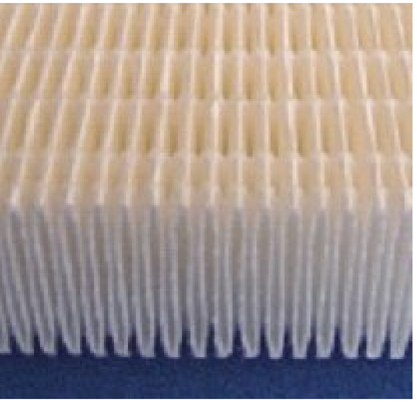
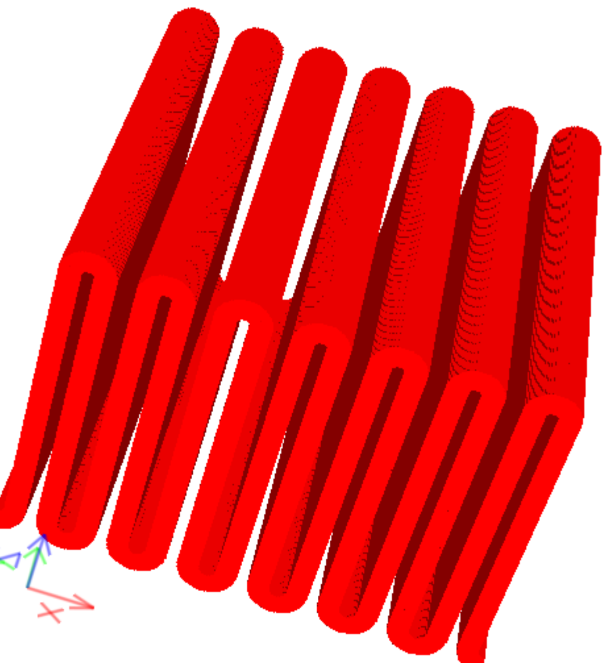
Computational Study of Dependence of Pressure Drop on Pleat Shape and Filter Media



Andreas Wiegmann, PhD wiegmann@itwm.fhg.de

Dr. Stefan Rief rief@itwm.fhg.de

Dr. Dirk Kehrwald kehrwald@itwm.fhg.de



Filtech 2007

Wiesbaden, February 27th, 2007.

Fraunhofer Institut Techno- und Wirtschaftsmathematik

Designing filter pleats via simulation

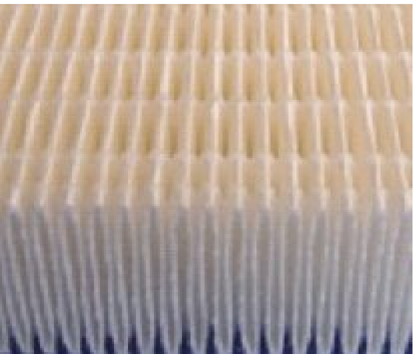
Filter design objectives:

- Minimize Space Requirements
- Minimize Pressure Drop
- Maximize Filter Efficiency
- Maximize Filter Capacity
- …

Pressure Drop

Filter Efficiency

Filter Capacity



How to design filter pleats via simulation

I How to design a pleat? – Macro scale geometry and permeability

II How to compute the pressure drop? – Macro scale pressure and velocity distributions.

III Where do particles deposit? – Macro scale size-dependent deposition location.

Scope for today.

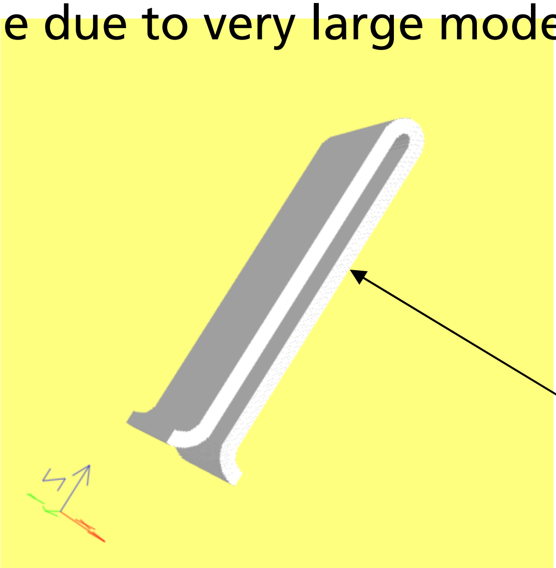
I What is a pleat, how does the modelling work?

\ pleat is defined by its shape, the media thickness
nd the media permeability.

he shape defines inflow and outflow regions. The inflow regions
ontains more dirt particles than the outflow region because the
orous region “filters” the dirt.

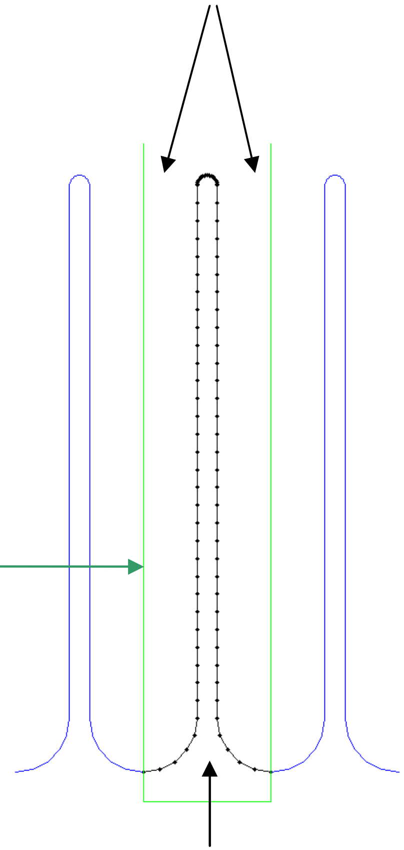
/ery simple model: Discretize as little cubes called voxels, Complexity
ossible due to very large models, here typically 60 x 60 x 400 cells.

