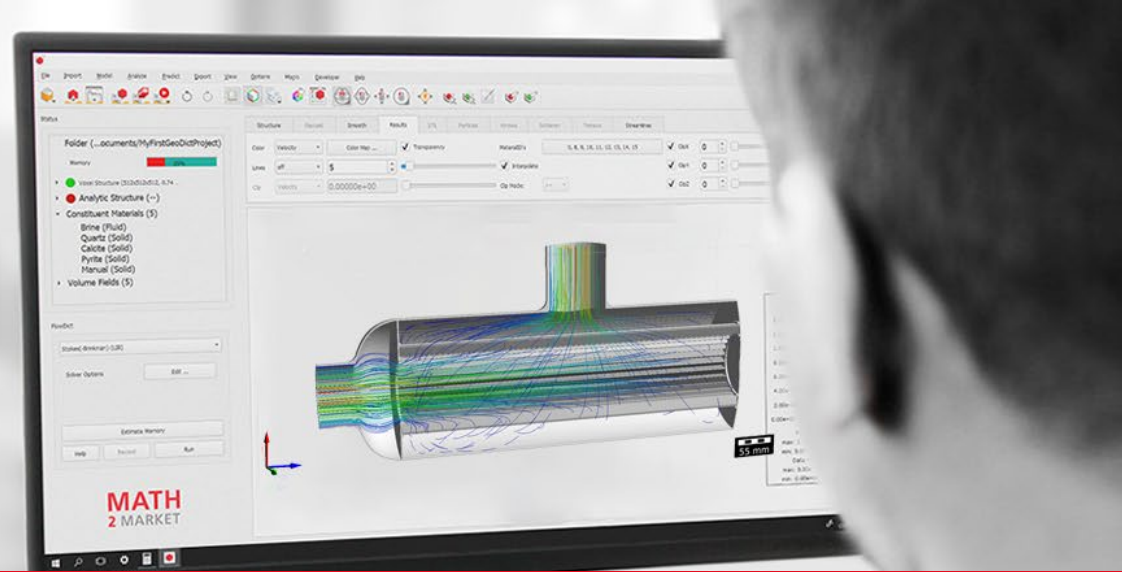

Filtration modeling and simulation with GeoDict, from filter media to filter element

FILTECH 2019

October 22.–24., 2019

Mehdi Azimian

Co-Authors: S. Linden, L. Cheng, C. Kühnle, A. Wiegmann

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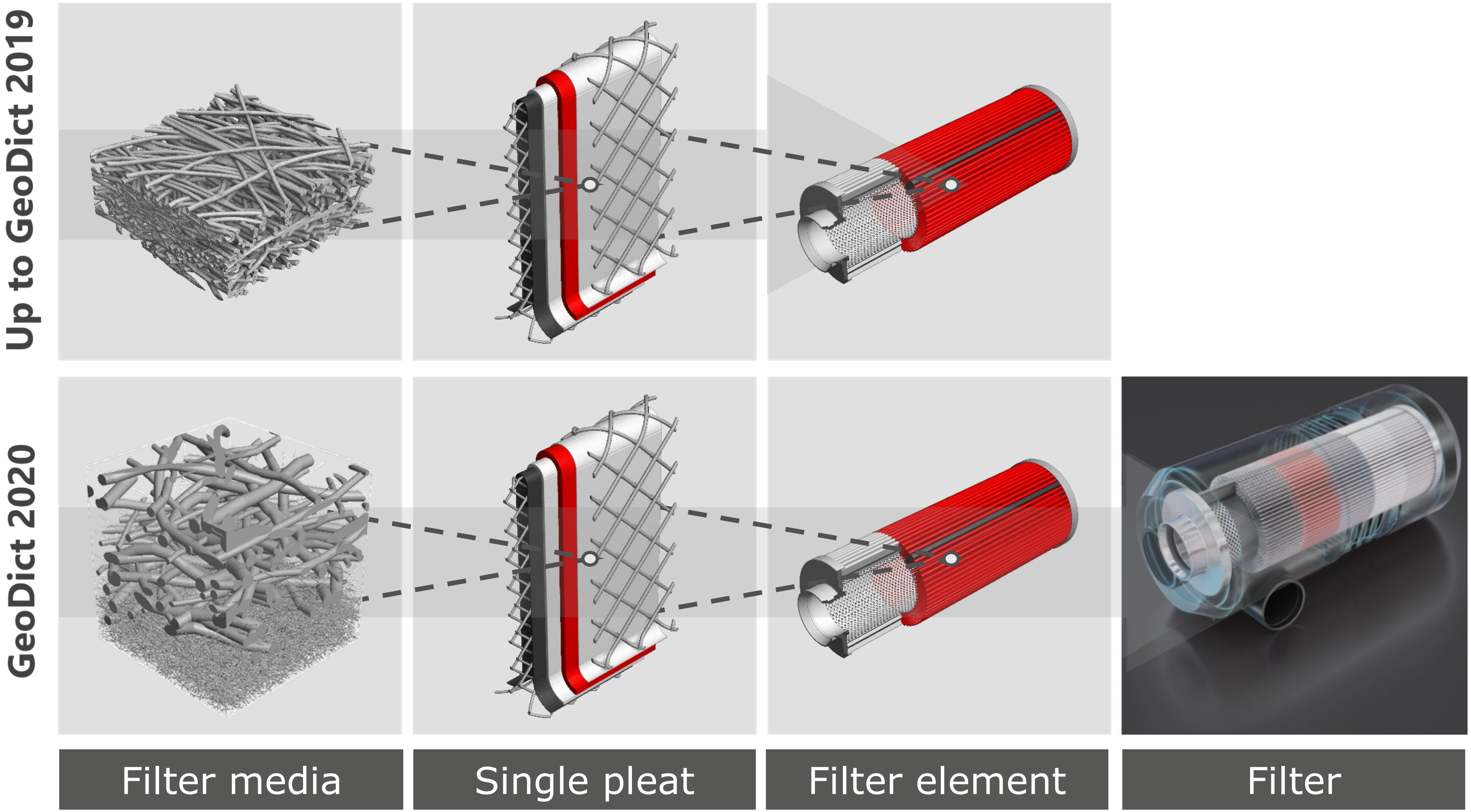
GeoDict

MATH 2 MARKET

Filter media and filter element

GeoDict

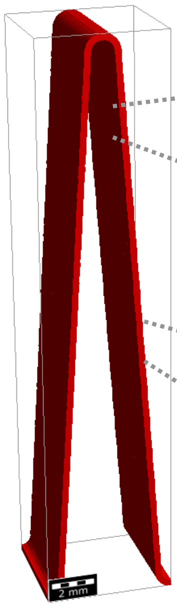


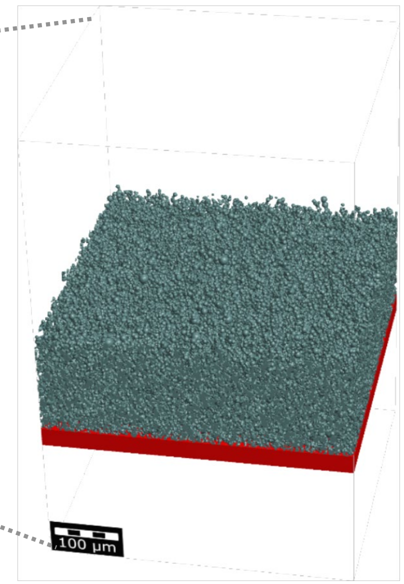
MATH 2 MARKET

Filter media simulation

Filter element simulation (Identification of parameters)

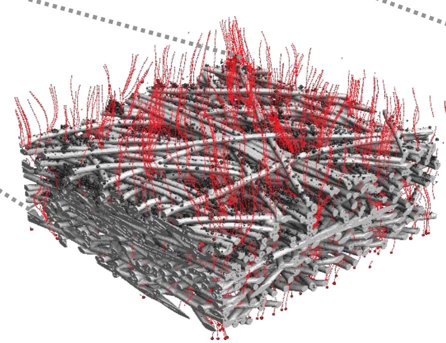
Estimate max. particles packing density & max. flow resistivity





Particles deposited on a grid frame

high resolution simulation to identify:
f_{max} & σ_{max} for cake filtration



Particles deposited in/on pleated filter element

Simulation requires:

f_{max}: max. particles packing density
σ_{max}: corresponding flow resistivity

Particles deposited through the micro-structure

high resolution simulation to approximate:
f_{max} & σ_{max} for depth filtration

