Concepts for Modeling Filter Media and Simulating Filtration Processes

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Math2Market GmbH

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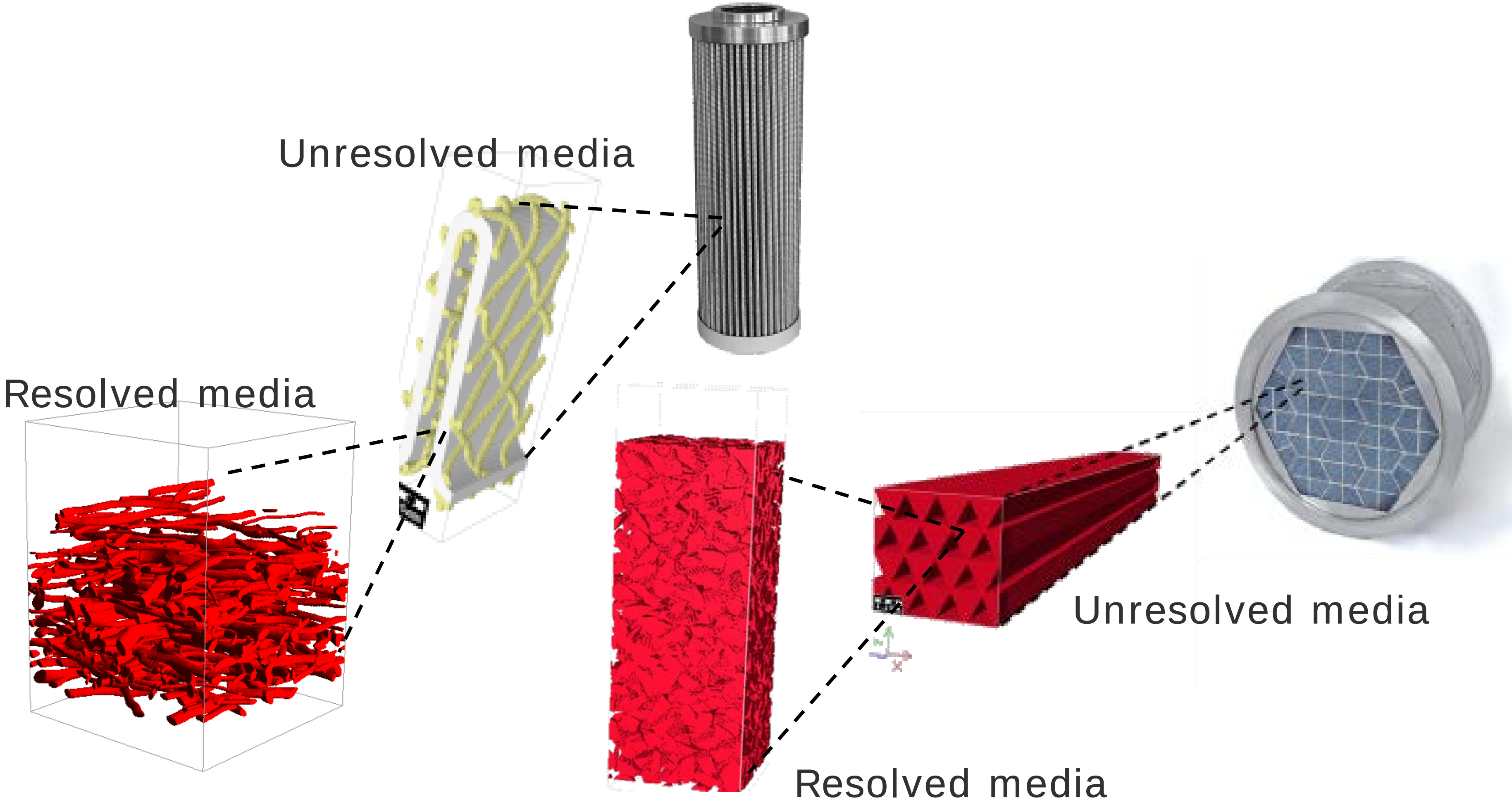
Math2Market GmbH
Promoted Industries

Filtration	Mostly automotive, filter media & filters 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

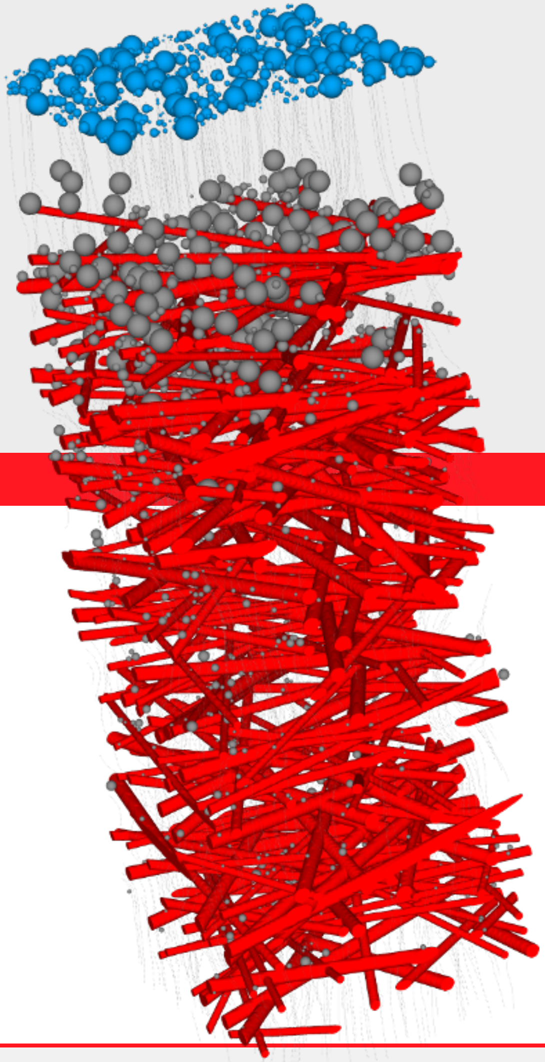
About the need for modeling and simulation

- The function of porous and composite materials results from the choice of raw materials and their micro structure, i.e. the distribution of the constituents, e.g. fibers, in space.
- The power of simple models to predict the effects of the micro structure is limited.
- µCT and FIB-SEM provide 3D images of existing materials with unprecedented resolution.
- From these, one can compute the material‘s properties to match measured properties.
- Models also convert into 3D images. From these, material properties can be determined without the need to manufacture the new materials first.
- GeoDict is the complete software solution for multi-scale 3D image processing, visualization, simulation-driven property characterization, material development, and process optimization.
- 11 of the top 100 market capitalized companies are M2M clients, including Shell and P&G, who introduced the concept of open innovation about 2 decades ago.
- In the future, companies will need to be on top of their materials. The days of trial and error are coming to an end as powerful research tools deliver scientific data of unprecedented depth. [http://www.economist.com/technology-quarterly/2015-12-05/new-materials-for-manufacturing]
- At M2M, we believe this is true in particular for filter media – the future has already begun!