Outflow region: “2” ½ channels



The pleat
extruded into 3D

Computational
domain with
periodic boundaries



Inflow region and channel

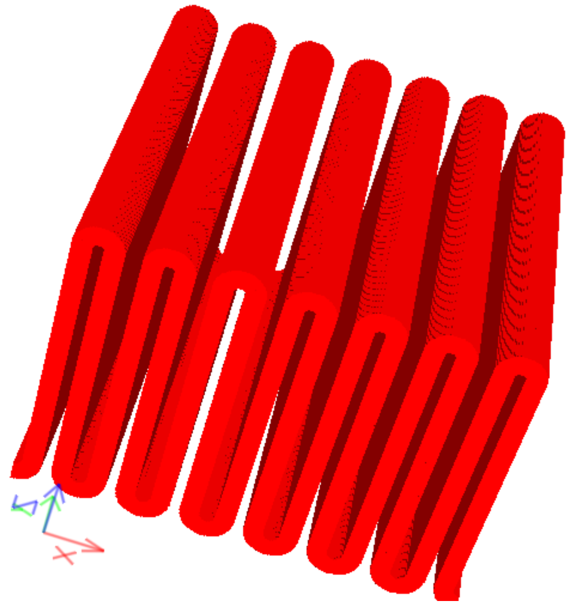
I Pleat design parameters

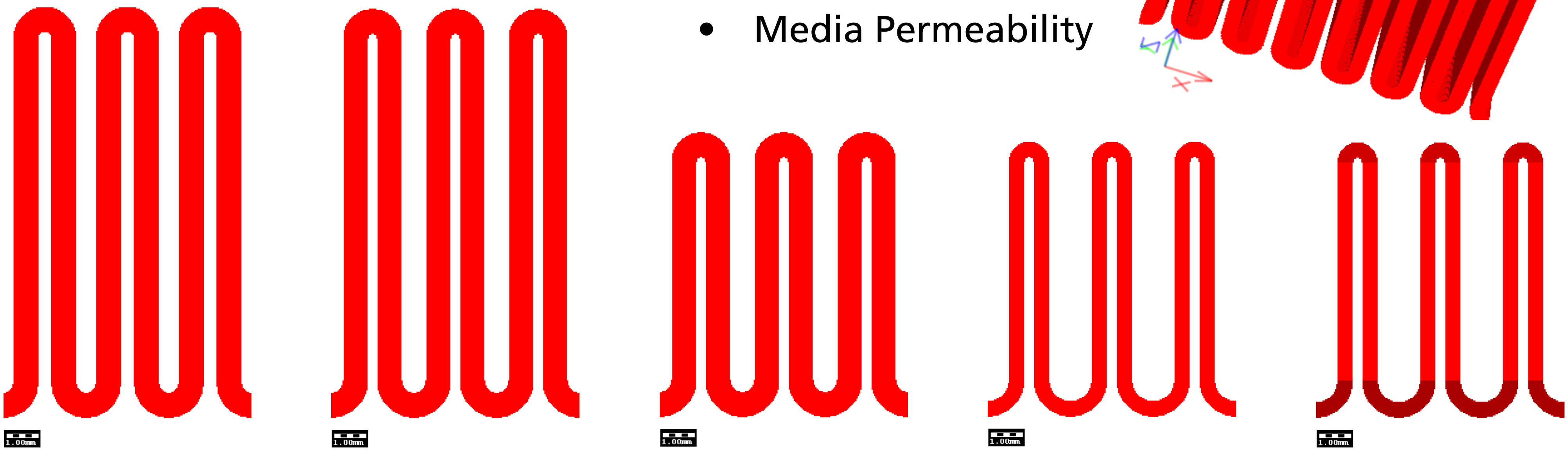
Fixed number of

2.5 mm pleats

Vary:

- Pleat radii
- Pleat length
- Media Thickness
- Media Permeability





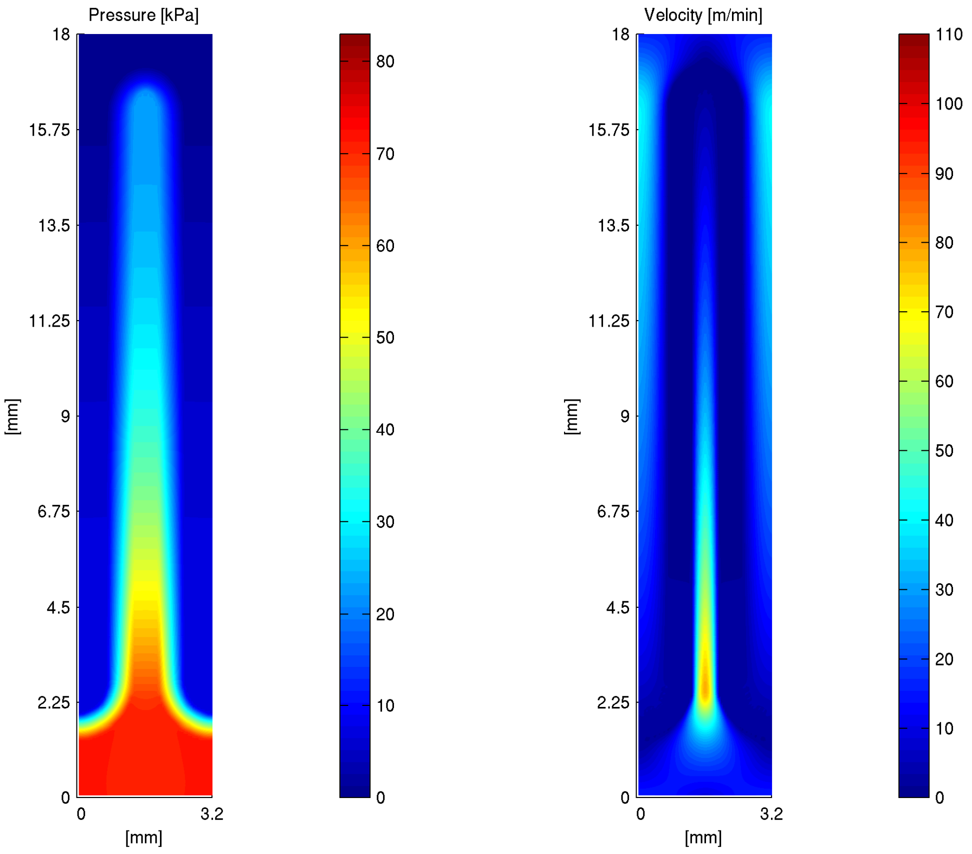
II Flow: Stokes-Brinkmann equations

$$
\begin{aligned}
-\mu\Delta\vec{u} + \nabla p + \kappa^{-1}\vec{u} &= \vec{\mathrm{f}} \text{ (momentum balance)} \\
\nabla \cdot \vec{u} &= 0 \text{ (mass conservation)} \\
\vec{\mathrm{f}} = (0, 0, f) &: \quad \text{force in flow(z)-direction,} \\
\kappa = \kappa(x, y, z) &: \quad \text{porous voxel permeability,} \\
\vec{u} &: \quad \text{velocity,} \\
\mu &: \quad \text{fluid viscosity and} \\
p &: \quad \text{pressure.}
\end{aligned}
$$