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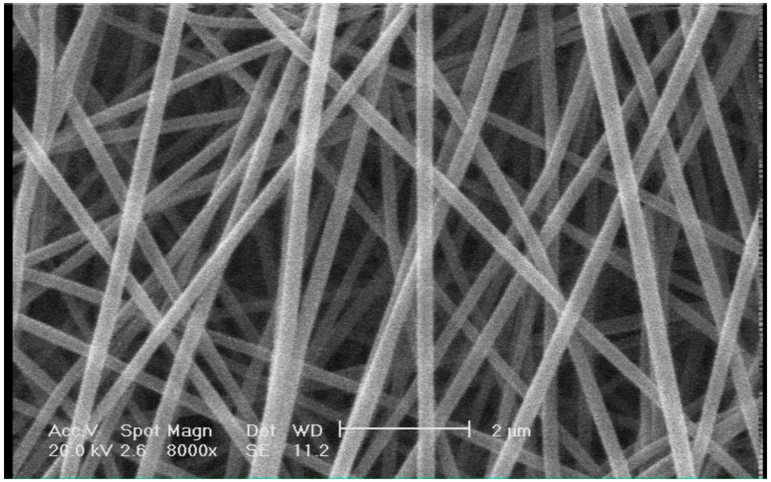
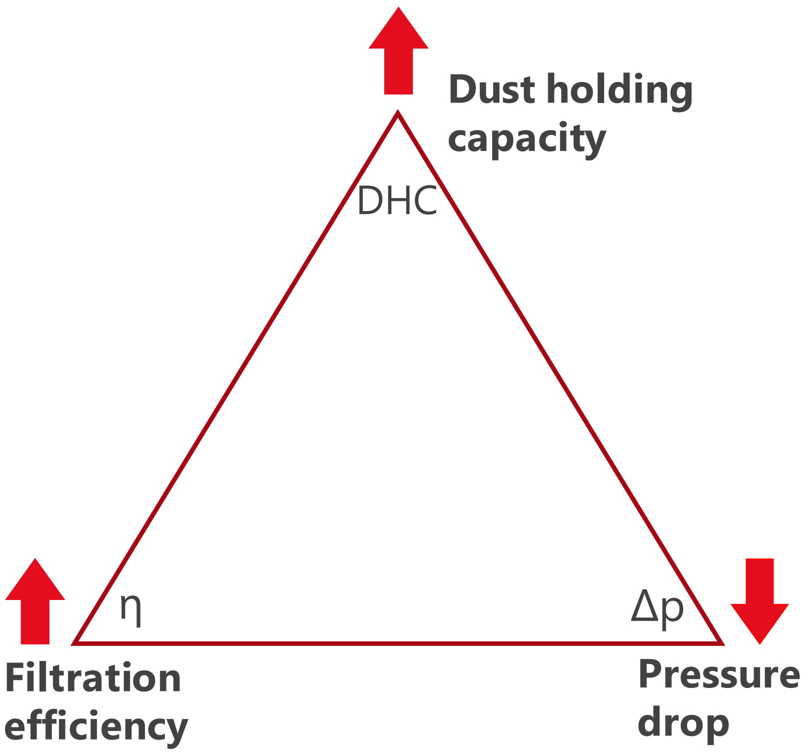
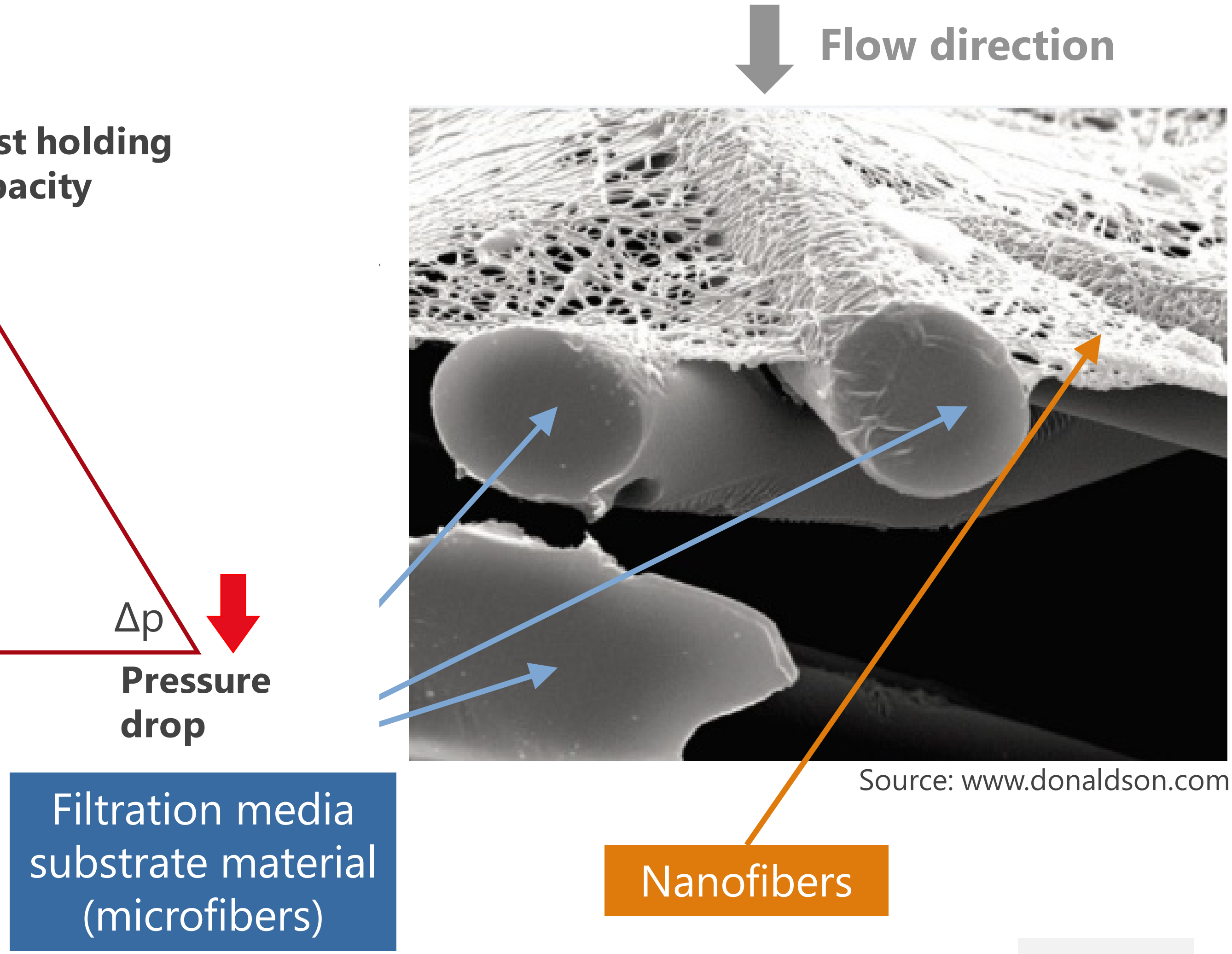


Flow and filtration simulation through nano-fibrous media

Why nanofibers?





Source: www.donaldson.com

Simulation of Slip Flow and Filtration for Nano-Fibrous Media

GeoDict

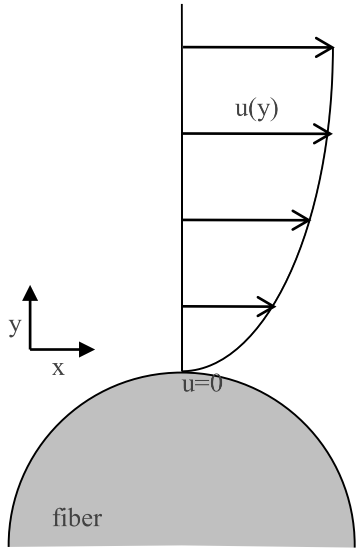
For microfiber

$$
\begin{aligned}
-\mu\Delta\vec{u} + \nabla p &= 0 \text{ (momentum balance)} \\
\nabla \cdot \vec{u} &= 0 \text{ (mass conservation)} \\
\vec{u} &= 0 \text{ on } \Gamma \text{ (no-slip on fiber surfaces)} \\
P_{in} &= P_{out} + c \text{ (pressure drop is given)}
\end{aligned}
$$

μ : fluid viscosity,

$\vec{u}$: velocity, periodic,

p : pressure, periodic up to pressure drop in flow direction.



MATH 2 MARKET

Simulation of Slip Flow and Filtration for Nano-Fibrous Media

GeoDict

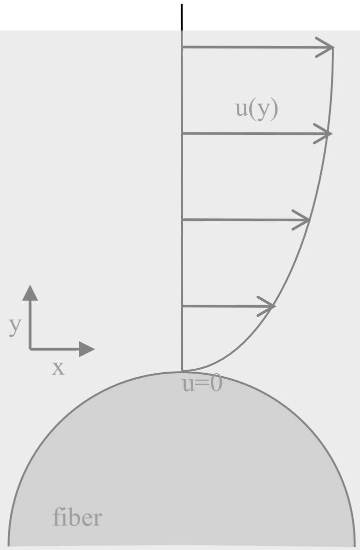
For microfiber

$$-\mu\Delta\vec{u} + \nabla p = 0 \text{ (momentum balance)}$$
$$\nabla \cdot \vec{u} = 0 \text{ (mass conservation)}$$
$$\vec{u} = 0 \text{ on } \Gamma \text{ (no-slip on fiber surfaces)}$$
$$P_{in} = P_{out} + c \text{ (pressure drop is given)}$$

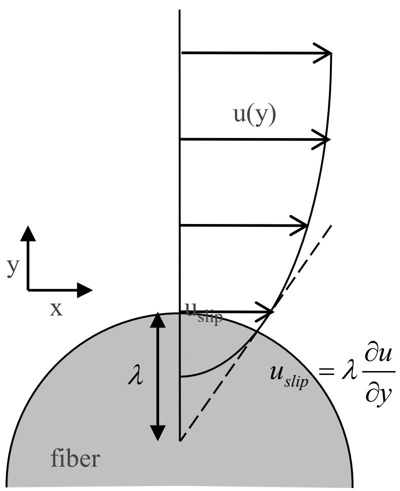
μ : fluid viscosity,

$\vec{u}$: velocity, periodic,

p : pressure, periodic up to pressure drop in flow direction.



For nanofiber



$$-\mu\Delta\vec{u} + \nabla p = 0 \text{ (momentum balance)}$$
$$\nabla \cdot \vec{u} = 0 \text{ (mass conservation)}$$
$$\vec{n} \cdot \vec{u} = 0 \text{ on } \Gamma \text{ (no flow into fibers)}$$
$$\vec{t} \cdot \vec{u} = -\lambda \vec{n} \cdot \nabla \left(\vec{u} \cdot \vec{t}\right) \text{ on } \Gamma \text{ (slip flow along fibers)}$$
$$P_{in} = P_{out} + c \text{ (pressure drop is given)}$$

$\vec{n}$: normal direction to the fiber surface,

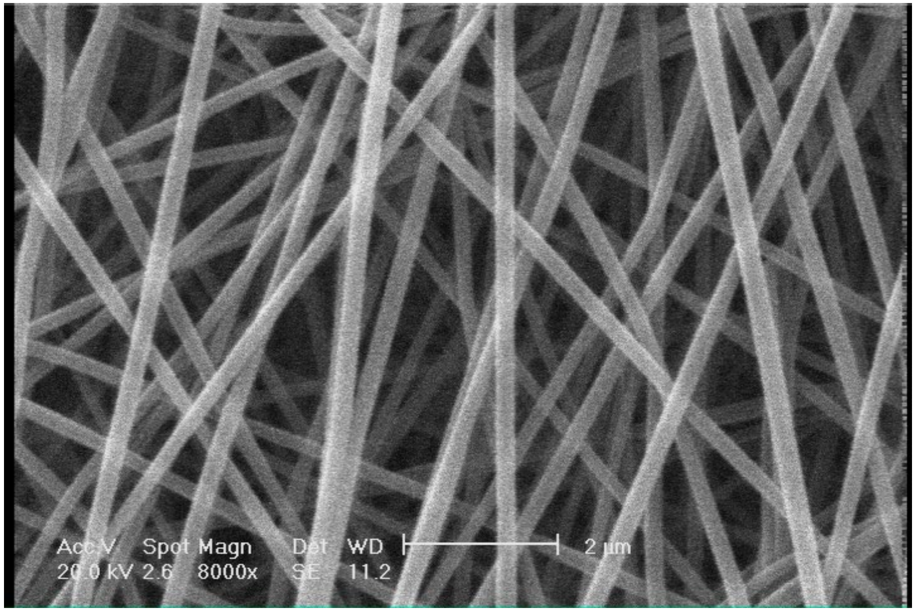
λ : slip length,

$\vec{t}$: any tangential direction with $\vec{t} \cdot \vec{n} = 0$.

