Simulation of Ceramic DPF Media, Soot Deposition and Pressure Drop Evolution Using GeoDict

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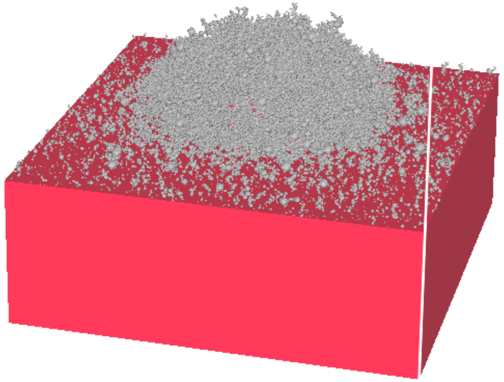

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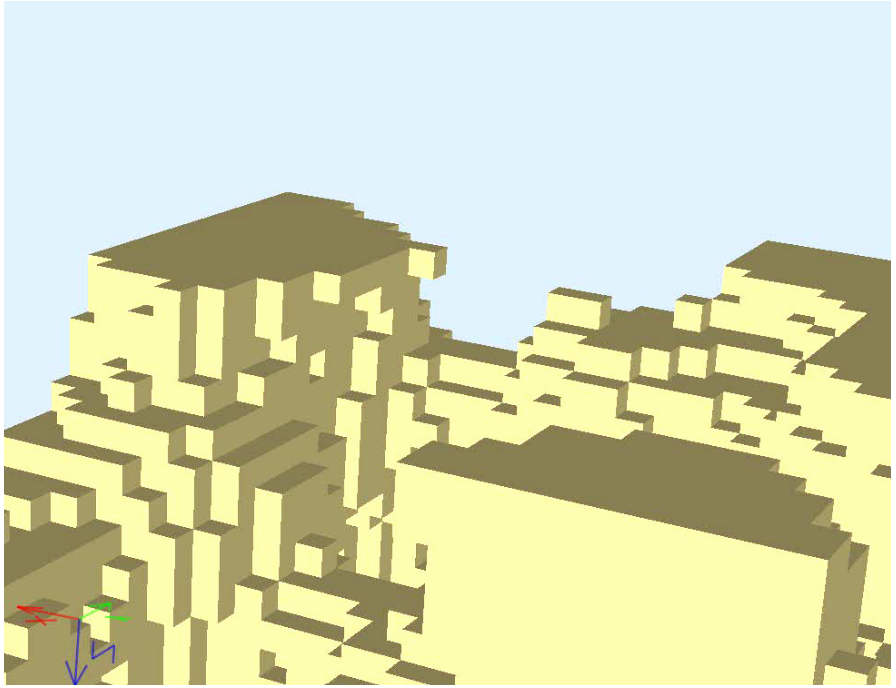
Outline

1. Virtual Structure Generation of DPFs
   - Fibrous Structures
   - Sinter Materials
2. Simulation of DPF Properties
   - Modeling and Simulation Approach
   - Example 1: Design Study of DPF Filters
   - Example 2: Micro Sieves
3. Summary

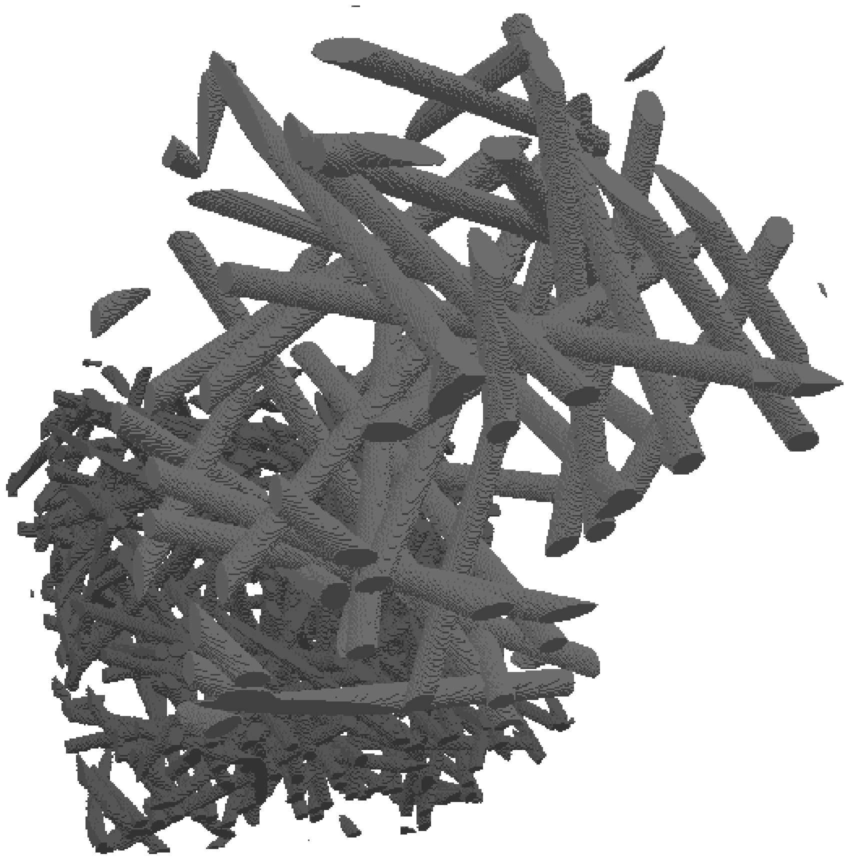


1. Virtual Structure Generation of DPFs

GEO DICT

Multilayer Virtual Fibrous Structure

- Stochastic generation of the structure with guaranteed adjustable properties, e.g.
  - Distribution of fiber diameters and cross sections
  - Fiber orientation
  - Porosity
  - Layer thickness
  - ...
- Stacking of layers with different parameters
- Use of highly flexible voxel meshes

