Soot Filtration Modeling and Simulation in Diesel Particulate Filters

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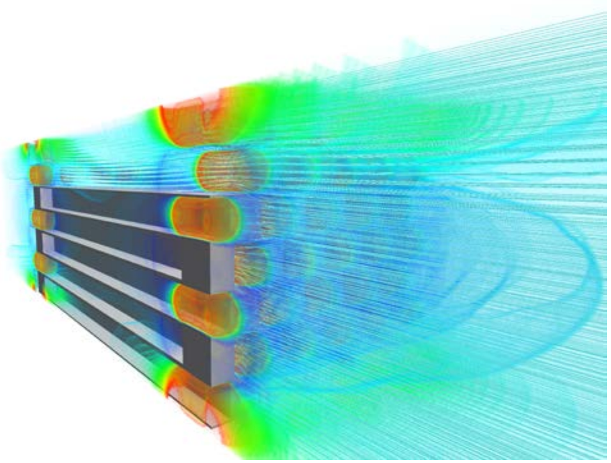


Math2Market GmbH and its GeoDict software
Some background information

- Math2Market creates & markets software to analyze/design porous & composite materials based on the material's geometric inhomogeneity
- M2Ms software is called GeoDict, the Digital Material Laboratory
- GeoDict works on µCT-based, FIB-SEM-based and intrinsic models - in all cases, the computer representation consists of 3-D images
- M2M was spun off in 2011 from Fraunhofer Institute for Industrial Mathematics
- M2M is based in Kaiserslautern, Germany, and privately owned
- M2M has more than 150 clients from around the world

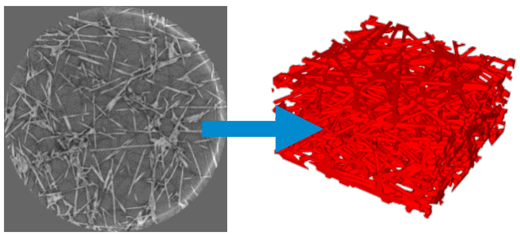
GeoDict The Digital Material Laboratory

We help our clients to profitably
engineer better materials and processes
through
digital solutions.

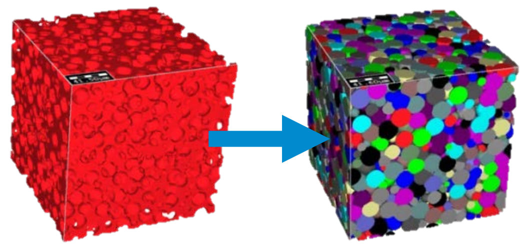
We believe that to understand is to improve.

GeoDict‘s Core Capabilities

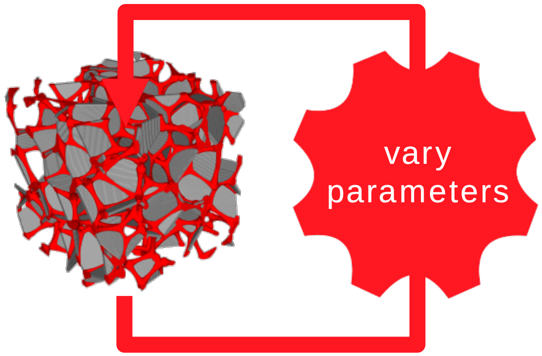
Import µCT & FIB-SEM



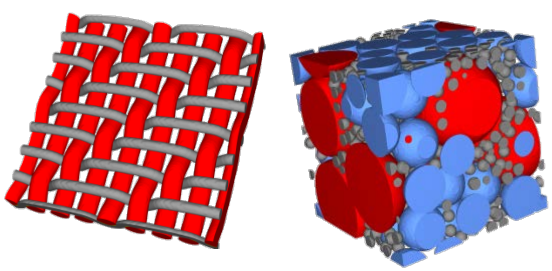
Analyze Materials



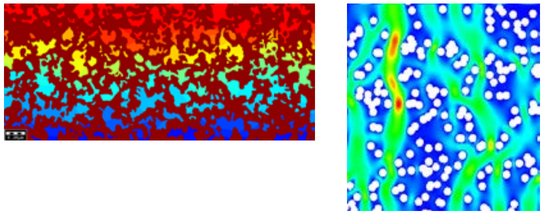
Optimize Materials



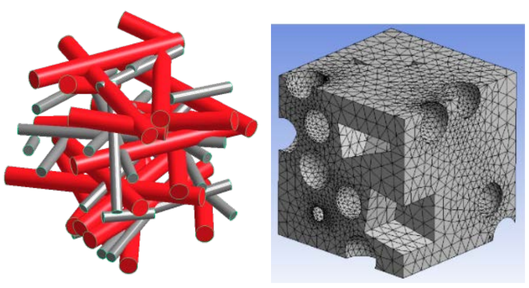
Model Materials



Analyze Properties



Export Materials



Selected Clients

Wir leben Autos.
GKD WORLD WIDE WEAVE
BOSCH
TU Clausthal Clausthal University of Technology
HAVER & BOECKER

IMTEK
VOLKSWAGEN AKTIENGESELLSCHAFT
FREUDENBERG INNOVATING TOGETHER
HUYCK.WANGNER
TOYOTA
UNIVERSITAS BERGENSIS

MANN+HUMMEL
UPPSALA UNIVERSITET
NASA
JÜLICH FORSCHUNGSZENTRUM
KIT Karlsruher Institut für Technologie
九州大学 KYUSHU UNIVERSITY
ZEISS

NRC-CNRC From Discovery to Innovation...
PURDUE UNIVERSITY
NONWOVENS COOPERATIVE RESEARCH CENTER NC State University
JRC EUROPEAN COMMISSION
Technische Universität Kaiserslautern
UNIVERSITE JOSEPH FOURIER SCIENCES. TECHNOLOGIE. SANTÉ

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DLR
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

TTRI Taiwan Textile Research Institute
RWTH AACHEN UNIVERSITY
THE UNIVERSITY OF TEXAS AT AUSTIN
DHBW Duale Hochschule Baden-Württemberg
cea
PAUL SCHERRER INSTITUT PSI

