15th FAD-Conference "Challenge- Exhaust Aftertreatment for Diesel Engines"
8.-9. November 2017, Dresden, Germany

Simulation of soot filtration in diesel particulate filter with GeoDict

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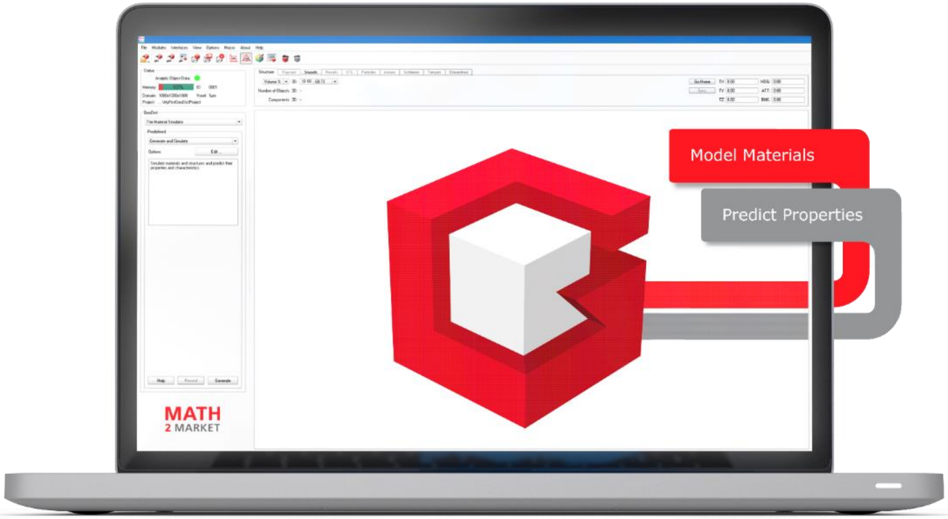
Math2Market GmbH,
Kaiserslautern, Germany



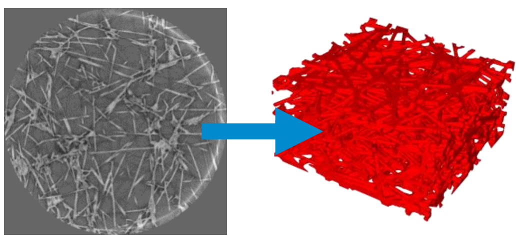
Math2Market GmbH promoted industries

Filtration	Filter media & filter elements for water, sludge, oil, air and fuel
Electrochemistry	Fuel cell media & battery materials, catalyst materials
Composites	CFRP, GFRP, mostly automotive, lightweight materials
Oil and Gas	Digital rock physics, digital sand control

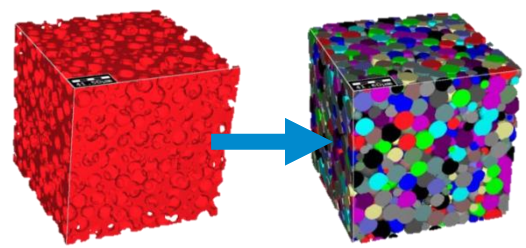
GeoDict introduction

With GeoDict you can...

