Research & Development

Customized solvers optimize filtration device design

With customized solvers, computational flow simulations optimize the design of filtration devices. This article considers the complex interactions of clogged filters which change flow fields. As the transport and deposit of solid particles are possible in arbitrary gas or liquid flows, solvers offer a potentially wide range of applications.

Simulation of filter applications

Flow simulations (Computational Fluid Dynamics, CFD) are already being used for the design of processing and chemical plants. By optimizing the flow, for example, pressure losses are significantly reduced resulting in a higher degree of plant efficiency. Aggregates as heat exchangers, are flown in more efficiently, and higher process stability is reached that leads to reduced downtimes of a plant.

In processing plants, flows with multiple phases often dominate, for example in mixing systems with free surfaces, gassed systems, as bubble columns or particle resp. droplet transport in separators or filters. In many cases, multiphase applications pose specific requirements on simulation techniques and, in addition, are often very computationally intensive. Frequently, the simulations cannot be implemented directly, due to the complex

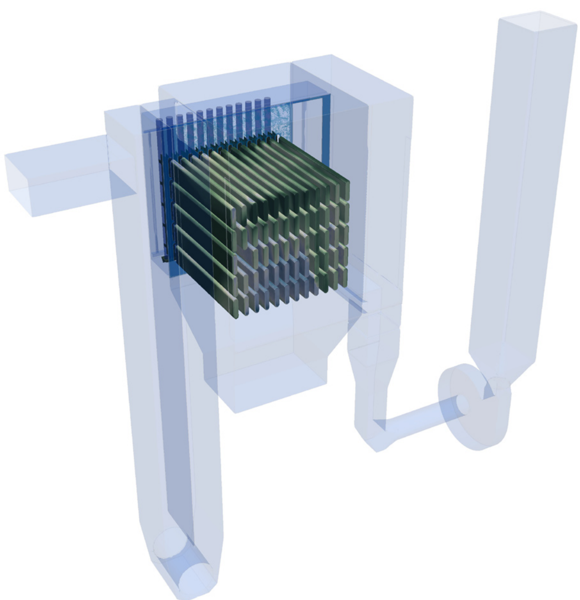

Figure 1. Simulation model with clogged filters.

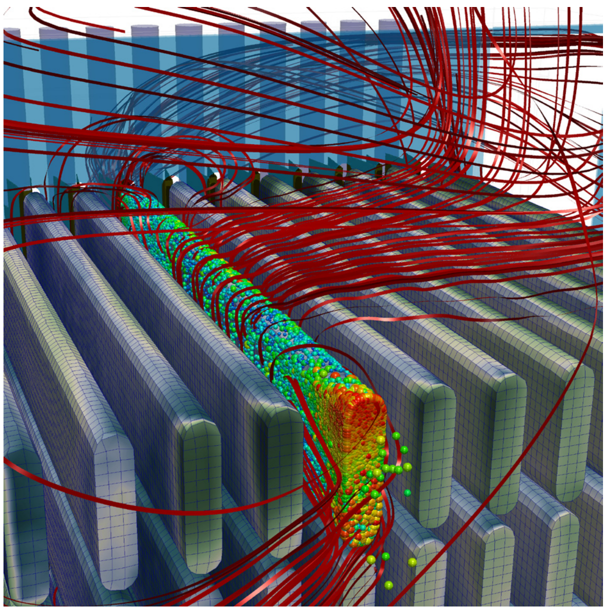

Figure 2. Detail of a dust separation demonstration plant.

transport processes or insufficient knowledge of the exact input parameters. For a reliable use of simulation methods in this field, special adaptations of the simulation methods to the specific issues and tasks are often necessary.

Particularly large improvements in the specialization of simulation applications have been achieved by the availability of Open Source CFD codes which already comprise high-performance multiphase modelling. The Open Source character allows a targeted extension of physical models for special applications and the optimisation of the solver for specific requirements, a customisation. In this context, DHCAE Tools GmbH created a particular solver for filter applications based on the CFD toolbox, OpenFOAM®.

Flow shift in filters

In many processes with filters, similar problems and issues for the interpretation occur, despite very different areas of use. For example, interactions between the load of the filter and the transporting flow have to be expected, both in the filtration of floating particles from water and in dust separation in large filter plants. For an unloaded, clean filter, particles preferentially deposit on the regions of the filters that have particularly strong flow through at the beginning.

If, however, particles have deposited on these regions, the amount of particles increases the local resistance for the continuous, transporting flow in these regions, and the flow diverges progressively.

With this shift, more particles are also transported into other filter regions. Obviously, the local load of the filter during the load cycle depends on the properties of the particles and process, such as the particle size, the mass, the duration of the load and the impacts on the inflow configuration involved.