Simulate filtration at different scales



Medium models and property simulations

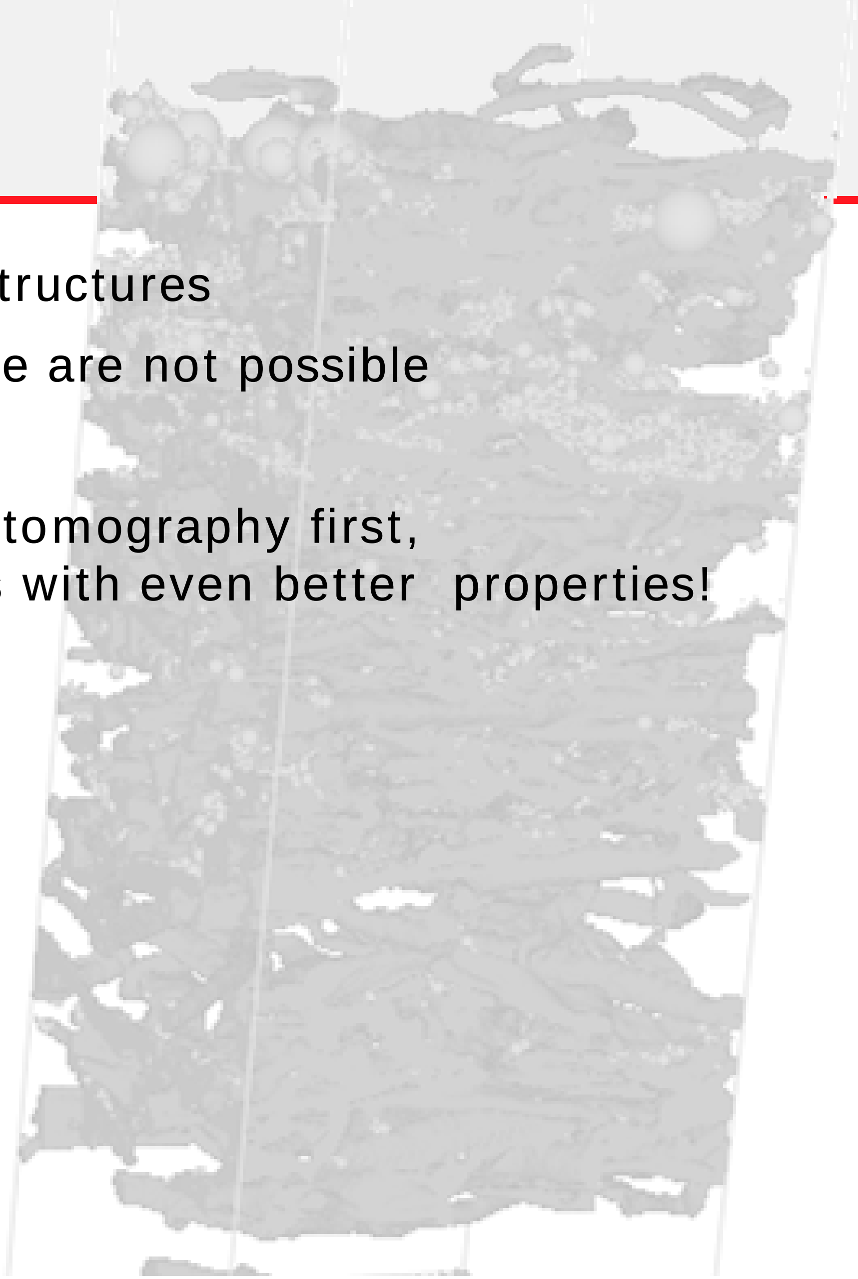


Simulate on µCT scans

(+) Allows simulations on real filter structures

(-) Modifications of the filter structure are not possible

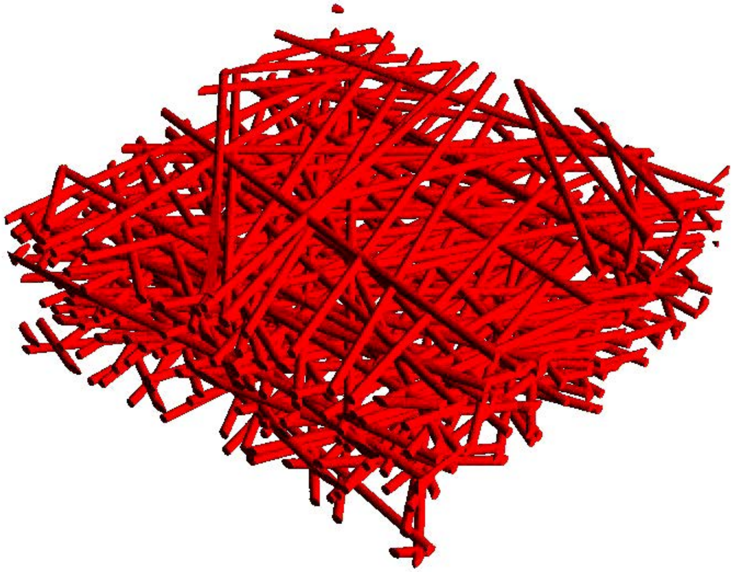
Aim: create a model that mimics the tomography first,
then modify it to find structures with even better properties!



Create 3D structure models

Input parameters needed (straight fibers):

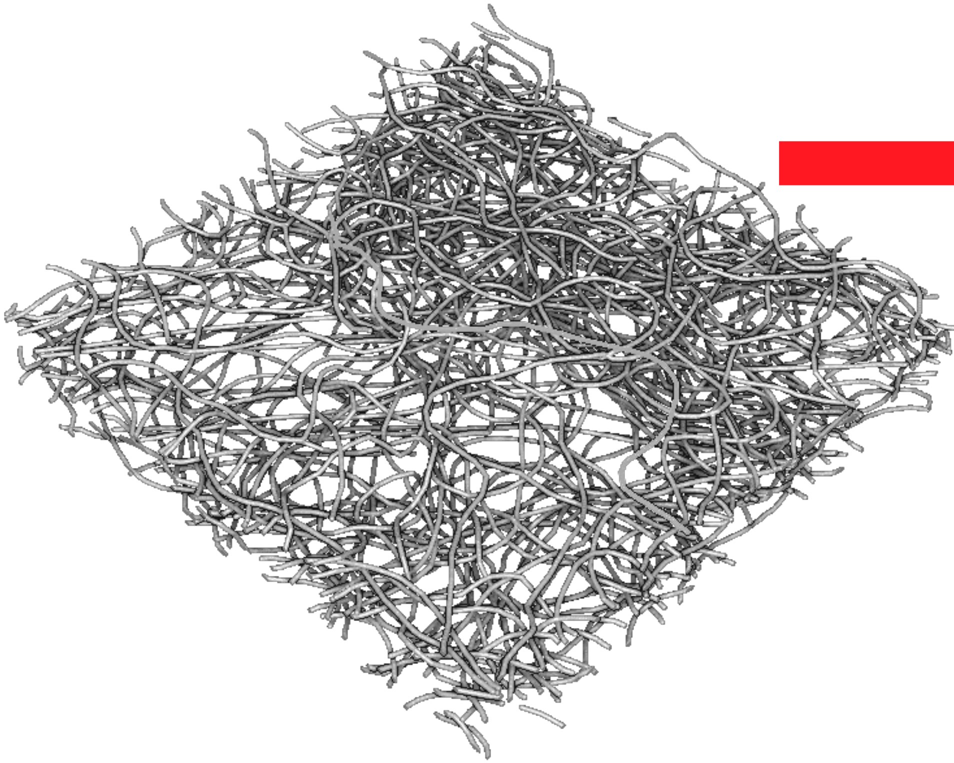
- Porosity
- Fiber type: cross sectional shape, diameter, length
- Fiber orientation tensor
- Thickness (height) of the filter media

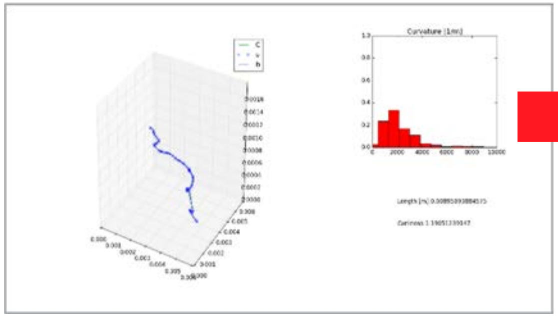


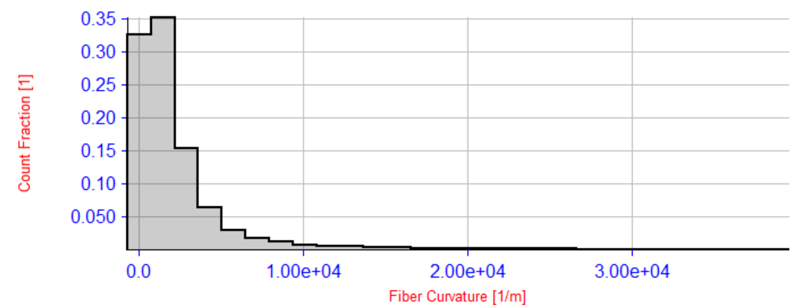
Parameters might be

- known from manufacturing process
- measured experimentally
- measured from CT image