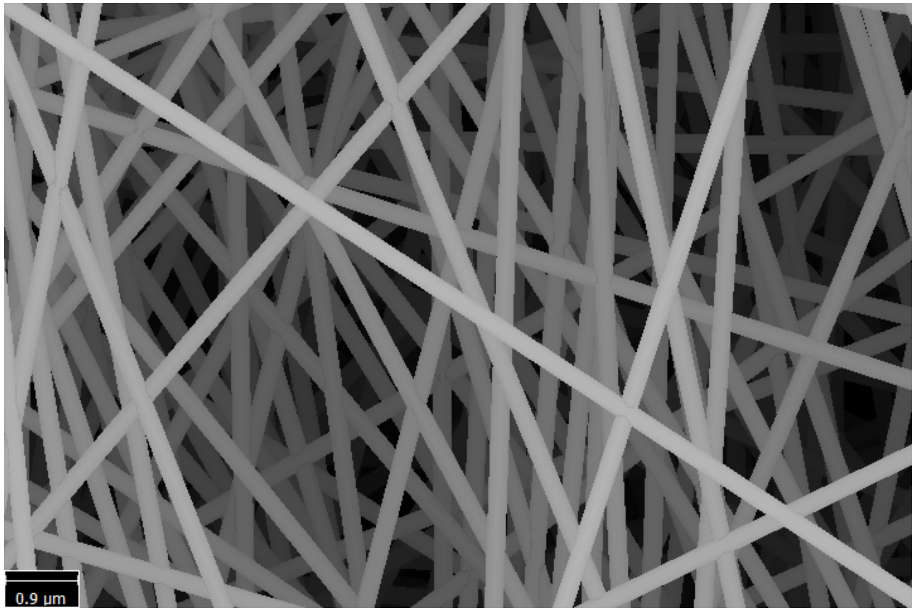
MATH 2 MARKET

Modelling of nano-fibrous media from SEM image

Real media (SEM)*

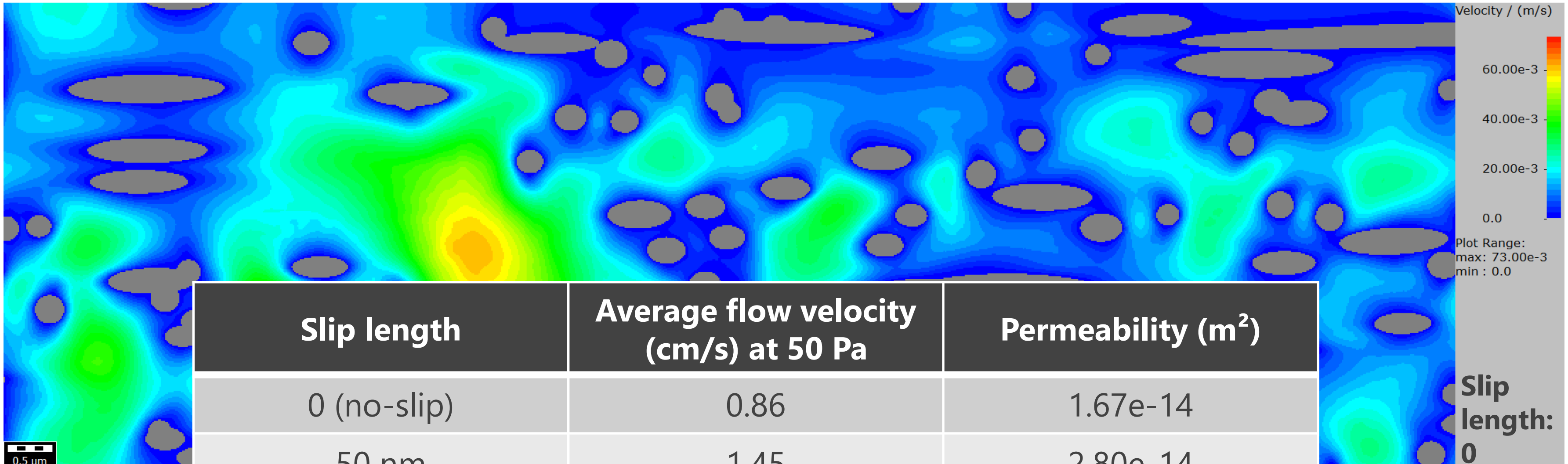


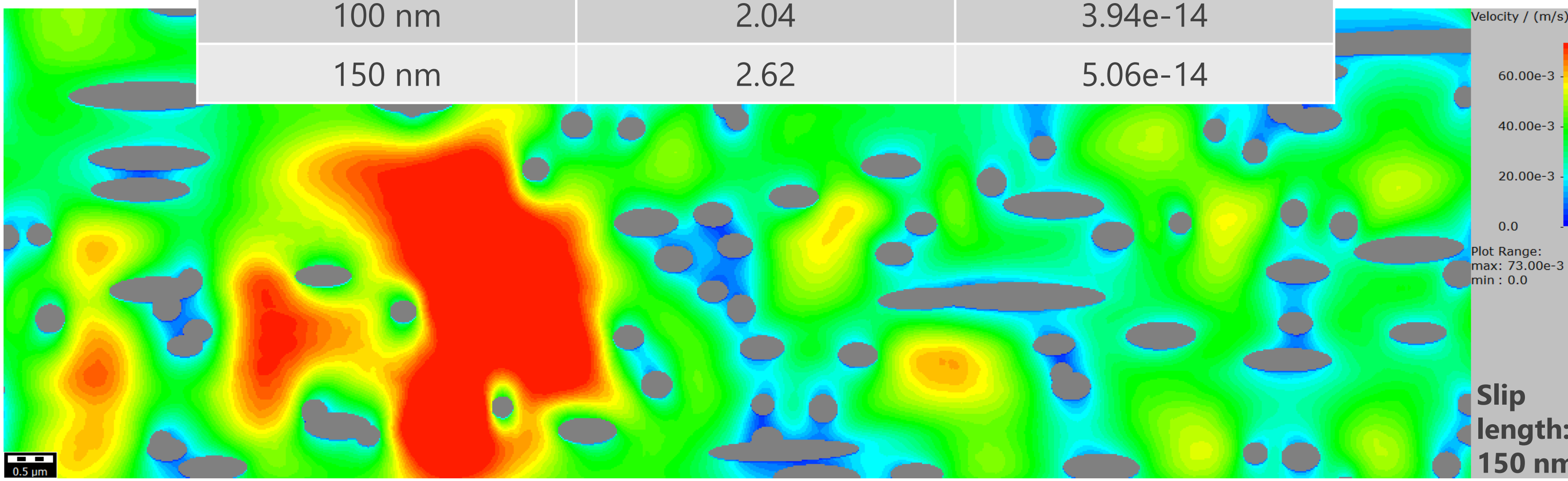
GeoDict 3D model based on SEM



Voxel length	16 nm (measured on SEM with GeoDict)	**Orientation**	Diagonal (0.27, 0.73, 0.00)
Fiber diameter	280 nm ± 40 nm (measured on SEM with GeoDict)	**Porosity**	82%
Size 2D	720 x 480 Pixels	**Size 3D**	720 x 480 x 328 Voxels

Comparison of Velocity Distribution





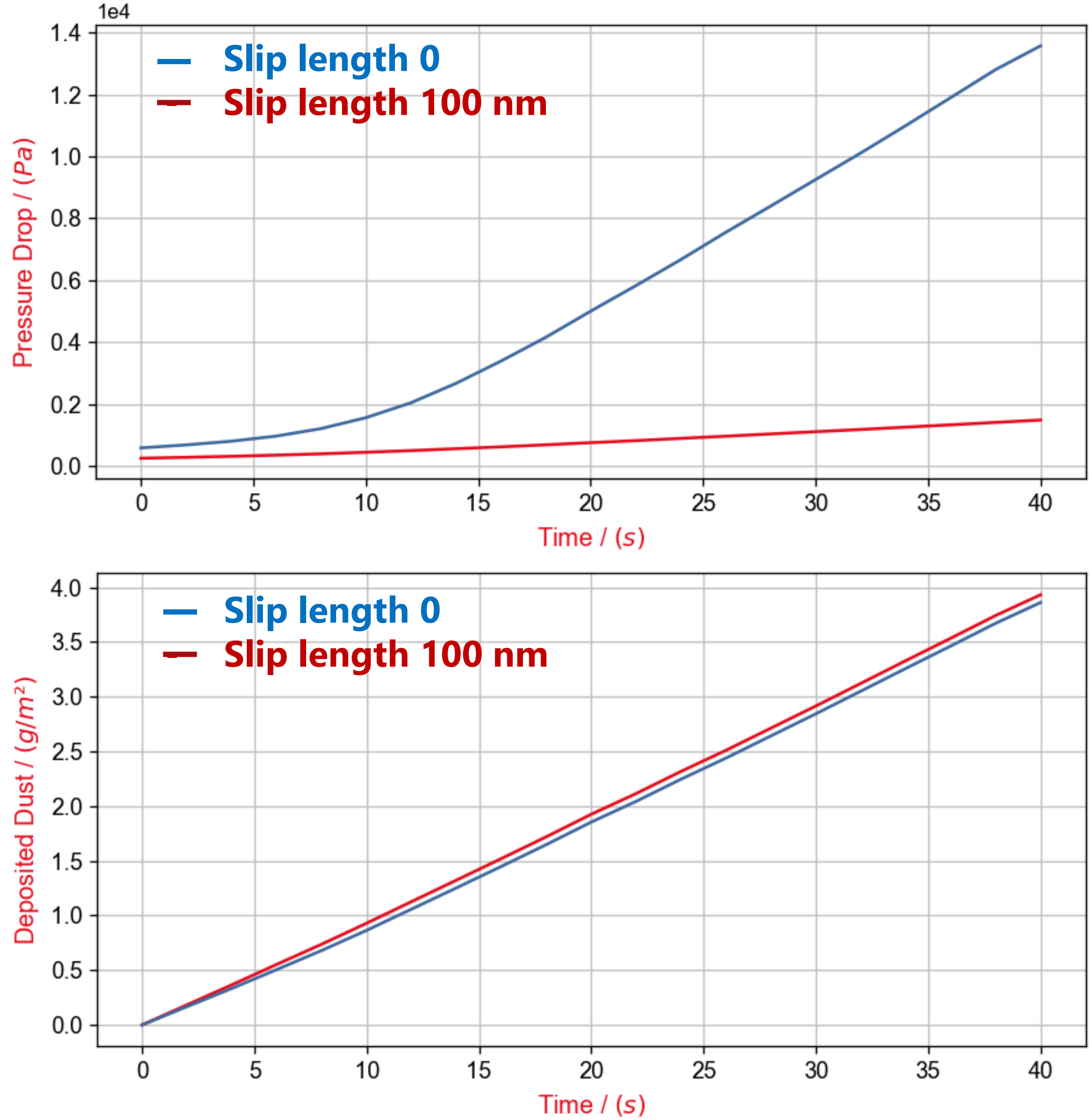
Slip length	Average flow velocity (cm/s) at 50 Pa	Permeability (m^2)
0 (no-slip)	0.86	1.67e-14
50 nm	1.45	2.80e-14
100 nm	2.04	3.94e-14
150 nm	2.62	5.06e-14