Both for an efficient design of the inflow resp. for an outflow of filters during the whole load cycle, and for an optimal arrangement of filters in the flow, specific models are necessary for the numerical simulation of the different filtration applications. These models are then capable of demonstrating these dynamic changes of resistance and the resulting shifts of the flow.

Simulation of filter applications

In the field of flow simulations, particle flows are often described with so-called Euler-Lagrange approaches. Here, the continuous flow is described with a stationary Euler approach using a locally fixed coordinate system, while the particle movement is calculated with a Lagrangian model with co-moving reference frames for each particle. The latter approach takes into account the respective impacting forces, such as resistance, inertia or gravity. Therefore, within the framework of the filter modelling tool, the transporting phase (air in dust separation or water in water filtration) through the unloaded filter is calculated in the first step.

In the second step, particles are added to the continuous flow. A Parcel model is used for the particle transport. Here, not each single particle has to be calculated, but a statistically sufficient number of packages (Parcels) is considered, each representing a particle cluster respectively according to the defined distribution of particle sizes. Based on the Lagrange approach, the trajectories of the particle packages are calculated up to their end position. The end position can be the deposition on the filter. Particles can also, through gravity, accumulate at the bottom or leave the flow region without depositing on the filter. After a certain amount of injected particle mass, and with that a deposition of particles on the filter, the continuous flow is simulated anew, taking into account the increase of the resistance on the filter. Then again, particles are added to the flow field, and they, considering the shift of the continuous flow, now deposit on other places. This iterative process between the recalculation of the continuous flow and the interaction with particles will be repeated as long as the total mass of particles to be considered is deposited. This results in a continuous series of snapshots of the whole loading process, showing the interactions on the transporting flow field, from the unloaded to the loaded filter before the de-dusting or the replacement of the filter medium. Finally, this already allows, in the planning stage, an efficient design of the filter process or of a filter plant, which leads to:

- optimised pressure losses with a higher energetic degree of efficiency,

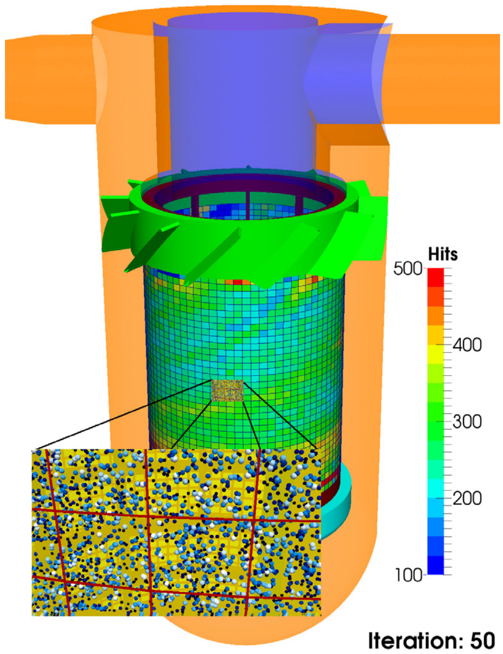

Figure 3. Water filtration simulation.

- a better utilization of the filter medium and
- a more stable process control during the whole loading process.

Tool verification and application cases

For the development of the simulation tool, comprehensive extensions were carried out, based on the CFD toolbox OpenFOAM. Special boundary conditions were created that enable a deposition of particles on region elements and an increase of the resistance for the continuous flow based on Darcy or Forchheimer approaches. A coupling procedure between particle transport and continuous flow was developed that enables a particularly computationally efficient particle transport and at the same time works completely in parallel to make use of modern multiple kernel CPUs effectively. The partial models developed here were verified with examples from the literature. The work of Michele Cagna (Cagna, 2003) served for this verification.

Here, the local particle distribution, the increase of resistance and the flow shift were replicated both numerically and experimentally under laboratory conditions. The pressure increase for the homogenous particle load could be reproduced exactly so that the correct realisation of the model is proven. At the same time the particle deposition in the case of an inhomogeneous loading could be replicated excellently.