µCT & FIB-SEM Import

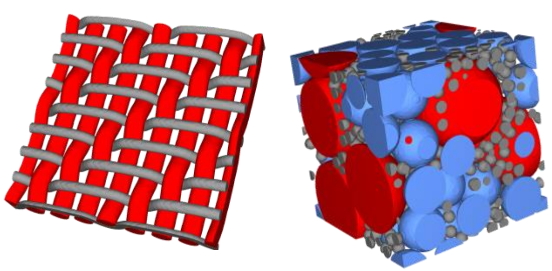


Analyse Materials

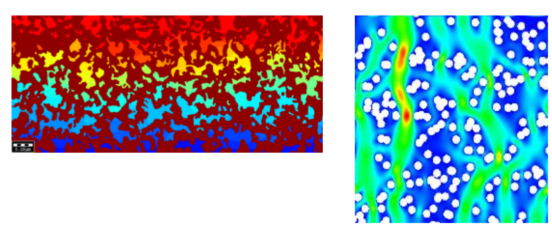


Optimize Materials

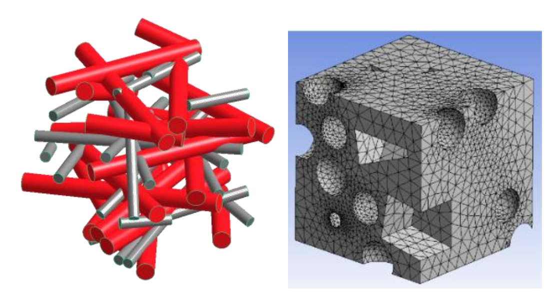
Model Materials



Analyse Properties

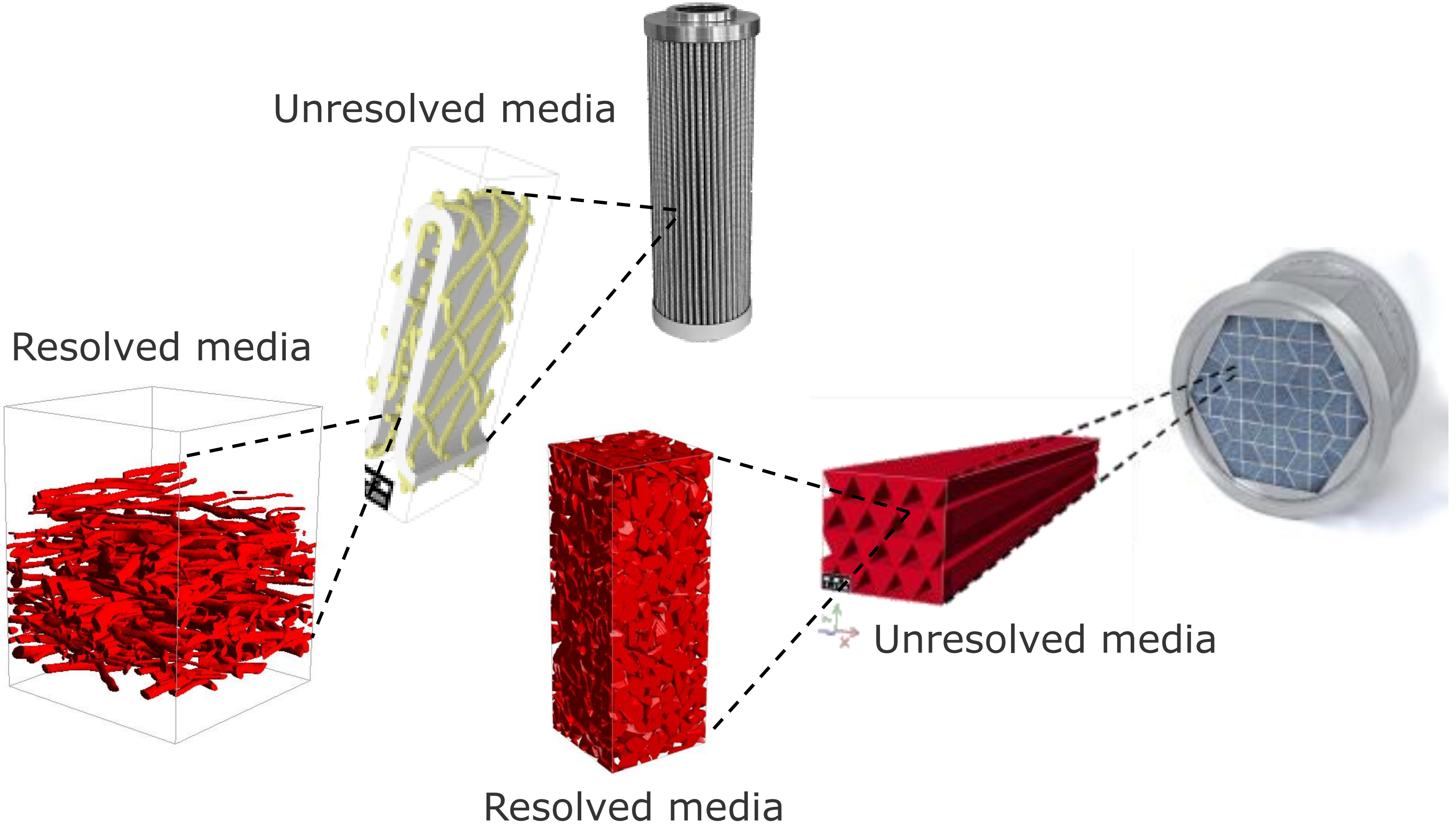


Export Materials

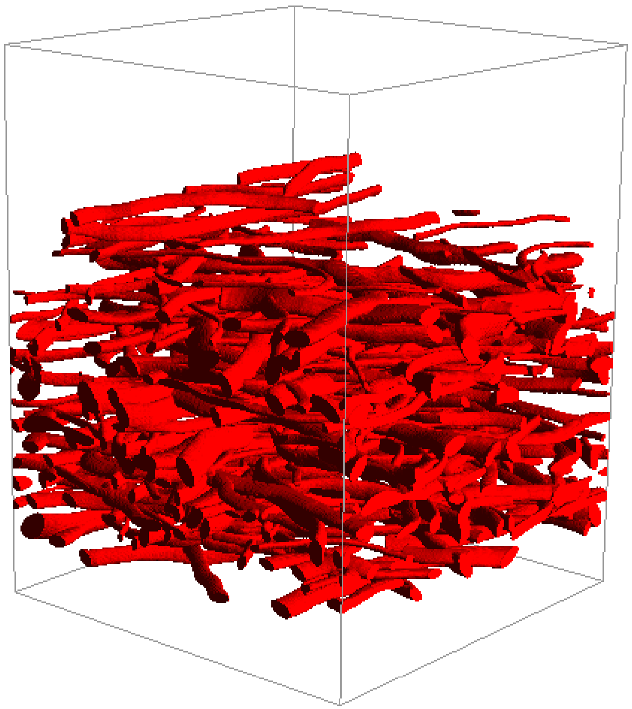


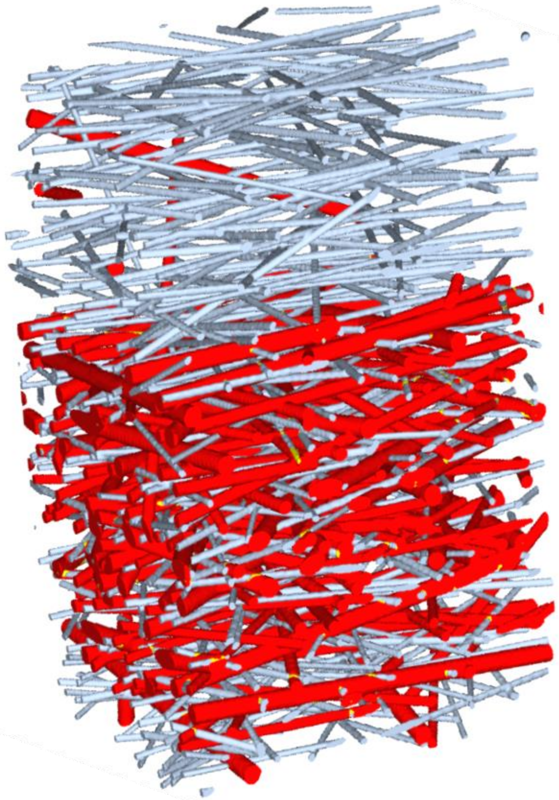
Media models, pleat models and filter models

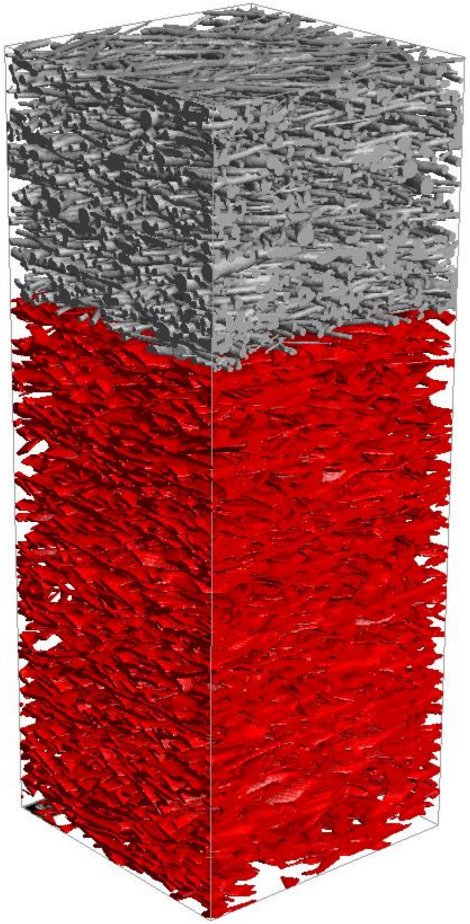
Simulate filtration at different scales



Create cellulose and layered media scale models



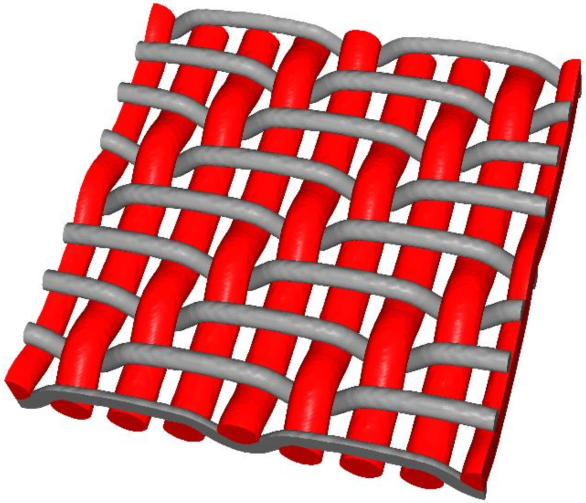


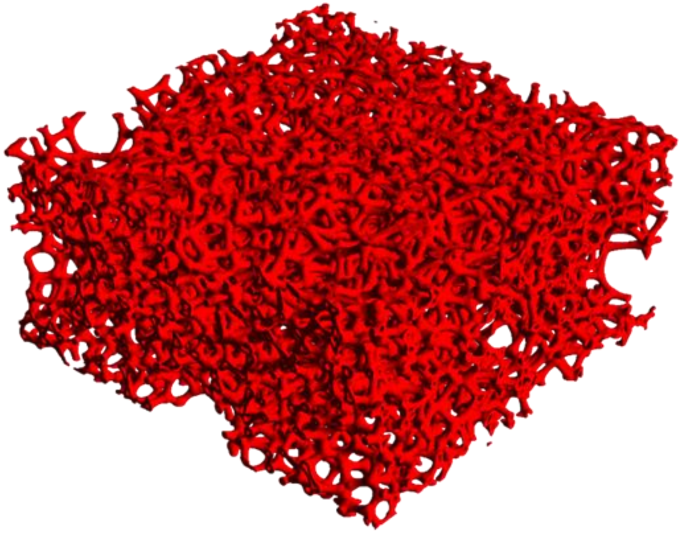


Cellulose nonwoven

Layered filter medium

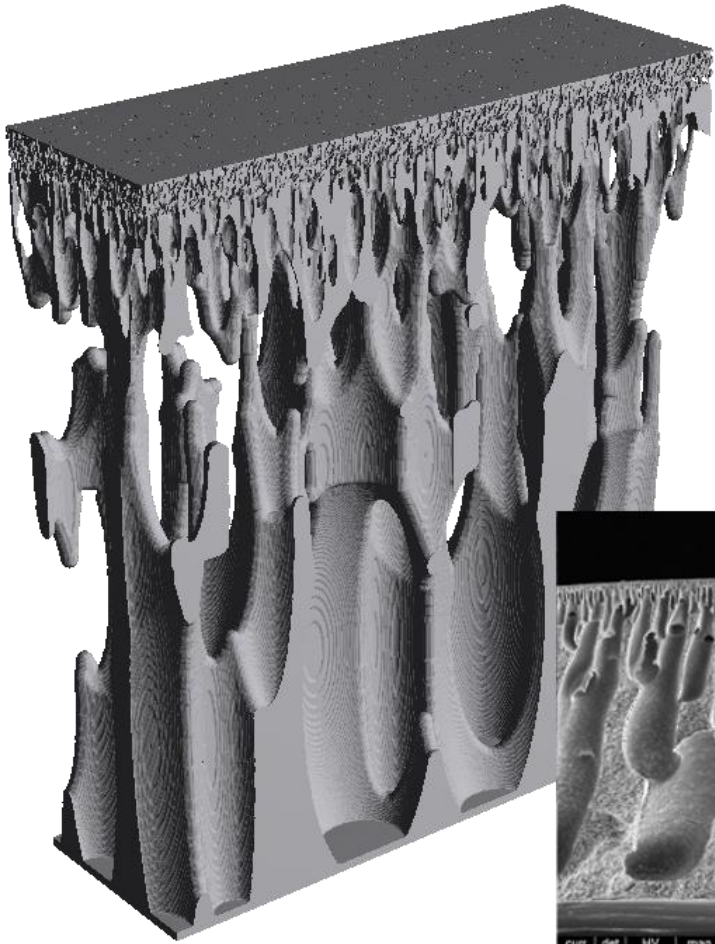
Create woven, foam and sintered media scale models

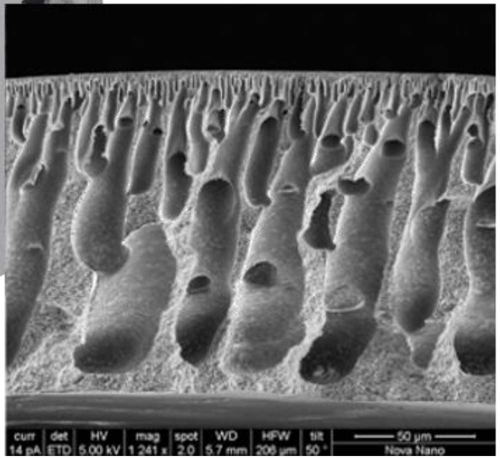




Metal wire mesh | Open-cell foam | Sintered ceramic

Model a desalination membrane from a SEM image





http://www.geodict.com/Showroom/structures.php

Modeling & simulation of soot filtration

Introduction to Diesel Particulate Filter (DPF)

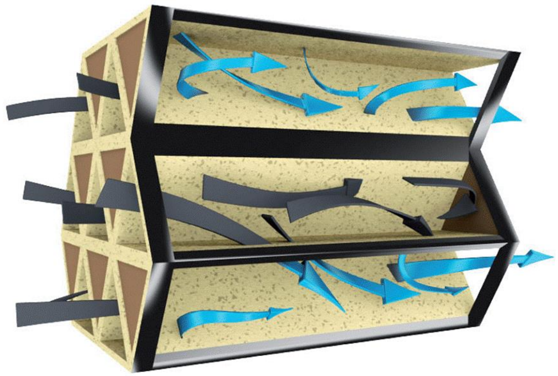
Goal:

Design & improve Diesel/Gasoline Particulate Filters (DPF/GPF) through fast simulations.