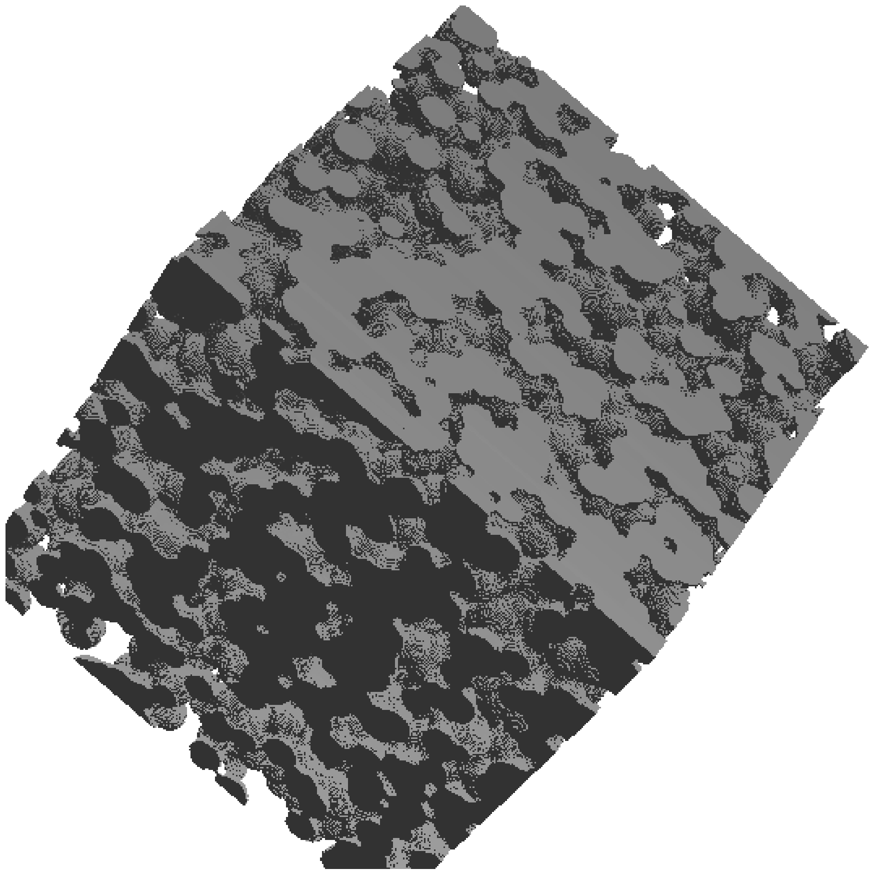


1. Virtual Structure Generation of DPFs

GeoDict

Virtual Sinter Structure

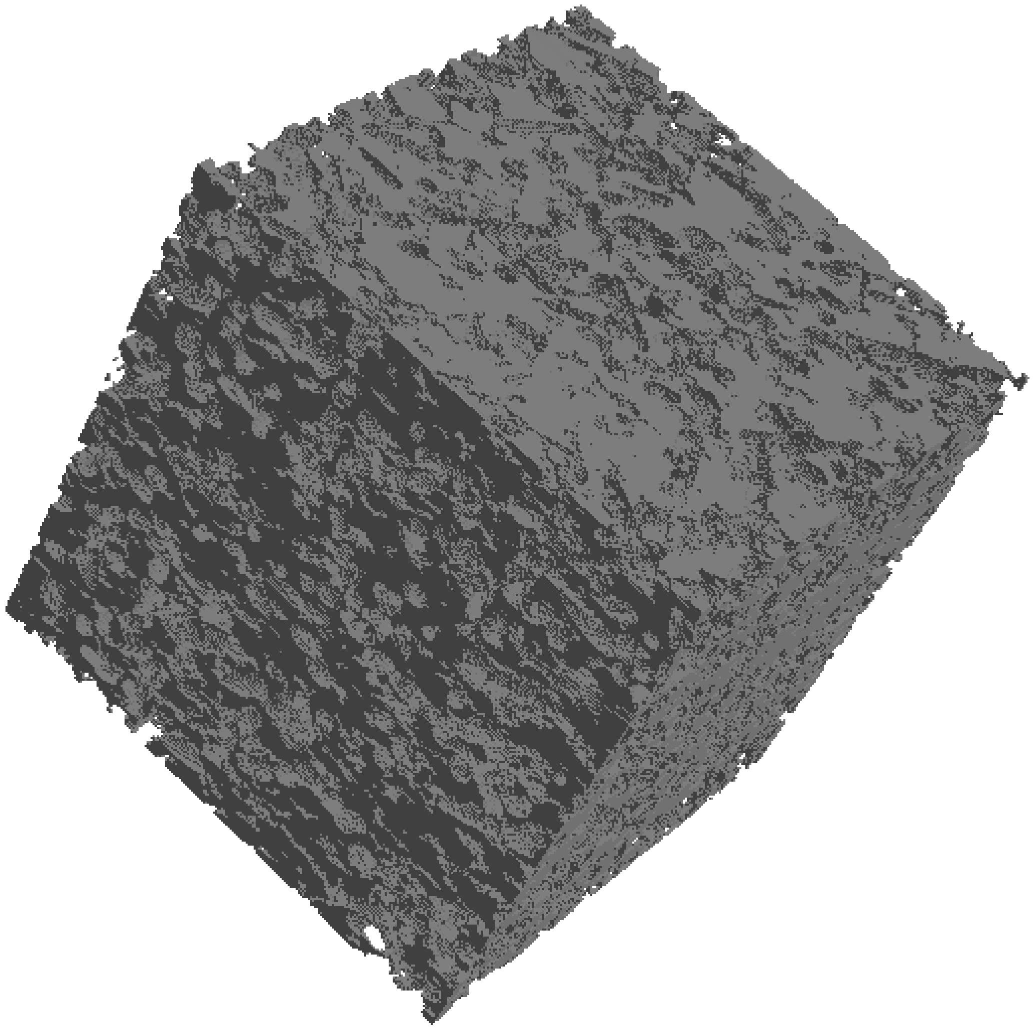
- Stochastic generation based on
  - Packings of spheres
  - Morphological operations (to generate sinter necks)
- Packings of spheres selected to match the initial grain size distribution of the sinter process
- Approach was applied in an industrial project when no tomographies were available due to
  - Difficult preprocessing of samples
  - Too coarse resolution



