A micro-macroscopic modelling of particle retention on porous media and its impact on flow behaviour

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Filter applications are important for the chemical, automotive and domestic appliances industries. In an ongoing project, DHCAE Tools develops an OpenFOAM® solver for the simulation of filters and particle retention in fiber structures.

In this research project, DHCAE Tools develops a new approach for a better modelling of filters based on different modelling approaches in OpenFOAM®, in particular DEM and parcel based Lagrangian particle transport.

A three-stage, continuous numerical method, covering the wide range of geometry scales, is implemented. Key aspect for this method is a consistent numerical modelling:

1. By means of microscopic approaches, the basic principles of particle movement, accumulation on filter fibers and the impact on the flow are analyzed. From this, numeric models and parameters for macroscopic simulation of filter applications are derived.
2. For macroscopic modelling, numerical approaches for modelling the filters in the complete plant model (resp. complete filter process) with local resistance characteristic and local particle retention are modelled.
3. Fluid-Structure-Interaction (FSI): In the further course of the project, we will develop numeric processes that forecast the deformation of filter media in the fluid flow caused by the local pressure distribution.

The microscopic modelling is implemented by a DEM approach in OpenFOAM®. The discrete interaction of single particles with fibers or other particles is considered. An iterative approach has been implemented to model a high amount of particles interacting with the fibers or particles amongst themselves and to consider the reaction to the continuous flow: After investigating a group of several thousand particles and following their paths until they stick on fibers or accumulate with other particles, the particles are frozen and added to fibers walls. After remeshing and recalculating the continuous flow field, a new particle loading procedure can take place. The result of the microscopic modelling is an increase of resistance for the continuous flow depending on the particle loading and the diameter fraction of particles that are able to pass the fiber. These distributions present the input of the macroscopic modelling.

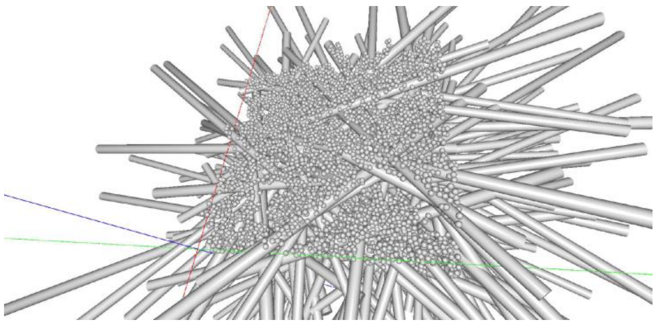

Figure 1 - Particles stick to fibers, OpenFOAM® DEM simulation

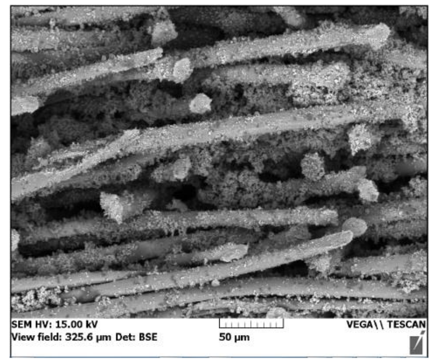

Figure 2 - Scanning electron microscope (SEM) inspection

In the macroscopic perspective, the particle transport in complete filter plants is considered.

In general, the distribution of the particle is inhomogeneous, not only between different filters, but even within a single filter element. This results in a continuously changing flow field during the operation, e.g. of the filter house in chemical engineering.

The new numeric models describe the interactions of discrete particles in a continuous flow with thin-walled, porous and non-porous media on a macroscopic scale. Due to the complex geometries of bag filter houses, the filter elements are modelled as 2D porous baffles instead of 3D porous zones.

An iterative algorithm was implemented to simulate the filter loading. Starting with a steady state flow field, a certain mass is injected as Lagrangian particles and tracked with a local time stepping (LTS) approach. The increasing particle concentration is stored on each single face of the filter baffle mesh. With the local particle concentration, the non-uniform resistance of the filter is recalculated. Finally, the new steady state flow field is calculated considering the new filter loading, and the iteration starts again.

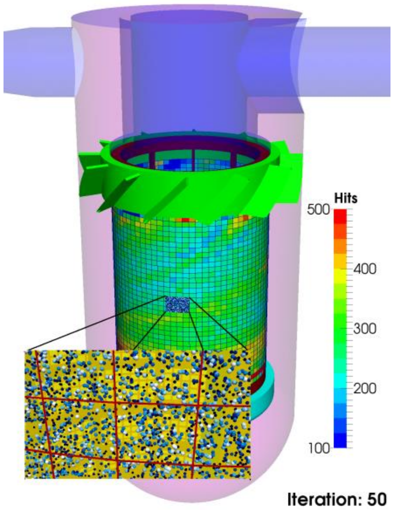

Figure 3 - Macroscopic modelling of a water filter device

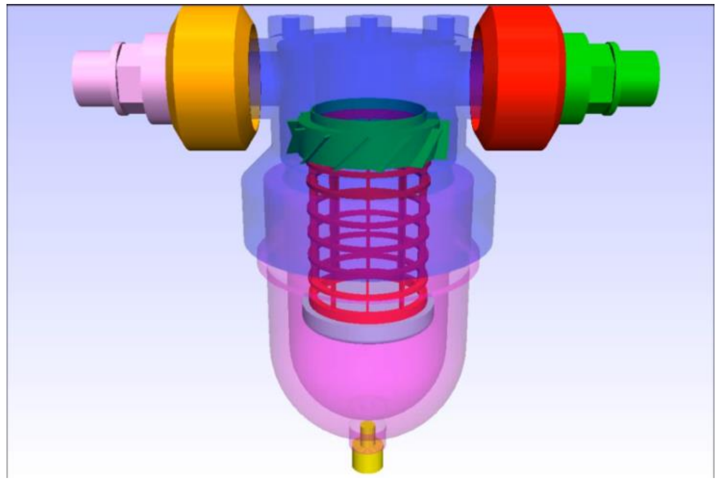

Figure 4 - A complete animation is provided on youtube: https://youtu.be/LPGNqUPsoc0

The pressure drop caused by the filters is calculated with the Darcy-Forchheimer Law. The corresponding coefficients depend on the local particle load and can be fitted with a polynomial approach based on the data of the microscopic modelling.

Several new boundary conditions have been developed, for example the damping of the turbulence across the filter baffle, the orientation of the velocity field and the correct calculation of the pressure drop.

The macro scale modelling approach allows the simulation of depth filter applications as well as surface filters with a filter cake up-building. The steady state particle tracking in combination with the SIMPLE algorithm for the flow field calculation result in a very efficient solver for a wide range of industrial scale problem sizes.

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