Simulation of air filtration in micro structures

Financially supported by

Stiftung Innovation Rheinland Pfalz

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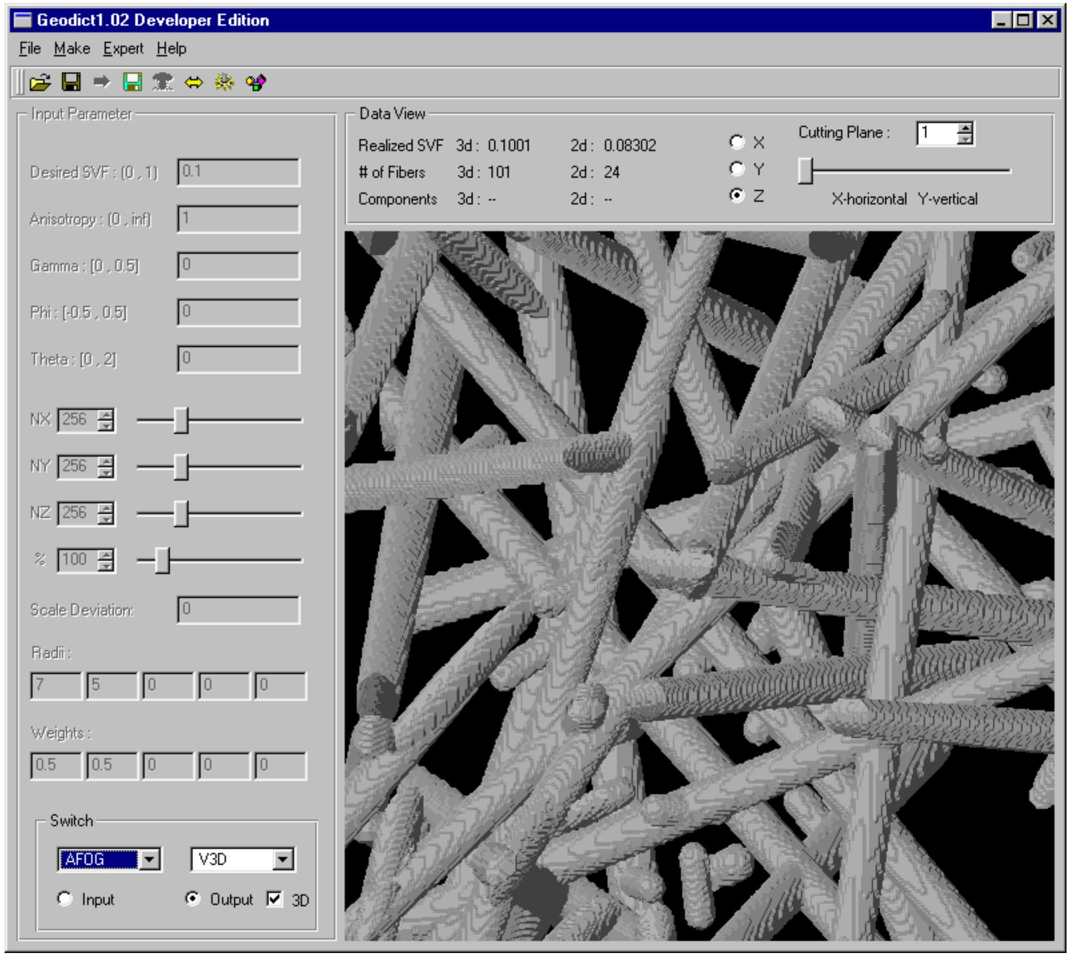
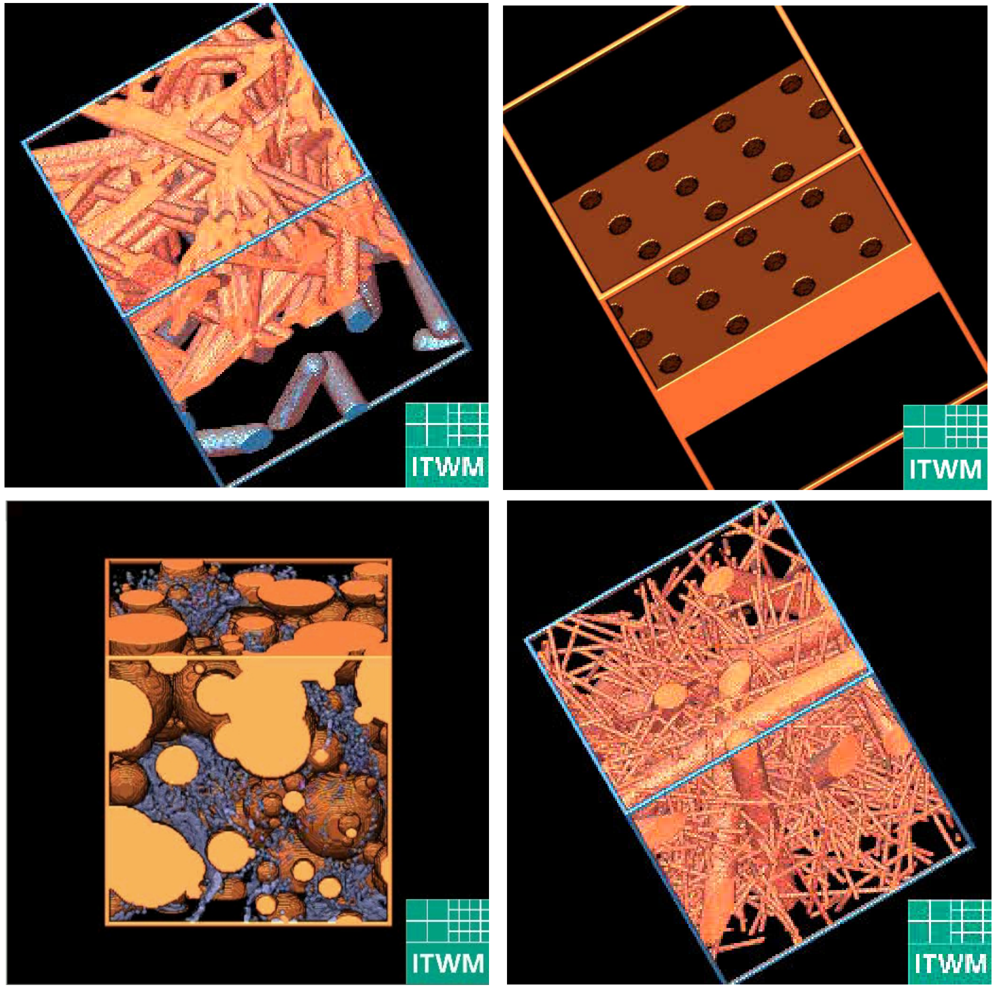
The Structure Generator, 3d