1. Virtual Structure Generation of DPFs

SEM image

Virtual Reconstruction



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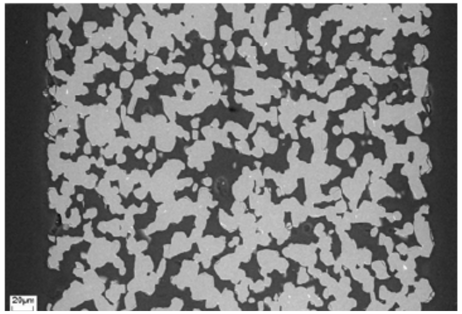
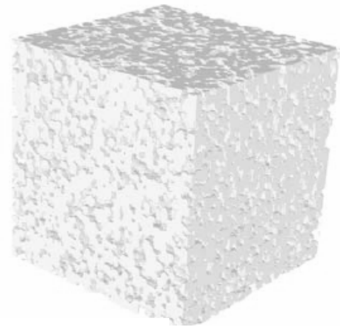
1. Virtual Structure Generation of DPFs

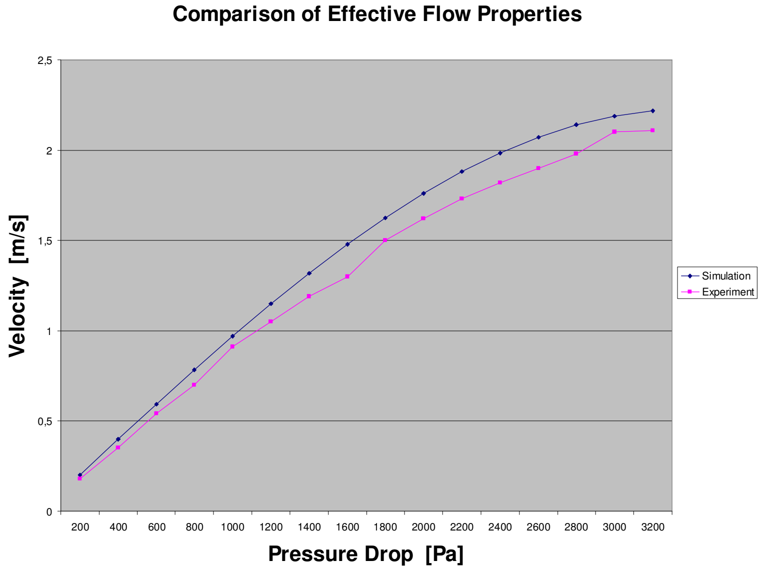
GEO DICT

Quality Measures for Virtual Structures

- "The Eye"
- Porosity, specific surface area
- Chord length distribution
- Pore size analysis
- Flow properties, e.g. effective permeability or flow resistivity
- Bubble point, capillary pressure curves
- Filtration properties
- Acoustic properties







GEO DICT

2. Simulation of DPF Properties

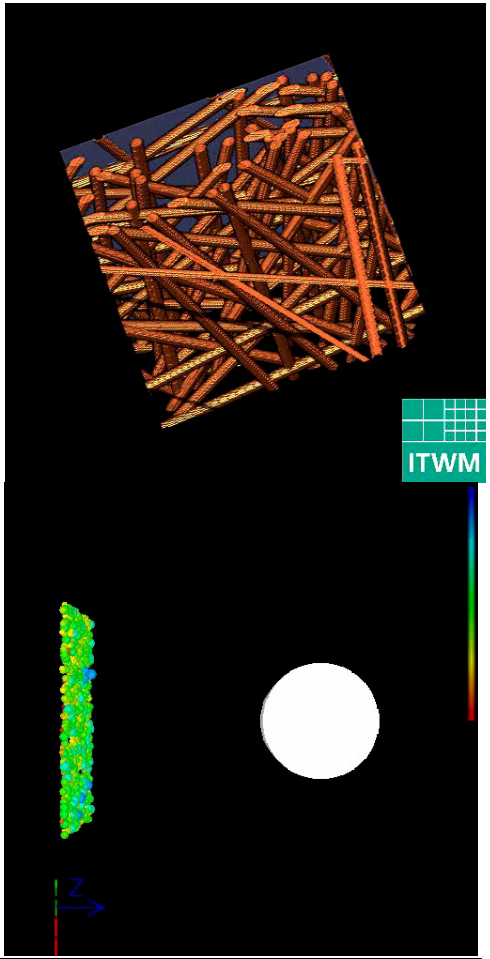
Simulation of Filtration Processes

OPTIMIZATION

1. Choose initial structural parameters
2. Generate / modify structure
3. Solve CFD problem
4. Compute particle transport and deposition
5. Compute filtration efficiency and pressure drop
6. Choose new material parameters