Fiber Curvature





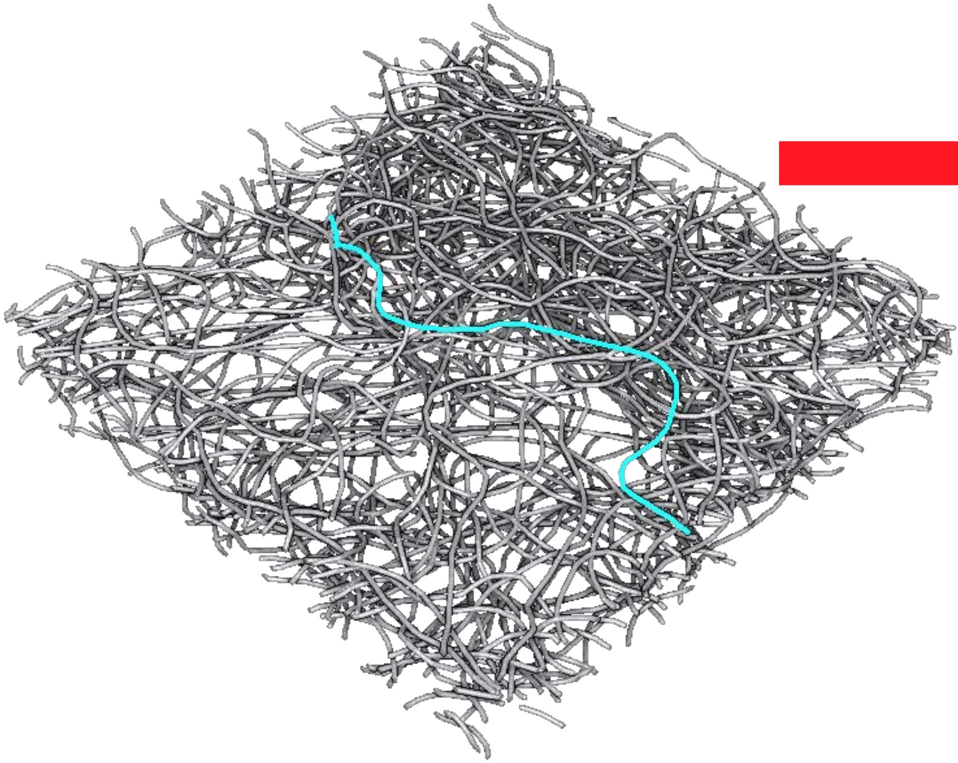


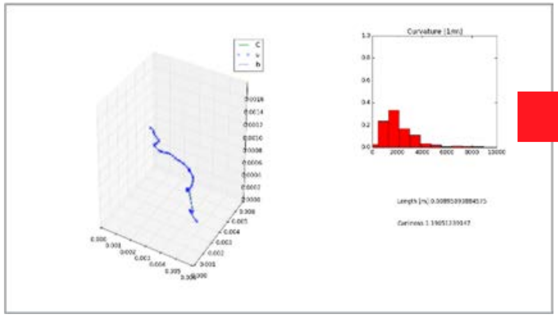
Segment image

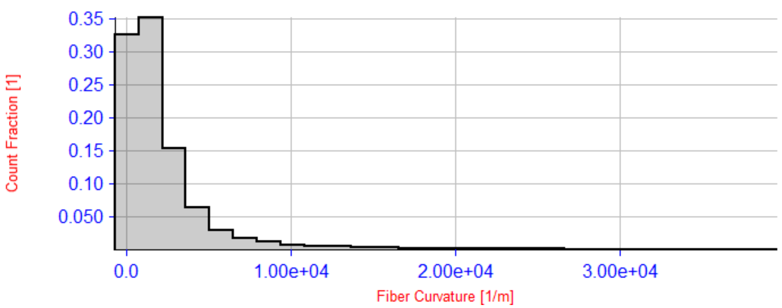
Identify fibers

Analyze every fiber individually and combine

Fiber Curvature



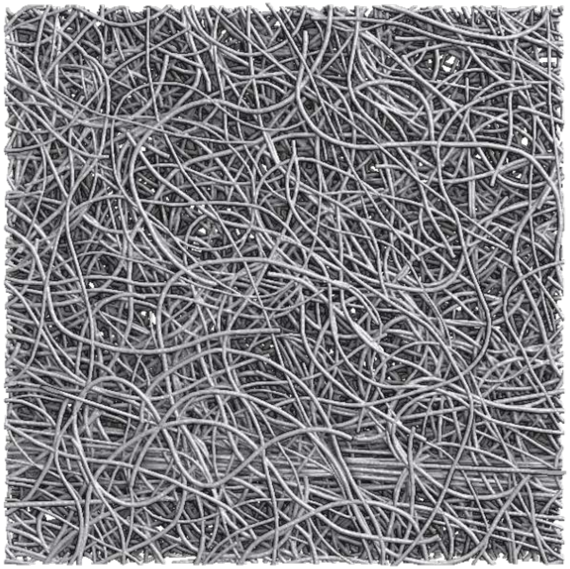




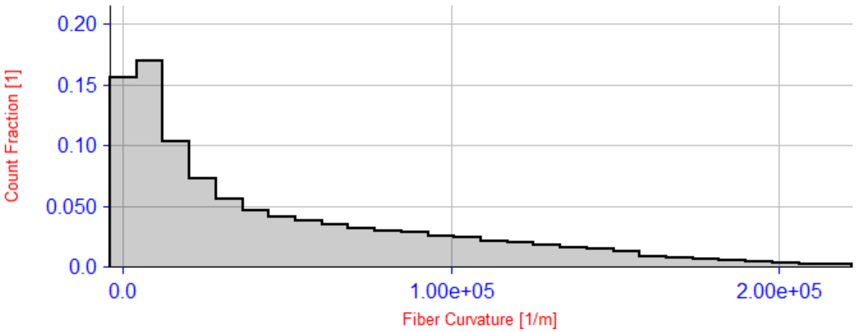
Segment image → Identify fibers → Analyze every fiber individually and combine

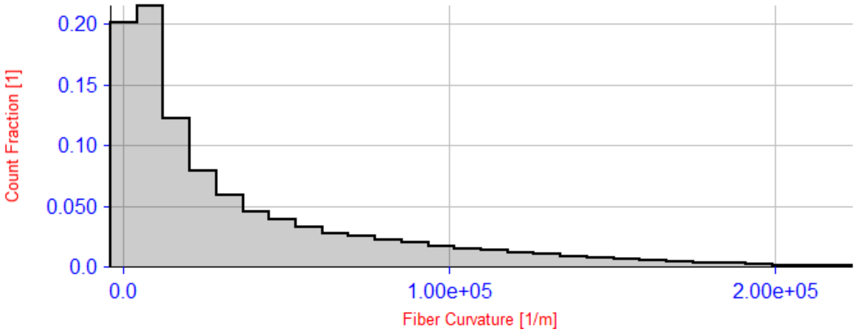
Estimated parameters used to generate a model of the gas diffusion layer

Original Structure



Modeled Structure

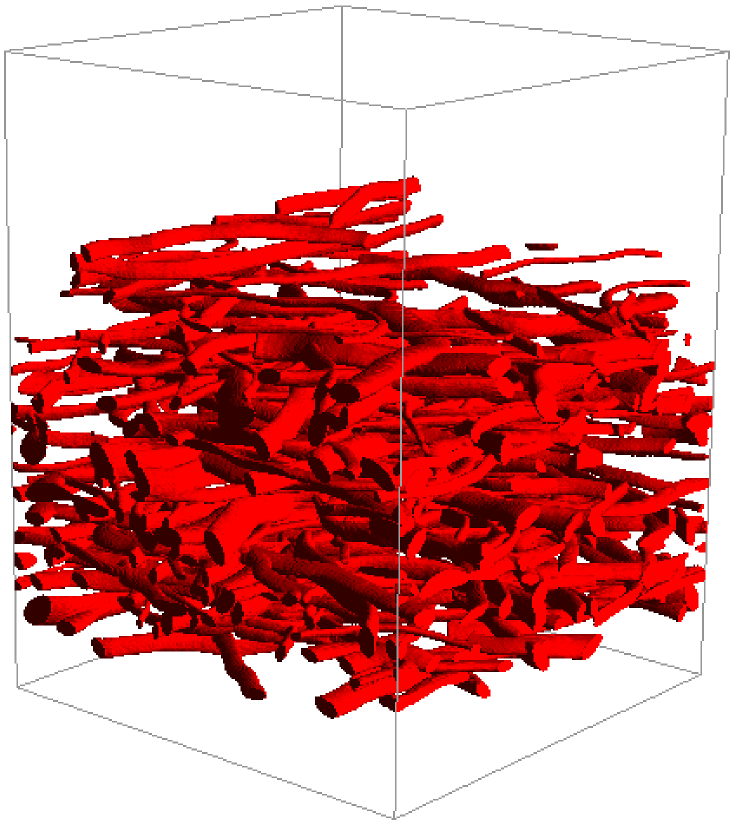




Create an oil filter model

- Ellipsoidal cr
  diameter dis
- Curved fiber
- Fibers orient
- 500 x 500 x
  1 µm voxel l

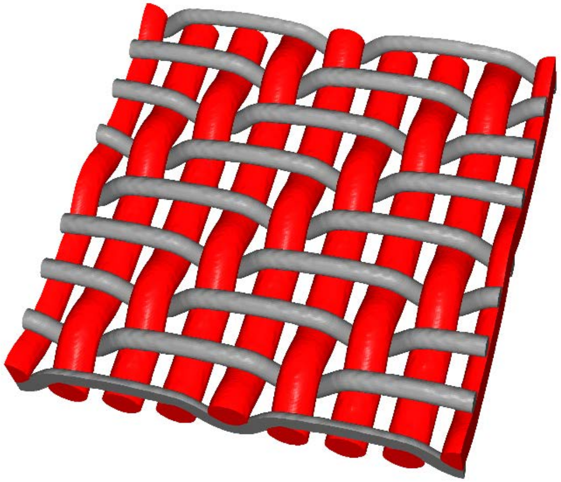
Create cellulose and layered media scale models