- lower pressure drop
- higher filter efficiency
- longer life time

Key element governing the performance of the DPF:

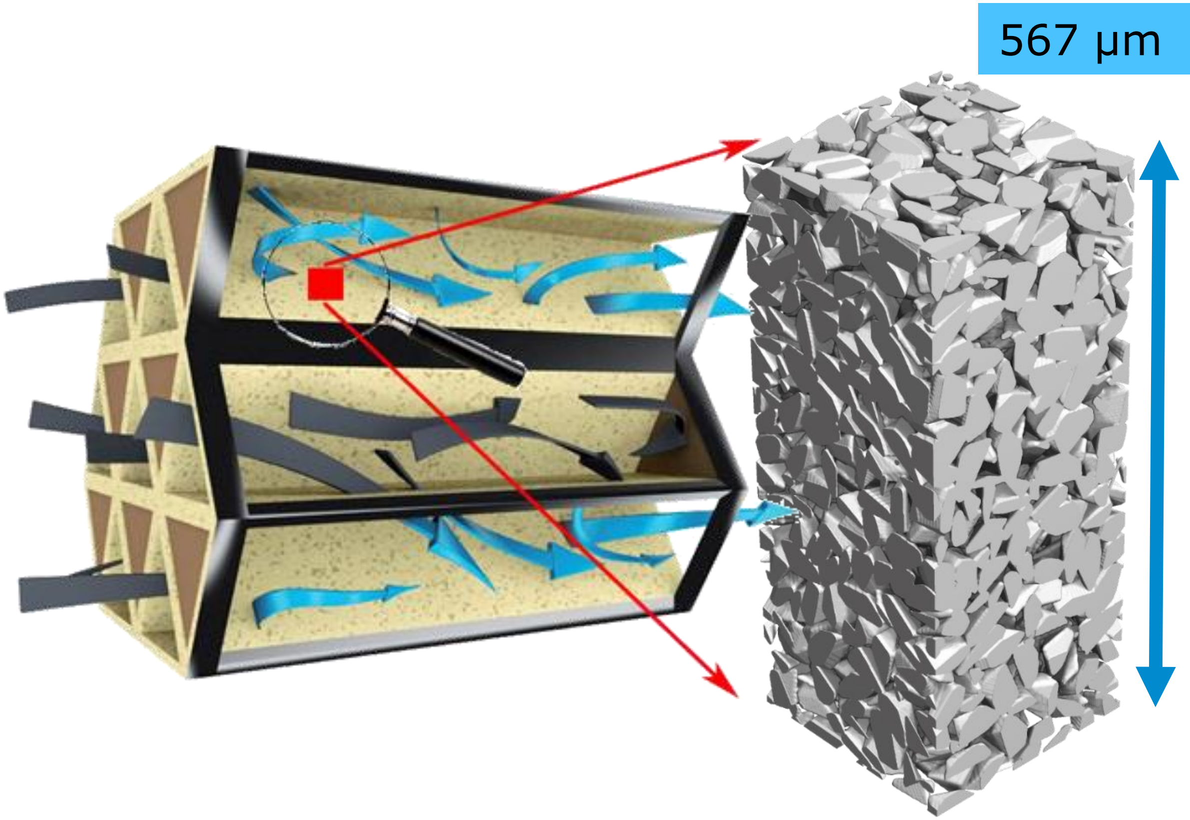
Ceramic filter media



Diesel Particulate Filter (DPF) simulations

Energy use of the DPF:

- Pressure loss across the (loaded) ceramic walls
- Pressure loss along the channels

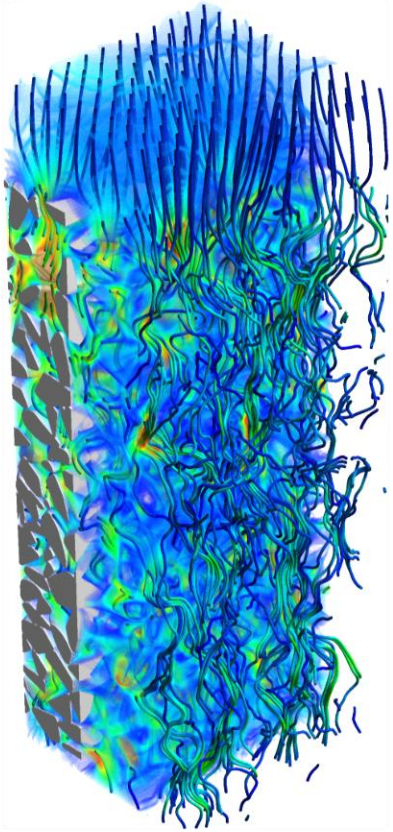


Step 1: Simulate pressure loss & solid loading across the wall

Step 2: Simulate pressure loss & solid loading along the channels

Step 1

Simulate pressure loss across the ceramic wall



Micro-structure

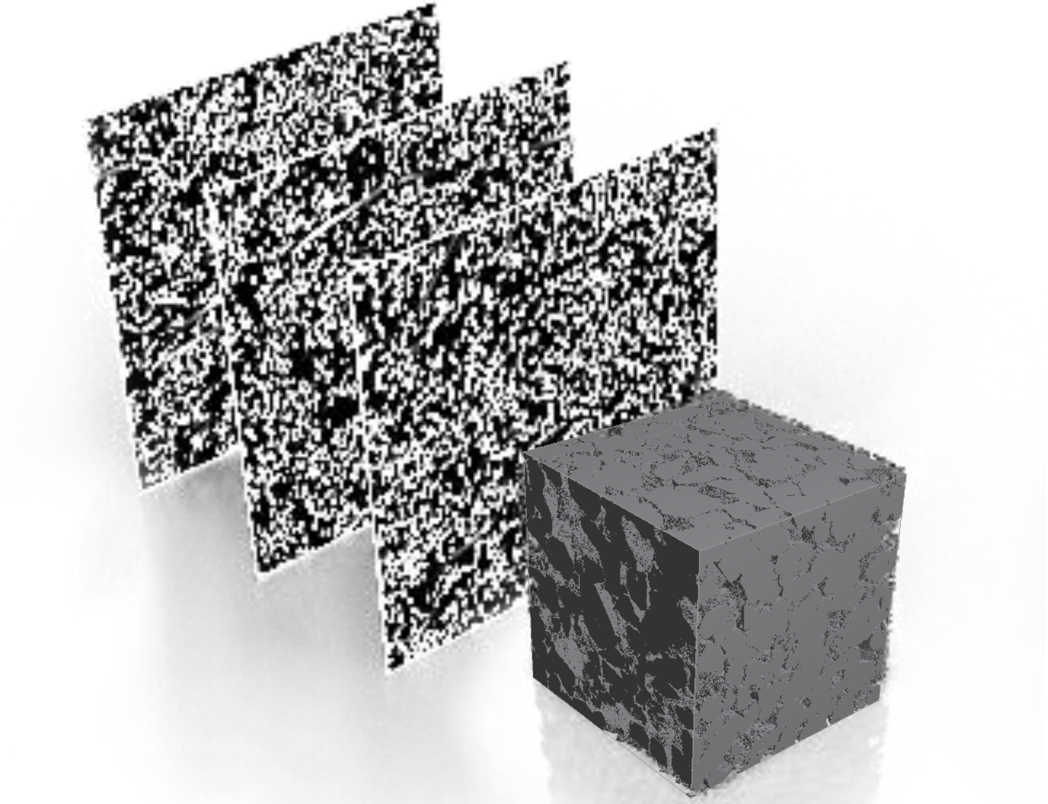
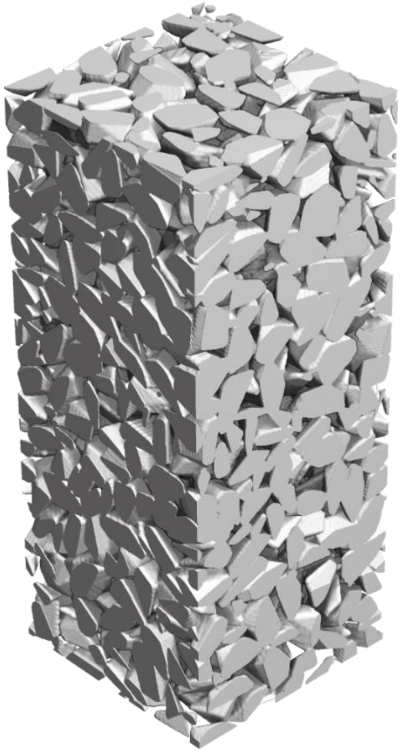