LIFETIME

Flow



Single Fiber Simulation

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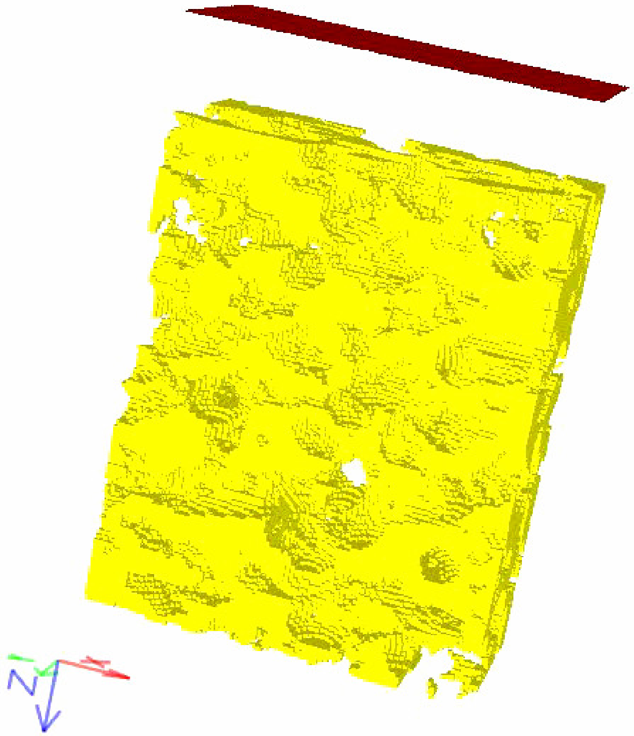
2. Simulation of DPF Properties



Flow simulation is based on Navier-Stokes-Brinkmann equations

$$\begin{aligned} -\mu\Delta\vec{u} + \nabla\vec{u}\cdot\vec{u} + \kappa^{-1}\vec{u} + \nabla p &= \vec{\mathbf{f}}, \qquad \text{(momentum balance)} \\ \nabla\cdot\vec{u} &= 0, \qquad \text{(continuity)} \end{aligned}$$

$+$ boundary conditions,

- $\vec{u}$: velocity
- p : pressure
- $\vec{\mathbf{f}}$: force (density)
- μ : fluid viscosity
- κ : permeability of porous voxel

Remark

- convective term optional -> fast flow
- Brinkmann term optional -> subgrid particle deposition and effective porous media

2. Simulation of DPF Properties

Lagrangian Particle Transport

$$\frac{d\vec{x}}{dt} = \vec{v}$$
$$\frac{d\vec{v}}{dt} = -\gamma\left(\vec{v}(\vec{x}) - \vec{u}(\vec{x})\right) + \frac{Q\vec{E}_{\circ}(\vec{x})}{m} + \sigma\frac{d\vec{W}(t)}{dt}$$

Particle Deposition

- Collision handling
- Adhesion model

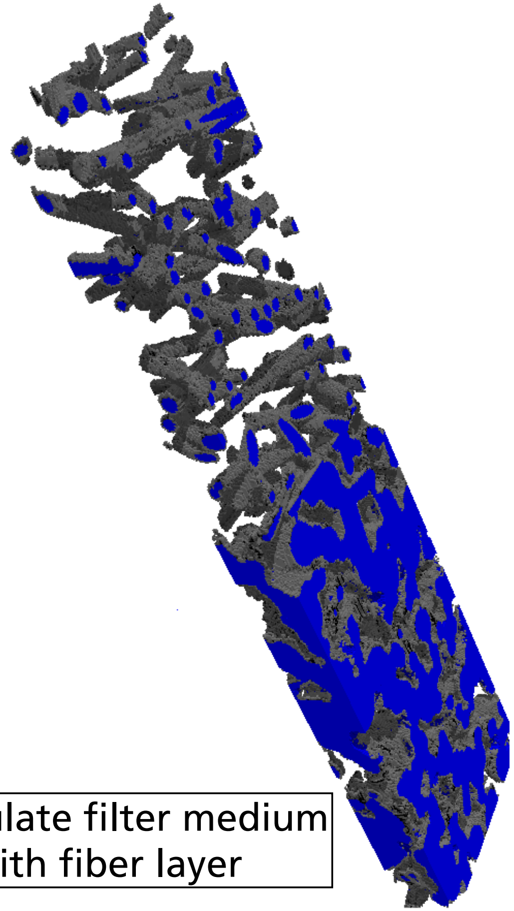
Modification of Geometry

- Solid deposition model (particles resolved by voxels)
- Porous deposition model -> small particles are handled as porous media
- Porous deposition model + subvoxel collision handling

2. Simulation of DPF Properties

Design Study of a Diesel Particulate Filter

- What is the effect of an additional fibrous layer on top of a sintered substrate ?
- Soot particles (~80nm) are much smaller than voxels (1µm) -> porous deposition model
- Navier-Stokes-Brinkmann model to handle free and porous flow
- Permeability and maximum degree of filling of porous voxels are determined by high resolution single fiber experiments
- Several hundreds of millions of particles are needed for a lifetime computation