Modeling & Simulation of Soot Filtration

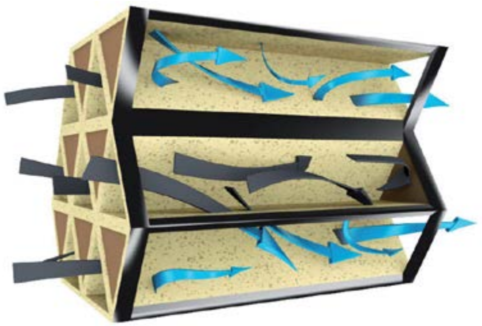
The Diesel Particulate Filter (DPF)

Description:

- Ceramic honeycomb with porous walls
- Channels alternately plugged at the ends
- Trap the particles over the whole size range

Goal: design a better DPF using simulations

- Lower pressure drop
- Higher filter efficiency
- Longer life time



Key element governing the performance of the DPF:
Ceramic filter media

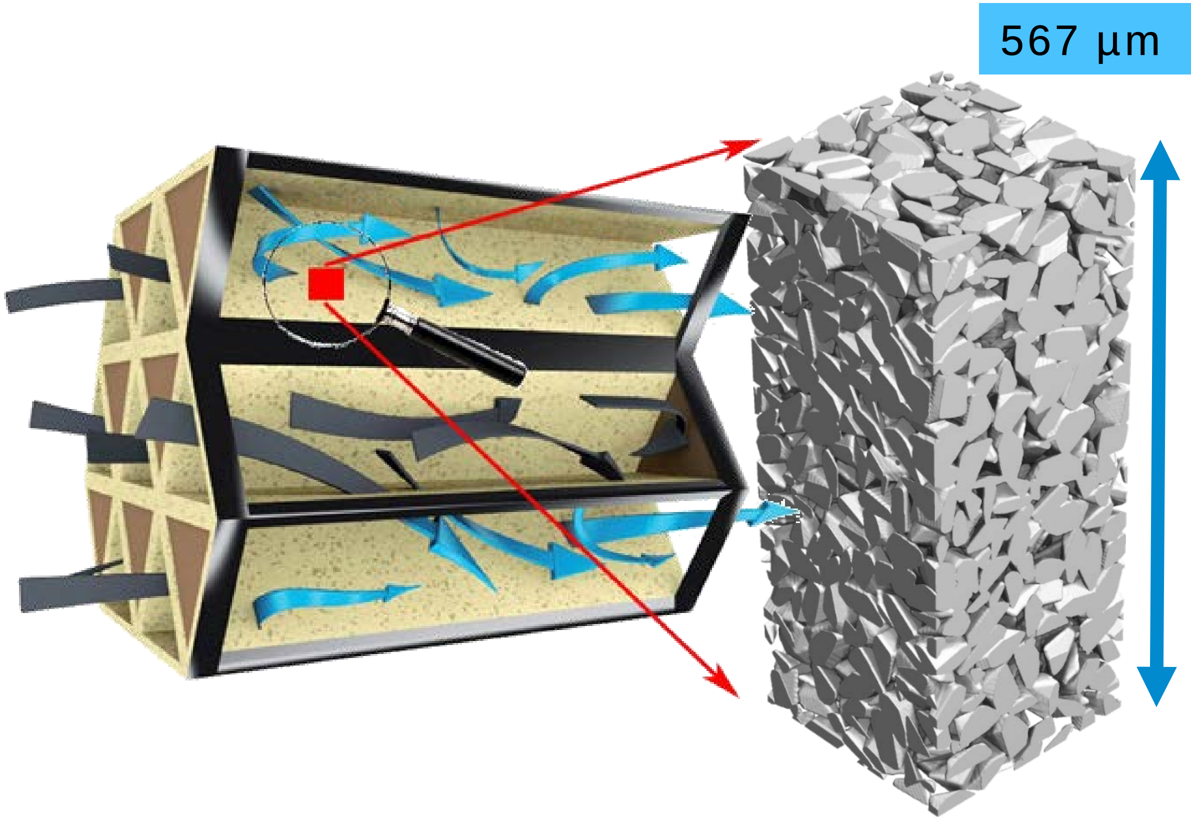
Diesel Particulate Filter Simulations

Energy use of the DPF:

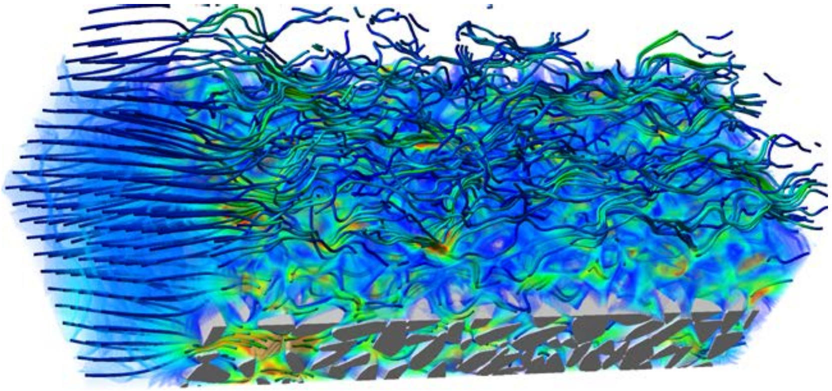
1. Pressure loss across the (loaded) ceramic walls
2. Pressure loss along the channels