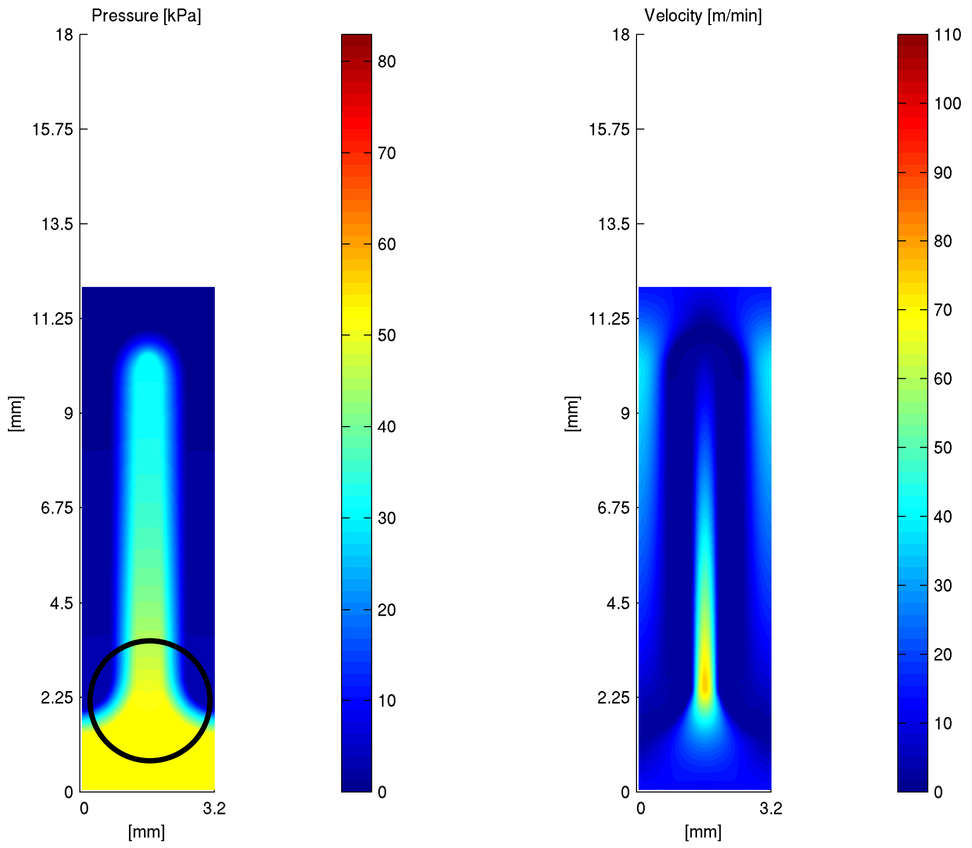
Same approach as on the micro scale!

The force corresponds to a mean flow velocity. The equations can be solved with a Lattice-Boltzmann method with periodic boundary conditions if the cutout is large enough and enough empty space is added in front and back.

II A shorter pleat has lower pressure drop



Pressure drop: 71 kPa



Pressure drop: 52 kPa

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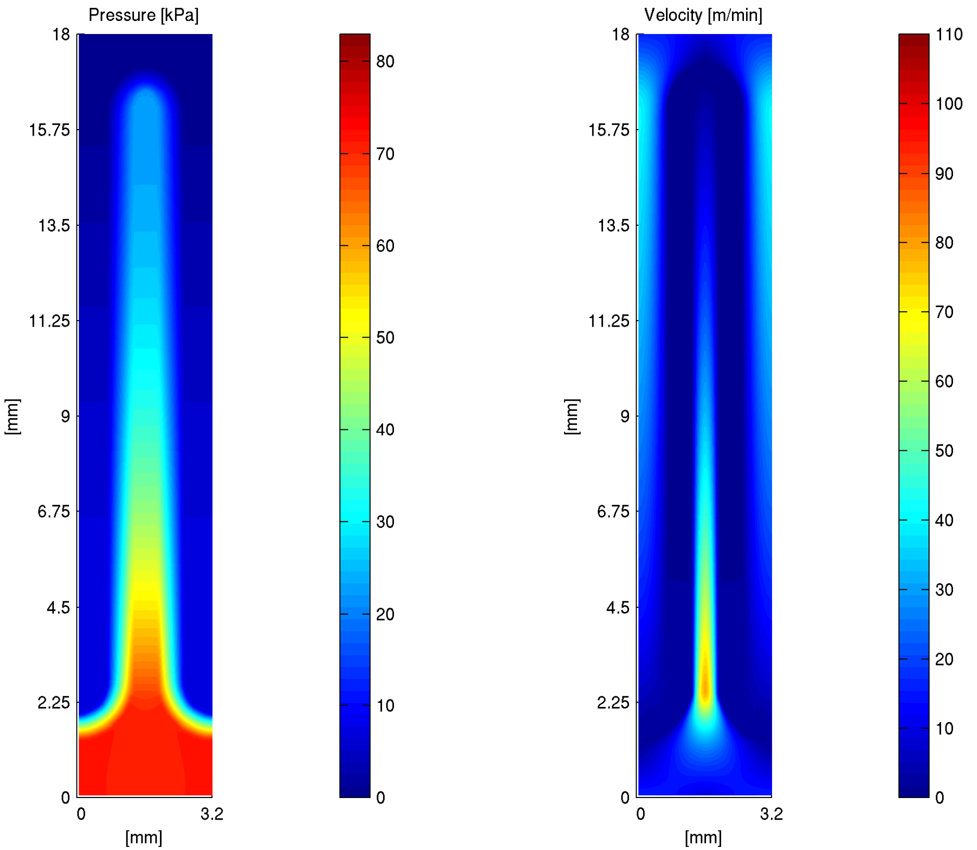
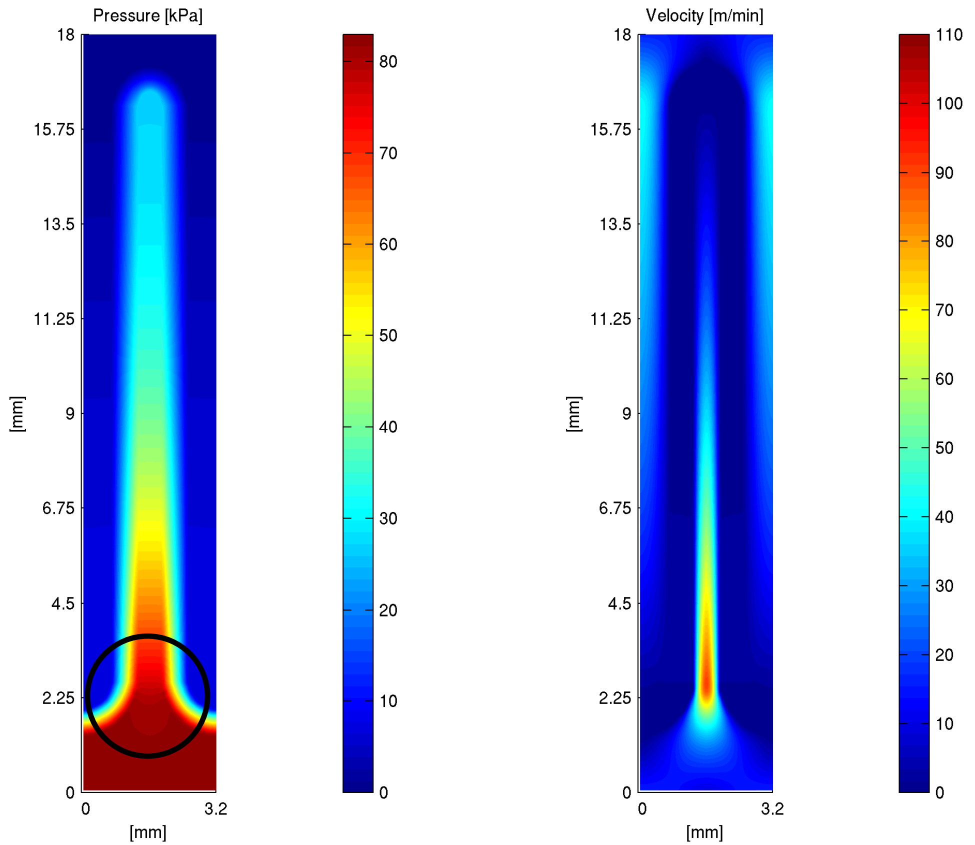
II Lower permeability in the fold yields higher pressure drop