Comparison of filtration simulation results

GeoDict

Settings of filter life-time single-pass simulations

Fluid	Air
Temperature	22 °C
Mean flow velocity	0.1 m/s
Solver	Stokes (LIR)
Batches	Each batch 2 s, in total 20 batches (40 s filtration)
Particles	10 different particle size classes from 100 nm to 460 nm
Test dust concentration	1 g/m^3
Particle density	2650 kg/m^3
Particle shape	Spherical



MATH 2 MARKET

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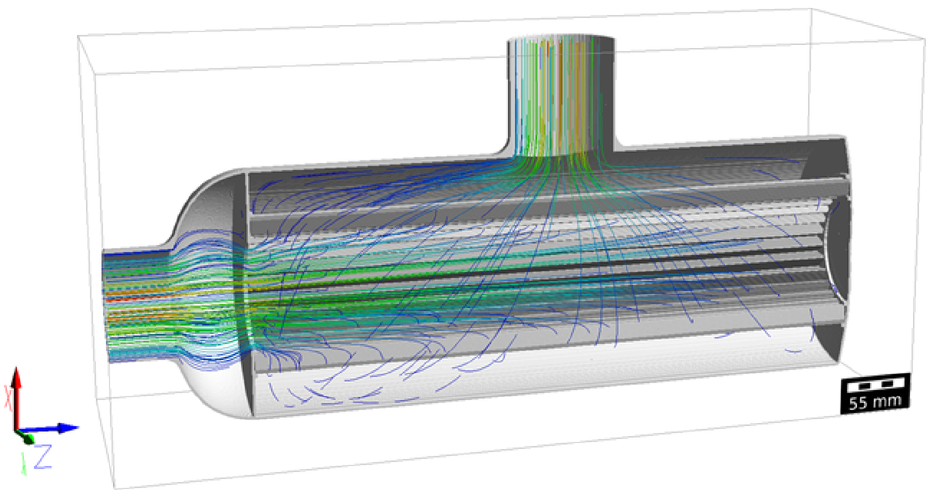
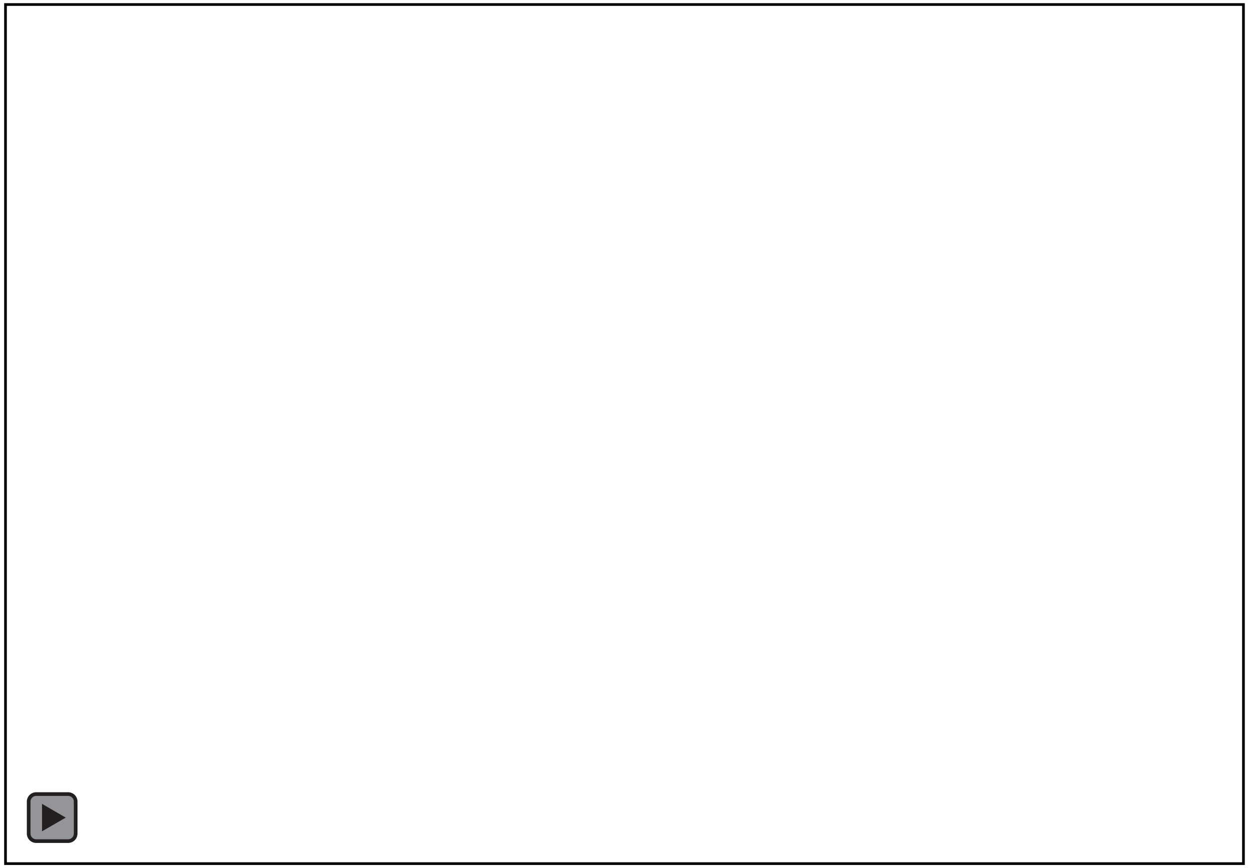
GEODICT



MATH 2 MARKET

Model of a filter



Goals

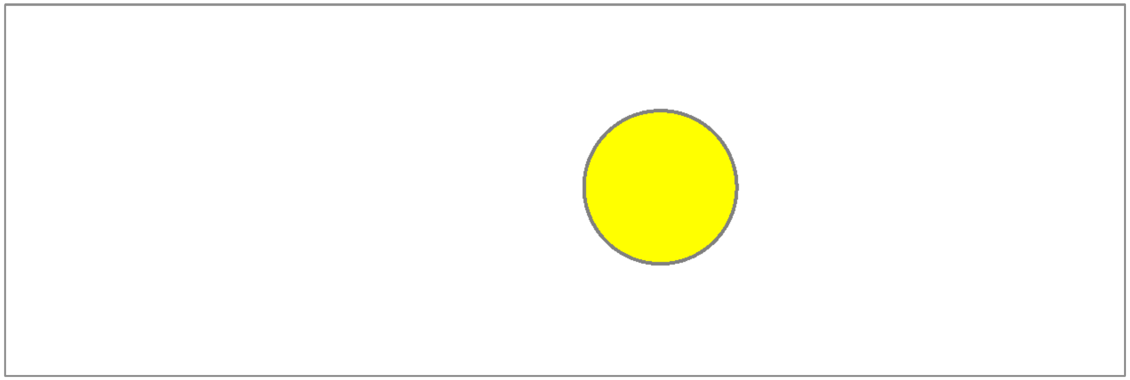
- Import geometric model of a filter (ImportGeo-CAD, ProcessGeo, editing tools)
- Predict pressure drop, efficiency, and life-time for this filter (FilterDict-Element)