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



3D Ceramic Microstructure

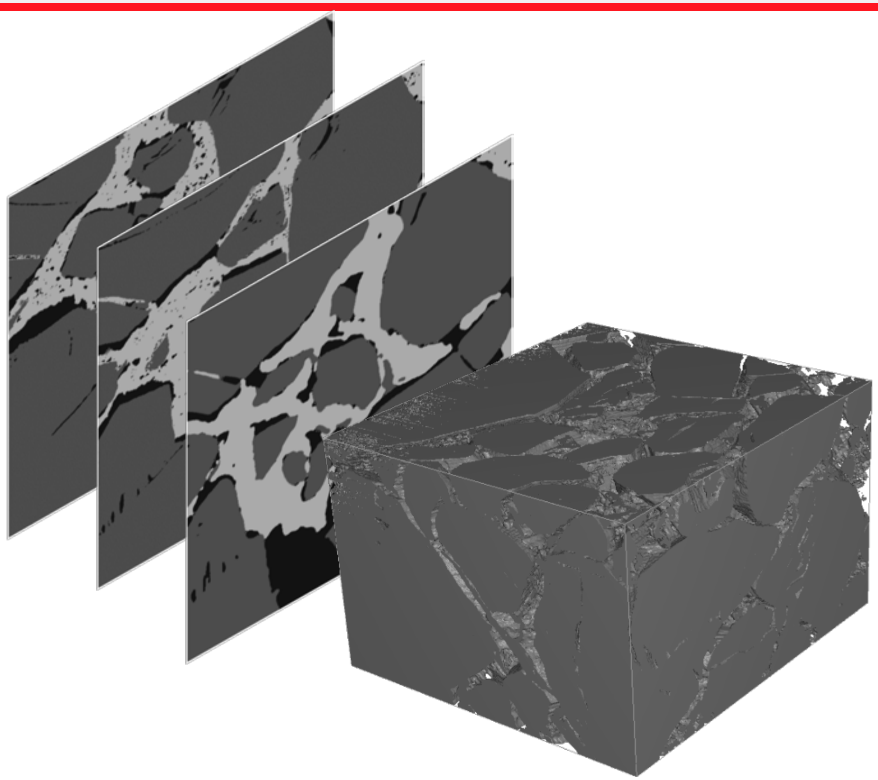
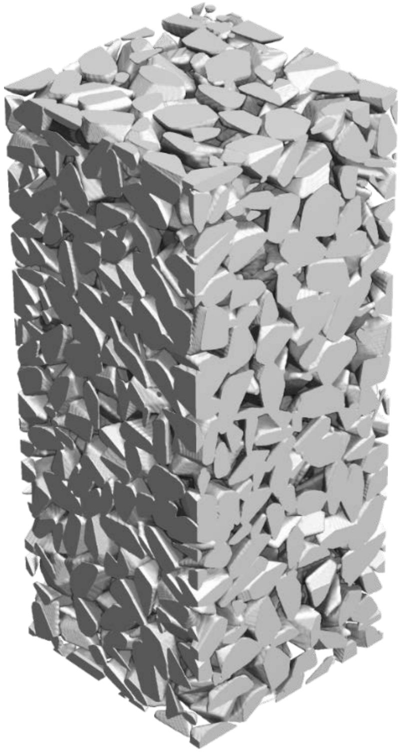


Image acquisition by µCT



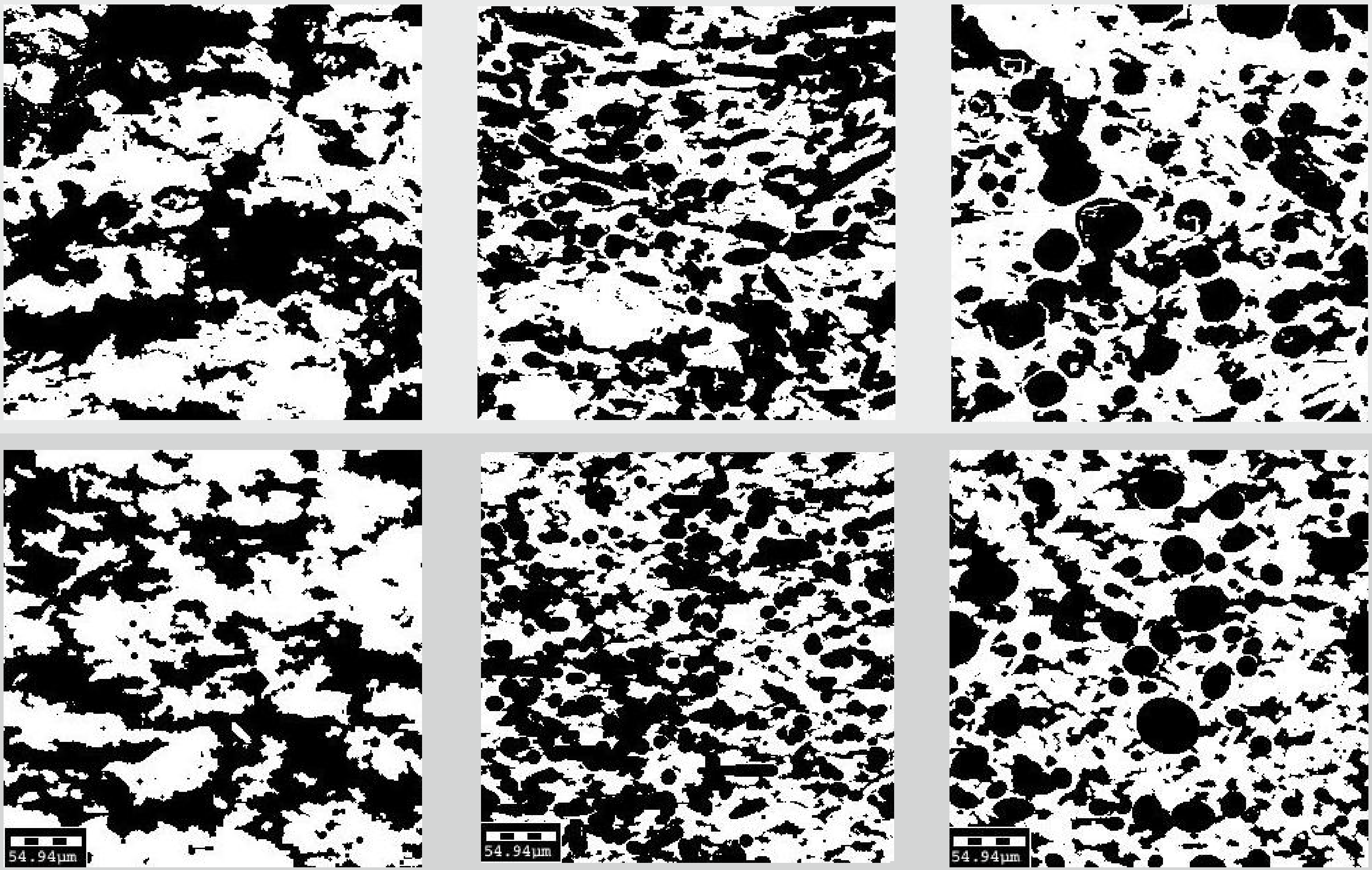
Modelled with GrainGeo

(+) Allows simulations on real filter structures.
(-) Modifications of the filter structure are not possible.