Image acquisition: µ-CT

(+) Allows simulations on real filter structures

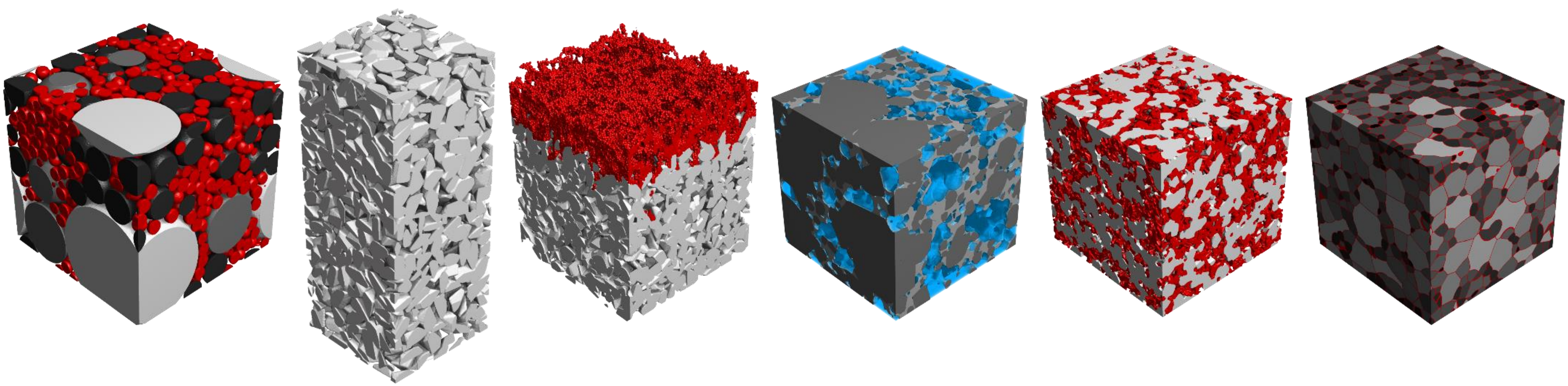
(-) Modification of the filter structure is not possible only through µ-CT images



Modelling with GeoDict structure generator modules

Micro-structure models with GrainGeo module

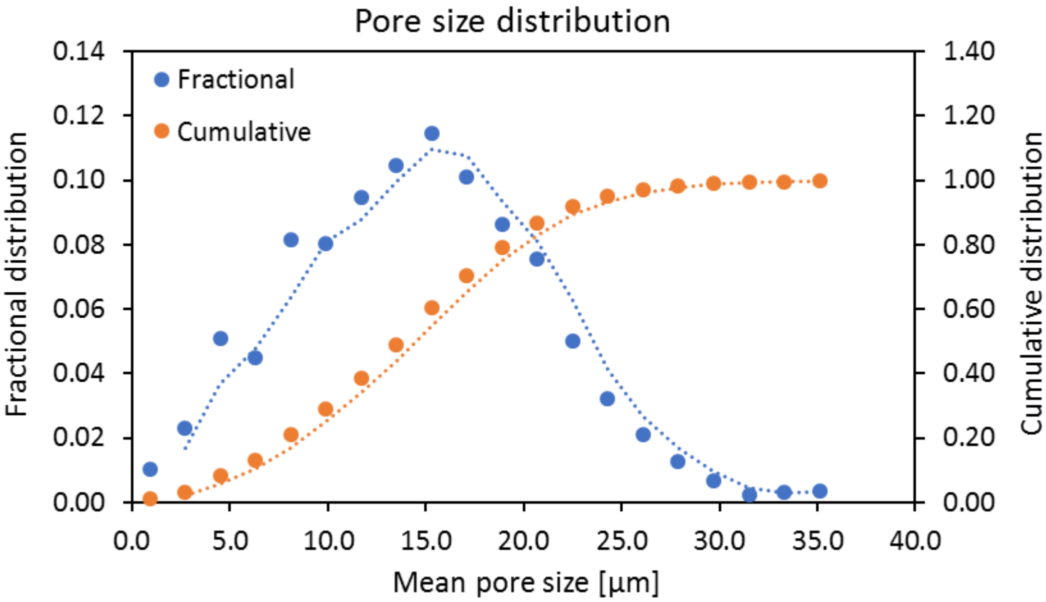
- Modelling of packed beds of spheres.
- Modelling of sintered ceramics.
- Modelling of catalyst layer and microporous layer in PEM fuel cells.
- Modelling of lithium ion cathodes and other battery materials.
- Modelling of rocks like sand-stone.
- Modelling of sphere packings with very high packing density.

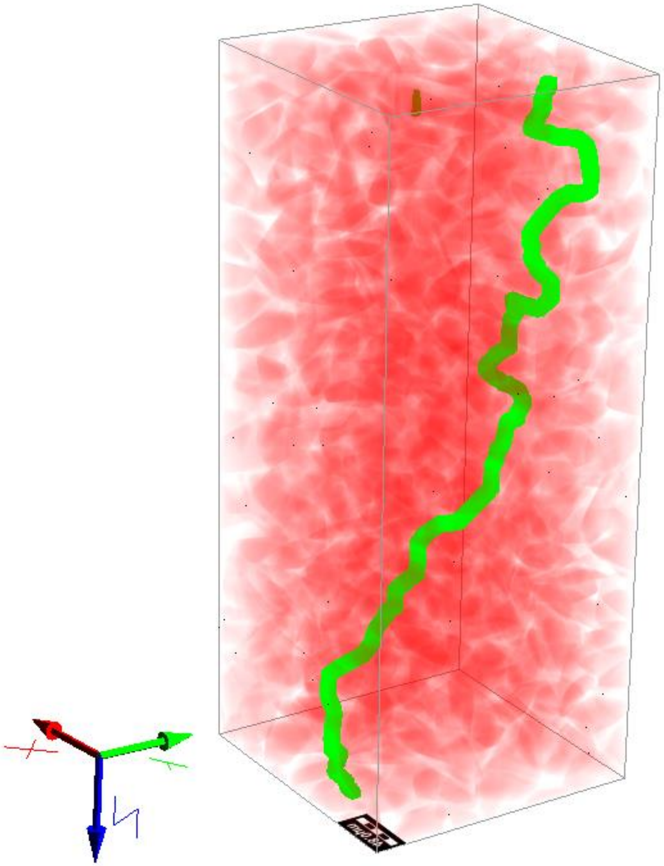


Ceramic model characterization

Characterizing the ceramic with PoroDict

Evaluation of the pore size distribution & percolation path



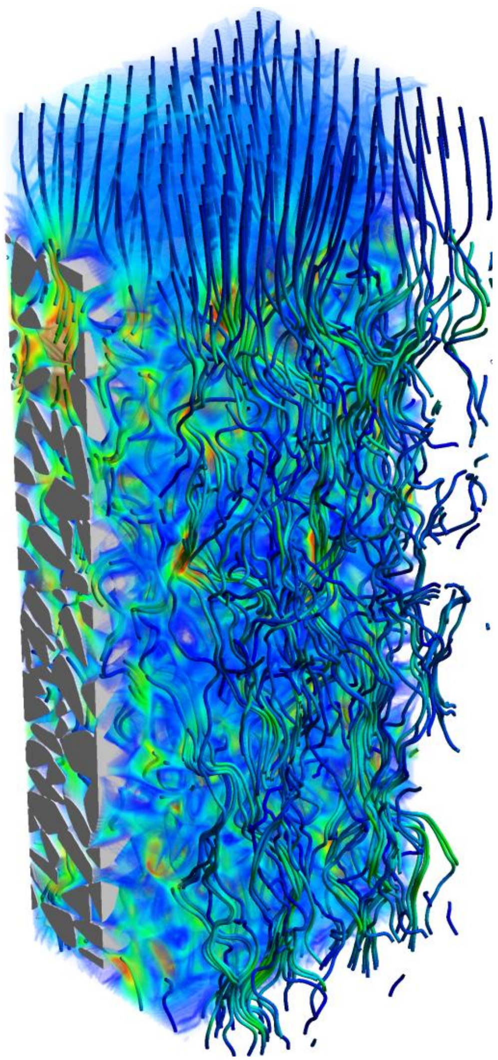


Maximum particle diameter [µm]	Path length [µm]
9.94	929.1

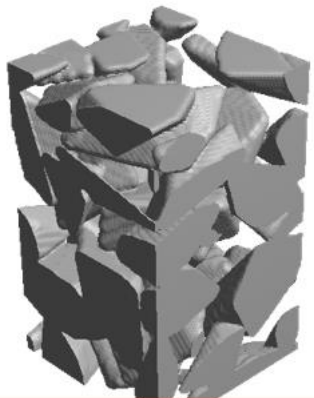
Ceramic model characterization

Characterizing the ceramic with FlowDict

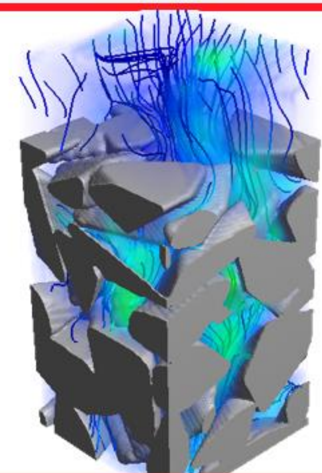
- Domain size: 256x256x630 Voxels
- Voxel length: 0.9 µm
- Ceramic porosity: 48.7 %
- Pressure drop is 252.8 Pa at mean air flow velocity of 0.04 m/s
- Flow resistivity: 1.115e+07 $kg/(m^3s)$
- Permeability: 1.63e-12 m^2