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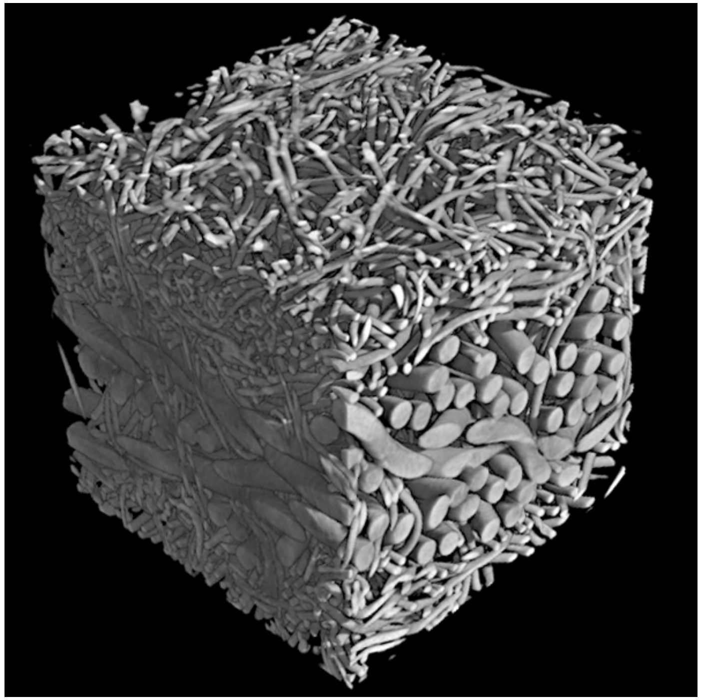
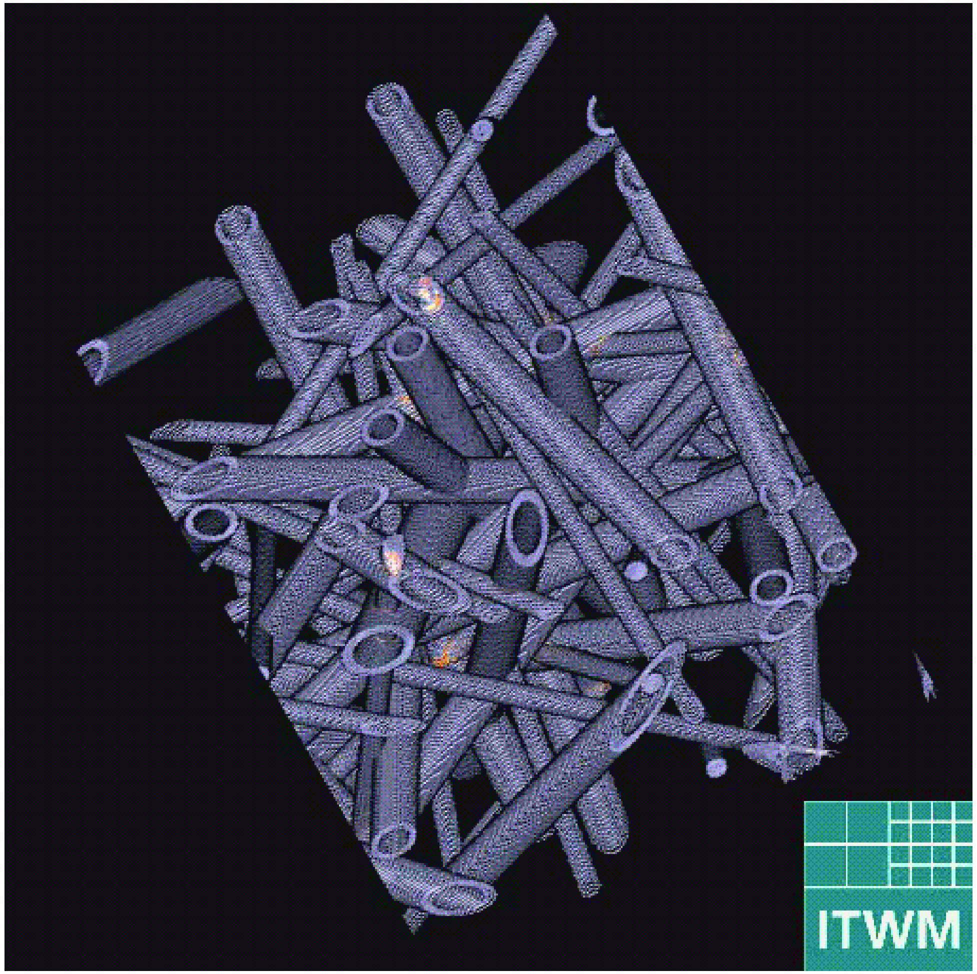
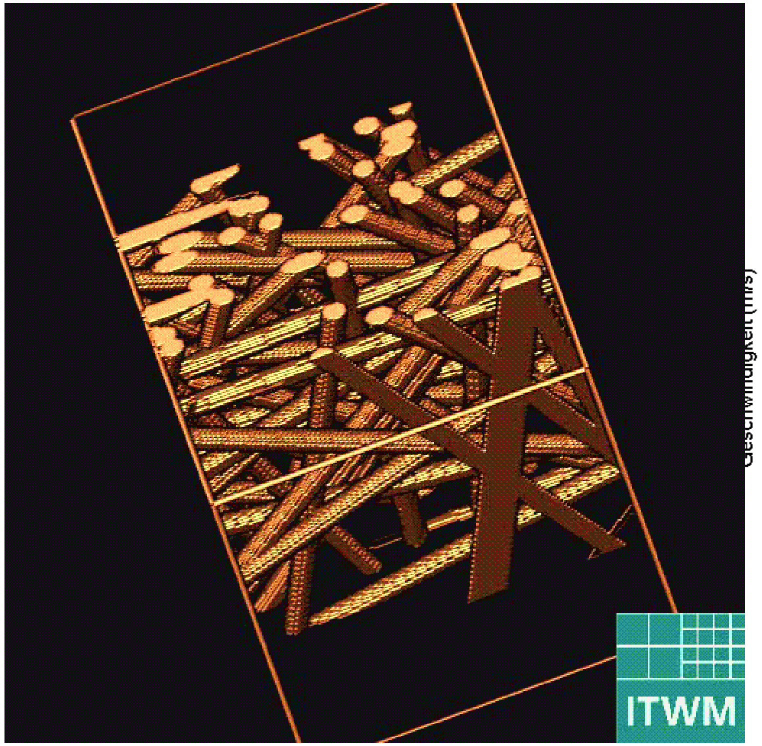
Real and Simulated Data