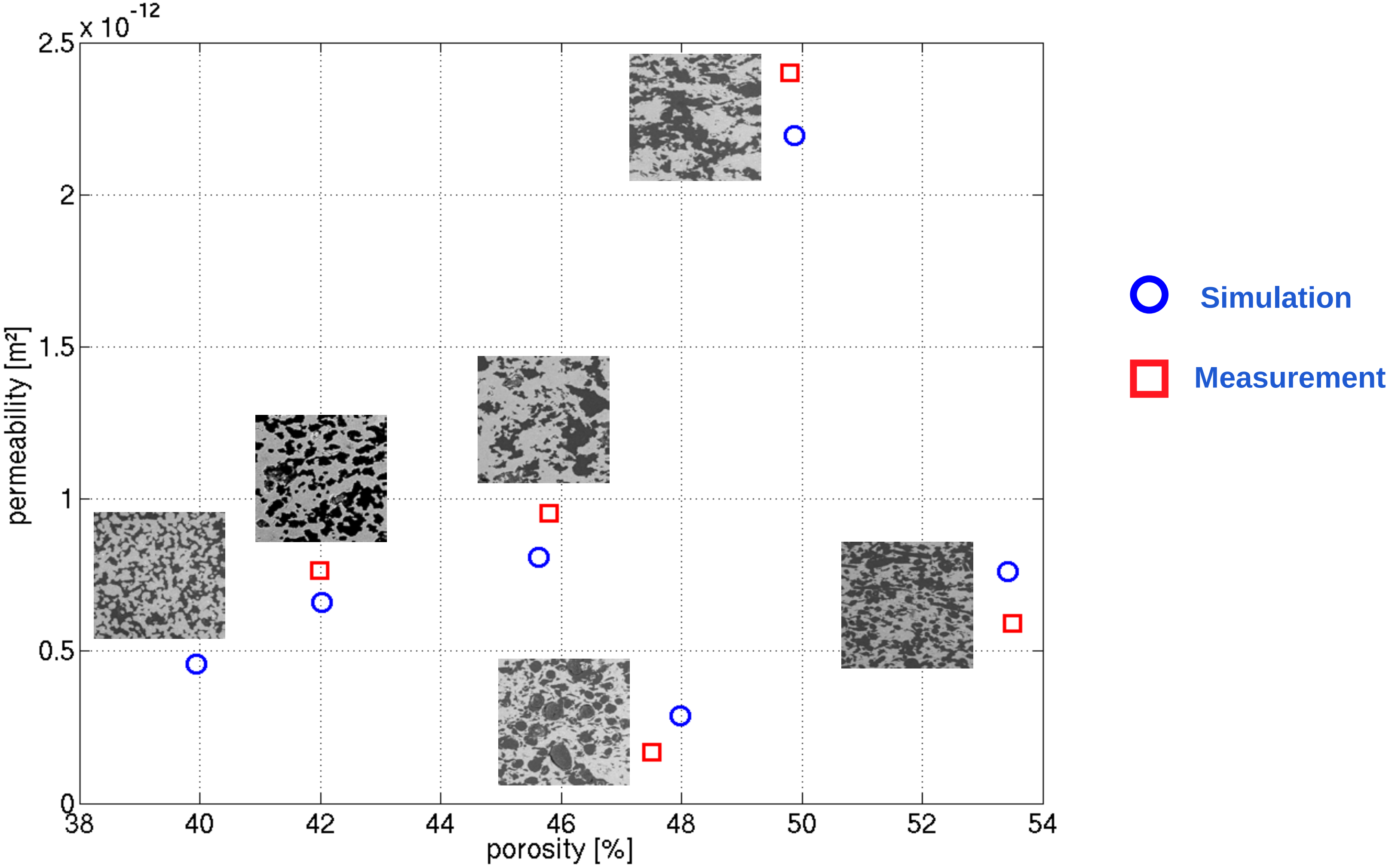
Binarized SEM Images from Polished Micrograph Sections and Modeled Sintered Ceramics

SEMs

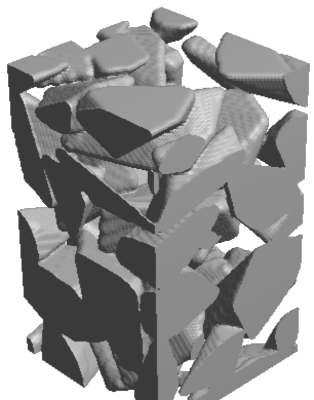
Models



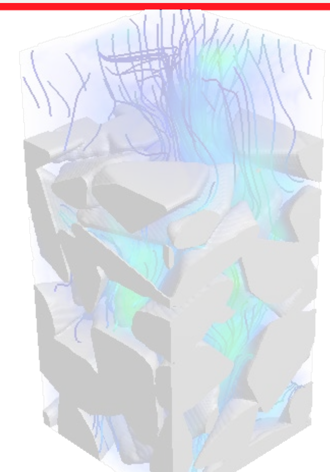
Measured Porosities and Permeabilities of Real Ceramics vs Modeled Porosities and Simulated Permeabilities on Modeled Ceramics



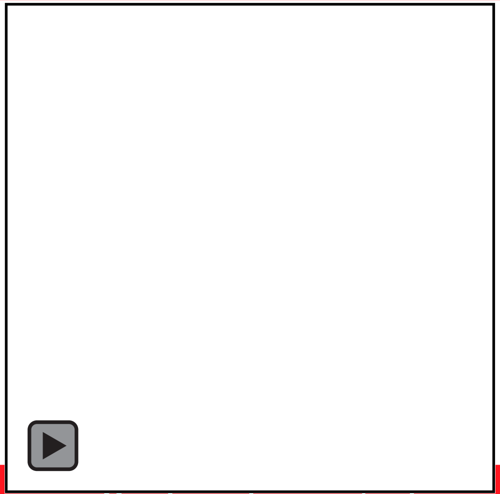
Filter Clogging Simulation with FilterDict-Media