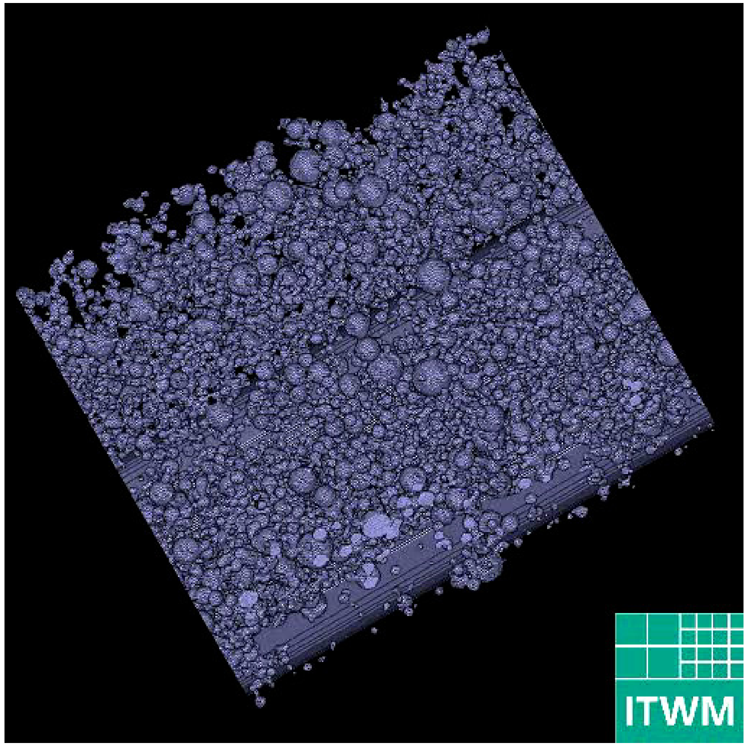


Particulate filter medium with fiber layer

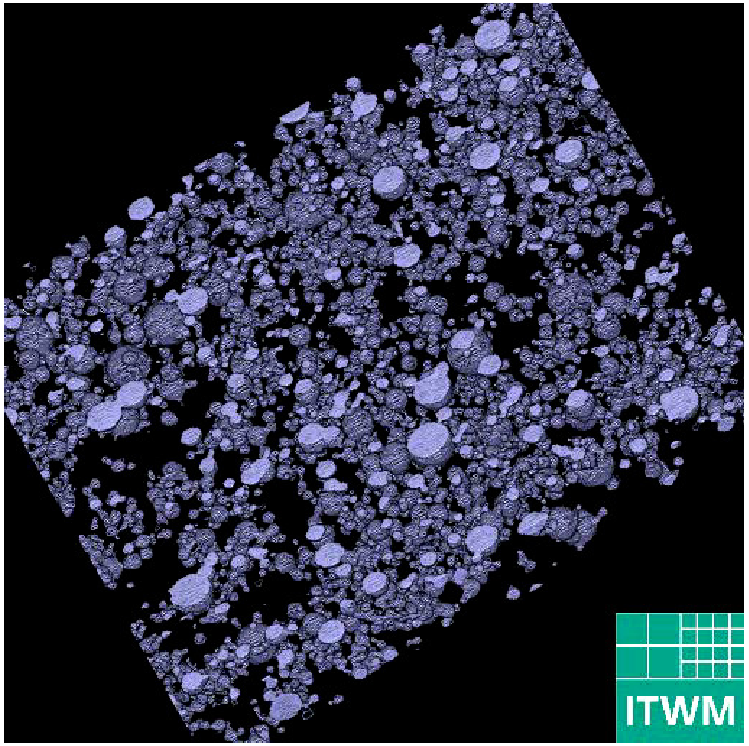
2. Simulation of DPF Properties

GeoDict

High Resolution Single Fiber Simulation



Cut-Out of Soot Layer



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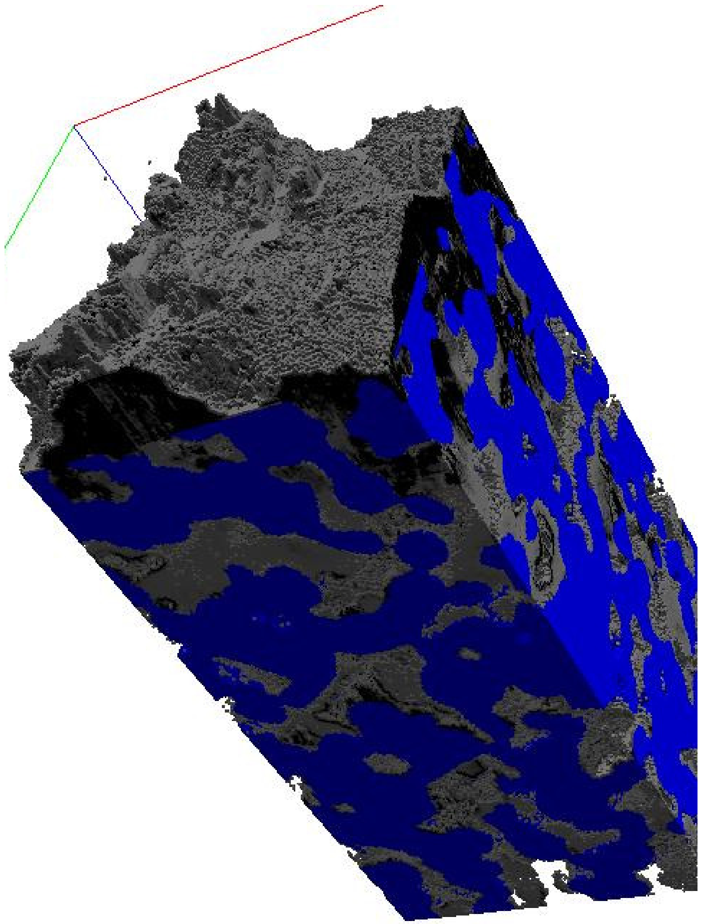
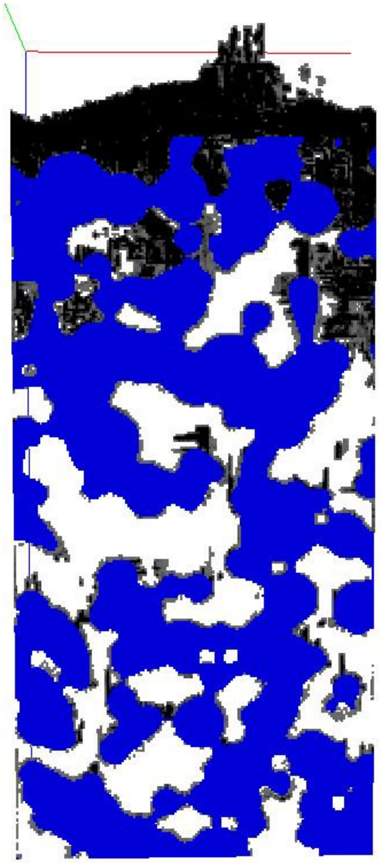
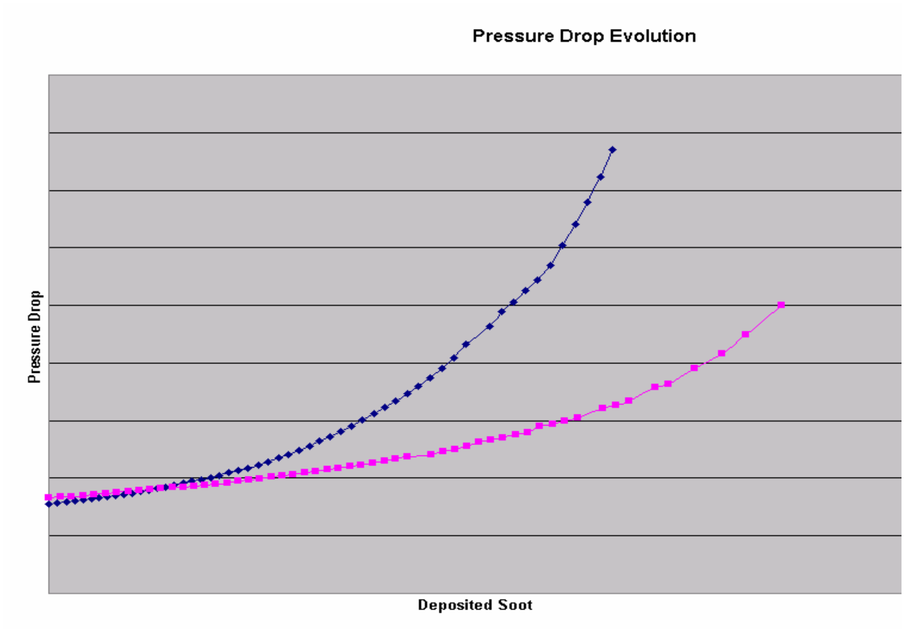
2. Simulation of DPF Properties