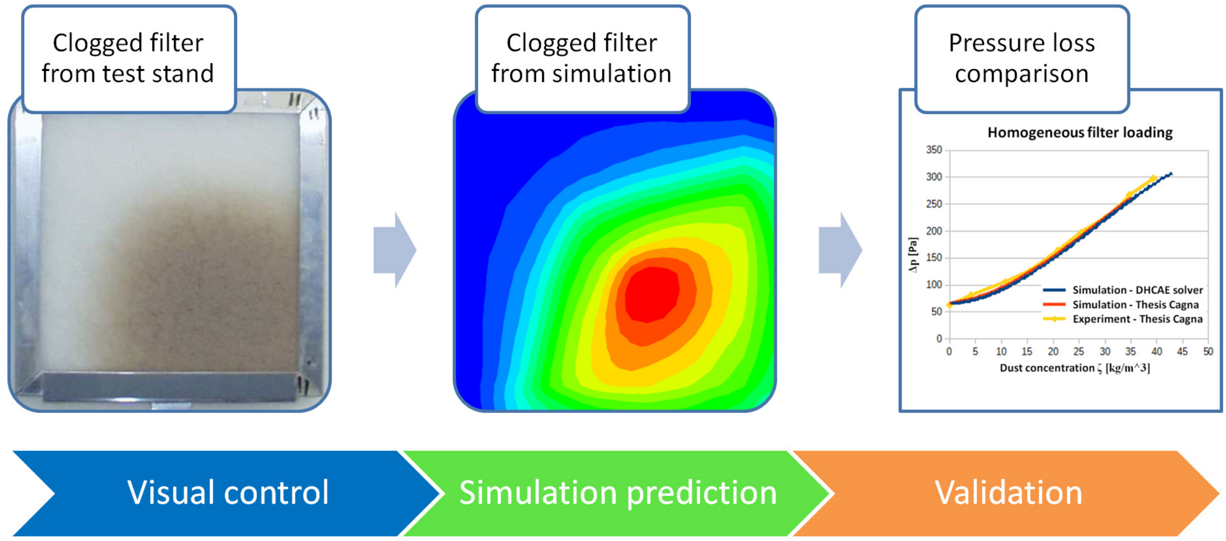

Figure 4. Verification of the solver against a PhD (Cagna, 2003).

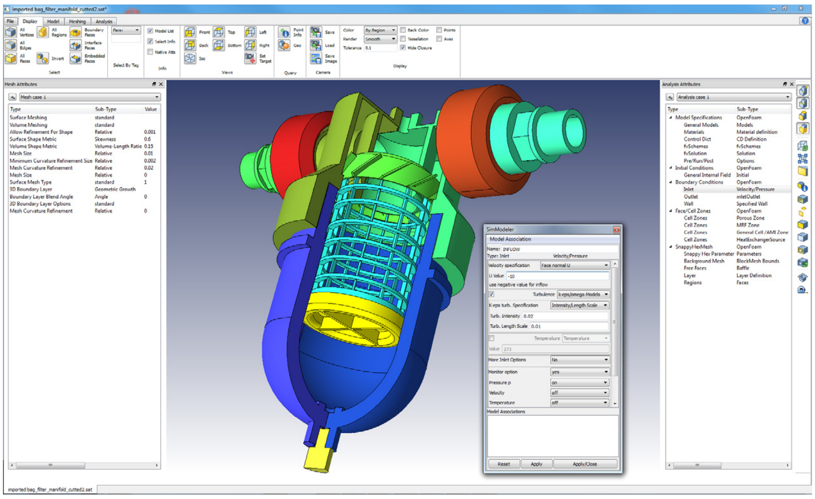

Figure 5. Modelling of a water filter.

The total modelling with the coupling to the continuous flow was validated in a real technical demonstration plant for air purification. For this purpose, experiments were carried out at a demonstration plant of the company Luehr in Stadthagen. By measuring the dynamic pressure on 10 of the 60 bag filters of the plant, the relative velocity of the flow through the filters and its change was evaluated during the load cycle. The filters were arranged in a block of 6*10 filters, and some measurement positions were located inside the filter block, others at the margin. The measurements of the filter flows showed that, obviously, the outer filters were clogged with particles first. The resistance of the outer filters increased first, and the gas flow shifted to the inner area of the filter block so that the flow velocity of the outer filters showed a falling tendency with increasing particle load whereas the inner filters showed an increasing tendency. In the first step, as the inflow data into the simulation, the filter characteristic of a single filter bag, in dependence of the load and flow velocity, was determined at the single test station. With this, the whole simulation process was depicted, based on the continuous flow in the filter plant, the successive input of particles and the continuous recalculation of the continuous flow, resulting from the changed resistance ratio on the 60 filters. The increasing and decreasing tendencies of the flow velocities in the inner and outer filter elements could be reproduced and, therefore, the continuous flow shift could be proved. With this, the whole plant with 60 bag filters was simulated on a typical workstation architecture in a few days. For extensive calculation models, a cloud implementation of the filter solver is also available.

Universally applicable

The modelling with an Euler-Lagrange approach allows a broad use of the simulation tool, both for gas and fluid systems with solid particles. Extensions on additional force fields that affect the particles and can influence their trajectories are easily implemented. The implementation based on Open Source solvers makes the calculation tool particularly cost-efficient and can flexibly be used on different machines because no licence costs or licence management systems for the solution are needed. On request, the whole solver can be used in a completely graphical user interface with CFD meshing, CAD based case-setup, monitoring and post-processing. With this, also other general CFD problems with or without heat transport, multiphase applications, e.g. mixing systems with free surfaces or also structural analyses based on Open Source solver technology, can be carried out. ●

Please contact the author for a full list of references.

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