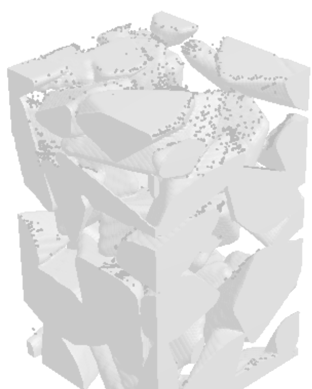
1. Model filter



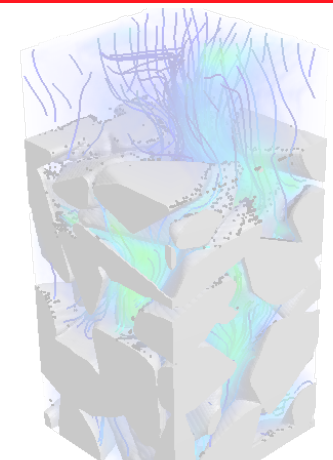
2. Compute flow field



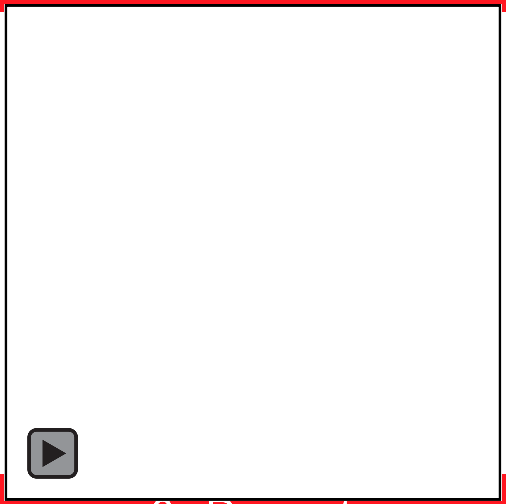
3. Track particles



4. Deposit particles



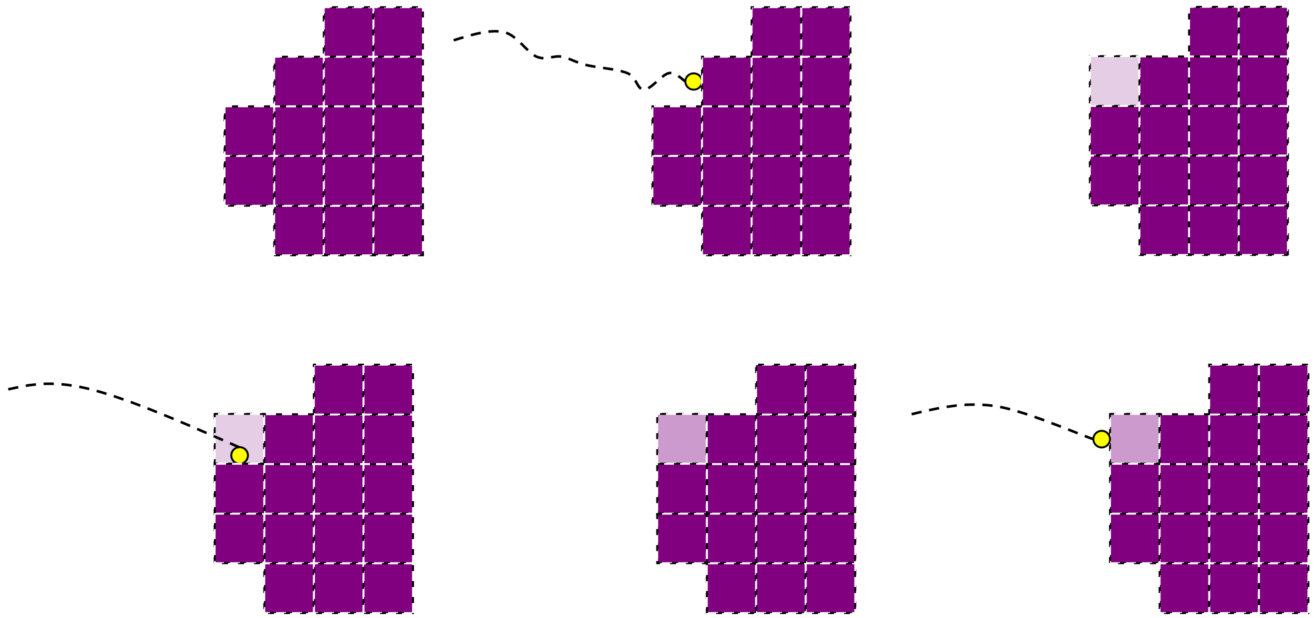
5. Update flow field



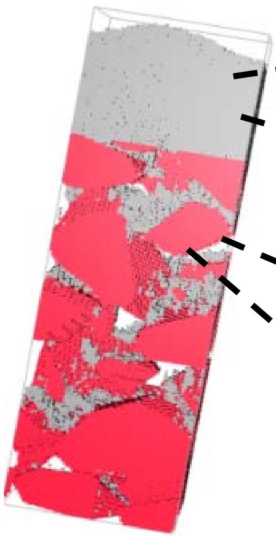
6. Repeat …

Simulation 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: $\sigma(f)$



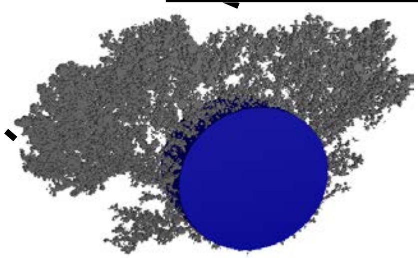
Parameter Identification
Estimate Packing Density and Flow Resistivity



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

- model soot as porous media requires:

f_{max} maximum soot packing density
σ_{max} corresponding flow resistivity



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

- high resolution simulation to approximate:

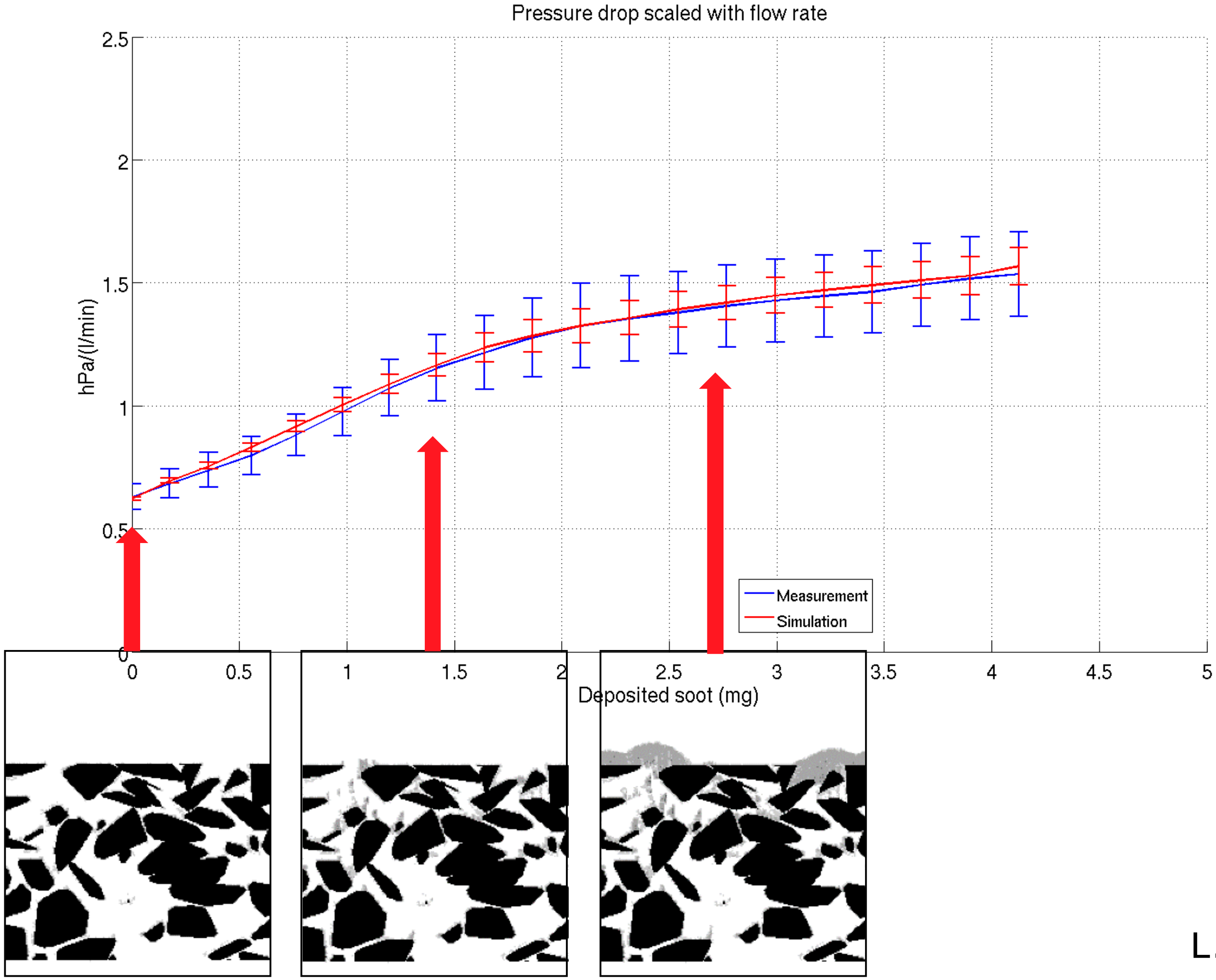
f_{max} & σ_{max} for <u>depth filtration</u>

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

- high resolution simulation to identify:

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

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.

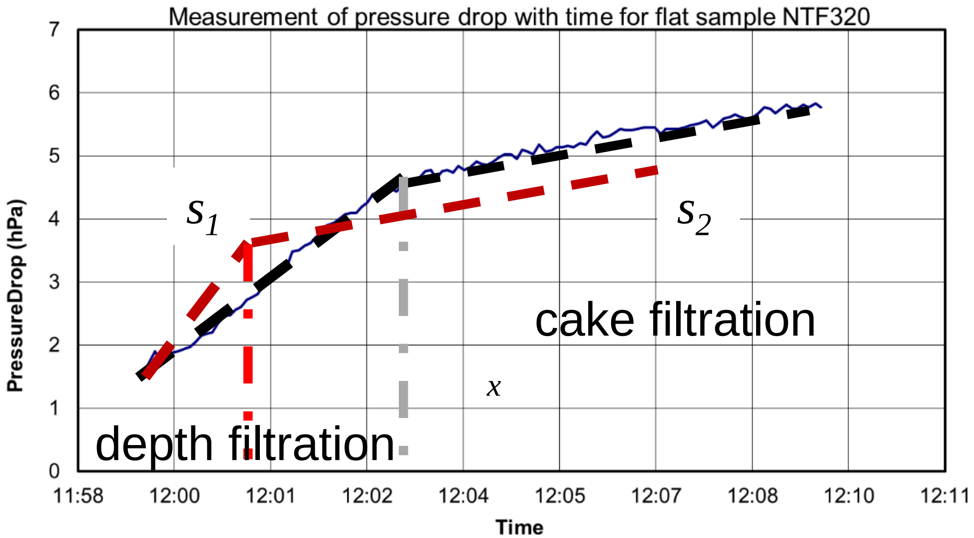
L. Cheng et al., WFC 11, 2012.

Spatial Particle Deposition over Time

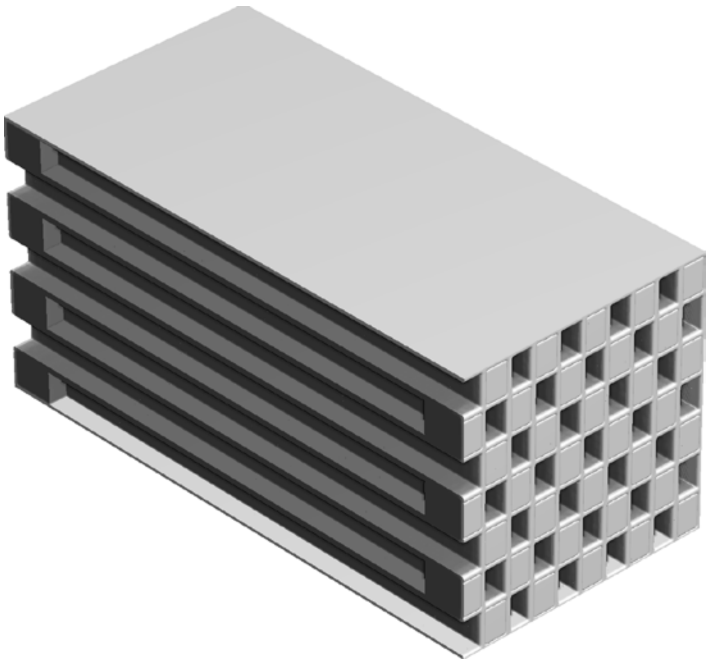
Reduced Pressure Drop by Use of an Innovative Coating