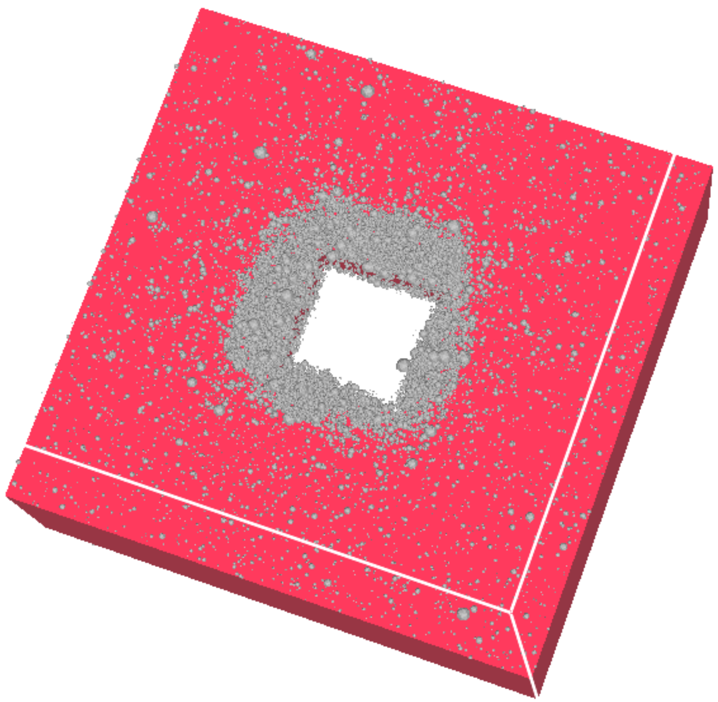


2. Simulation of DPF Properties

GEO DICT

Micro Sieves – Study of Different Deposition Models

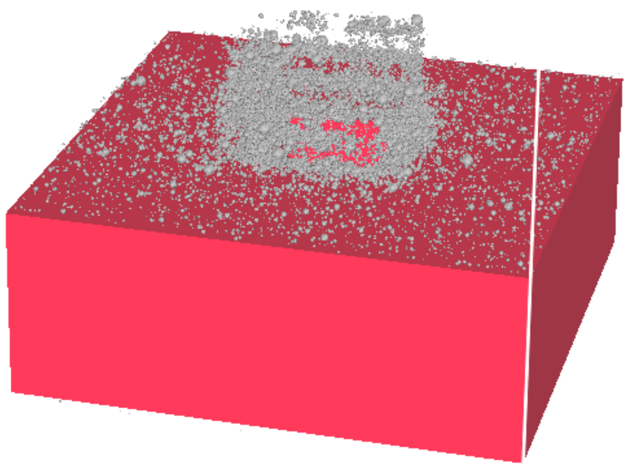
- 20 µm x 20 µm holes in periodic arrangement
- Soot particles (~80nm) are much smaller than voxels (1µm)
- Navier-Stokes-Brinkmann model to handle free and porous flow
- Comparison of porous voxel approach w/o subvoxel collision handling