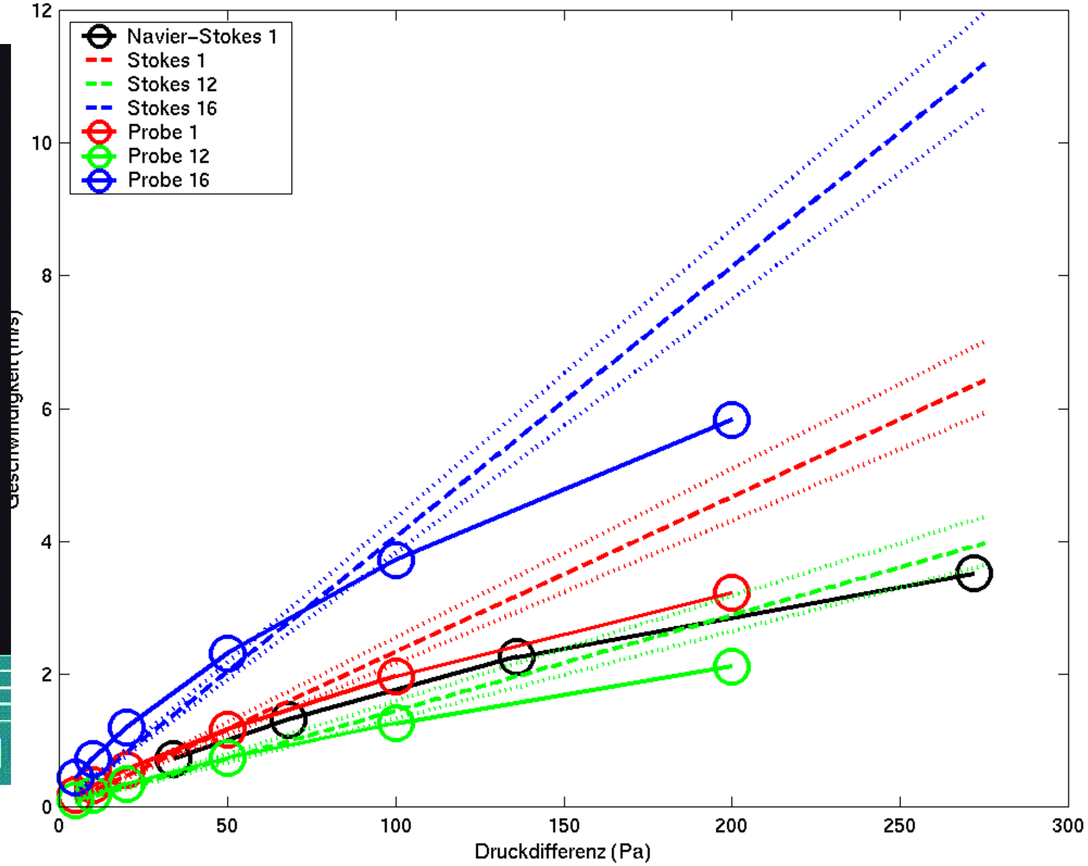




Simulations and analysis can be performed on real and simulated data.

Flow Solver Validation: Navier-Stokes





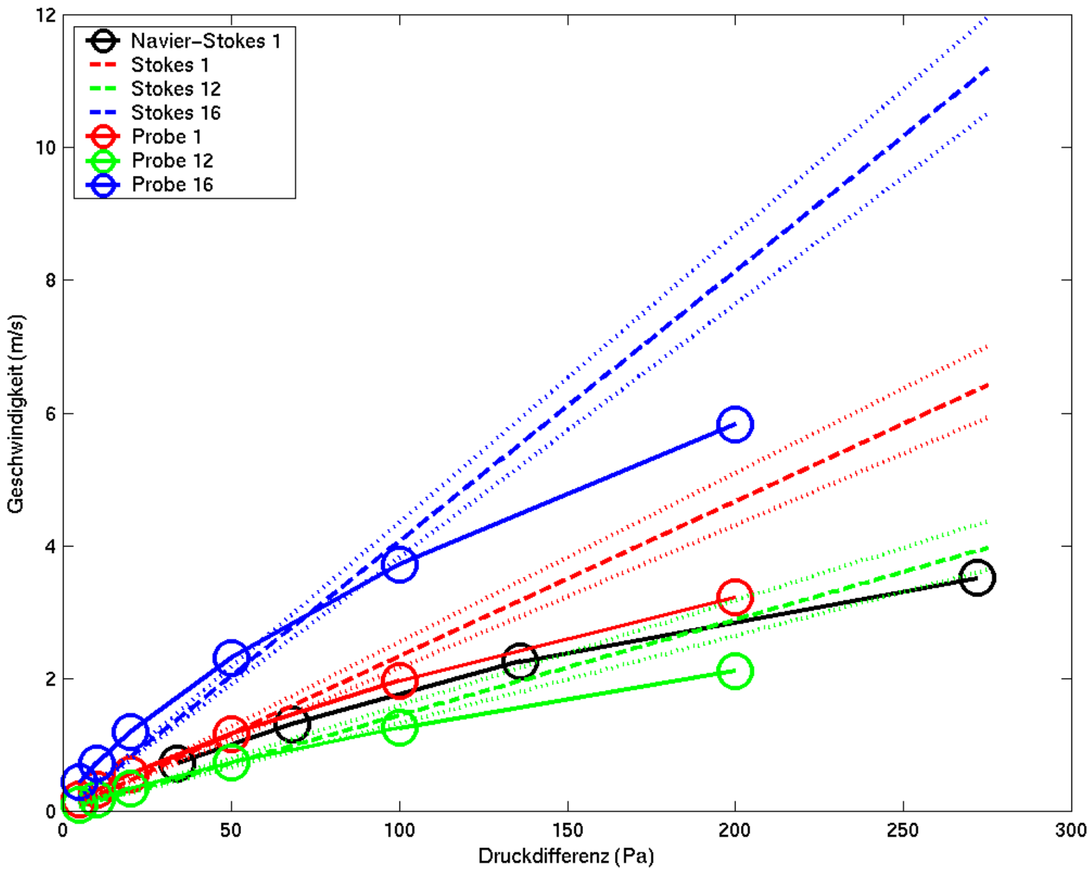
Validation: Stokes vs. Navier-Stokes

The plot shows pressure difference vs. mean flow velocity for three samples of 75g (blue), 100g(red) and 122g(blue) per m².