Cellulose nonwoven

Layered filter medium

Create woven, foam and sintered media scale models

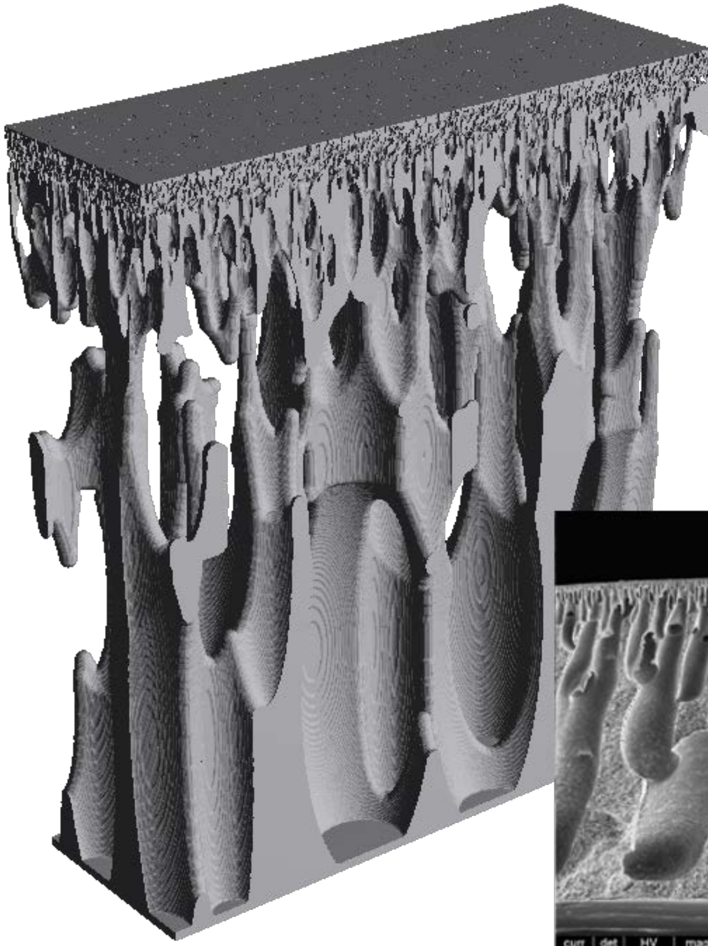


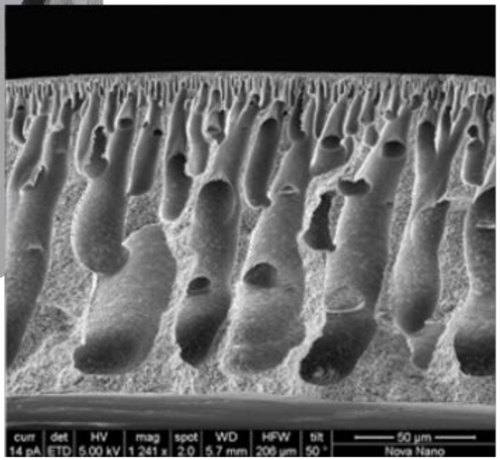
Metal wire mesh

Open-cell foam

Sintered ceramics

Model a desalination membrane from a SEM image

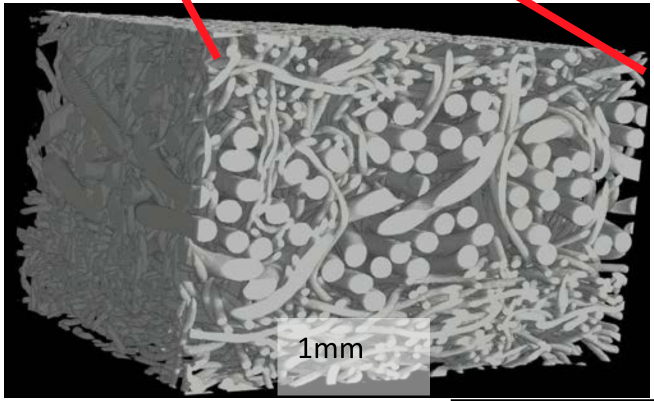




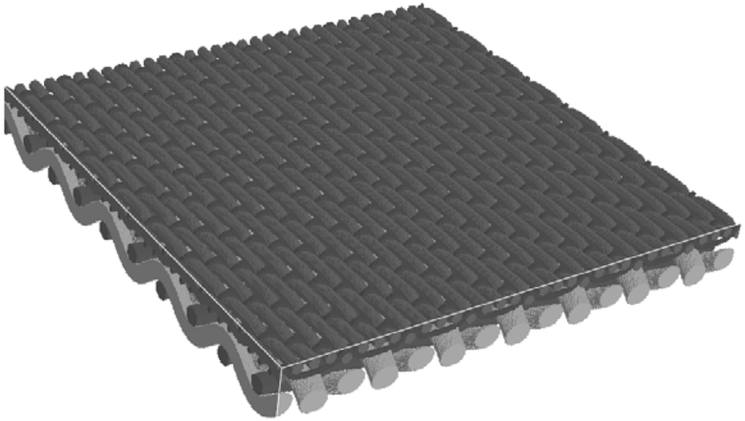
http://www.geodict.com/Showroom/structures.php

µCT scan and models of a felts

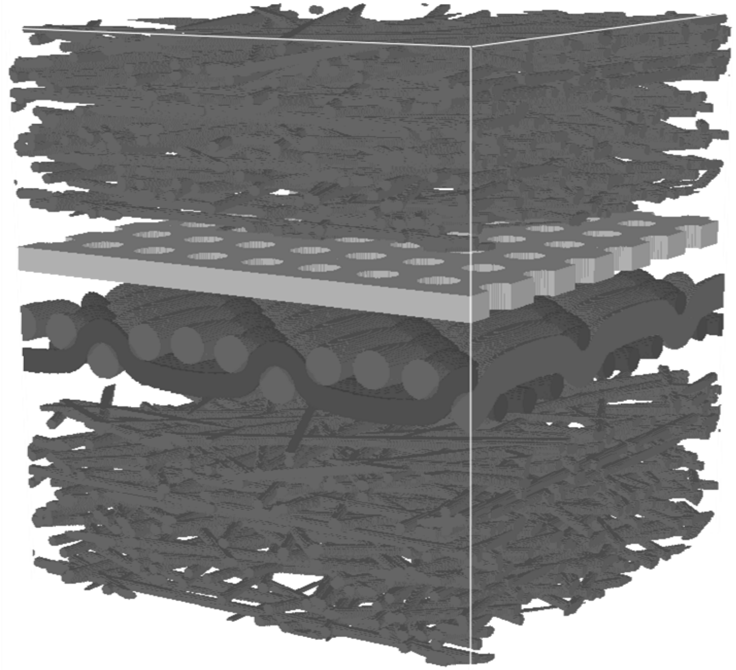
Paper machine



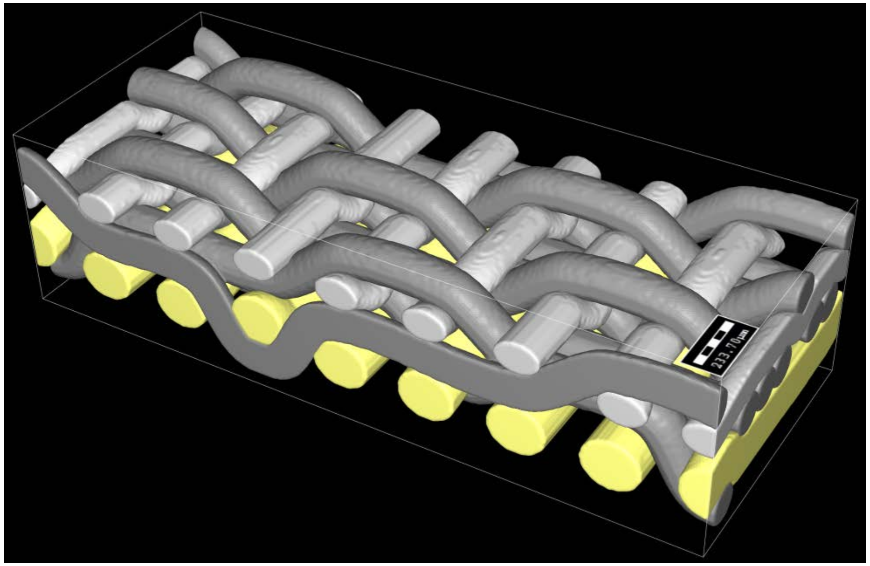
Tomography

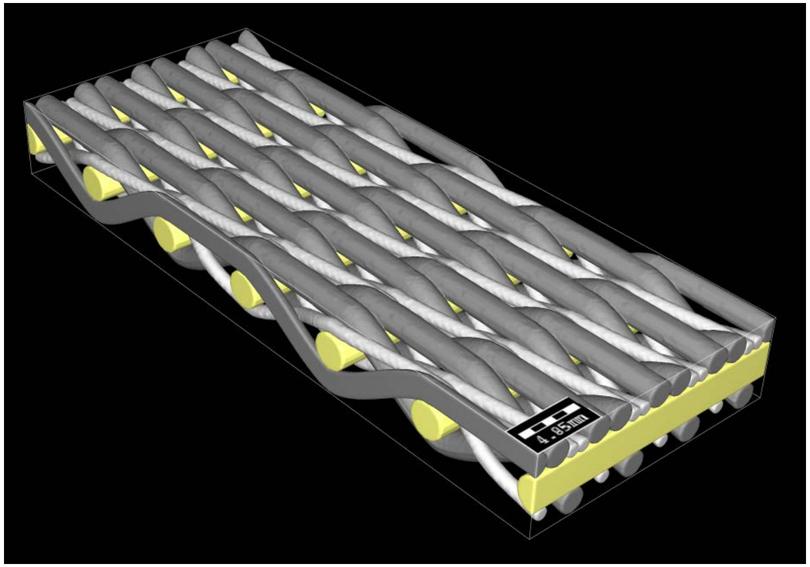


Forming fabric and dewatering felt



Woven Metal Wire Meshes: Complex weave models





Left: Model of a two-layer weave based on a CT-scan.
Right: Model of a complex one-layer twill Dutch-weave.

Flow Simulation
Stationary Navier-Stokes flow

$-\mu\Delta\vec{u} + \rho(\vec{u}\cdot\nabla)\vec{u} + \nabla p = 0$ (momentum balance)

$\nabla\cdot\vec{u} = 0$ (mass conservation)

$\vec{u} = 0$ on Γ (no-slip on surface)

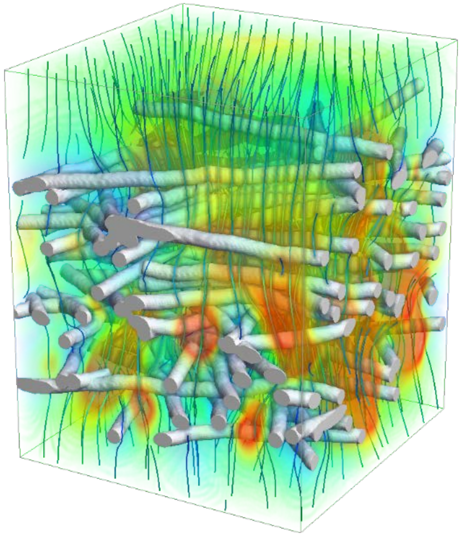
$P_{in} = P_{out} + const$ (pressure drop is given)

$\vec{u}$: velocity

p: pressure

μ: dynamic viscosity

ρ: fluid density



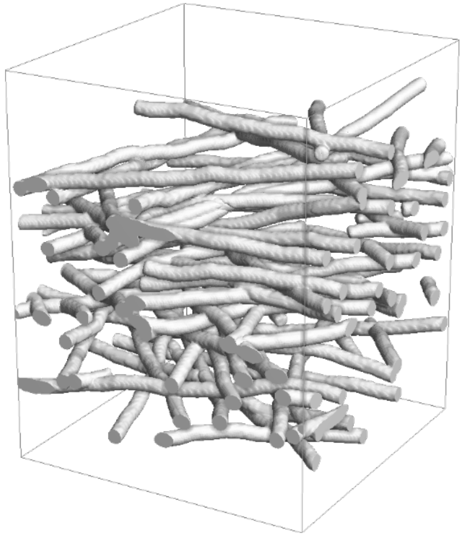
Filter Efficiency Simulations

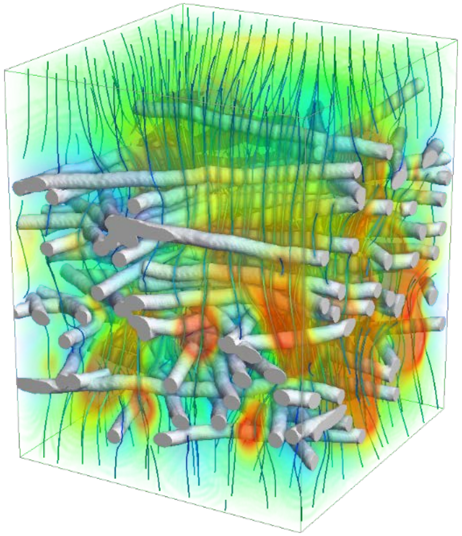
Basic idea:

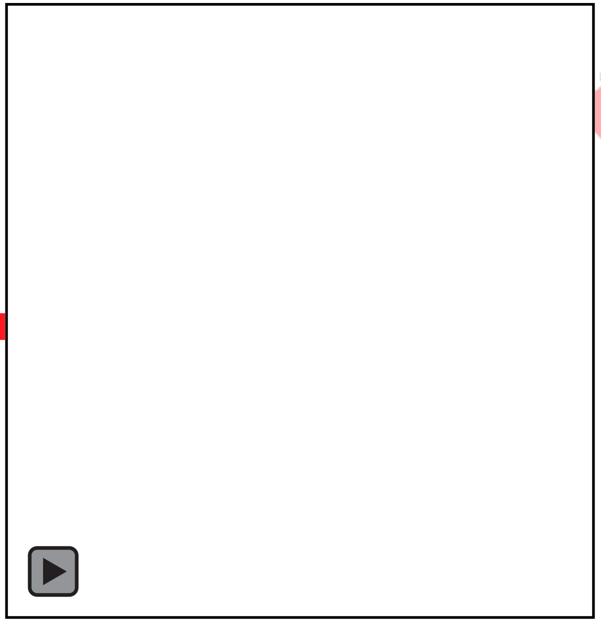
1. Filter media model
2. Determine flow field
3. Track particles (filtered or not?)

Result:

- Percentage of filtered particles



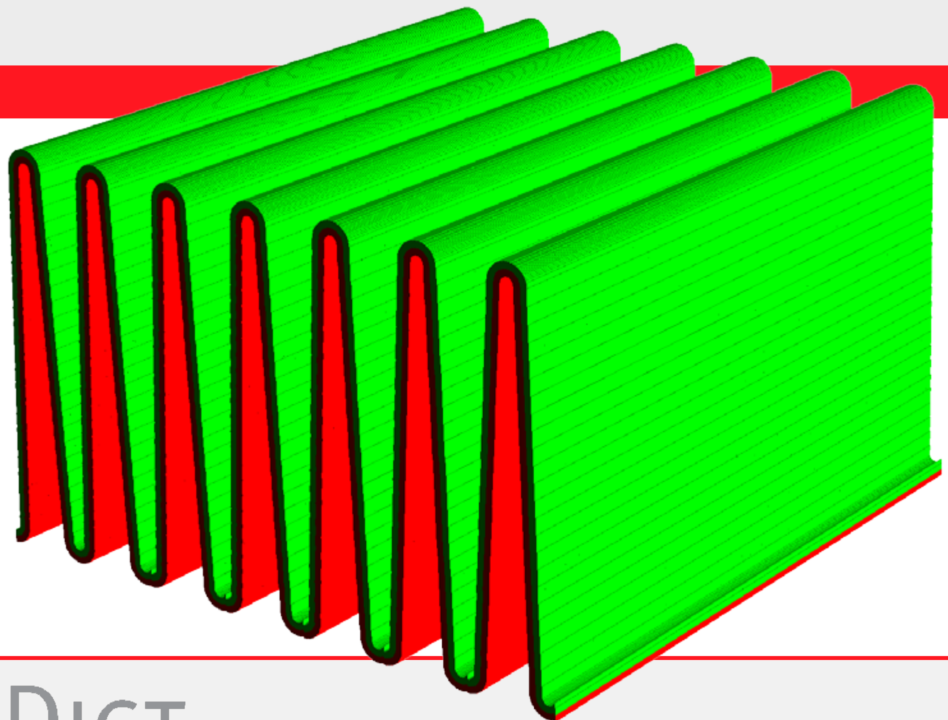


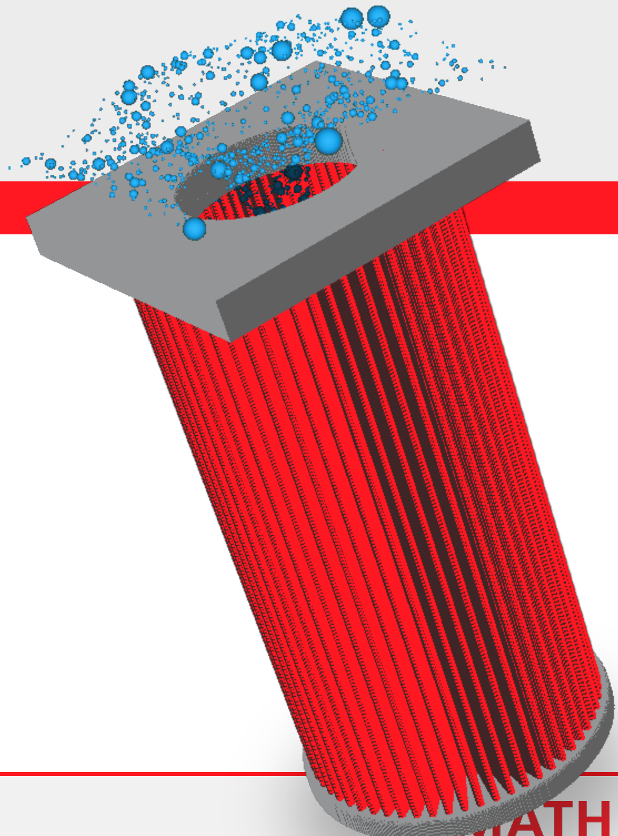


Filter life-time simulations

Filter Capacity and Life Time

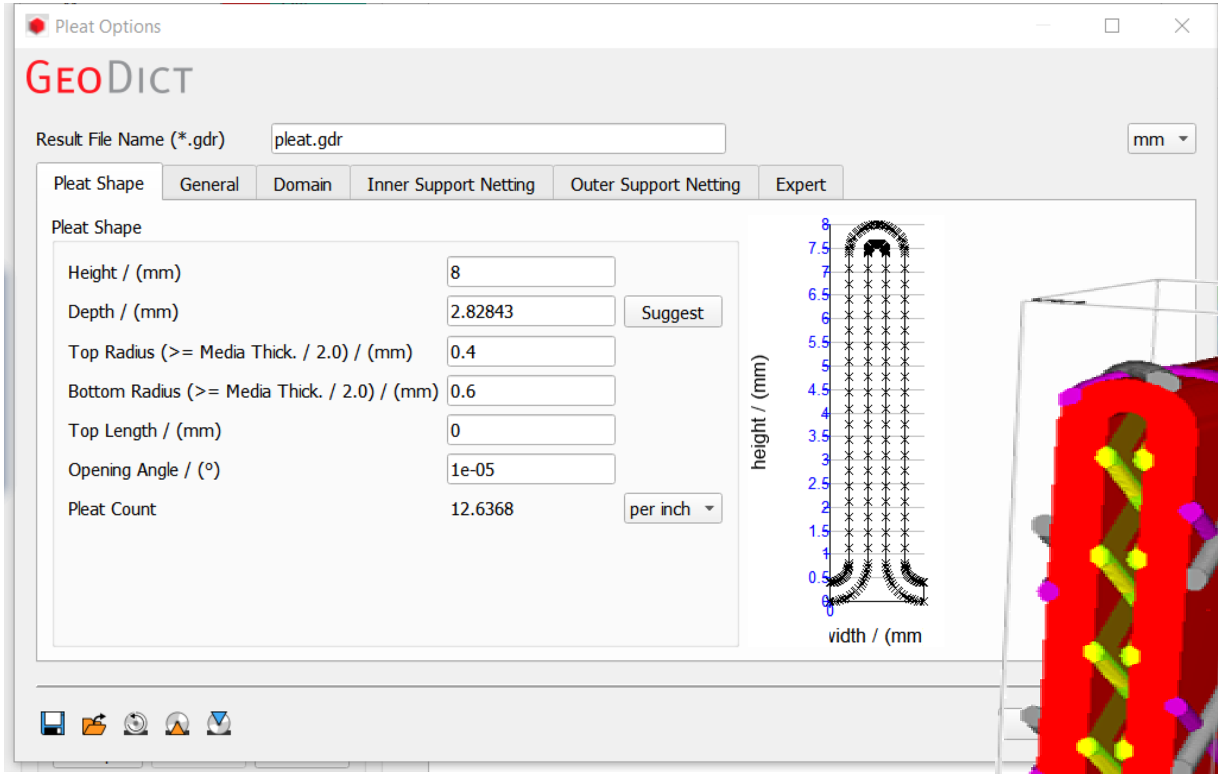
Pleat models and property simulations

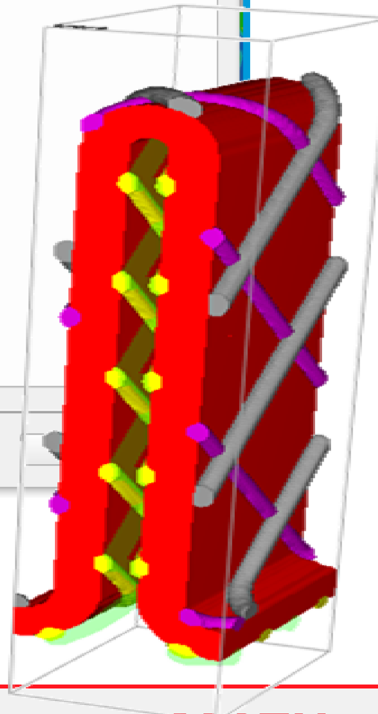




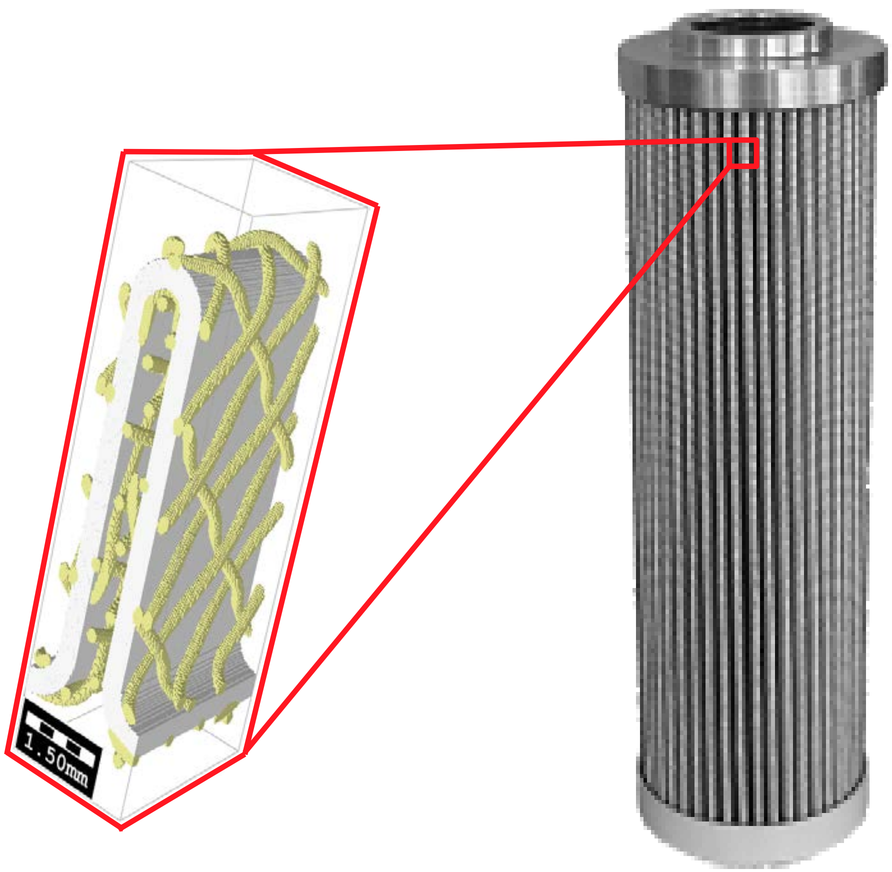
Pleat model

- Pleat Generator accounts for
  - Height
  - Width
  - Inner support
  - Outer support
  - Layered media
  - Angeled pleats
  - Etc.



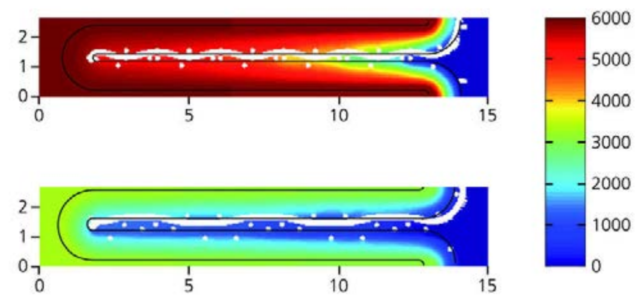


Hydraulic filter with supported pleat



Source: webpage Argo-Hytos

ARGO HYTOS



Two effects lead to pressure loss:

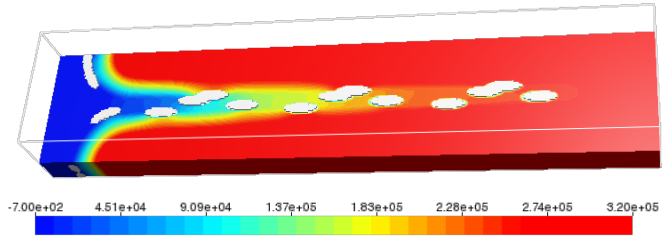
1. Across the filter media
2. Along the outflow channels

A support mesh prevents the collapse of the outflow channel

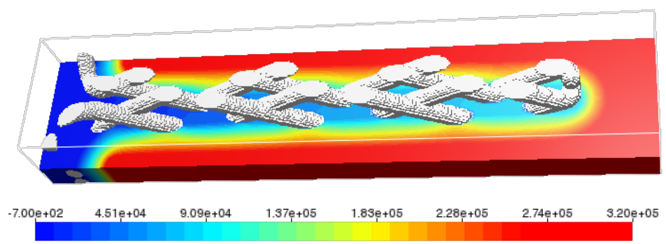
Optimized hydraulic filter

- Same pleat count
- Vary channel width by weave pattern & wire diameter

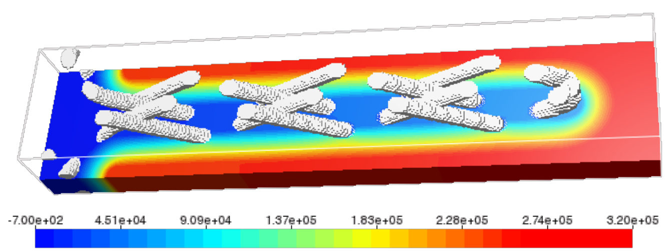
Trying different parameters, the pressure drop could be lowered by more than 35%, by reducing the pressure loss along the outflow channel.



Narrow Channel: 4 bar



Thick Wire: 3.1 bar



Thin Wire: 2.7 bar

Wiegmann, O. Iliev, and A. Schindelin, Computer Aided Engineering of Filter Materials and Pleated Filters, Global Guide of the Filtration and Separation Industry by E. von der Luehe. VDL - Verlag, 2010, pp 191-198.

The optimized filter element …

Innovation in filtration

Focus on user benefits

ARGO-HYTOS sets the standard with the introduction of EXAPOR®MAX 2

Higher machine availability, longer service intervals and lower operating costs. These were the development goals for the new generation of filter elements.

With the introduction of **EXAPOR®MAX 2**, ARGO-HYTOS is opening a new chapter in filtration for hydraulic and lubrication systems.

The structure of the specially developed 3-layer filter material was designed for optimum performance, using glass and polyester fibers of different finenesses combined with an improved hybrid support fabric (patent pending) made of stainless steel and polyester. This sets the standard for:

- **Pressure loss**
- **Dirt holding capacity**
- **Flow fatigue stability**

The plastic sleeve used on the **EXAPOR®MAX 2** for the first time offers the following benefits:

- **Custom label**
- **Protection from damage**
- **Improvement of flow fatigue stability**

For the user, these improvements bring:

- **Extended service intervals**
- **Higher operational reliability**
- **Improved oil cleanliness**
- **Increased performance**
- **Positive element identification**
- **Reduced operating and maintenance costs**

Extended service intervals

Higher dirt holding capacity and improved flow fatigue stability are of particular importance in achieving extended service intervals.

The new performance-oriented structure of the filter material makes a substantial contribution to improving dirt holding capacity, reducing pressure losses and improving the differential pressure stability. The improved hybrid support fabric (patent pending) dissipates electrostatic charge completely, gives the best possible flexural strength while reducing pressure losses. The plastic sleeve shrunk onto the filter bellows ensures that it tightly fits the edges of the hole, which has a positive effect on flow fatigue stability. These improvements make a substantial contribution to increasing the life of the filter elements.

Higher operational reliability

When used on existing machinery with fixed service intervals, **EXAPOR®MAX 2** filter elements bring greater operational reliability, minimizing the risk of sudden machine downtimes as well as reducing downtime caused by time-consuming and expensive maintenance work.

Improved oil cleanliness

A high degree of oil cleanliness has a positive effect on both the life of components and that of the hydraulic medium itself. To meet rising standards, in the new generation of filter elements the filter fineness has been improved to 10 µm(c) compared with 12 µm(c) previously. The **EXAPOR®MAX 2** filter elements are available in filter finenesses of 5 µm(c), 10 µm(c) and 16 µm(c).

Increased performance

The factors that influence pressure loss could be worked out with the aid of calculations and flow simulations, and the structure of the filter material optimized accordingly. The result is a reduction in pressure losses in the pleat of up to 50% and up to 40 % in the filter element. Conversely, this means that at a constant pressure loss the **EXAPOR®MAX 2** filter elements can achieve a flow rate that is up to 65 % higher. The substantial reduction in pressure losses allied to an improved dirt holding capacity leads to an increase in power density, so that, depending on the application, smaller filters could be used.

Positive identification of elements

The plastic sleeve used on the **EXAPOR®MAX 2** filter elements can be printed as required. This substantially improves positive identification and is an important feature for building up and securing a strategic spare part business.

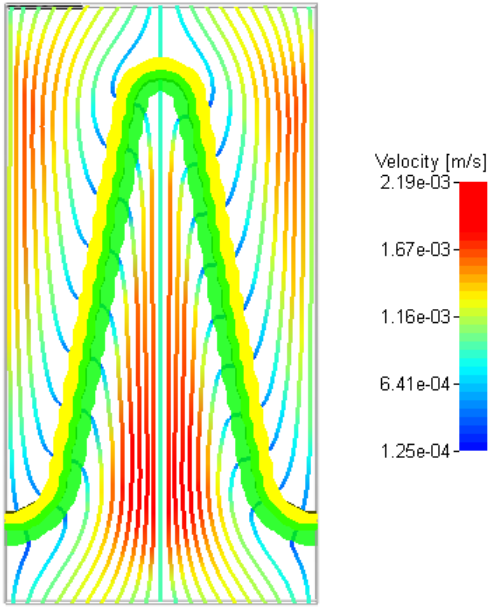
Reduced operating and maintenance costs

These innovations work together to reduce operating and maintenance costs and bring about an improvement in the productivity and economy of machinery and plant.