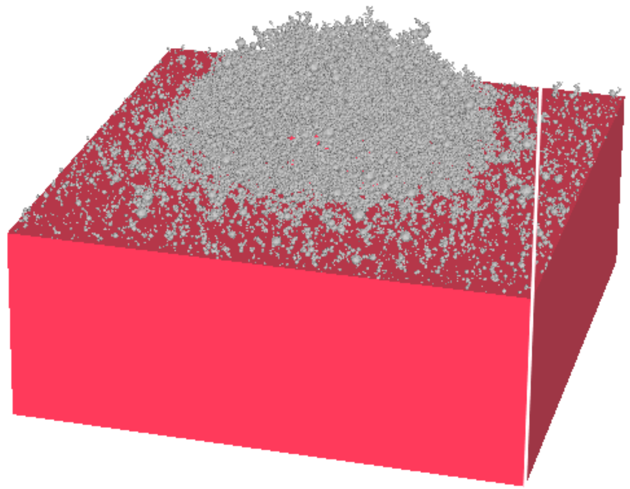
2. Simulation of DPF Properties

GeoDict

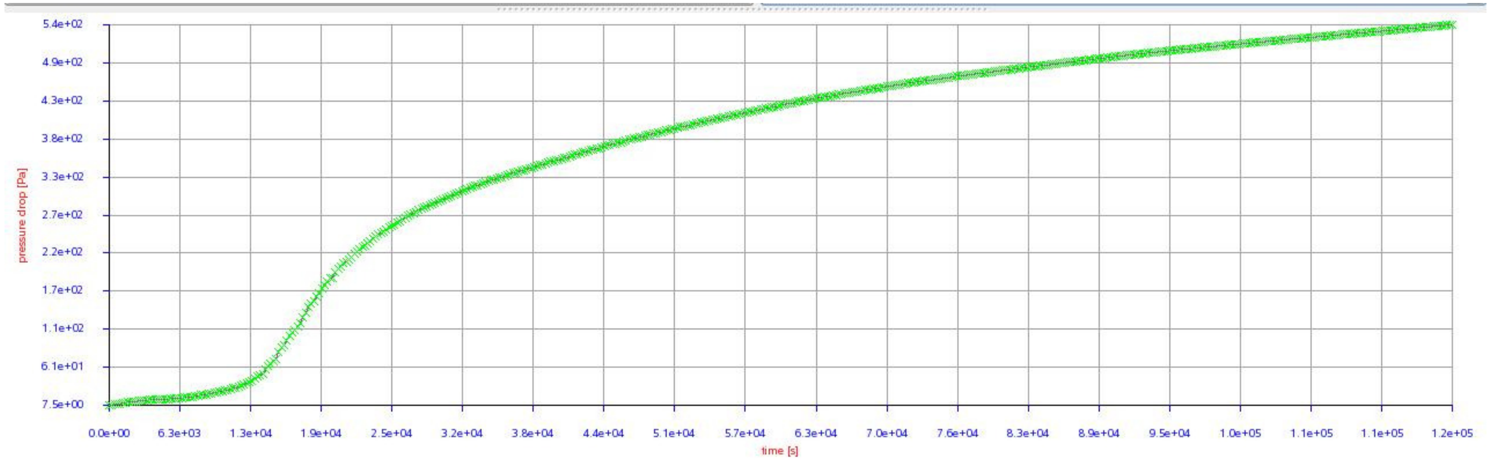
Porous Deposition Model



Porous Deposition Model with Subvoxel Collision Handling



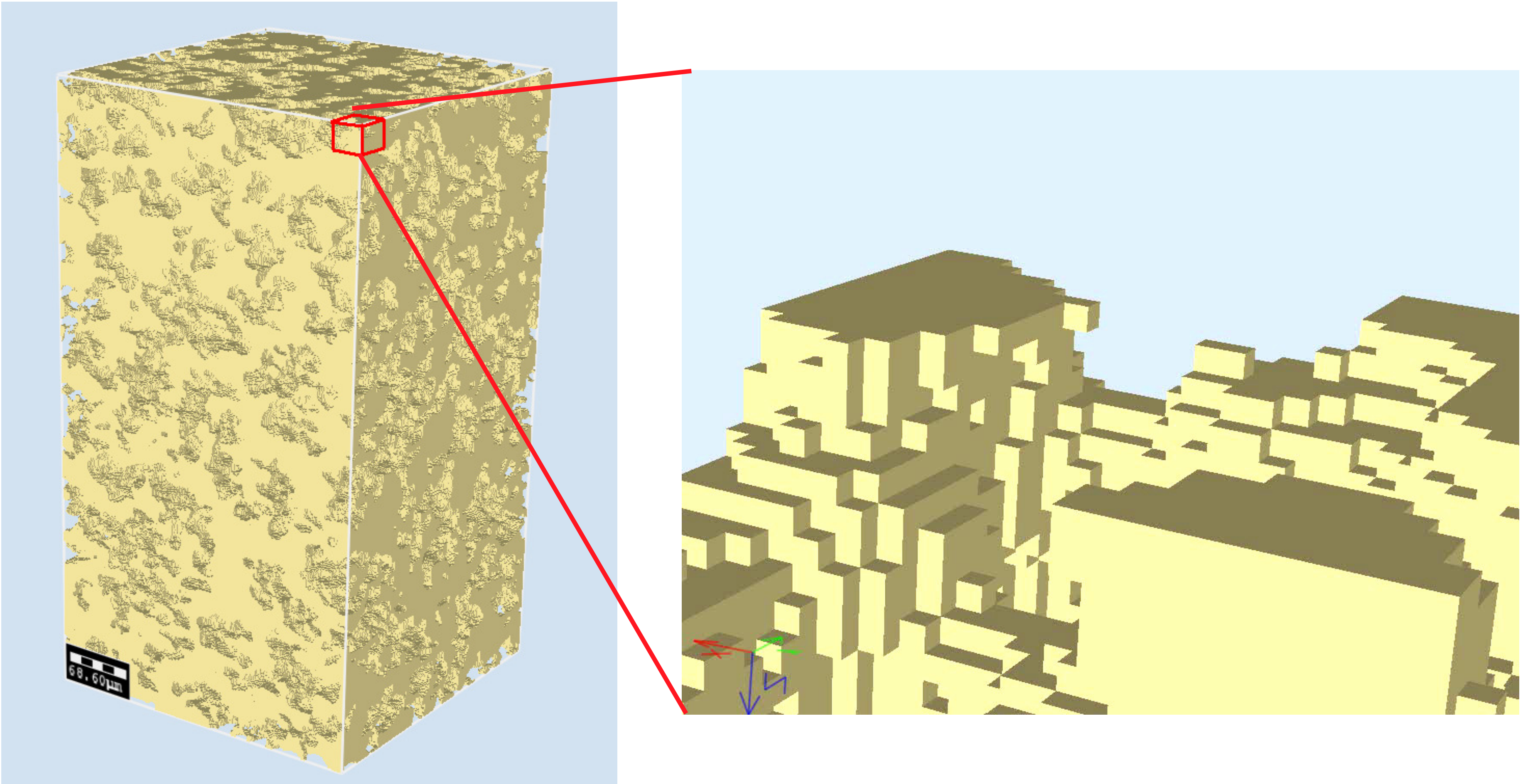
2. Simulation of DPF Properties



Backpressure Evolution

Filter Efficiency Evolution

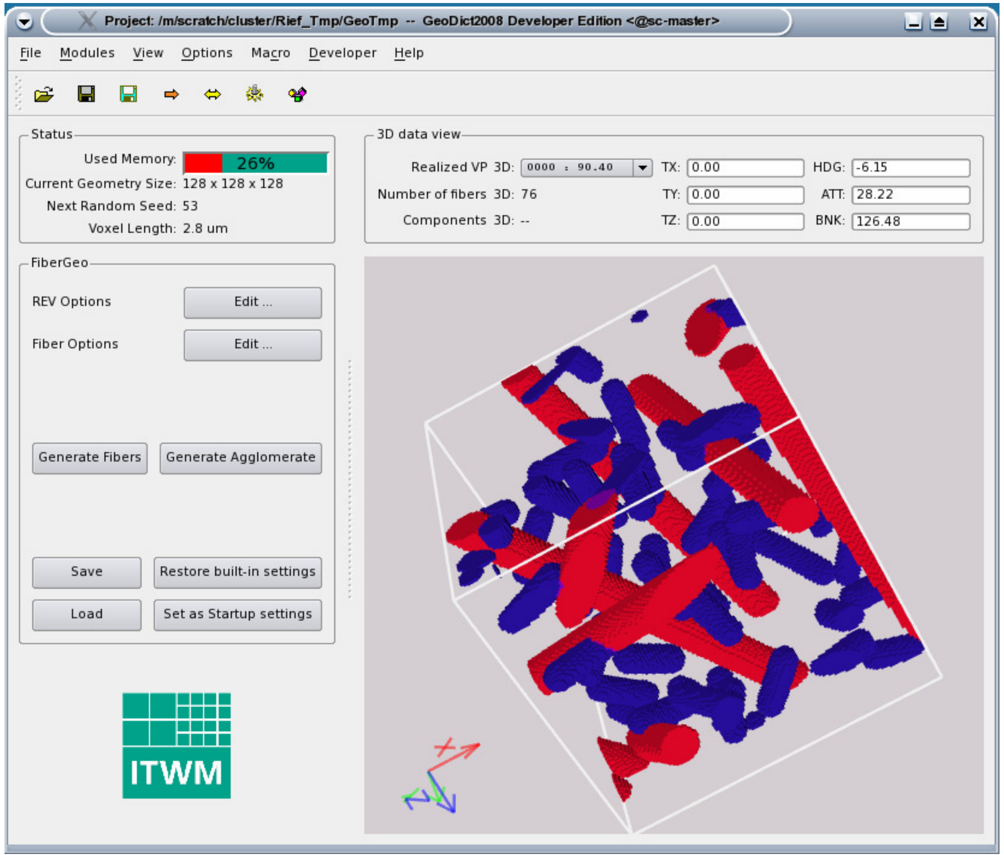
2. Simulation of DPF Properties



3. Summary (and more ...)

GeoDict

- FiberGeo, SinterGeo, WeaveGeo, GridGeo, PackGeo (Structure generation)
- ProcessGeo (3d image processing)
- LayerGeo (building media stacks)
- ImportGeo (Tomography, STL, etc.)
- PoroDict (Pore size analysis)
- FlowDict (Flow properties)
- FilterDict (Filtration)
- DiffuDict (Effective diffusion)
- SatuDict (Capillary pressure curves)
- ElastoDict (Effective elasticity)
- ThermoDict (Heat conductivity)
- ExportGeo (Fluent, Abaqus)
- AcoustoDict (acoustic absorption properties)



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GeoDict Development Teams

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GEO DICT

Software for Generation, Simulation, Visualization:

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www.geodict.com

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