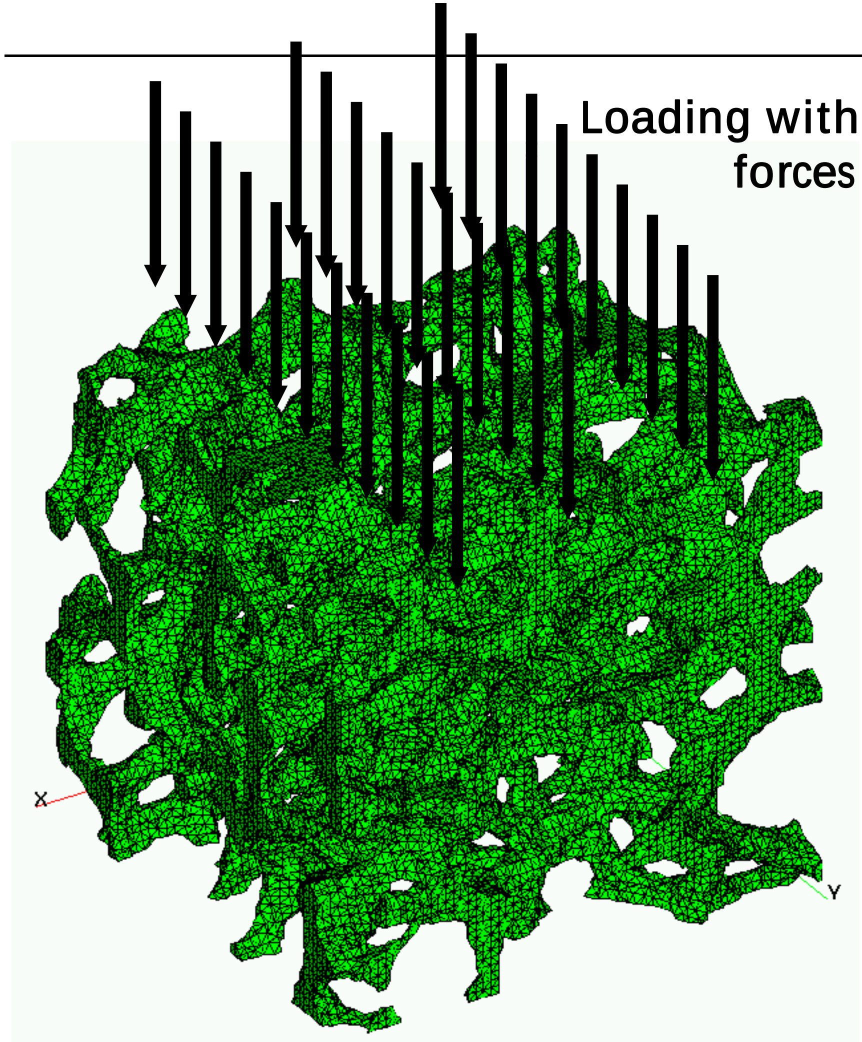
Full curves are measured (6 data pairs per sample), dashed lines show result of Stokes calculations with standard deviation under variation of the simulated sample (qualitative behavior is correct for density variation of the samples).

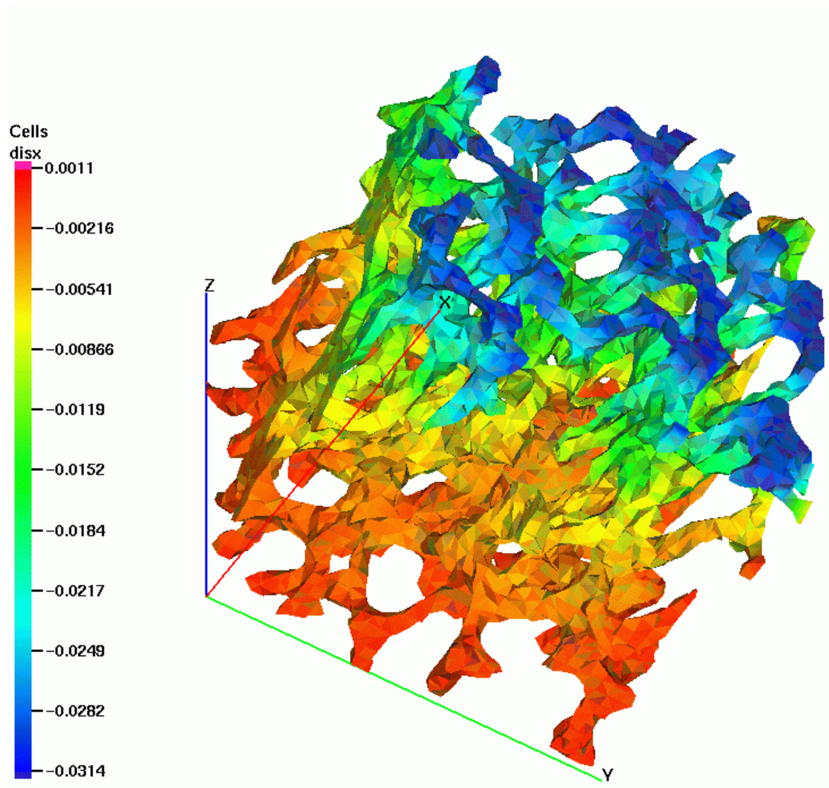
The full black curve shows results of Navier Stokes simulation for 100g per m² sample agrees extremely well with red curve, as it should.

Measurements were unknown when simulations were performed.