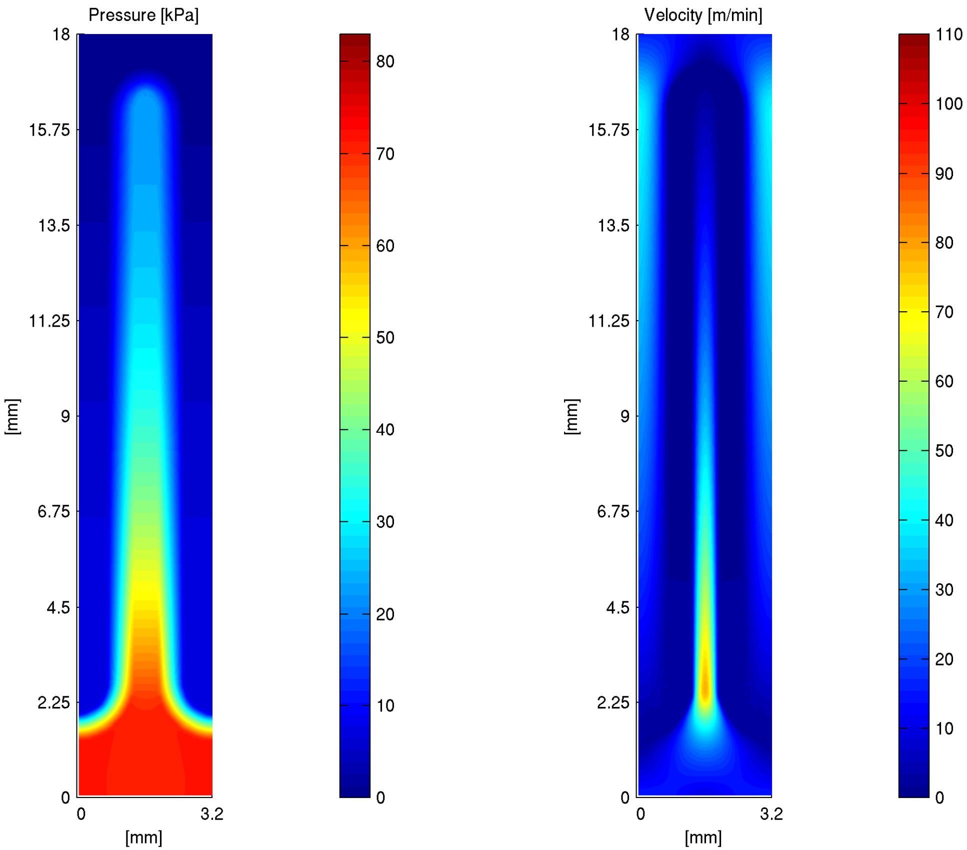


Pressure drop: 71 kPa

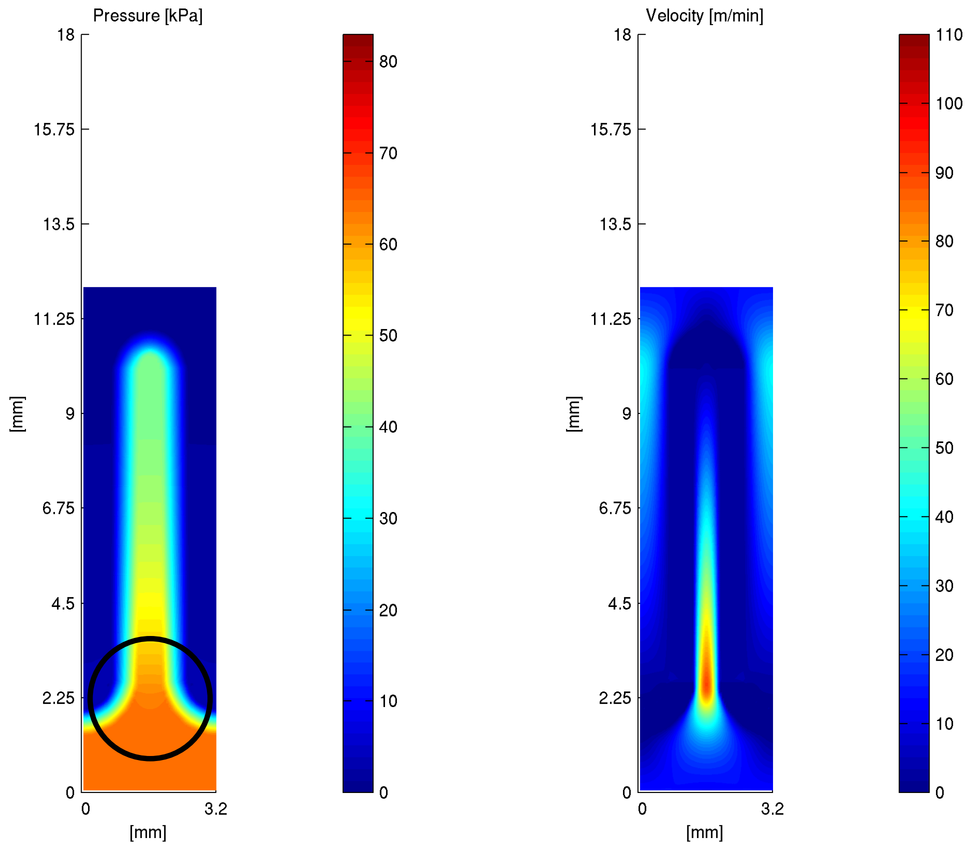


Pressure drop: 82 kPa

II Short pleat and low permeability almost balance



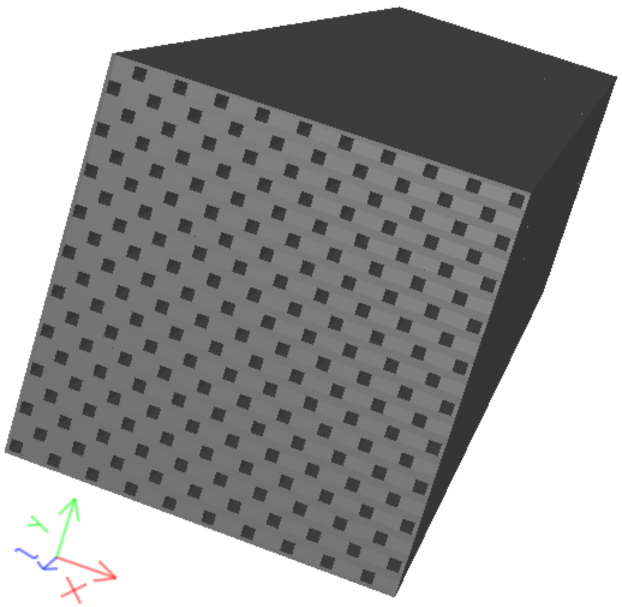
Pressure drop: 71 kPa



Pressure drop: 64 kPa

II Scope of the pleat design and flow computations

- Agreement with measurements is excellent, one industrial partner is considering to file a patent partly based on joint work using this type of simulation.
- Approach is possible because velocities are low, no boundary layers or vortices occur.
- The simulation is not limited to pleats: One application under consideration are diesel particulate filters:



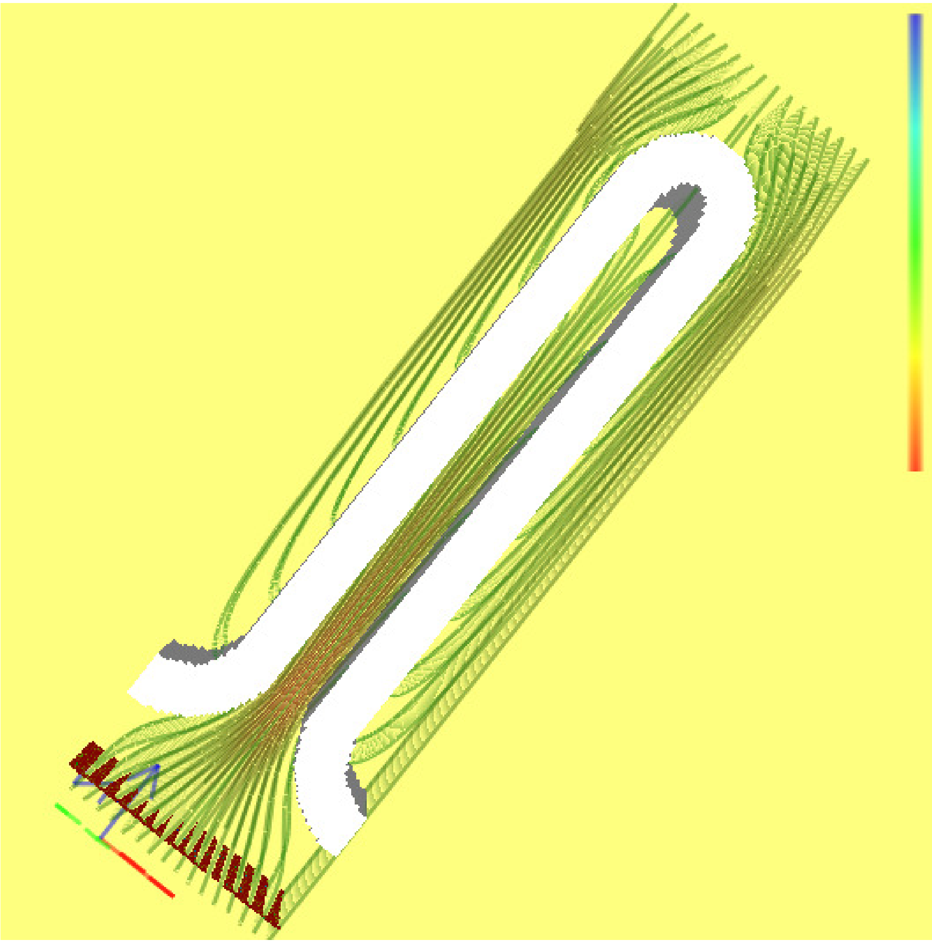
III Lagrangian description of particle motion: Considers inertia via friction and diffusion via Brownian motion

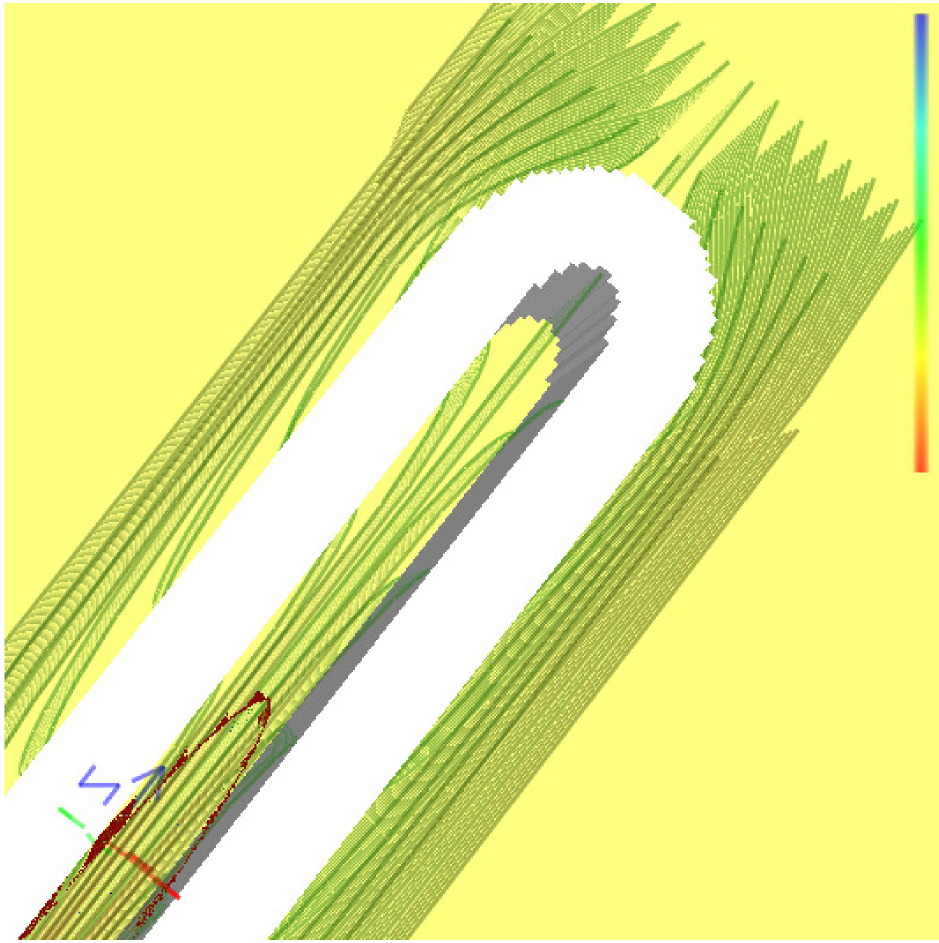
$$
\begin{aligned}
d\vec{v} &= -\gamma \times (\vec{v}(\vec{x}) - \vec{v}_\circ(\vec{x}))\, dt + \sigma \times d\vec{W}(t) \\
\frac{d\vec{x}}{dt} &= \vec{v} \\
\gamma &= 6\pi\rho\mu\frac{R}{m} \\
\sigma^2 &= \frac{2k_B T\gamma}{m} \\
\left\langle dW_i(t), dW_j(t) \right\rangle &= \delta_{ij} dt
\end{aligned}
$$

t:	time
$\vec{x}$:	particle position
$\vec{v}$:	particle velocity
R:	particle radius
m:	particle mass
T:	ambient temperature
k_B:	Boltzmann constant
$d\vec{W}(t)$:	3d probability (Wiener) measure
$\vec{v}_\circ$:	fluid velocity
ρ:	fluid density
μ:	fluid viscosity

Same approach as on the micro scale!