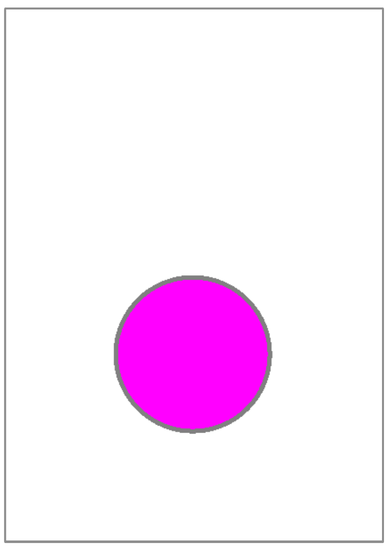
REVIEW OF FILTER IMPORT

GEODICT

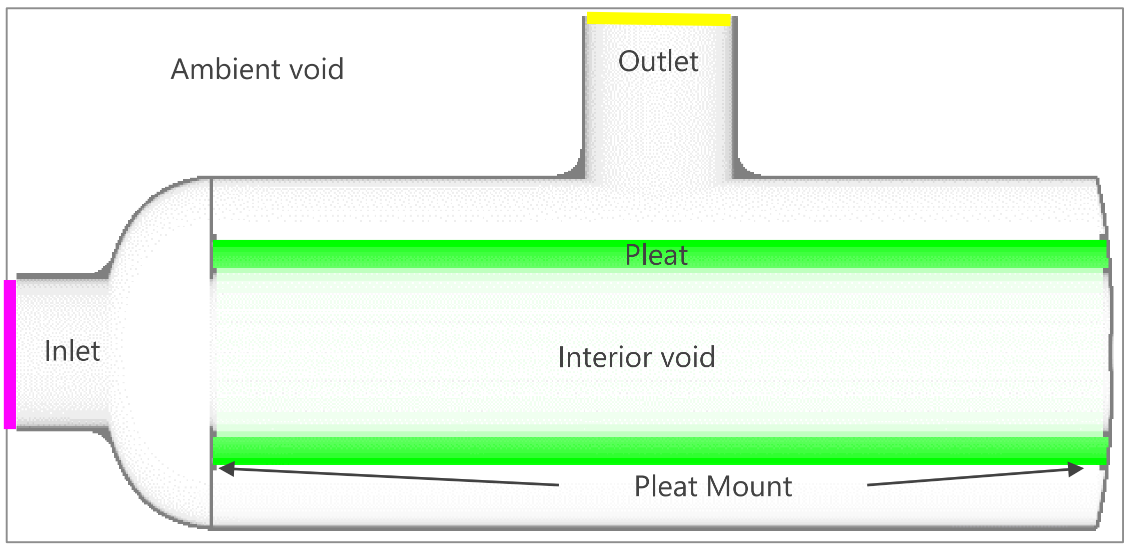
Make sure that the pleats are well resolved, otherwise use a smaller voxel length!

