The Physics of Dust Filter Caking

By Bastian Bach, Stefan Zacher, Eberhard Schmidt, Safety Engineering/Environmental Protection, University of Wuppertal, Germany and Wolfgang Timm, Fluent Germany

SURFACE FILTERS are used to separate particles from gases in order to reduce emissions, separate products, or clean process gases. To do this, a porous filter medium is percolated by the gas, whereby the particles first stick to the surface of the medium and then to the developing and thickening layer of dust. The filters are characterized by a high particle collection efficiency, especially for particles in the low micrometer range. Thus they are useful in processes that must comply with severely limited dust emissions. Using surface filters, it is possible to decrease dust concentrations from hundreds of g/m^3 to only a few mg/m^3 or less.

The layer of dust, also known as the filter cake, has to be removed periodically from the surface of the filter medium to reduce the resistance to flow and therefore the pressure drop. Filter cake removal happens by using short intermittent bursts of compressed air. The pressure drop across the filter cake, which is additional to that across the filter media itself, is strongly dependent on the cake's structure, which includes its porosity and the filtration conditions.

Because the derivation of a dust cake structure from experimental data is laborious and expensive, CFD has been used to provide insight into the formation of a typical filter cake. Since the tracking of particles of many sizes is needed for such a simulation, the discrete phase model in FLUENT has been used. To model the separation and deposition of particles and their effect on the flow field, user-defined functions (UDFs) were developed to account for the diameters of the particles in addition to their mass points.

A plane filter with an area of 0.25 mm^2 and a thickness of 450 µm was considered in a three-dimensional domain. The mesh near the filter consisted of hexagonal cells with volumes of 1000 mm^3 each. The filter was characterized by an initial pressure drop of 100 Pa. A quasi-stationary injection of particles was carried out from random start positions above the inlet with a perpendicular approach to the filter. The spherical particles were linearly distributed between 1 and 10 µm in

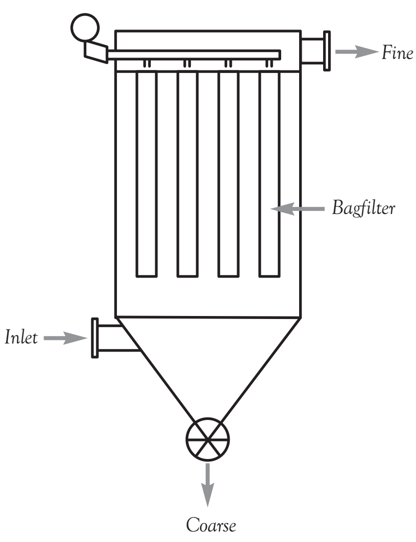
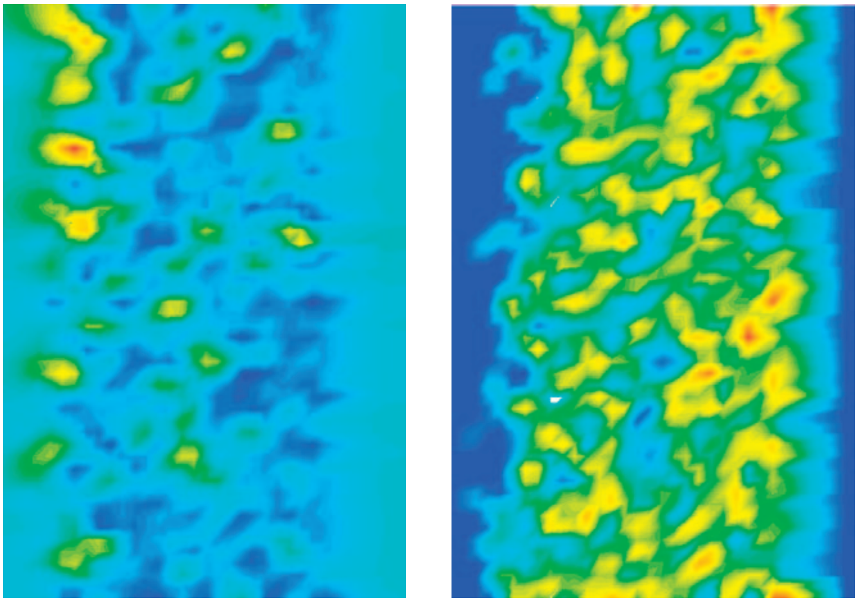
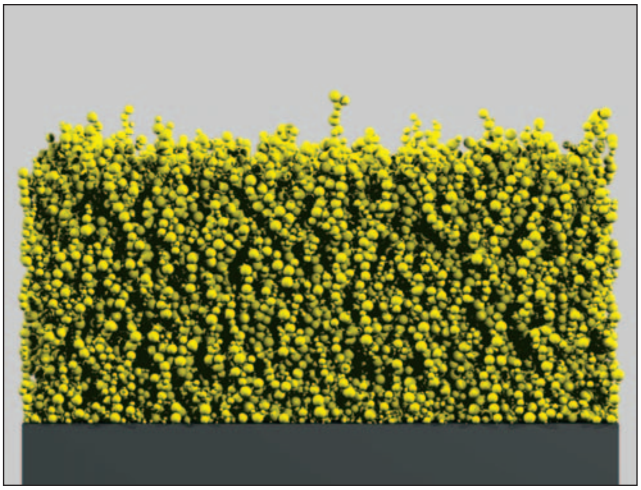