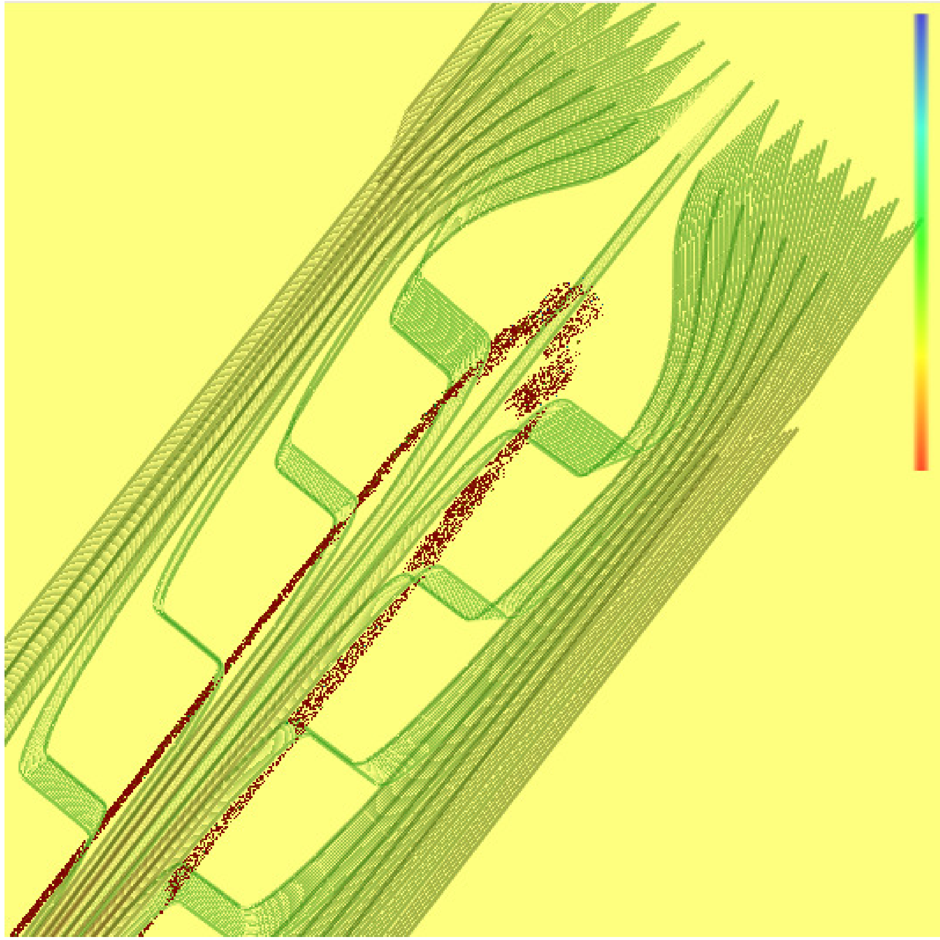
III Stream lines and tracked particles

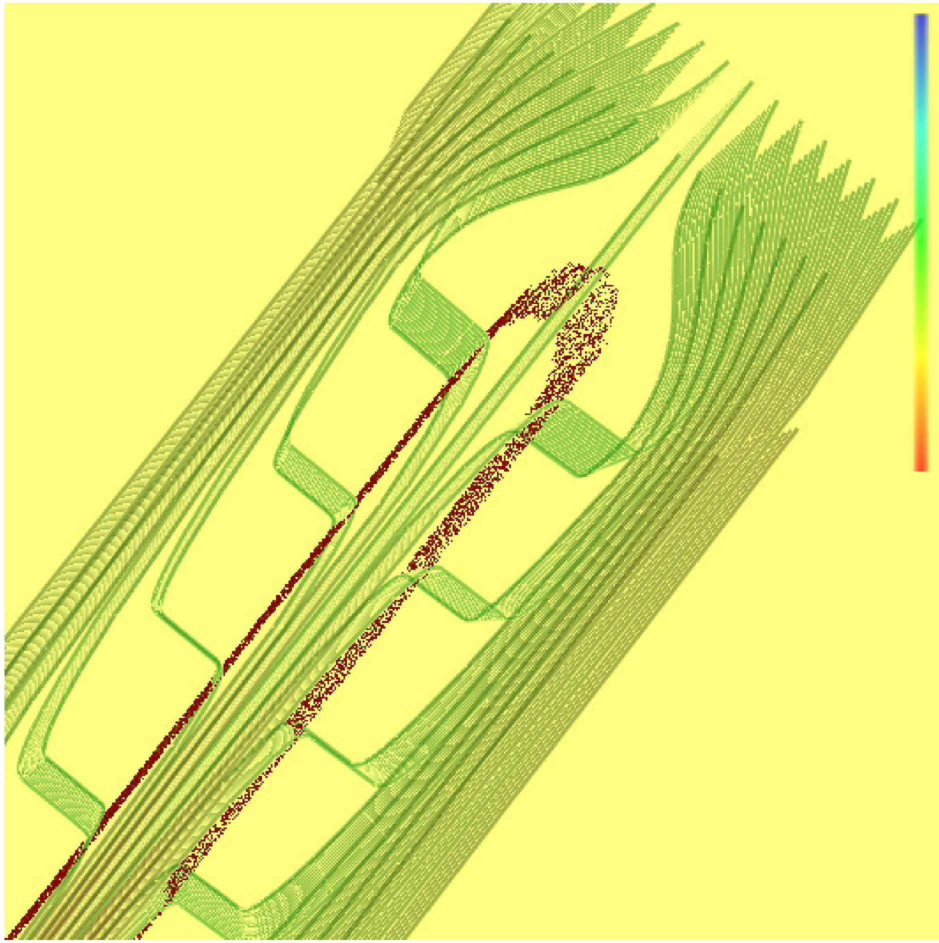




At the moment, particles are collected as they enter the porous media.