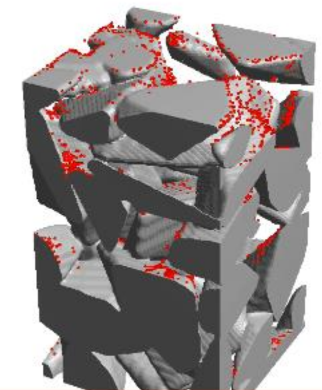
Filter life time simulation with FilterDict-Media



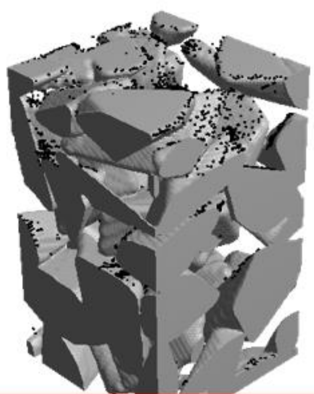
1. Model filter



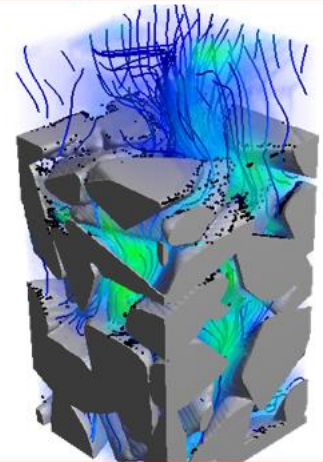
2. Compute flow field



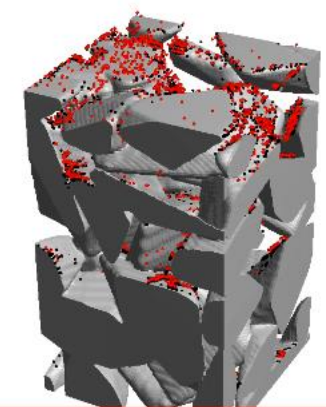
3. Track particles



4. Deposit particles



5. Update flow field



6. Repeat ...

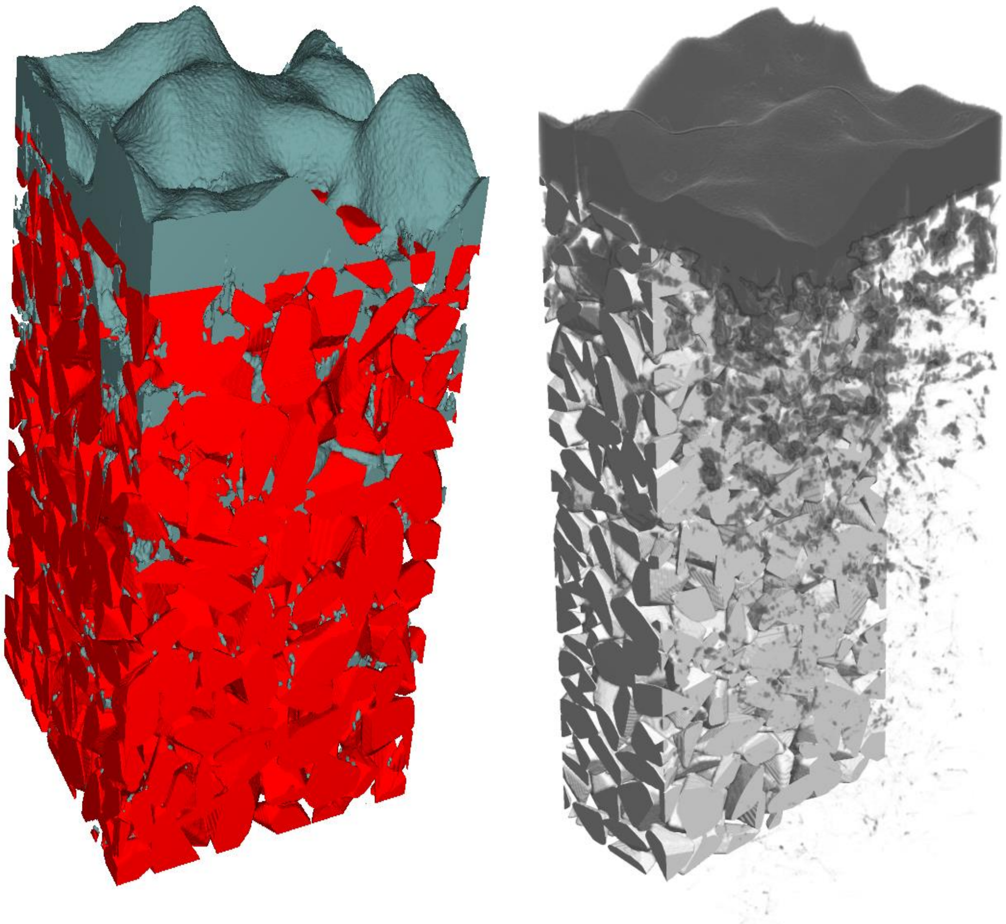
Analysis of cermaic filter performance

Analysis of the filtration performance with FilterDict-Media

Simulation of soot particles deposition.

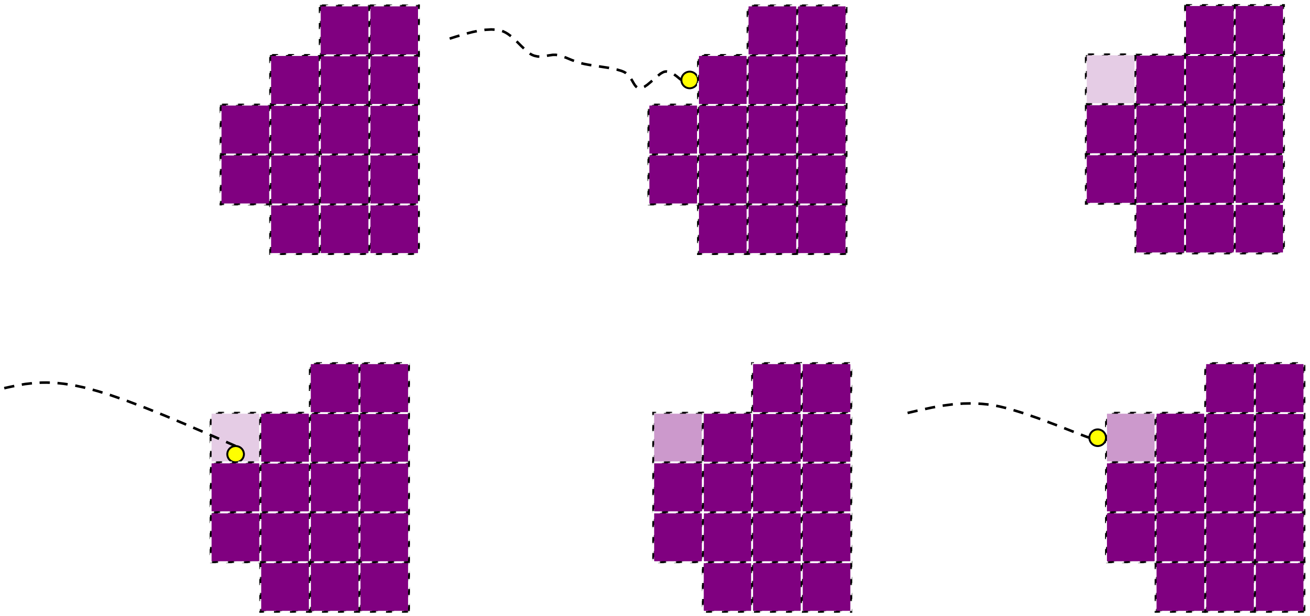
Evaluation of fractional filter efficiency.

Evaluation of pressure drop in depth filtration & cake filtration regimes.