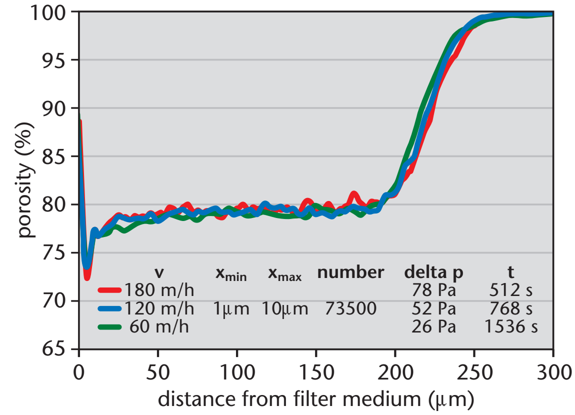
Diagram of a typical bag filter unit



Contours of velocity (left) and molecular viscosity (right) on a planar surface inside the filter cake



Three-dimensional filter cake composed of 73,500 particles with equally distributed diameters from 1 to 10 μm



Porosities of thin layers inside the filter cakes parallel to the filter medium as a function of the distance from the filter medium

diameter, and released in ten groups of 49 each (490 total). After each group of injections, the flow field of the gas stream through the particle layer and filter medium was calculated anew. The particles were released with a velocity equal to the filter face velocity, defined as the volumetric flow rate divided by the filter face area. Three filter face velocities were used: 60, 120 and 180 m/h. The resistance to the gas flow caused by the separated particles forming the filter cake was accounted for by influencing the viscosity and velocity components inside each cell, according to calculated values of the specific resistance model of Rudnick and First [1].

After 150 calculation loops, the filter cakes were composed of 73,500 particles. For the case of ideal filtration, the particles do not penetrate the filter medium, but are deposited upon its planar surface. The predicted porosities of thin layers inside each filter cake and the average porosity of the entire filter cake parallel to the filter medium and as a function of the distance from the filter medium, were found to be in accordance with formerly simulated [2] and experimentally determined [3, 4] data for all of the cases studied. The porosity, structure, height, and pressure drop of the filter cakes were found to differ among the cases. If the pressure drop across the filter cake is small, the cake does not compress and offer additional flow resistance as the particles build up. If the pressure drop across the filter cake exceeds a critical value with ongoing filtration time, the flow forces overwhelm the integrity of the cake structure. When this happens, the cake compresses, and a sudden decrease in porosity and sharp increase in pressure drop across the cake occur. The effect of filter cake compression was not included in the CFD model.

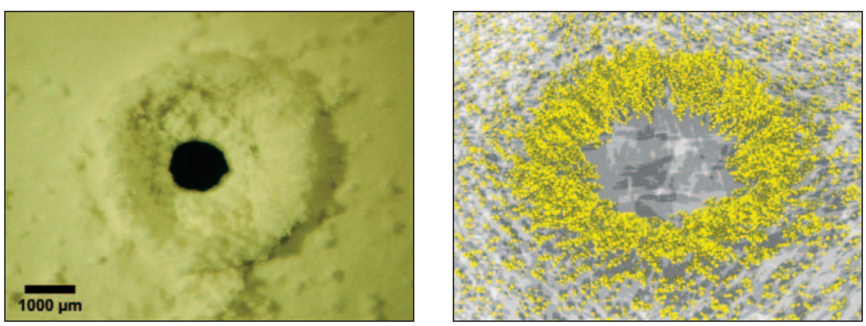
An average porosity close to 80% was determined in all three cases. Assuming 0.005 kg of particles per cubic meter of raw gas and knowing the deposited mass of particles, a theoretical filtration time was predicted for the three filter face velocities used with the model.

In ongoing studies, a pinhole bypass through a leak in a surface filter is being considered. Pinholes are small holes which may be formed during regeneration or during filtration. Probable sites are the pores between yarns in woven fabrics, places where a synthetic felt was needle-punched in manufacture, small ruptures caused by mechanical stress, or holes generated by pyrophoric particles. Using CFD, the influence of pinholes on filtering capacity is being assessed. Of particular interest is whether or not pinholes will limit a filter's ability to comply with dust emissions regulations during normal operation. In the first of these simulations, the formation of pinhole craters by separated particles that do not penetrate the pinhole was observed, consistent with experiments. ■

References:

1. Rudnick, S.N., First, M.W.: Specific Resistance (K2) of Filter Dust Cakes: Comparison of Theory and Experiments. Third Symposium on Fabric Filters for Particulate Collection, EPA-600/7-78-087, 251-288, 1978.
2. Schmidt, E.: Simulation of three-dimensional dust structures via particle trajectory calculations for cake-forming filtration, Powder Technology 86, 113-117, 1996.
3. Schmidt, E., Löffler, F.: The Analysis of Dust Cake Structures, Part. Part. Syst. Charact. 8, 105-109, 1991.
4. Schmidt, E.: Zur Kompression von auf Filtermedien abgeschiedenen Staubschichten, Staub - Reinhaltung Luft 53, 10:369-376, 1993.

Visualization is by POV Raytracer. www.povray.org



Pinhole "craters" generated by experiment (left) and CFD simulation (right)