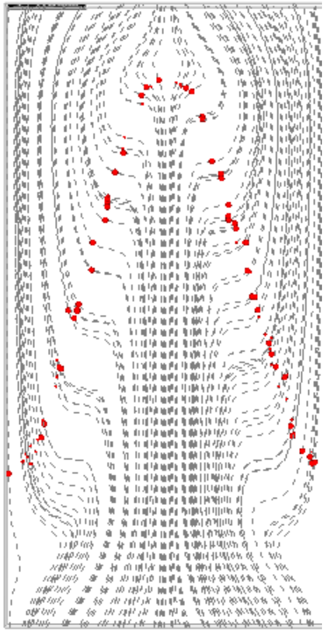
A new design for hydraulic filter lowers the pressure drop by 40-50 %

Patent granted to Argo-Hytos in 2009

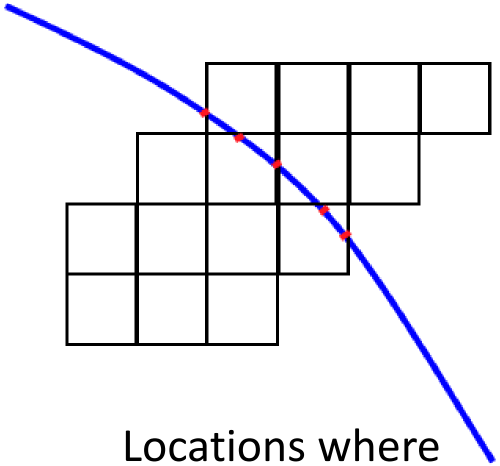
Pleat scale: filtration simulation



First, compute the flow in the pleat

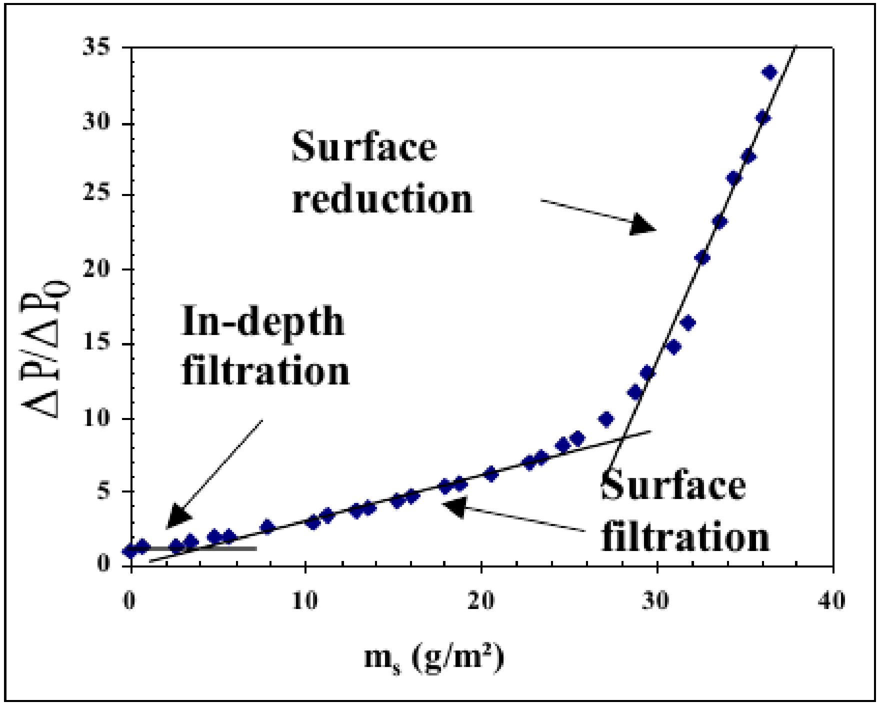


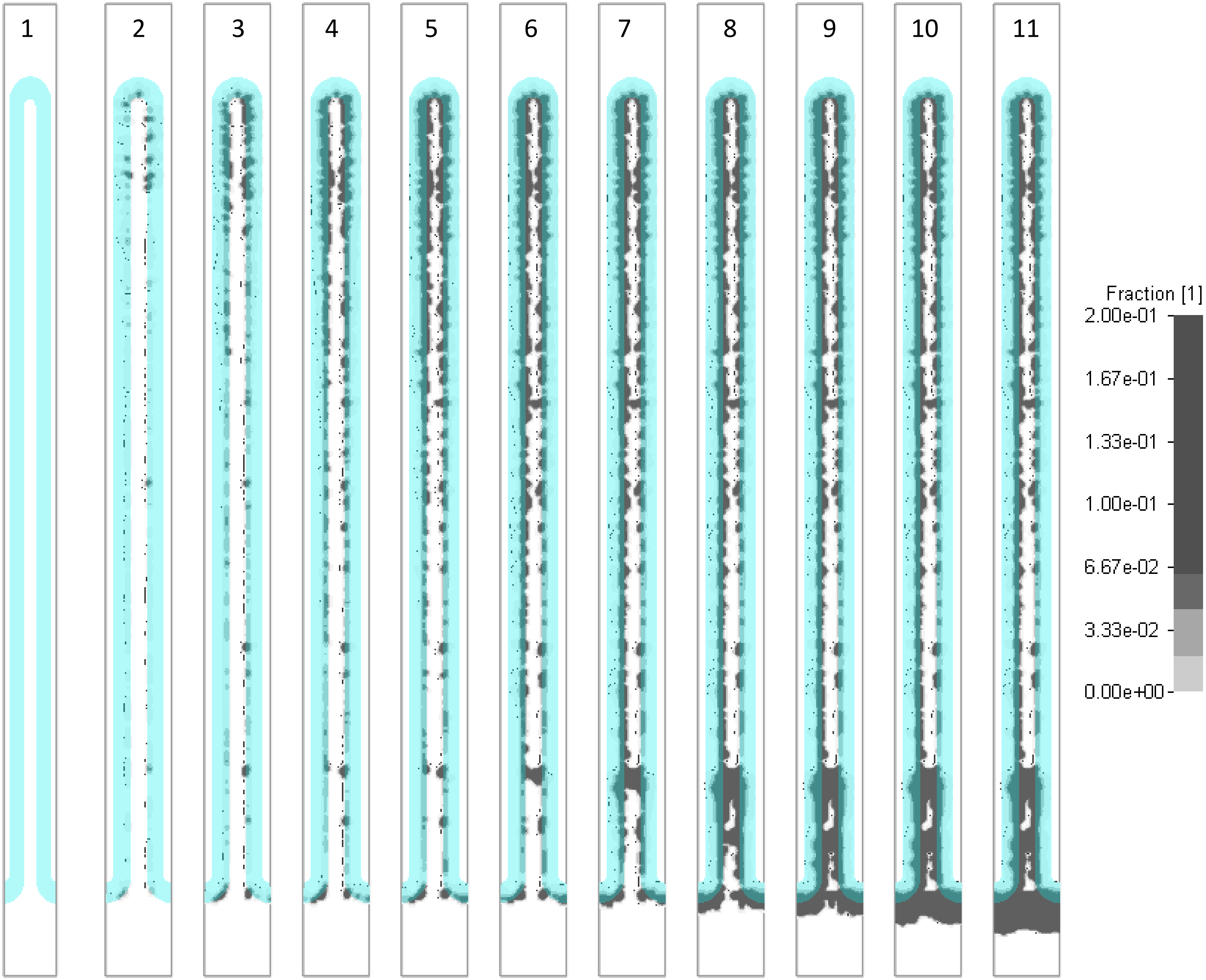
Then, track the particles and find the trajectories following the flow field without obstacles.



Locations where particles cross the media are found and the probability of particles being captured in the media is determined.

Compare with experimental data

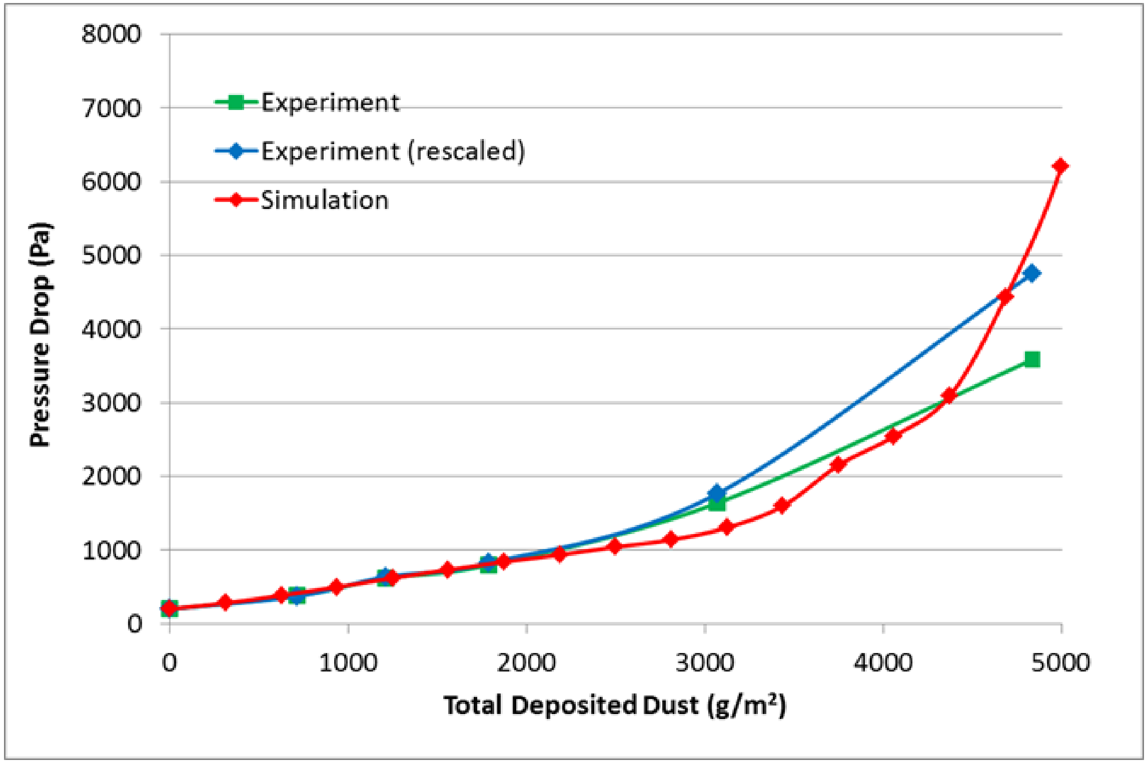




The particle deposition with time

Agreement with experimental data

- Pressure drop vs. load of a pleated filter
- Rescale to constant flow rate, what the pump was asked to do but did not do
- Simulation results compared with experimental measurements (rescaling done w.r.t. fluctuations in the volumetric flow rate)



*Pierre-Colin Gervais, Experimental and numerical study of clogging of pleated filters. PhD thesis, CNRS, LRGP, UMR 7274, Nancy, F-54000, France, 2013.