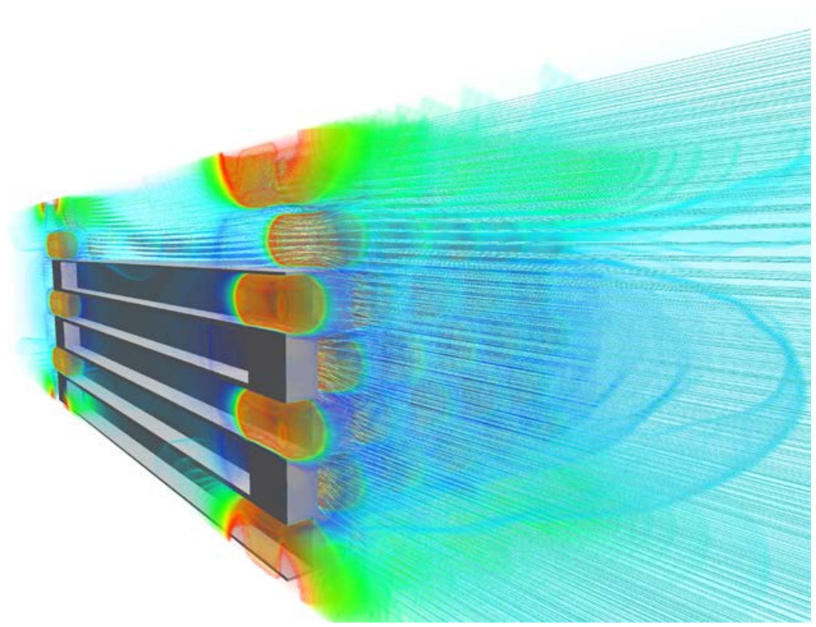
After fast initial pressure drop increase (slope s_1, depth filtration phase)
follows long slower pressure drop increase (slope s_2, cake filtration phase)

- 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*



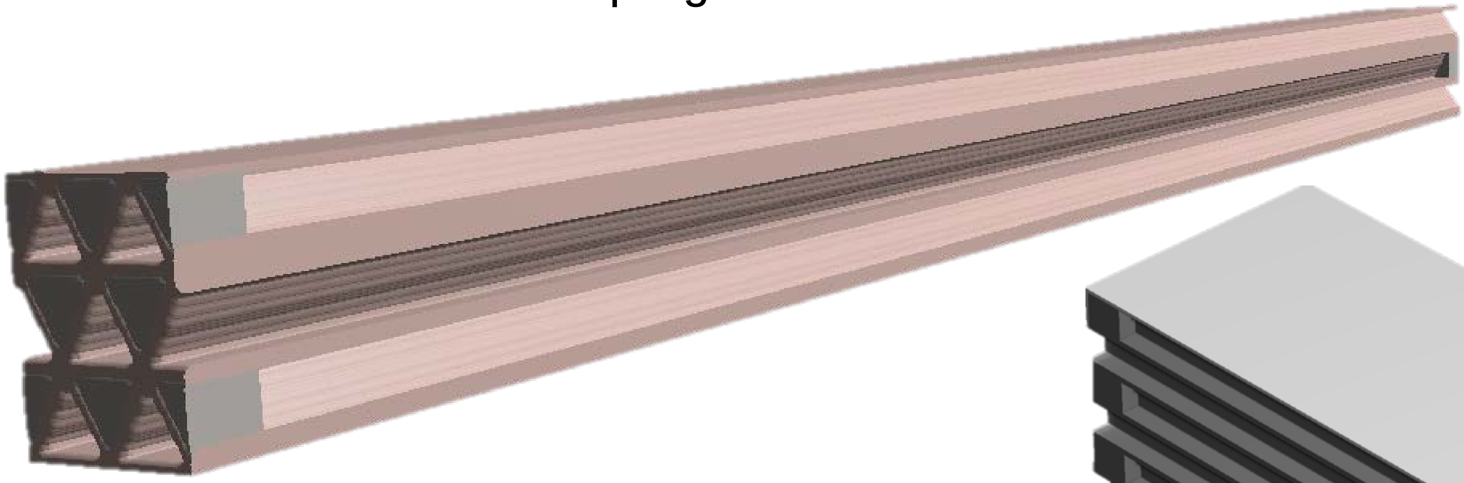
Step 2
Simulate pressure loss along the channels

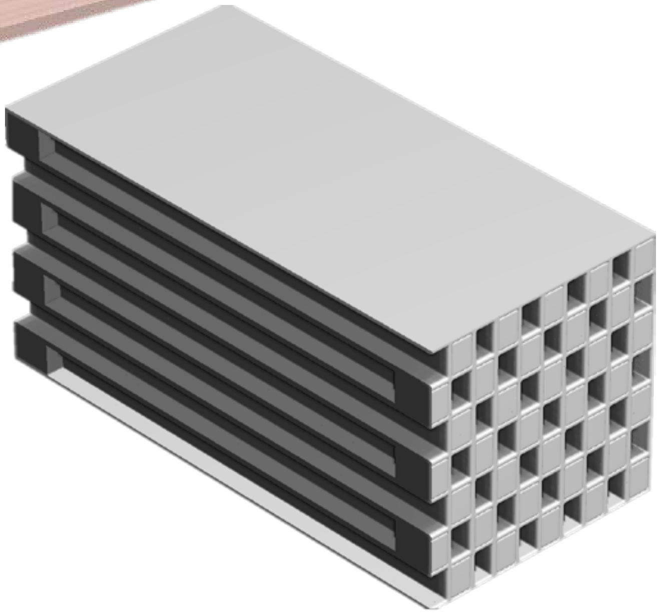




Designing Honeycombs with GridGeo

- Triangular or square channels
- Channels alternately plugged at the ends
- Thicknesses of wall and plugs