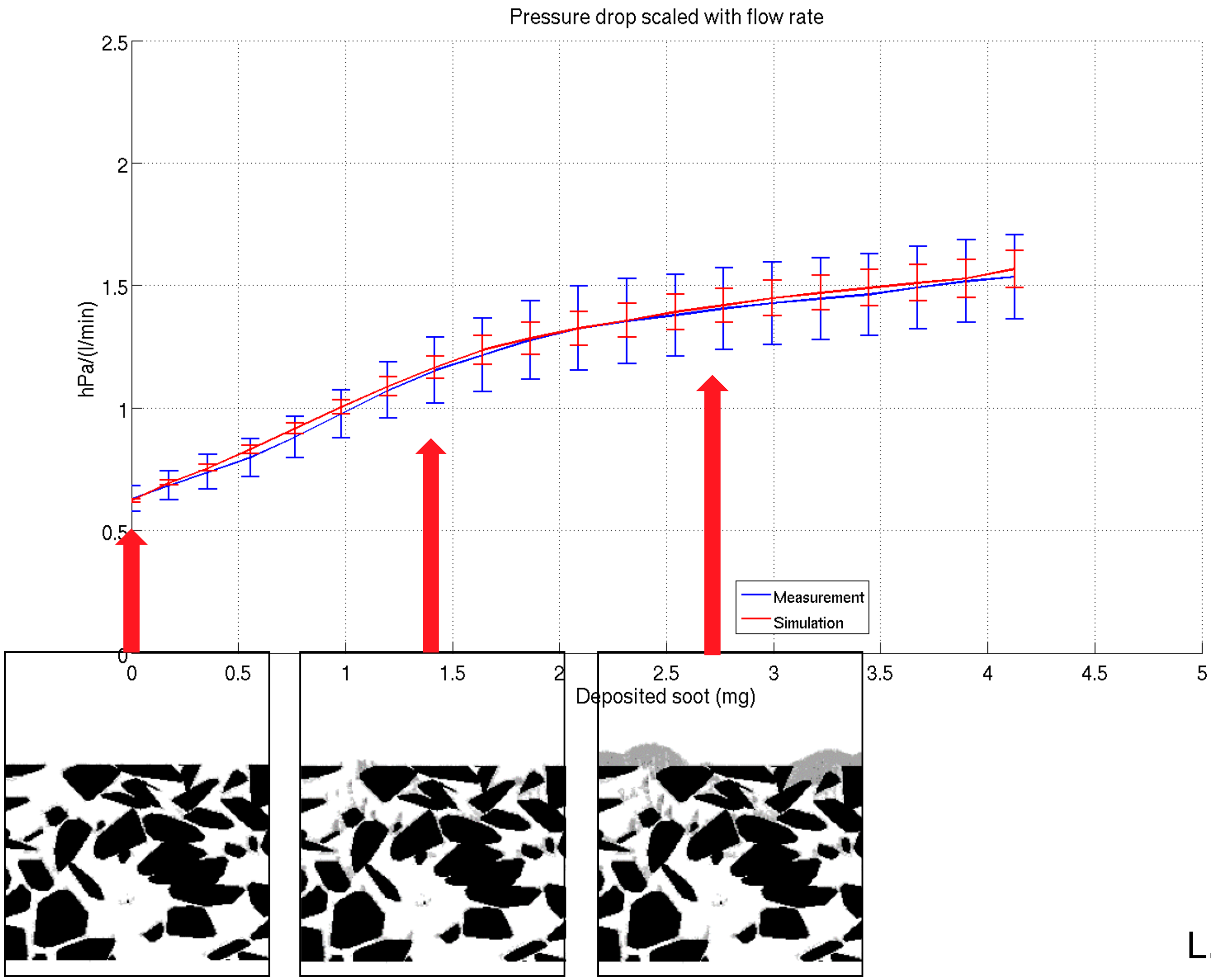


Filtration of unresolved particles:
Solid, empty, or porous (& permeable) grid cells

- Soot particles (25~600 nm) are smaller than the grid size.
- Deposited particles do not fill the computational cell, but form a permeable media.
- Define how much a cell can get filled: f_{max}
- Define flow resistivity depending on the degree of filling: $\sigma(f)$



Experimental and simulated pressure drop evolution



- Error bars induced by 5 measurements and 5 different realizations of the digital structure.
- Match achieved by introducing different parameters f_{max} & $\sigma(f)$ for depth & cake filtration.

L. Cheng et al., WFC 11, 2012.

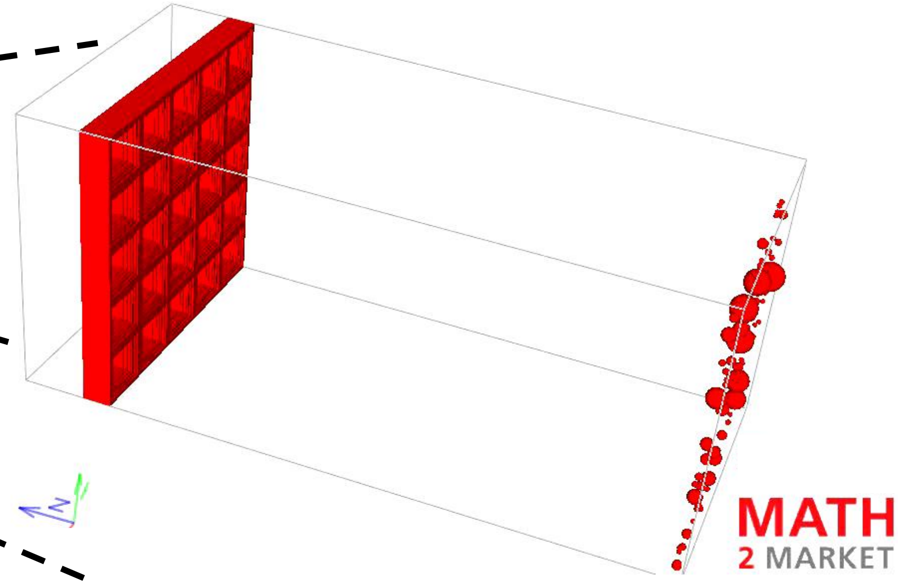
Particle filtration multi-scale approach

Soot deposited in <u>ceramic DPF</u>

- soot as porous media simulation requires:

f_{max} maximum soot packing density

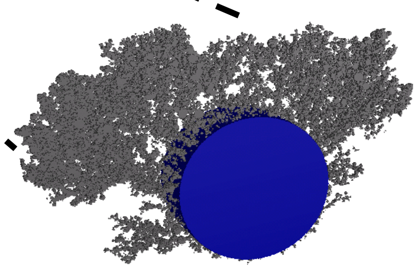
σ_{max} corresponding flow resistivity



Soot deposited on a <u>grid frame</u>

- resolved soot simulation to identify:

f_{max} & σ_{max} for <u>cake filtration</u>

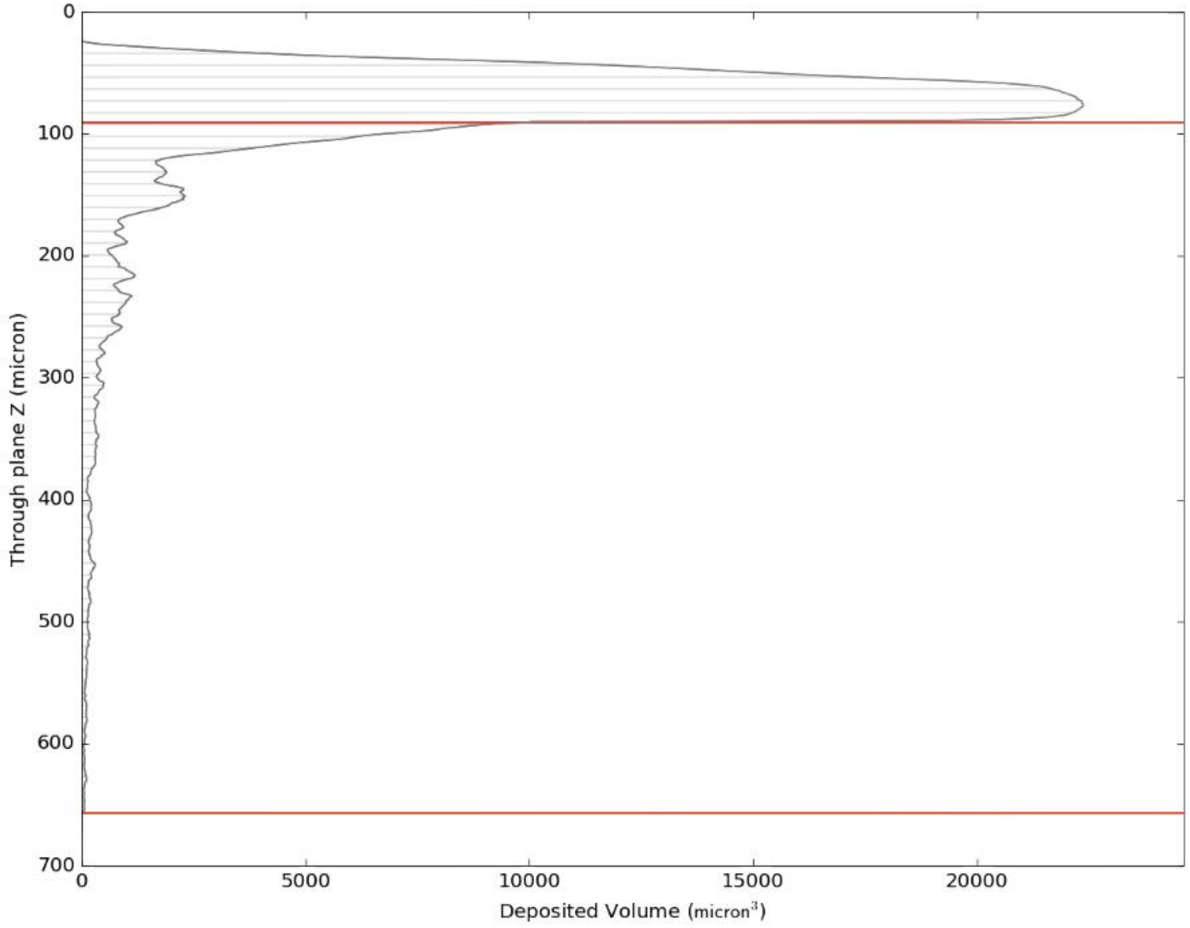


Soot deposited on a <u>single grain</u>

- resolved soot simulation to approximate:

f_{max} & σ_{max} for <u>depth filtration</u>

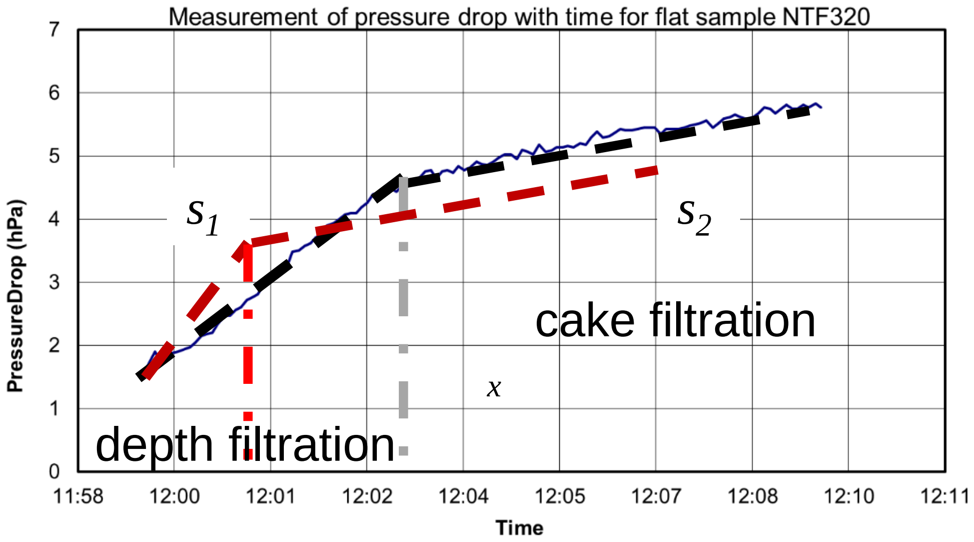
Spatial particles deposition over time



Reduced pressure drop over time

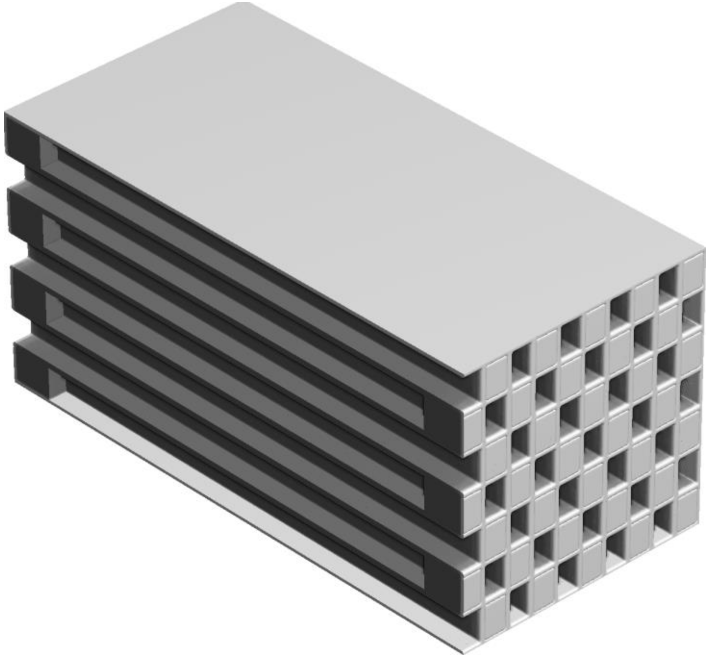
After fast initial pressure drop increase (slope s_1, depth filtration phase)
follows long slower pressure drop increase (slope s_2, cake filtration phase)

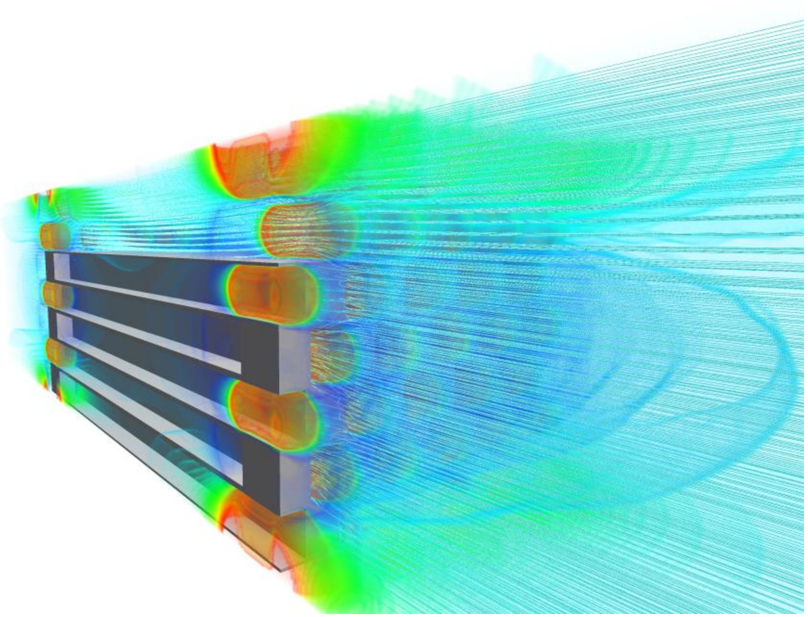
- Matched experiment with simulations
- Shortened depth phase to lower pressure drop during cake phase
- Fraunhofer IKTS manufactured ceramic, experiment matched simulations, and patent was granted: *Particulate filter, No. DE102012220181 A1*



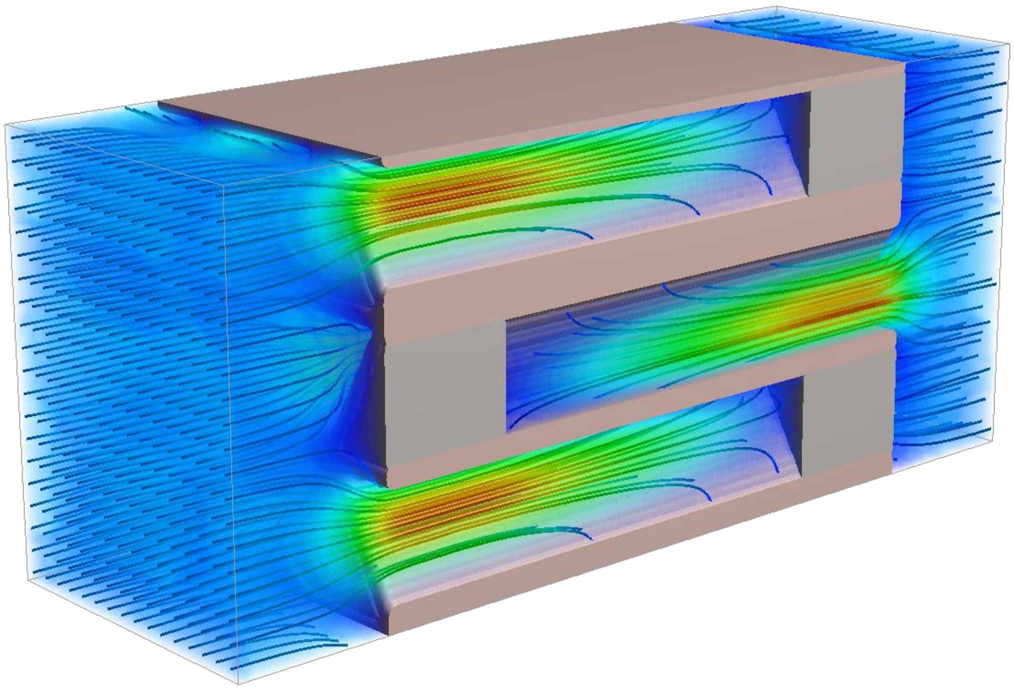
Step 2

Simulate pressure loss along the channels





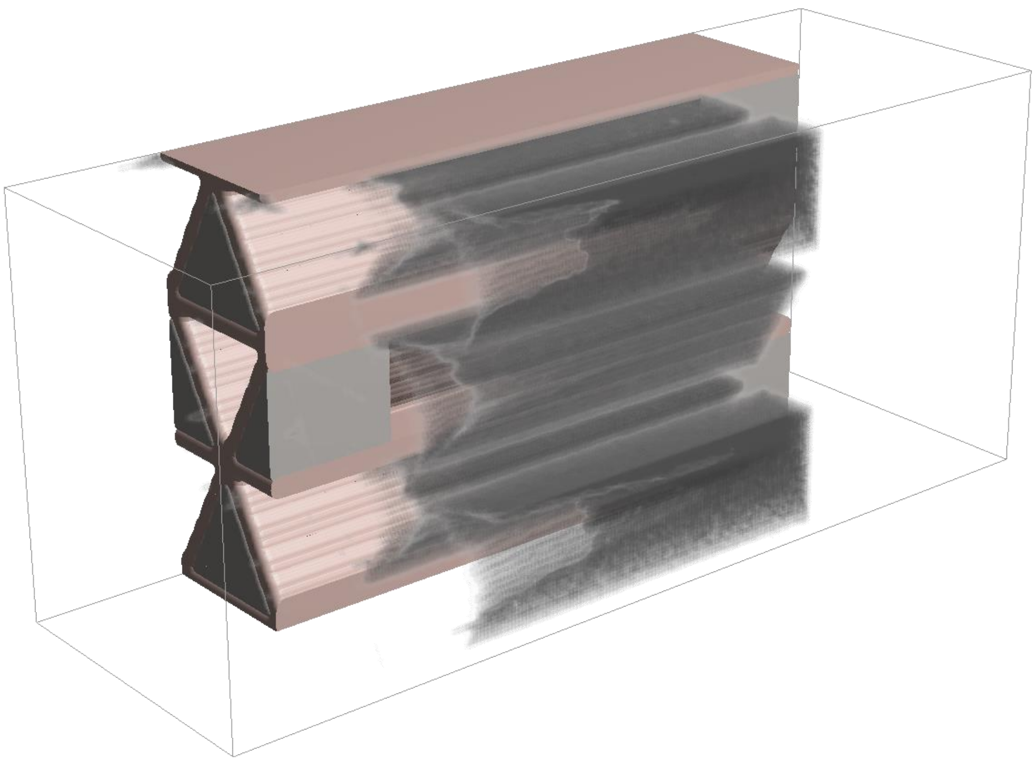
Pressure drop along channels (FlowDict)