2D Top View

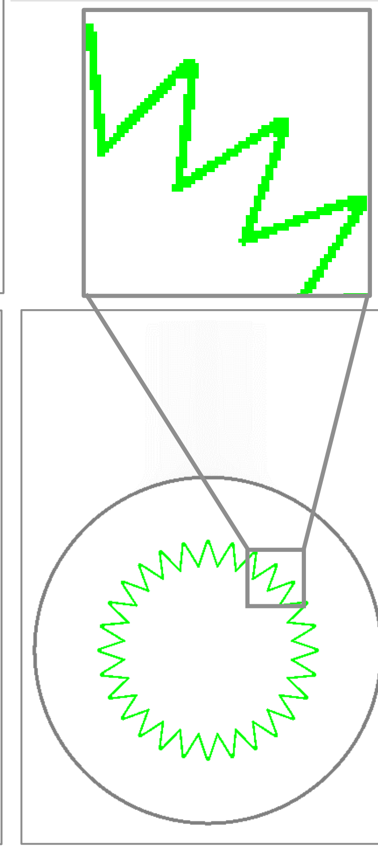




2D Front View



2D Side View

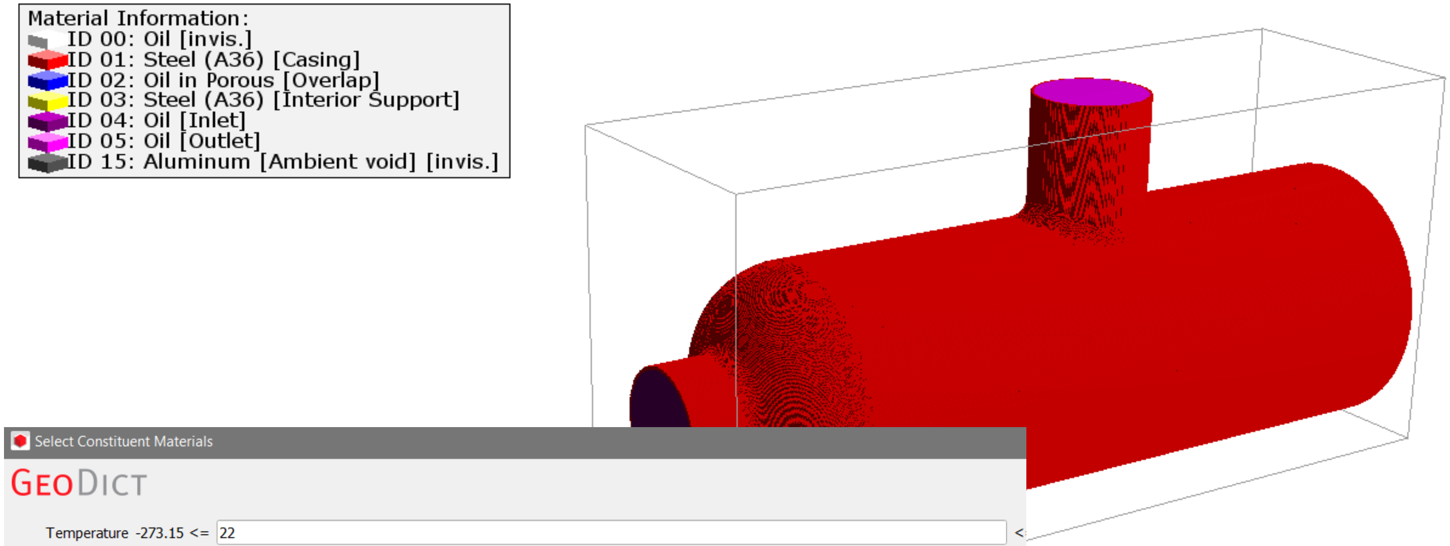


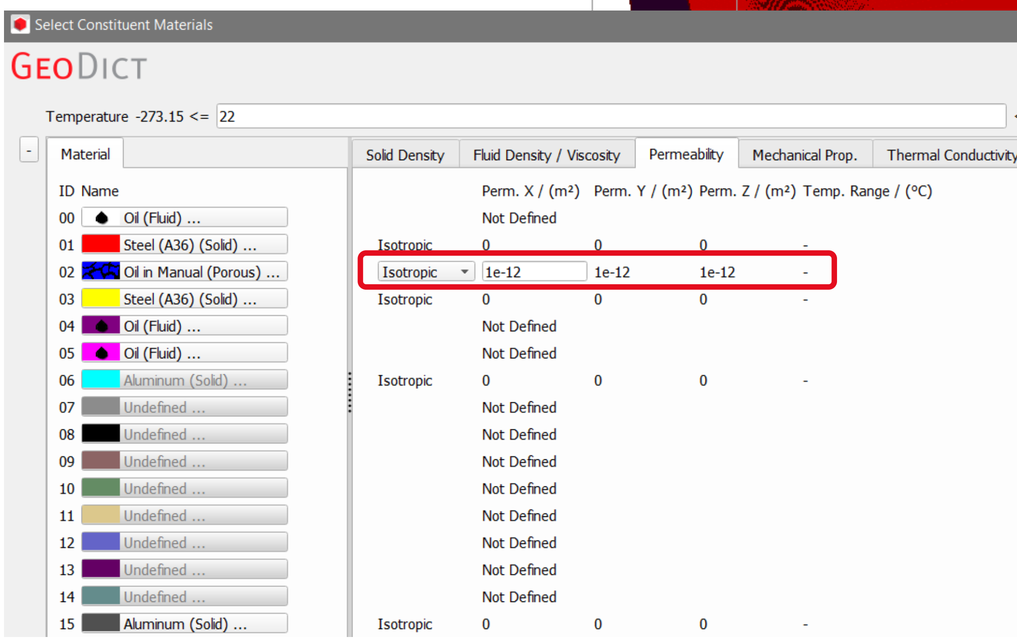
2D Interior View

MATH 2 MARKET

Assign Constituent Materials and Permeability

GeoDict

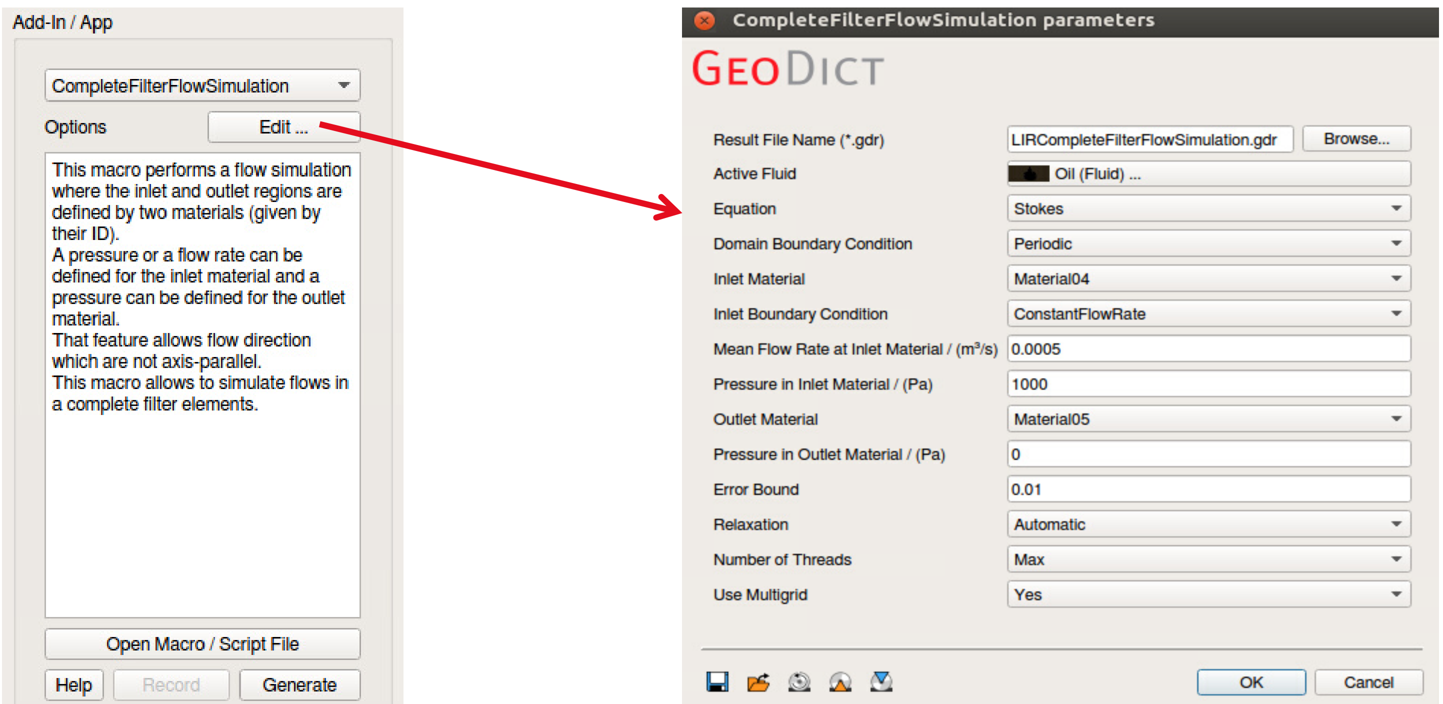




MATH 2 MARKET

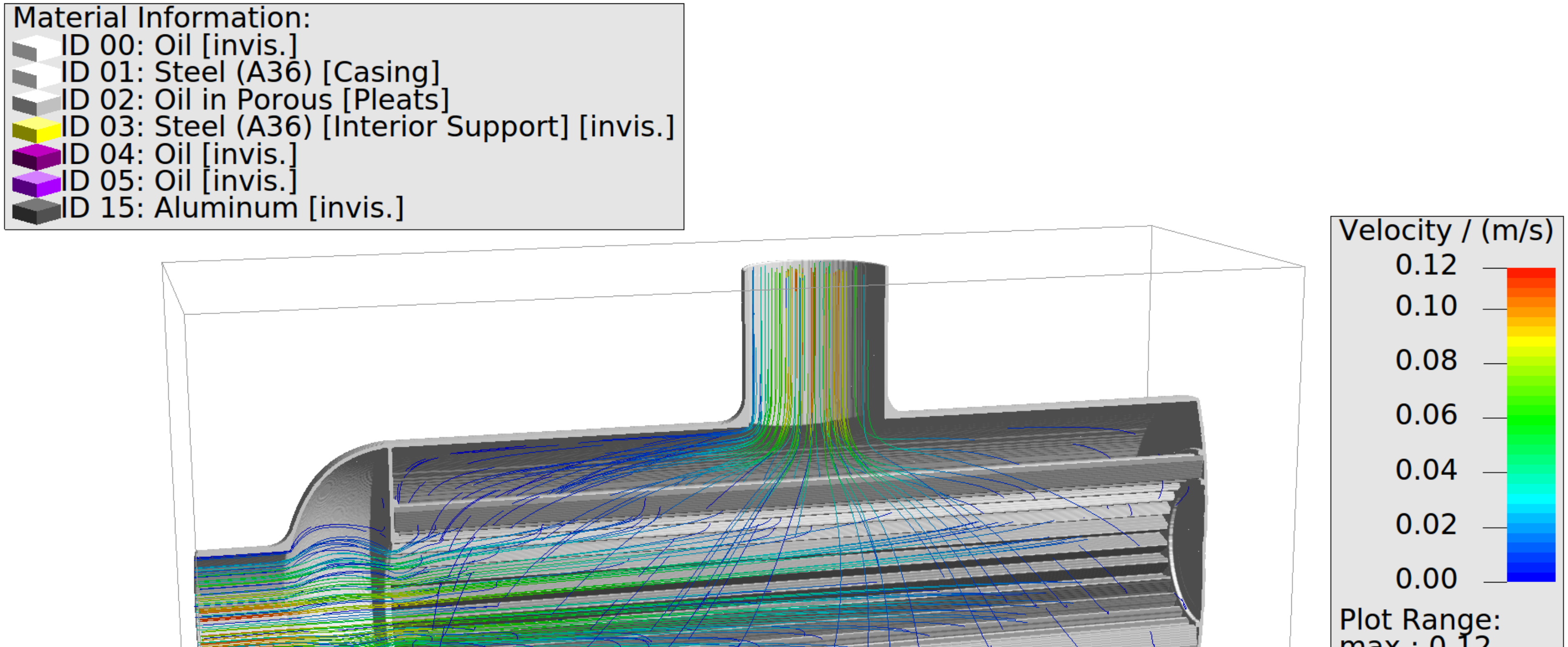
RUN THE FILTER FLOW SIMULATION

- Select **Add-In/App → FilterDict** for a predefined script
- Click Edit… for the **CompleteFilterFlowSimulation** predefined script
  - Set the Result File Name
  - Choose inlet material (ID 04) with inlet pressure / or mean flow rate at inlet
  - Choose outlet material (ID 05) with outlet pressure



Filter flow simulation results

GeoDict



Fr Sep 13 2019 (2020 Build 36420)

Domain: 581 x 400 x 1237 Voxel: 500 µm Load Structure

Input Map | Log Map | Post Map | Results | Flow Visualization | Metadata

Report | Plots | Map

Volume flow rate : 0.5 l/s.
Average flow velocity over 0.006558 m² through the inlet : 0.0762428 m/s.
Pressure at the inlet material 4 : **71151.1 Pa**.
Pressure at the outlet material 5 : 0 Pa.
Pressure difference between inlet and outlet : **71151.1 Pa**.

--- Iterations: 2950, Runtime: 418.398 s, Number of Cells: 2078569, Memory usage: 505.522 MB, and stopped successfully for **error bound** ---