Conclusions

Conclusions

- We saw 3d models for filter media, pleats and whole filters, where the media models could also result from µCT scans of existing media
  - Cellulose, glass and synthetic fibers
  - Ceramics
  - Open cell foams
  - Weaves
- On the models one can predict
  - Pore Size measures
  - Pressure drop, flow resistivity, permeability,
  - Filter Efficieny
  - Filter Life Time / Dust Holding Capacity
- Simulations, combined with experiments, can lead to
  - New knowledge, such as more detailed information, parameter study
  - Quantification of phenomena such as different filtration stages
  - And also patents and long term commercial benefits

Thank you!

Visit us @ www.geodict.com

Tracking Particles in a Flow Field

Impulse — Stokes Drag — Electrostatic Force

$$m\frac{d\vec{v}}{dt} = 6\pi\mu\frac{R}{C_c}\left(\vec{u} - \vec{v} + \sqrt{2D}\frac{d\overrightarrow{W}(t)}{dt}\right) + Q\vec{E}$$

Cunningham Corrected Particle Radius ($\frac{R}{C_c}$)

Brownian Motion ($\sqrt{2D}\frac{d\overrightarrow{W}(t)}{dt}$)

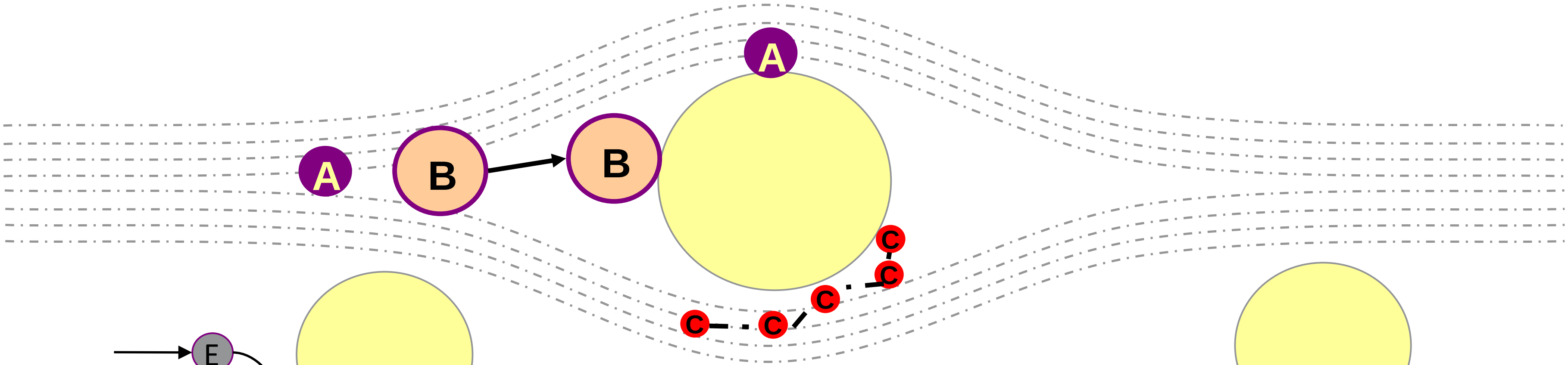
$\vec{v}$	: particle velocity [m/s]	μ	: dynamic viscosity [kg/m·s]
$\vec{u}$	: fluid velocity [m/s]	Q	: particle charge [C]
R	: particle radius [m]	E	: electric field [V/m]
C_c	: Cunningham correction	D	: Diffusivity [m²/s]
m	: particle mass [kg]	$d\overrightarrow{W}$	: 3D Wiener process

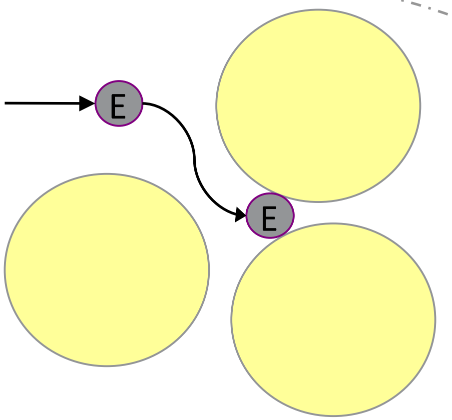
Filtration Effects I

A: direct interception

B: inertial impaction

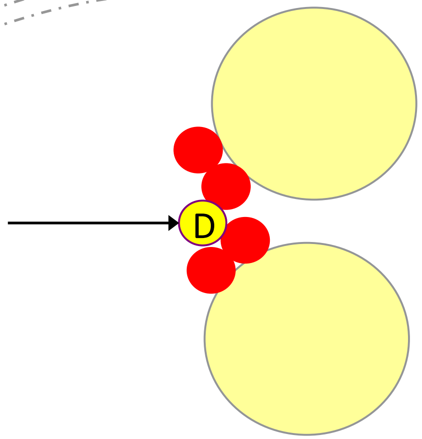
C: diffusional deposition





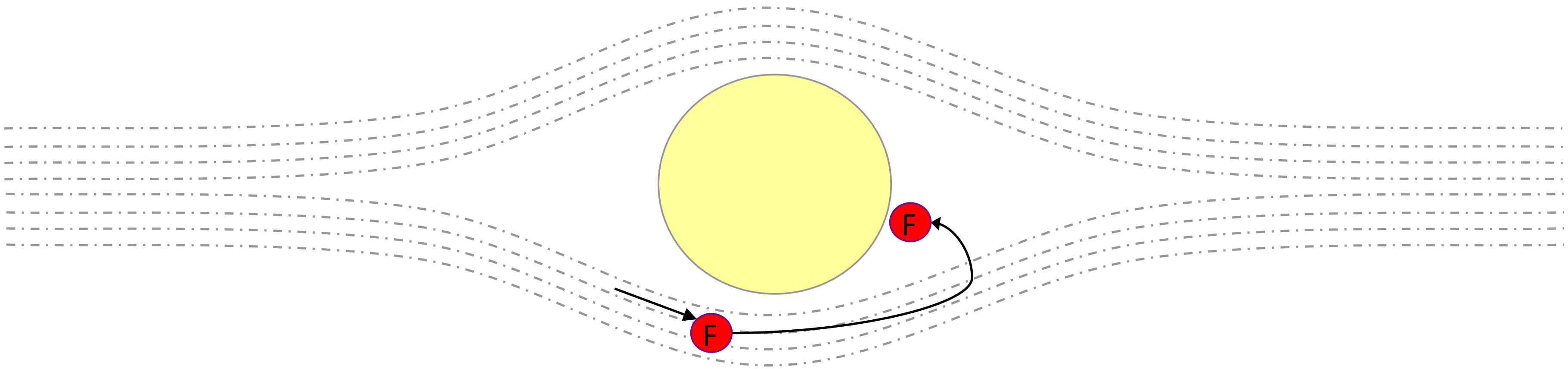
D: clogging

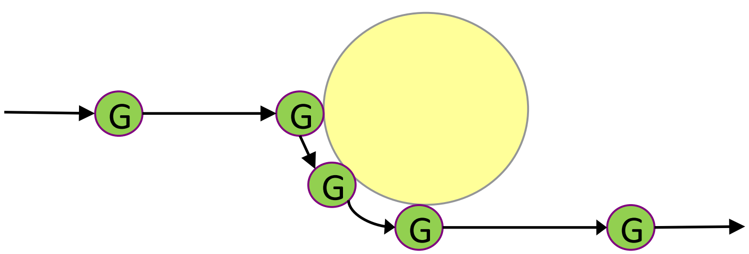
E: sieving



Filtration Effects II and modes of particle motion

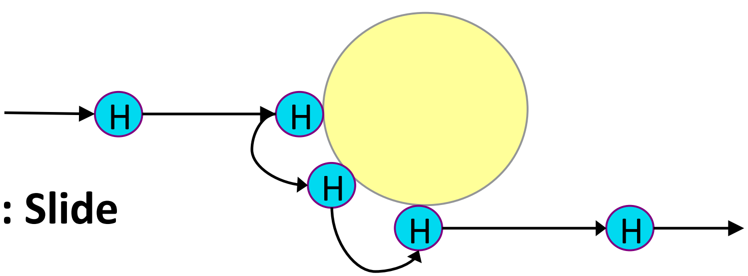
F: electrostatic attraction





G: Slide

H: Bounce



Collision model

Caught on firstst touch

Hamaker

Sieving