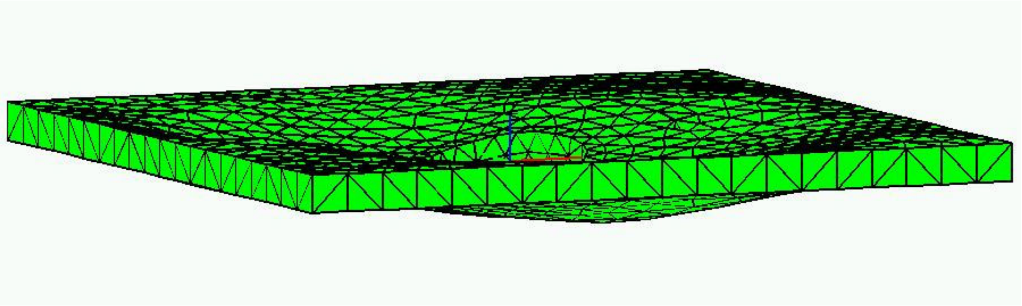
Elasticity Solver: Effective Properties of a Foam

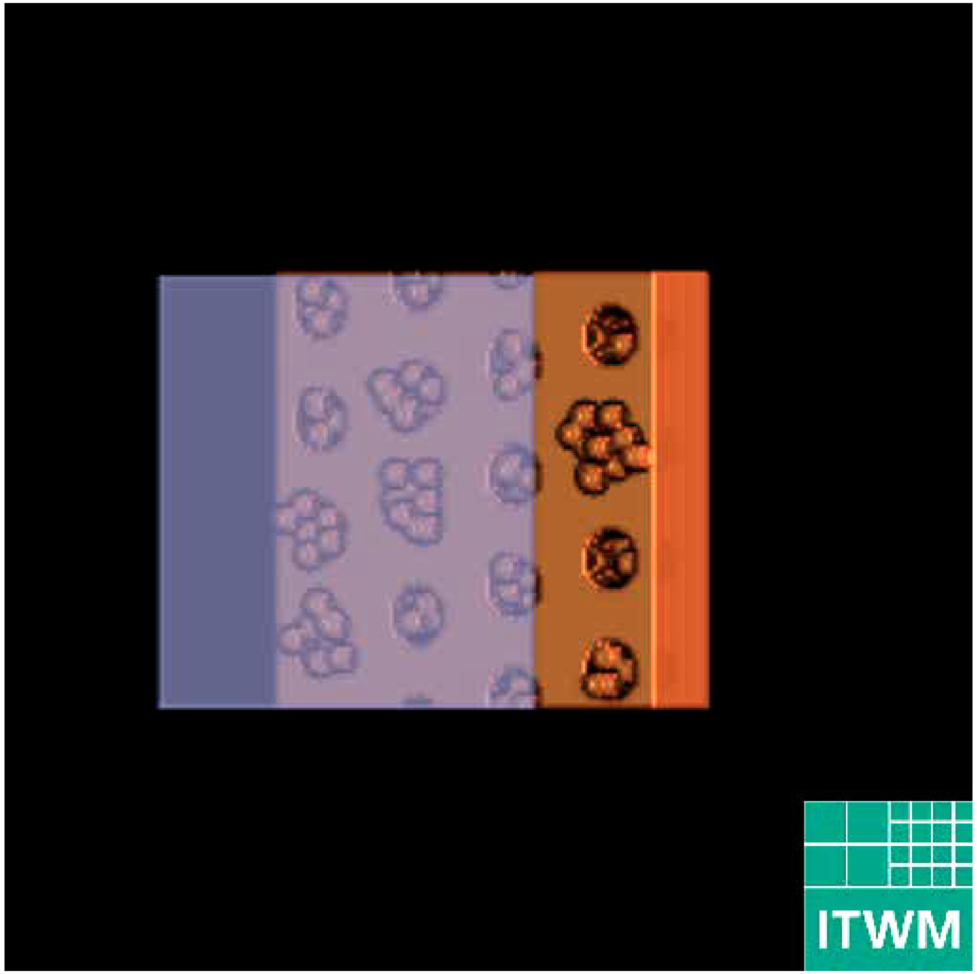




Calculation of displacements and effective elastic tensor (Young modulus, Poisson ratio)

Coupling of flow and elasticity solvers





Mechanisms of Filtration

Knowing the flow field and

the particle fiber

interaction, the filter

efficiency can be predicted.

Particle impact by:

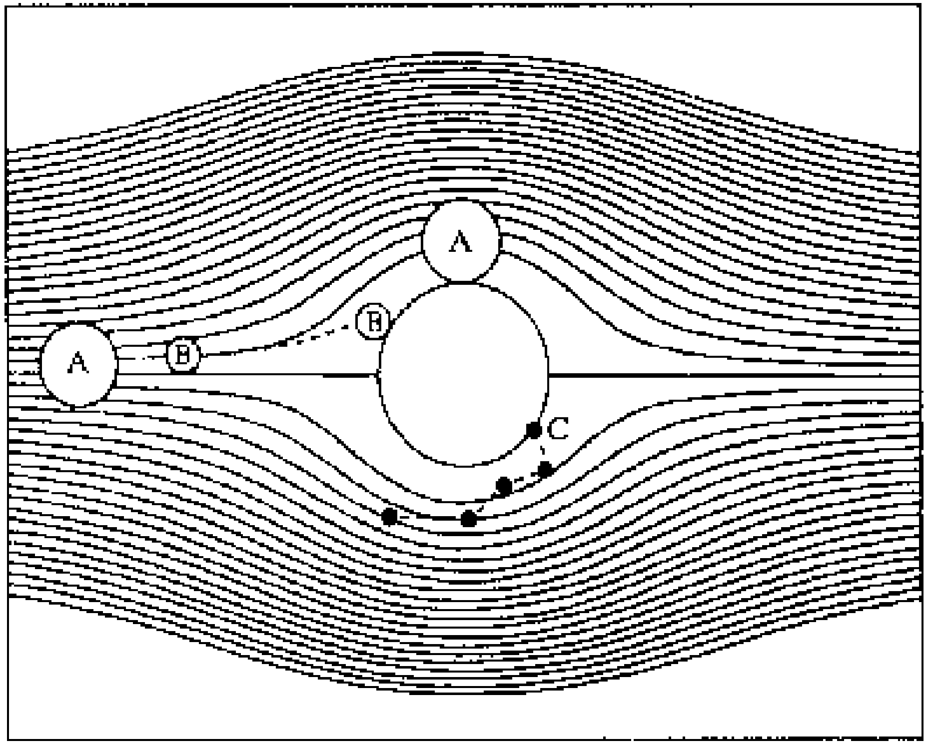
A: direct interception

B: inertial impaction

C: diffusional deposition

D: other effects (gravity,...)

E: Multiple fiber interception



Methods for the Simulation of Filtration Properties

- Geometry generated stochastically or from tomography
- Flow field from solving the (Navier-) Stokes equations
- Stochastic differential equation for particle motion in a flow
- Particle fiber interaction

Lagrangian Description of Particle Motion in Complex Environments

Equation of motion: $$\frac{d\vec{r}}{dt} = \vec{u}$$

$$d\vec{u} = -\gamma(R_P) \times (\vec{u} - \vec{v}(\vec{r}(t))dt + \sigma \times d\vec{W}(t)$$