III Stream lines for transparent media, and particle "media entrance" positions





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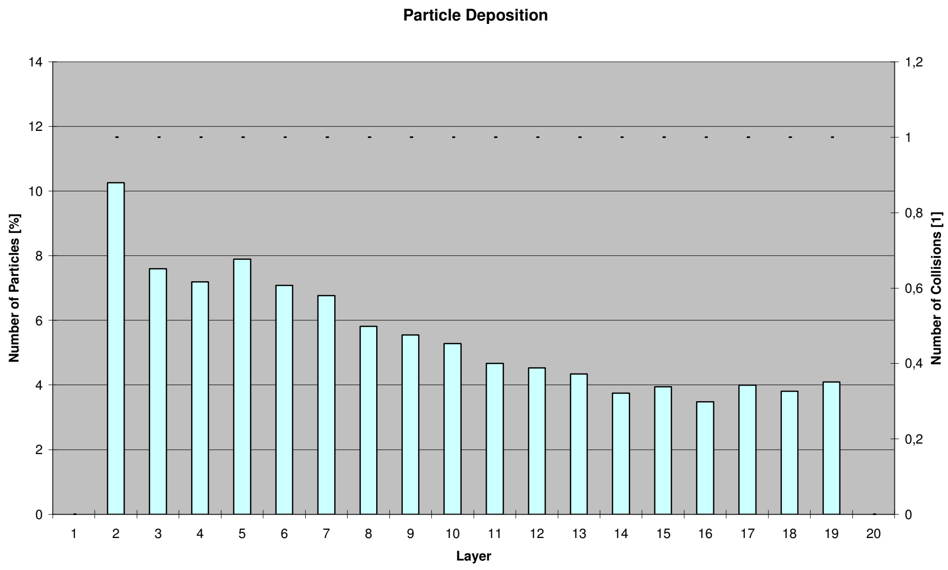
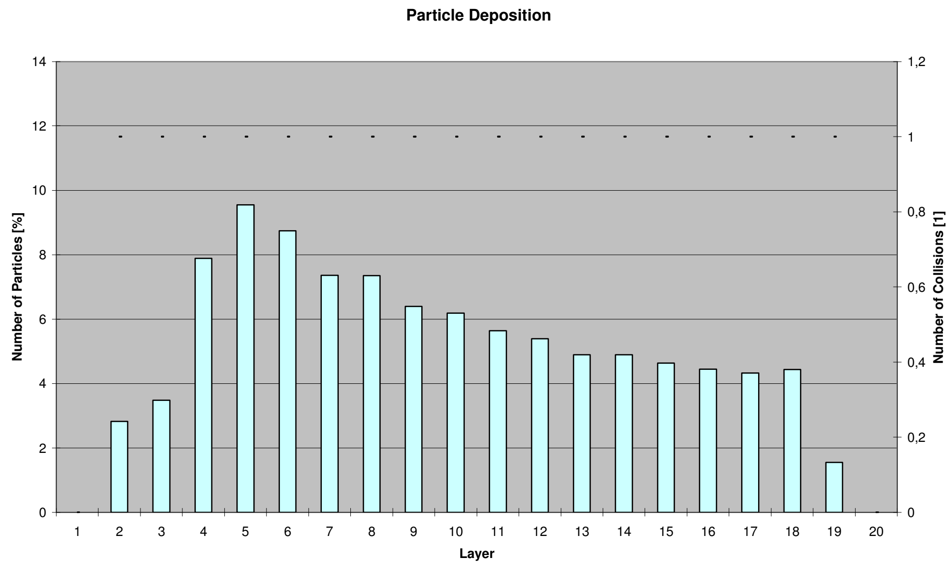
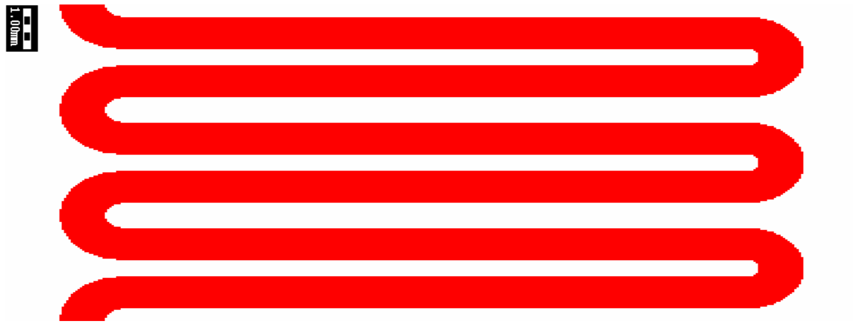
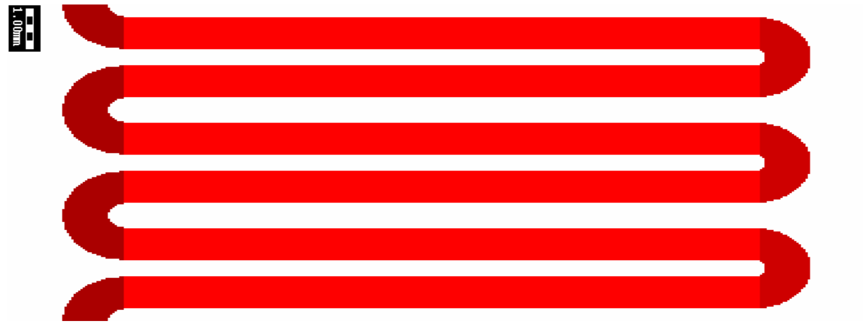
III Particle “entrance” location over the pleat for uniform and non-uniform permeability.









III Scope of the particle deposition simulation

- Consider fluid viscosity – air, oil, etc. are possible
- Consider varying particle sizes, inertia and diffusion are represented
- Consider pleat shape
- Consider media thickness and permeability
- Could easily introduce layers for the media

IV Significance for Filter Capacity simulations

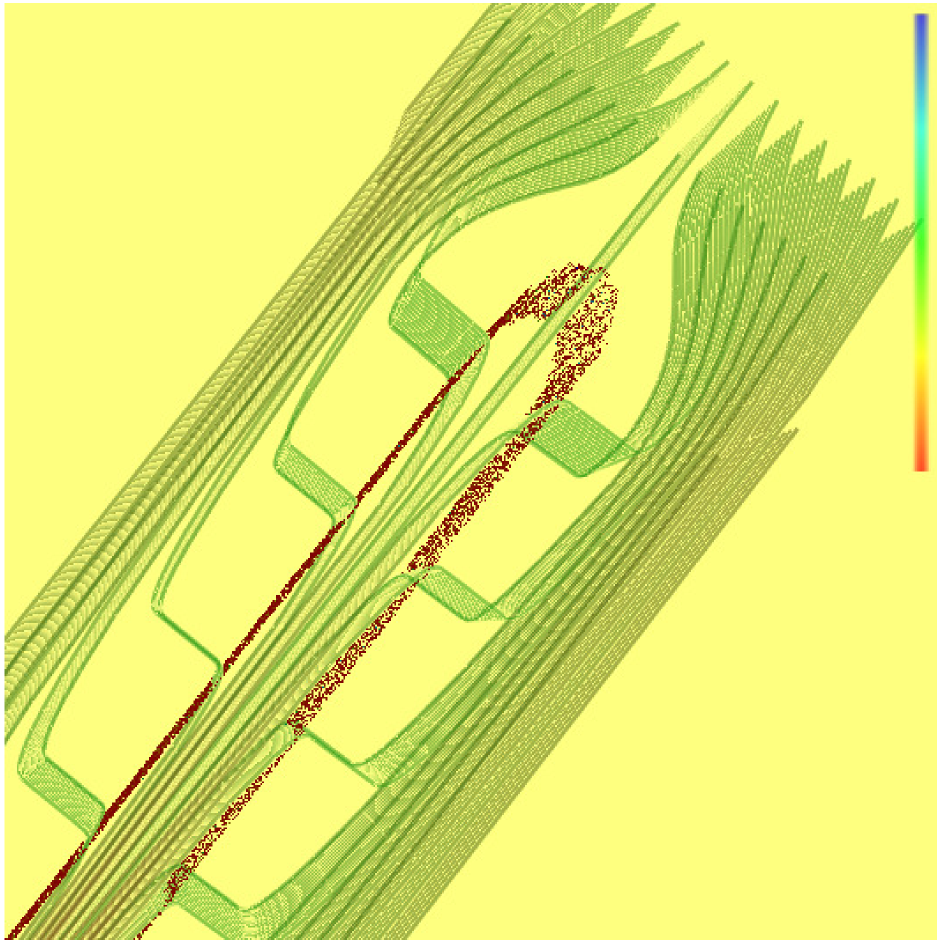
At the moment, particles are collected as they enter the porous media.

This information can be used as input into micro scale simulations.

On the micro scale particles are deposited, the local filter efficiency is computed and a local permeability under loading is computed.

This permeability is found in various regions of the pleat, and then inserted back into the pleat scale simulation.

A new pressure drop, new velocity field, and finally new particle entrance positions are computed.