MATH 2 MARKET

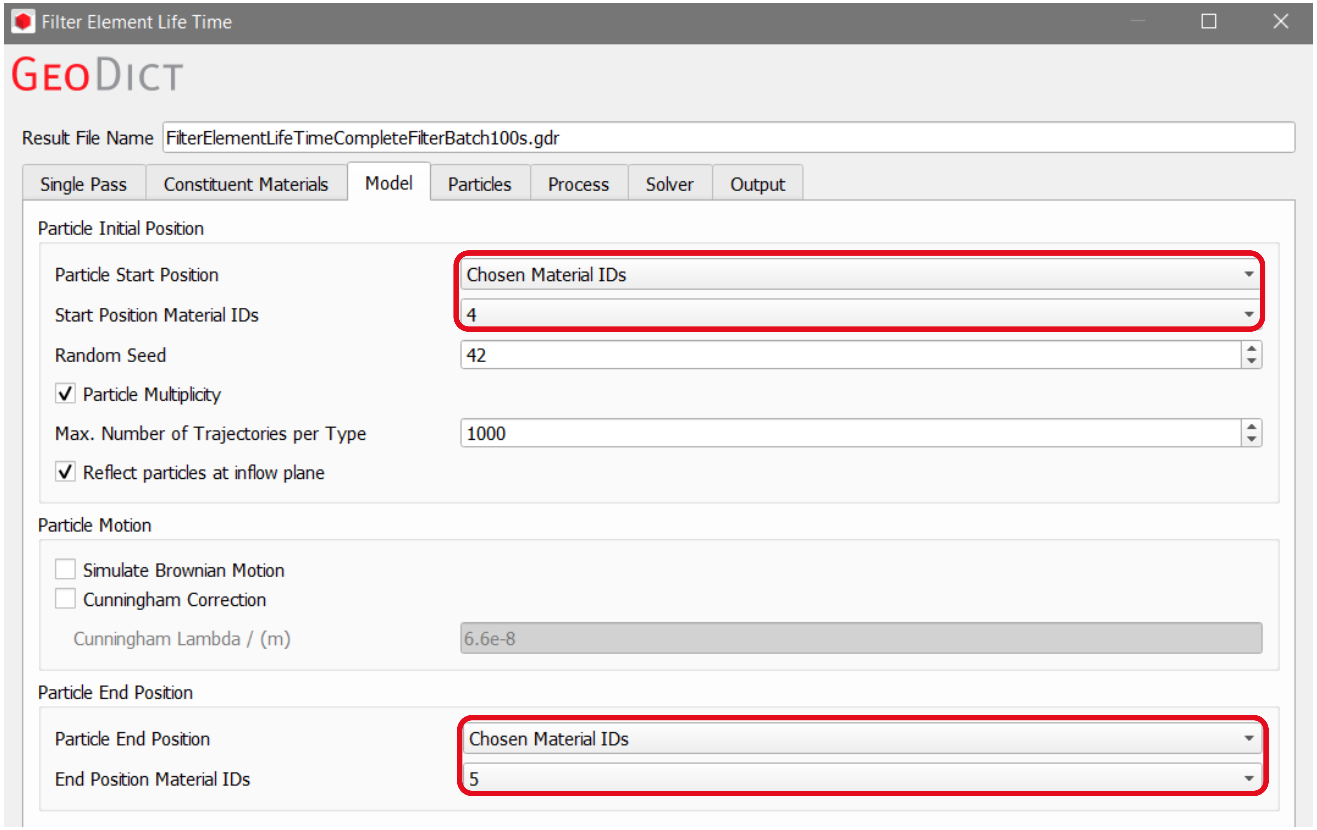
Filter flow simulation results

GeoDict

MATH 2 MARKET

FILTRATION SIMULATION SETTINGS

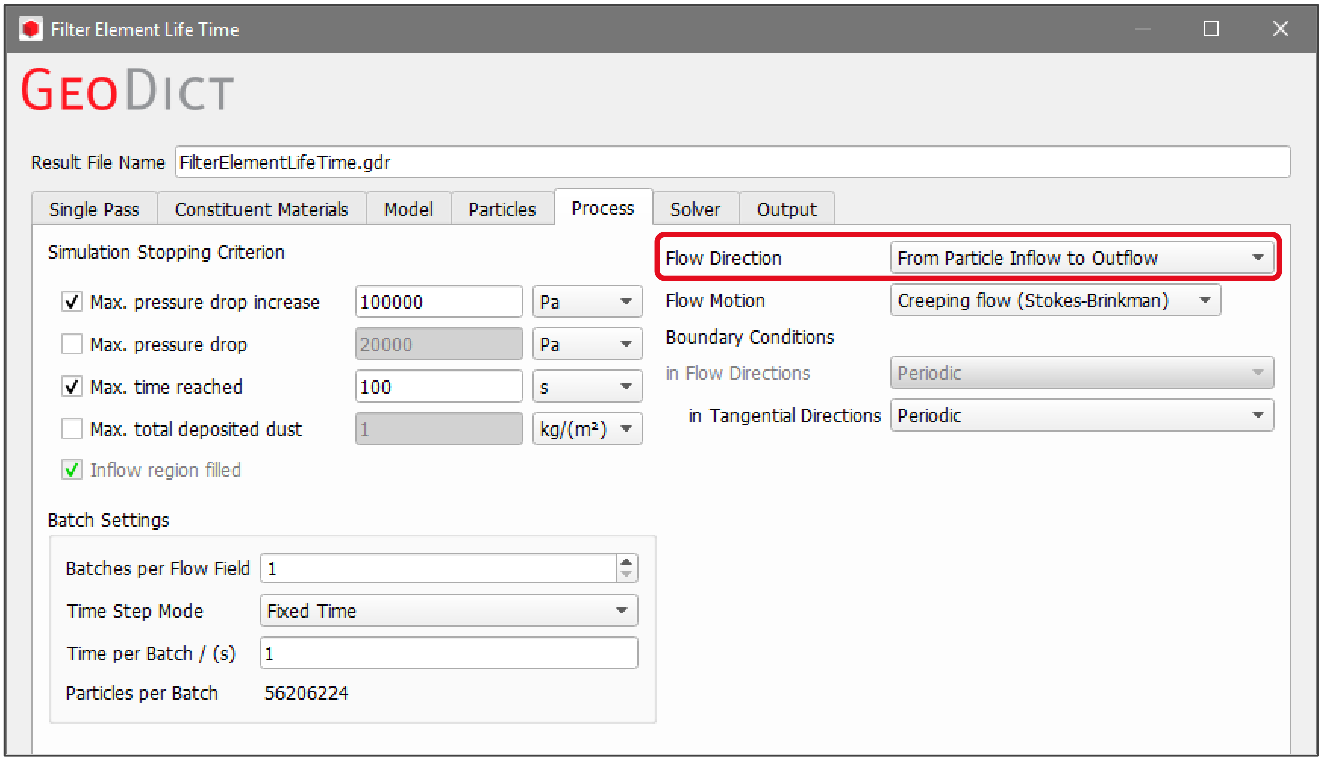
- Setup the FilterDict-Element Life-Time simulation parameters
- Choose inlet material (ID 04) as particle start position
- Choose outlet material (ID 05) as particle end position



FILTRATION SIMULATION SETTINGS

GEODICT

Change flow direction from “z” to “From Particle Inflow to Outflow”.



MATH 2 MARKET

Filtration simulation

GeoDict

- Movement of particles can be animated
- Simulation and analysis of depth and cake filtration
- Particles are shown 50 times larger here (for better visualization)

MATH 2 MARKET

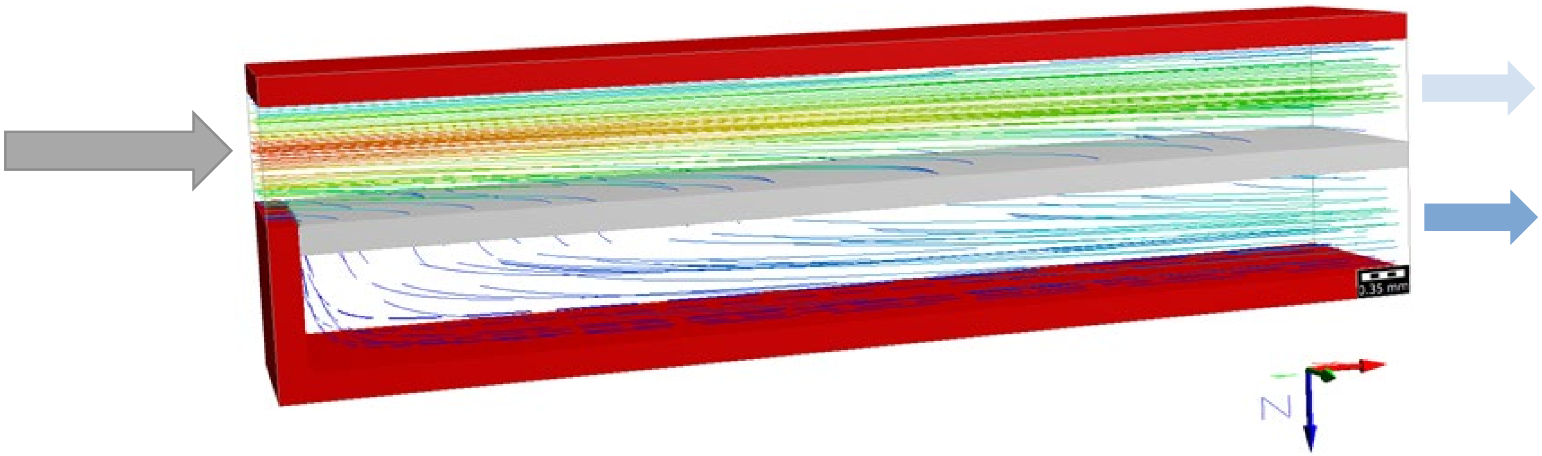
Filtration simulation

GeoDict

- Particles are trapped inside a vortex
- Filter design not optimal
  - Increased pressure drop
  - Increased simulation runtime

MATH 2 MARKET

Contents

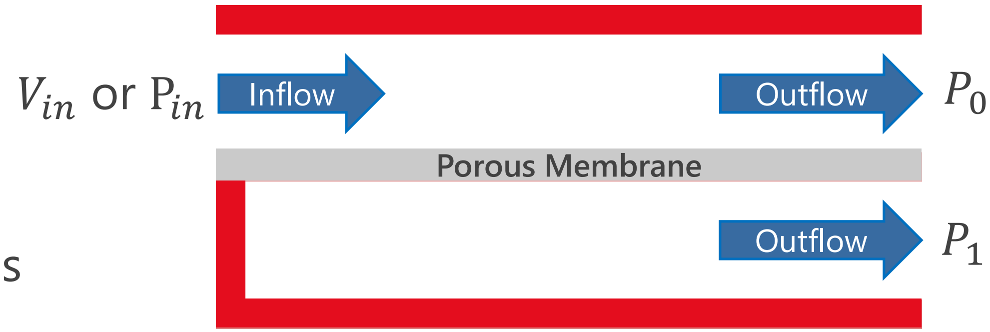


MATH 2 MARKET

Cross-flow filtration

- In cross-flow filtration particles travel tangentially across the surface of the filter rather than into the filter
  - Fluid with particles enters the filter element from one side
  - Flow is split in two directions due to a pressure difference before and after a porous membrane
  - Particles get deposited on top of the porous membrane

- GeoDict2020 allows to set up and perform cross flow simulations easily!



Example of a simple cross-flow filtration setup with an inflow region at the top-left and two pressure outflow boundaries at the top-right and bottom-right

REVIEW OF STRUCTURE PREPARATION

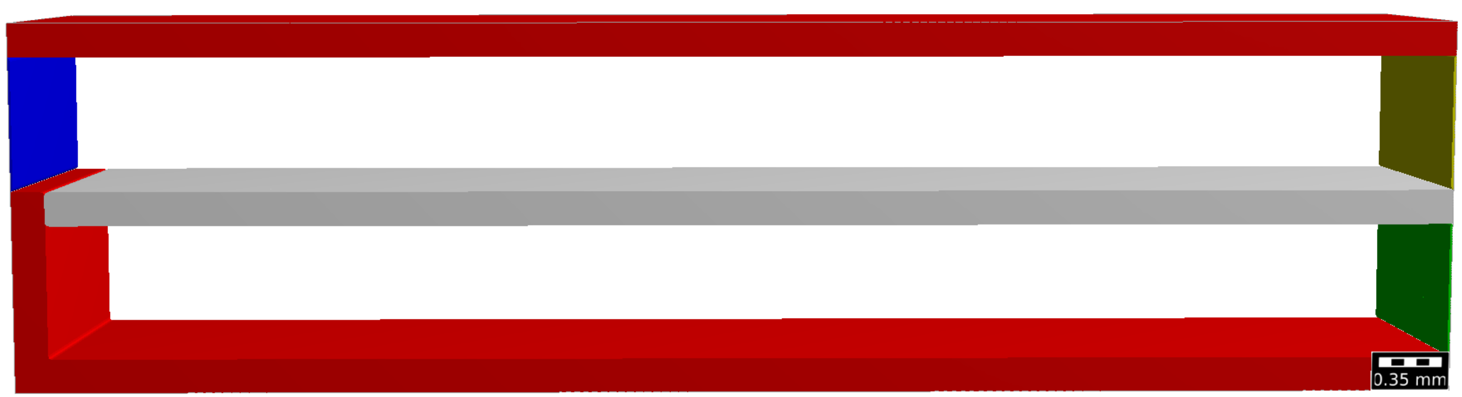
GEODICT

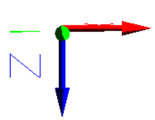
The structure preparation is ready and the simulation setup can be started.