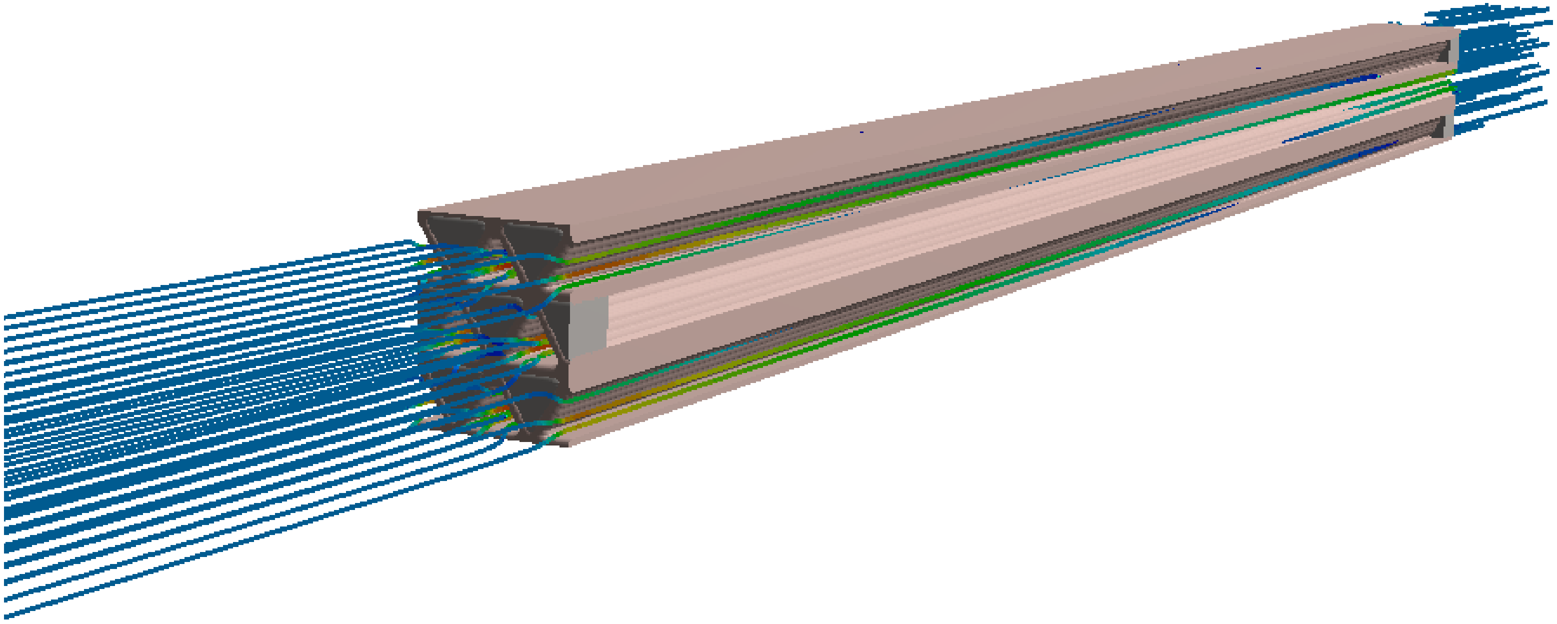




Pressure Drop along the Channels

Required input from step 1:

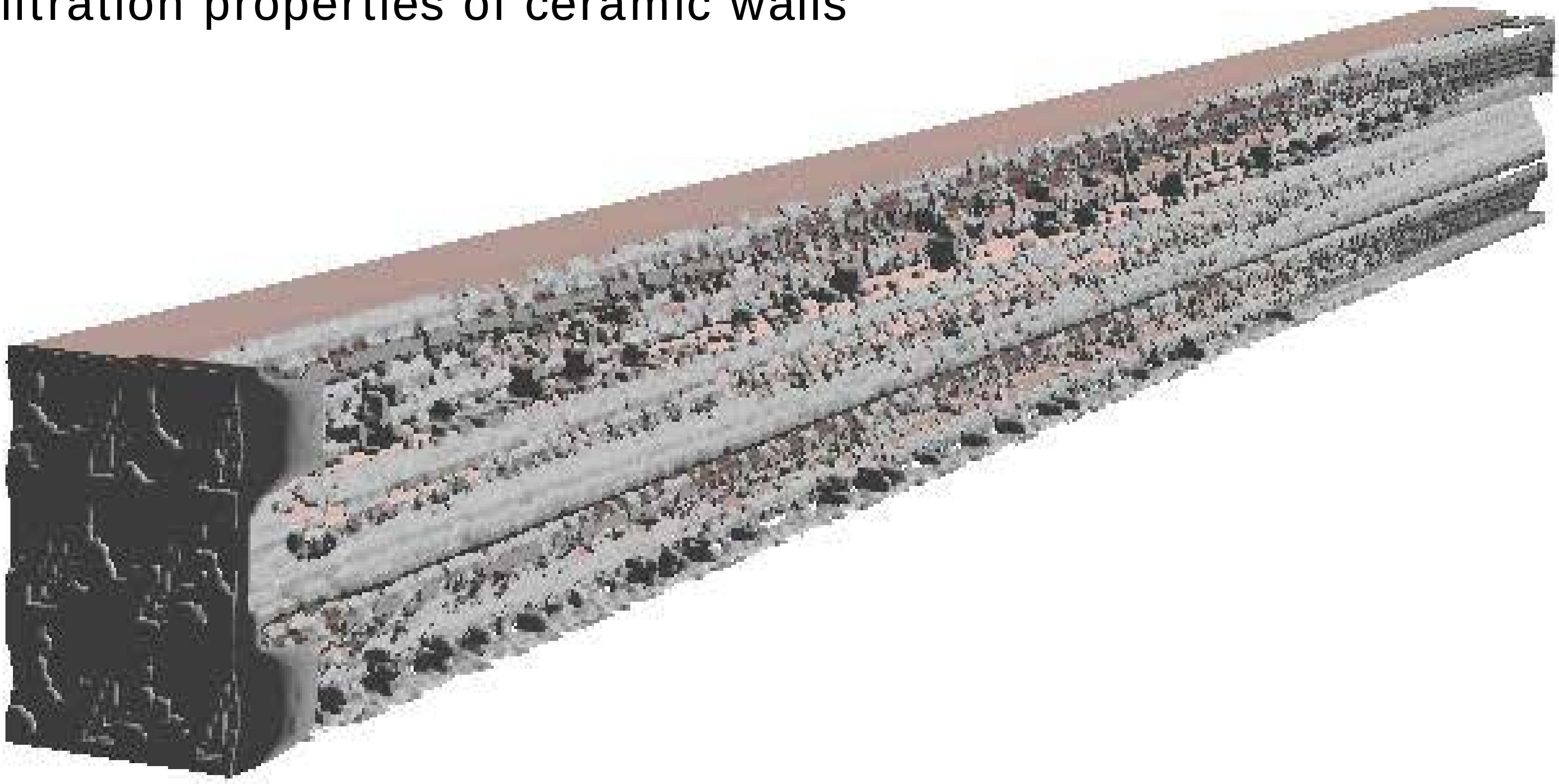
- Permeability of ceramic walls



Soot Deposition along the Channels

Required input from step 1:

- Permeability of ceramic walls
- Filtration properties of ceramic walls



Simulation of the Clogging Process of a Honeycomb Filter

Summary

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

- Multi-scale simulations bridge the scales between filter material design and filter design.
- Developed an improved DPF with Fraunhofer IKTS (patent granted).

Thank you for your attention.