$$\gamma(R_P): \text{ friction coefficient}$$

$$d\vec{W}(t): 3\text{-dimensional Wiener process}$$

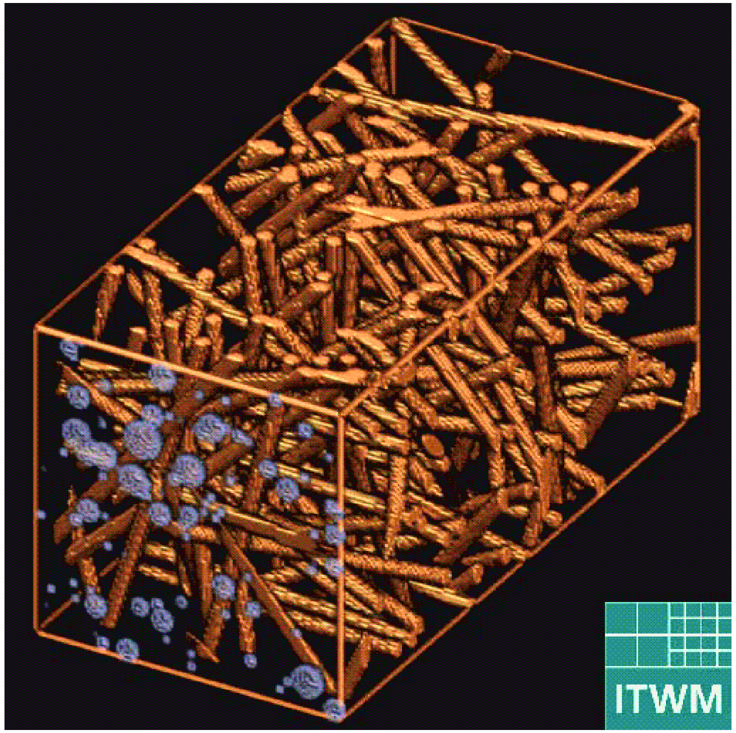
$$\langle d\vec{W}(t) \times d\vec{W}(t) \rangle = dt$$

$$\sigma = 2k_B T/(m_P * \gamma): \text{ Fluctuation Dissipation Theorem}$$

Particle – Fiber Collisions (Boundary Conditions)

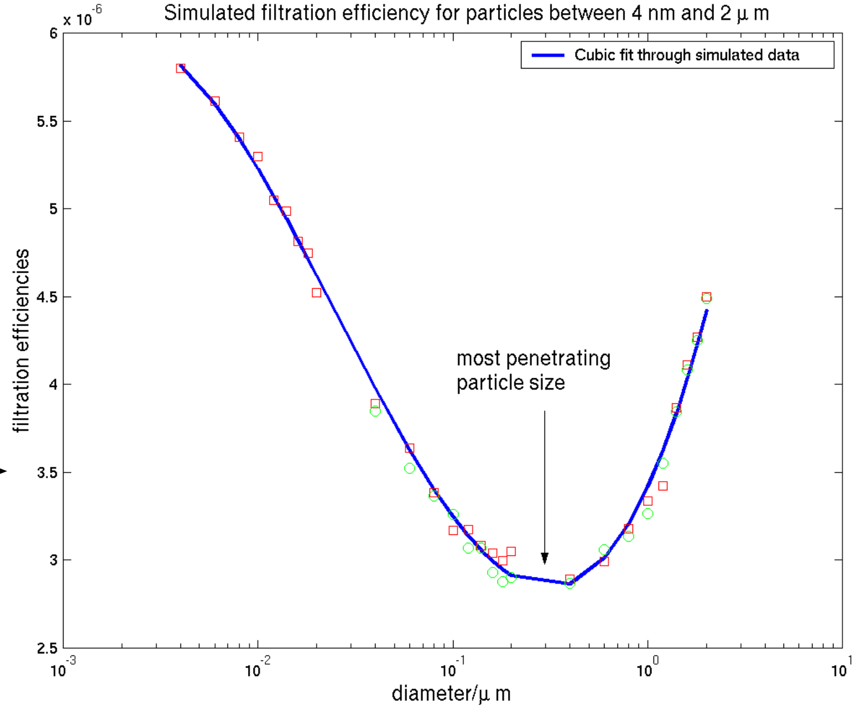
- Particles loose momentum and energy at collision
- Particles can bounce if adhesion force is overcome
- Many fiber interactions are taken into account (sieving)
- Soot models
- ... (other effects could be modelled)