Material Information:
ID 00: Air [invis.]
ID 01: Casing
ID 02: Air in Porous [Membrane]
ID 03: Air [Inlet]
ID 04: Air [Upper Outlet]
ID 05: Air [Lower Outlet]

Domain size: 684 x 176 x 128 voxels

Voxel length: 10 µm

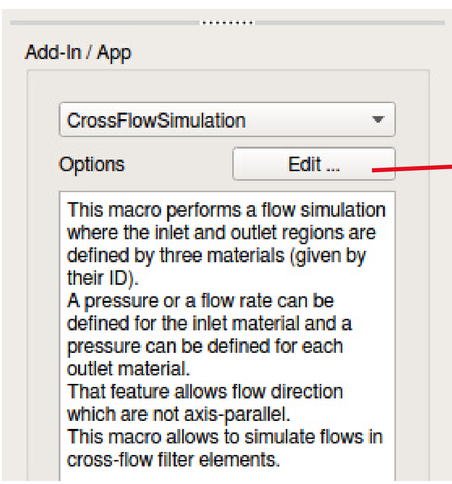


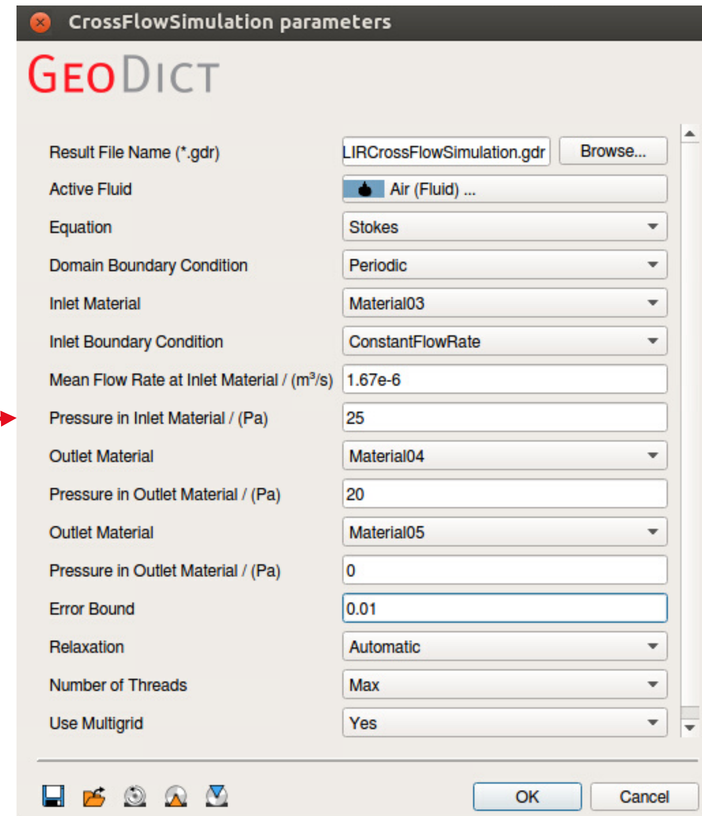


MATH 2 MARKET

Run a cross-flow simulation with FlowDict GeoDict

- Select **Add-In/App → FilterDict** for a predefined script
- Click Edit… for the **CrossFlowSimulation** predefined script
  - Set the Result File Name
  - Choose inlet material (ID 03) with inlet pressure / or mean flow rate at inlet
  - Choose outlet material (ID 04 and ID05) with outlet pressures

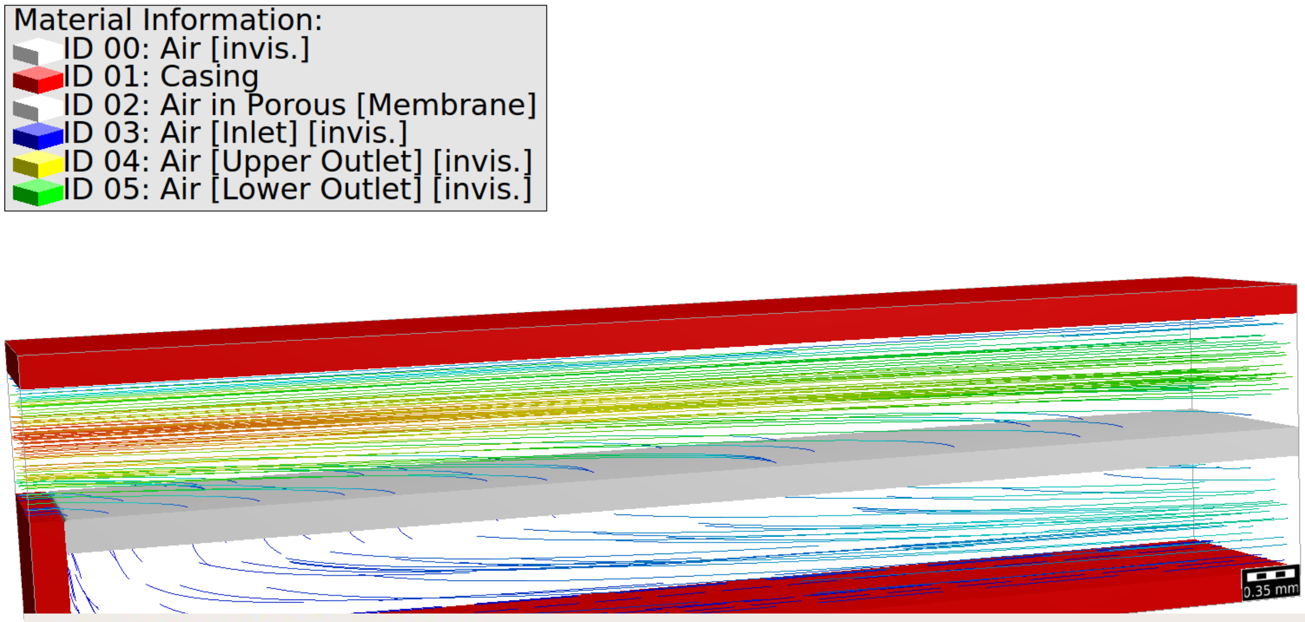


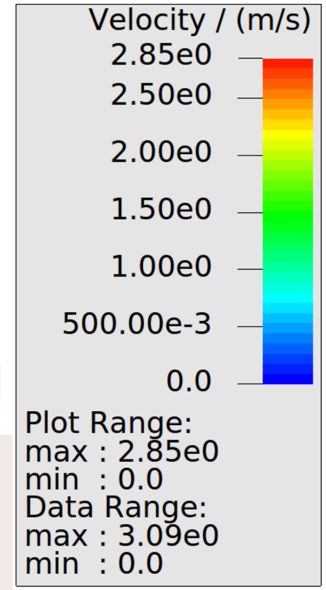


MATH 2 MARKET

Cross-flow simulation results

GeoDict





Fr. Aug. 2 2019 (2020 Build 35313)

Domain: 684 x 128 x 176 Voxel: 10 µm Load Structure

Input Map | Log Map | Post Map | Results | Flow Visualization | Metadata

Report | Plots | Map

Volume flow rate : 0.00167 l/s.
Average flow velocity over 8.192e-7 m² through the inlet : 2.03835 m/s.
Pressure at the inlet material 3 : **25.4313 Pa**.
Pressure at the outlet material 4 : 20 Pa.
Pressure at the outlet material 5 : 0 Pa.

--- Iterations: 2550, Runtime: 12.618 s, Number of Cells: 14736, Memory usage: 40.115 MB, and stopped successfully for **error bound** ---

MATH 2 MARKET

Cross-flow simulation results

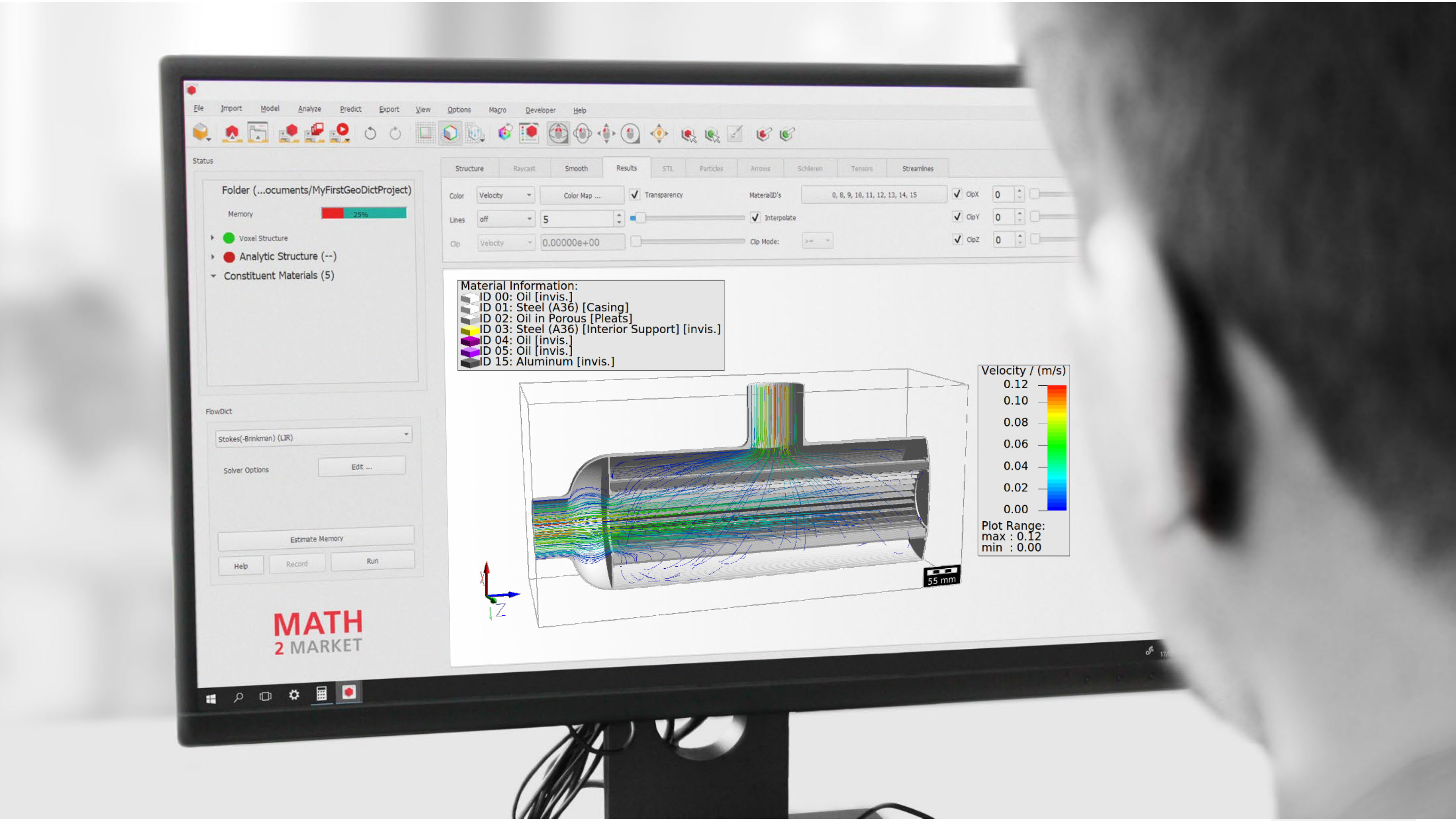
GeoDict

MATH 2 MARKET

CROSS-FLOW FILTRATION SIMULATION

THANK YOU FOR YOUR ATTENTION.

GEODICT



MATH 2 MARKET