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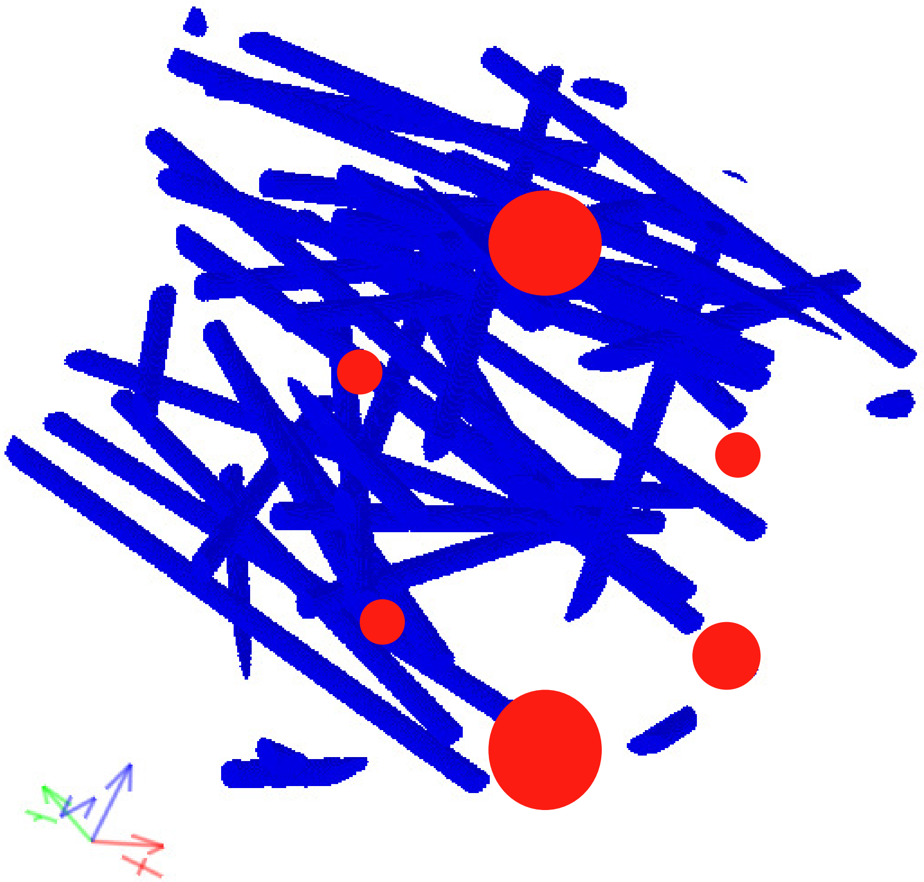

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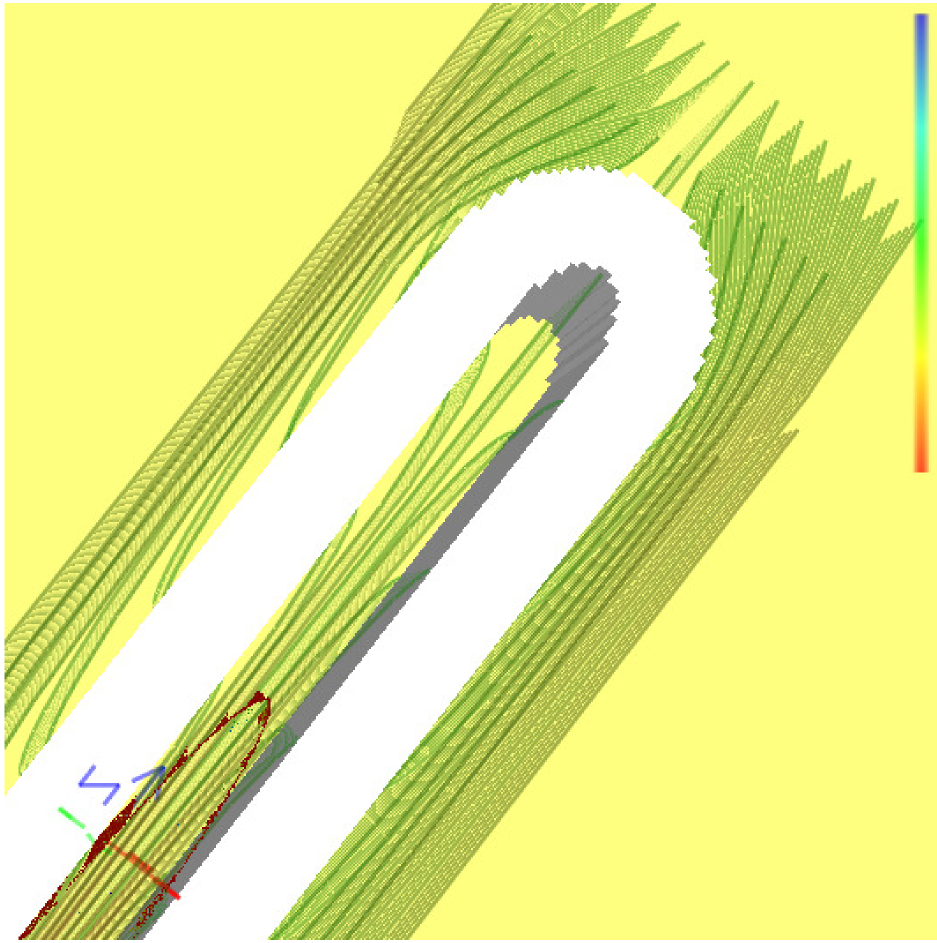

IV Summary and outlook

- Parameterized pleat model based on voxels
- Grid generation simple and automatic due to the use of cubic grid cells
- Pressure drop computation agrees with (confidential) measurements, can be tried after Software release (in 2007).
- Simulation of particle media entrance location is a mile stone on the way to filter efficiency and filter capacity simulations on the pleat level

GeoDict development teams

The GeoDict Team
Andreas Wiegmann
Jürgen Becker
Kilian Schmidt
Heiko Andrä
Ashok Kumar Vaikuntam
Rolf Westerteiger
Christian Wagner
Mohammed Alam
Jianping Shen

The PoroDict Team
Andreas Wiegmann
Jürgen Becker
Rolf Westerteiger

The FilterDict Team
Stefan Rief
Kilian Schmidt
Arnulf Latz
Andreas Wiegmann
Christian Wagner
Rolf Westerteiger
Stephan Nowatschin

The SatuDict Team
Jürgen Becker
Volker Schulz
Andreas Wiegmann
Rolf Westerteiger

The PleatDict Team
Andreas Wiegmann
Oleg Iliev
Stefan Rief

The FiberGeo Team
Andreas Wiegmann
Katja Schladitz
Joachim Ohser
Hans-Karl Hummel
Petra Baumann

WeaveGeo & PleatGeo
Andreas Wiegmann

The SinterGeo Team
Kilian Schmidt
Norman Ettrich

The RenderGeo Teams
Carsten Lojewski
Rolf Westerteiger
Matthias Groß

The Lattice Boltzmann Team
Dirk Kehrwald
Peter Klein
Dirk Merten
Konrad Steiner
Irina Ginzburg
Doris Reinel-Bitzer

The Elastic Solver Team
Heiko Andrä
Dimiter Stoyanov

The EJ Solver Team
Andreas Wiegmann
Liping Cheng
Aivars Zemitis
Donatas Elvikis
Vita Rutka
Qing Zhang

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Find out more:

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Thank you for attending this presentation.

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