Required input:

- Permeability of ceramic wall from micro-scale simulation

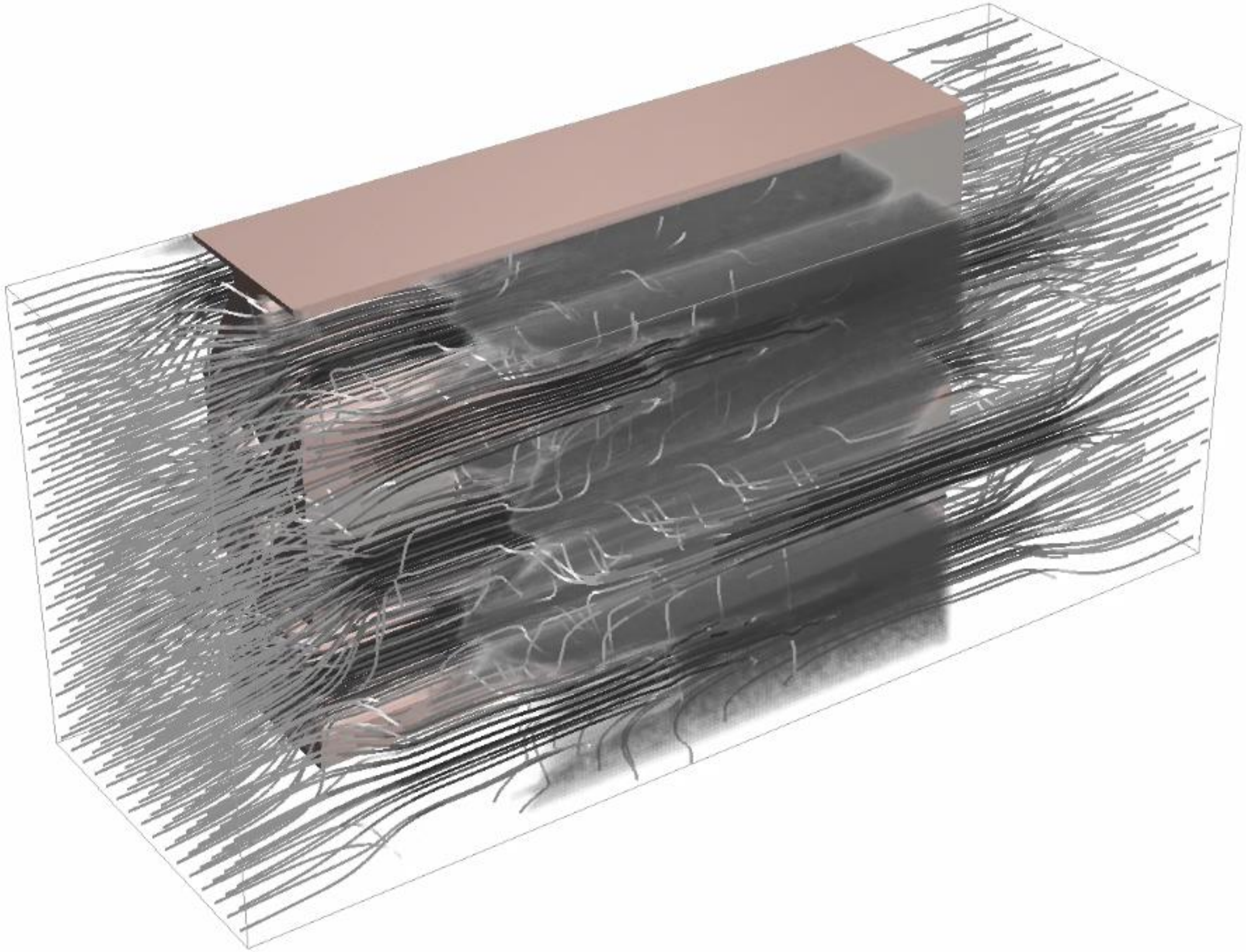
Soot filtration on DPF honeycomb (FilterDict-Element)



Required input:

- Permeability of ceramic wall from micro-scale simulation
- Filter efficiency of each particle size
- Maximum packing density & corresponding flow resistivity

Modeling & simulation at unresolved media scale

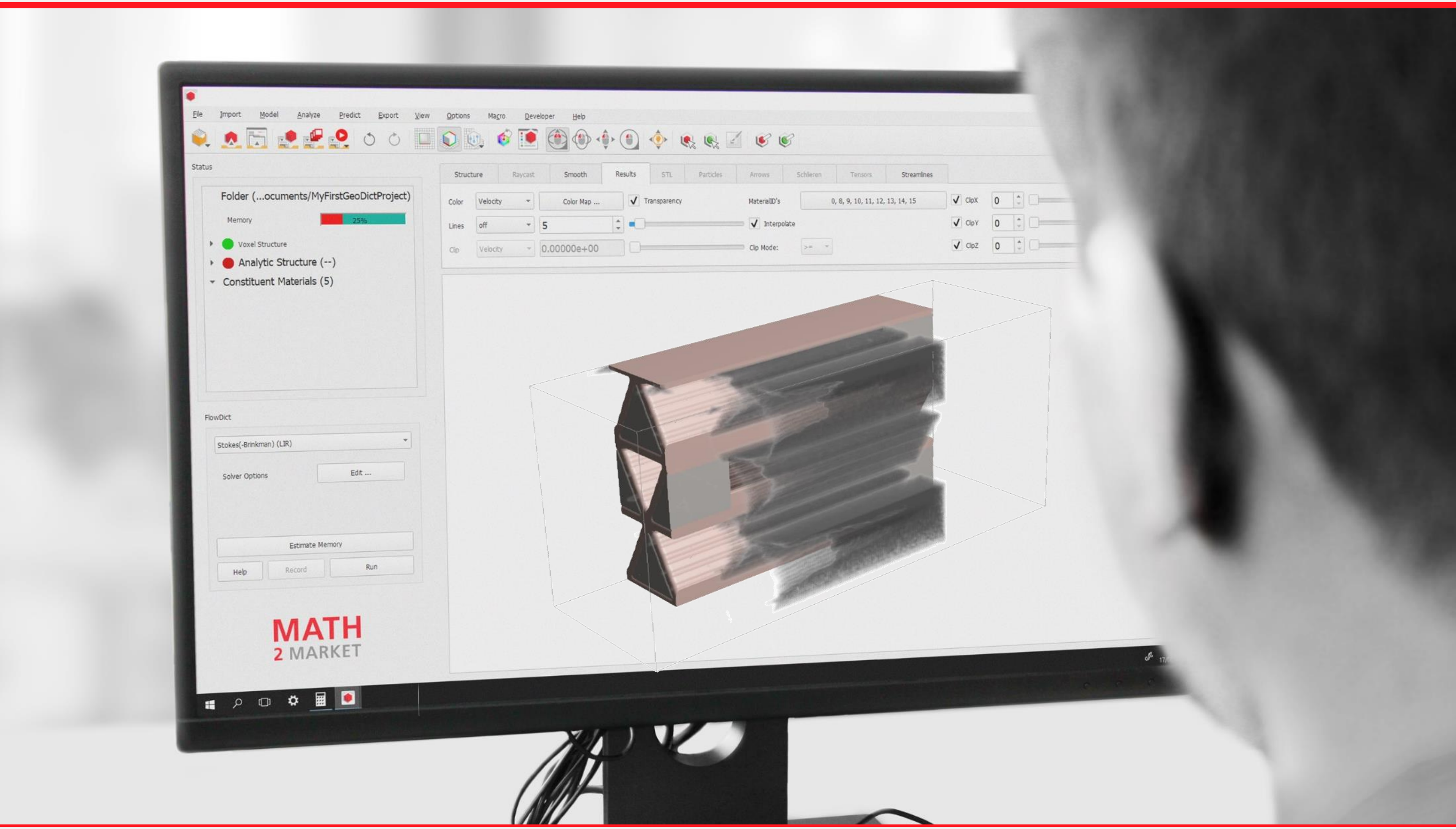


Summary

1. Simulate pressure drop & soot loading across the ceramic wall
   - Model ceramic materials
   - Determine pressure drop evolution and soot loading
2. Simulate pressure drop & soot loading along the channels
   - Model honeycomb structures
   - Determine pressure drop evolution and soot loading

- Multi-scale simulations bridge the scales between filter media design & filter element design
- Developed an improved DPF with Fraunhofer IKTS (patent granted)

Thank you for your attention.



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