Filtration Efficiency, Filter Loading and Most Penetrating Particle Size



From Structure

To Function



Particle – flow – fiber interaction

Filtration efficiencies, filter loading...

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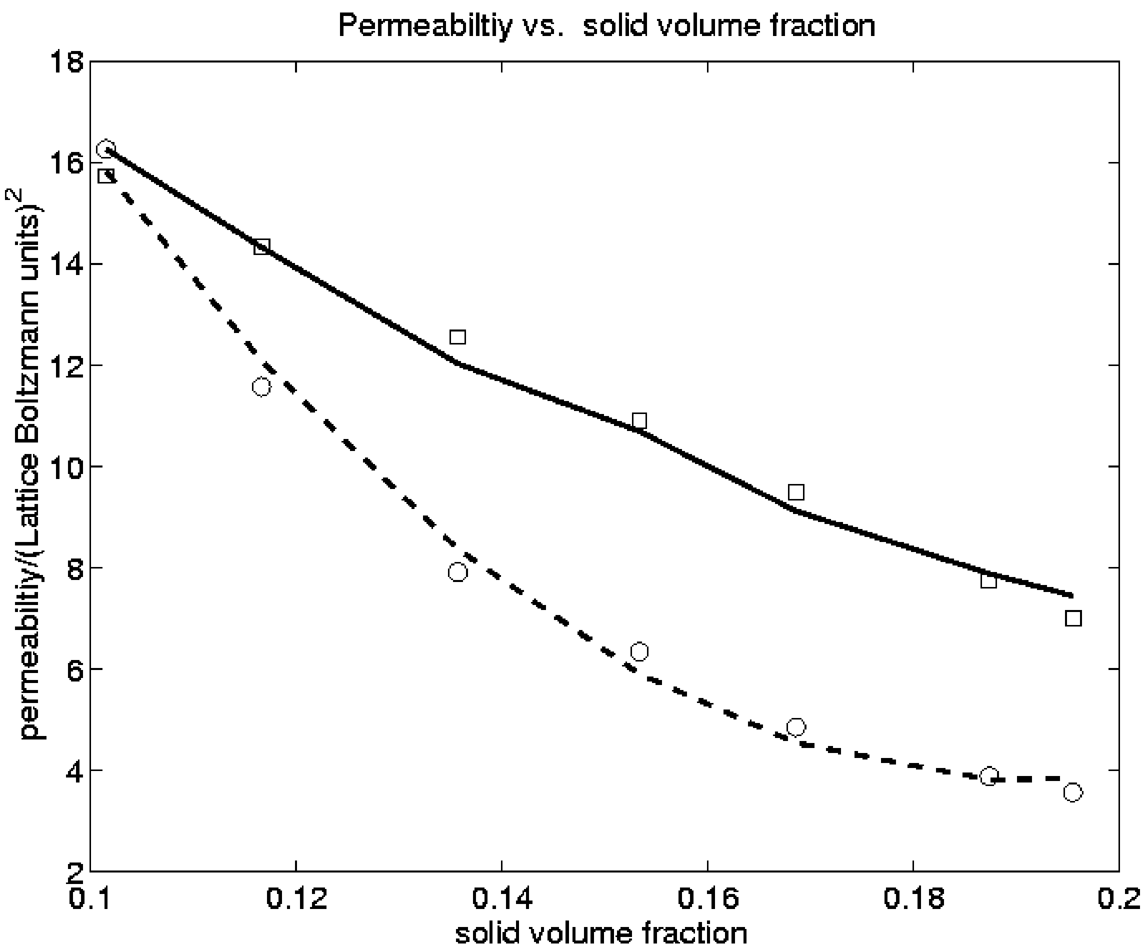
Filter Clogging

Particle radius	Rp=6
Fiber radius	R=4
SVF_empty	10%
SVF_clogged	19%

Permeability Decrease during Clogging



Solid line: decrease of overall permeability

Dashed line: decrease of clogged layer permeability

Summary

Algorithms calculate:

- Particle filtration efficiency
- Most penetrating particle size
- Distribution of captured particles in the microstructure
- Clogging dynamics

Dependent on

- Particle size
- Fluid fiber interaction
- Fluid properties (viscosity, temperature)
- Media solid volume fraction
- Fiber anisotropy
- Geometric fiber properties

Virtual material design of filter media will be done