net reaction:



Additionally there are several dissolution reactions, since the formation of sulphurous and carbonic acid results in an ion chemistry mechanism that depends on the pH-value and the limestone and SO<sub>2</sub> concentrations of the droplets [3]. This was implemented by means of an externally evaluated lookup table that was coupled with the discrete phase using FLUENT's particle scalar UDF, which allows additional droplet properties to be defined. Once the total sulphur content in a droplet has been evaluated, the new concentration of each ion is obtained from the table and stored in the respective DPM scalar. With this information the calculation of the SO<sub>2</sub> partial pressure at the droplet-gas interface and the respective sink terms is possible to ensure SO<sub>2</sub> mass conservation in both phases of the domain.

The results obtained from the simulation are in very good agreement with real-life scrubbers. Austrian Energy & Environment AG now includes FLUENT with these special models in their scrubber design workflow. The polyhedral cell technology has proved to be a significant improvement in terms of meshing flexibility and simulation time, enabling engineers to perform a complete scrubber simulation within a few days. The reliability of the results has meant that they need to rely less on field tests as well. ■

## References:

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- 2 Mundo, C. and Tropea, C.: Numerical and Experimental Investigation of Spray Characteristics in the Vicinity of a Rigid Wall. Experimental Thermal and Fluid Science, 15:228-237, 1997.
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