

FILTRATION MODELING AND SIMULATION WITH GEODict, FROM FILTER MEDIA TO FILTER ELEMENT

FILTECH 2019
October 22.–24., 2019

Mehdi Azimian

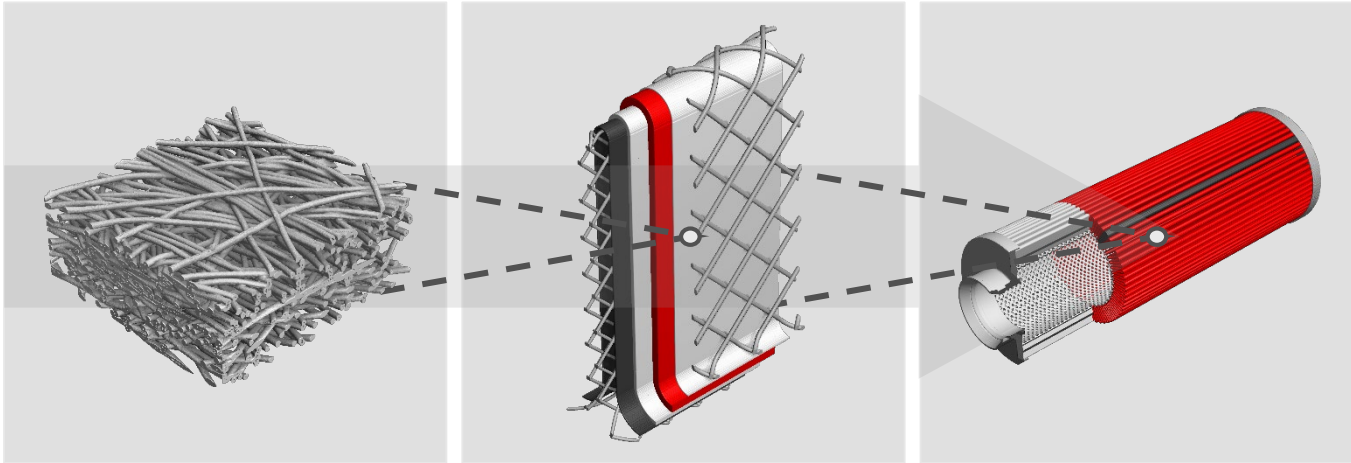
Co-Authors: S. Linden, L. Cheng, C. Kühnle, A. Wiegmann

- | | |
|---|---|
| 1 | Introduction |
| 2 | Simulation of slip flow and filtration through nano-fibrous media |
| 3 | Simulation of filters (complete filter with housing) |
| 4 | Simulation of cross-flow filtration |

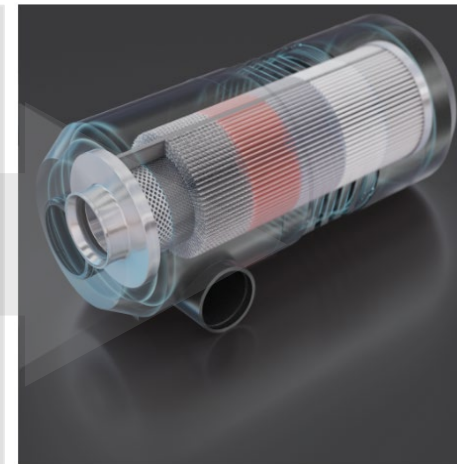
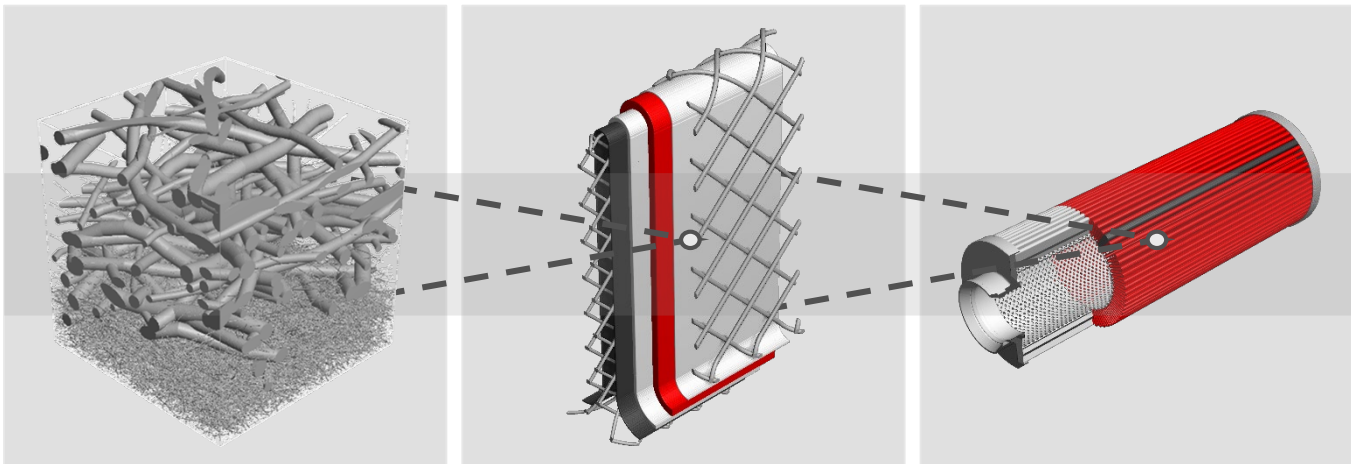
FILTER MEDIA AND FILTER ELEMENT

GEODICT

Up to GeoDict 2019



GeoDict 2020



Filter media

Single pleat

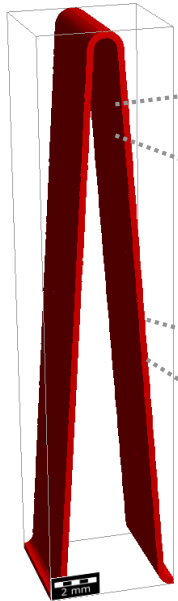
Filter element

Filter



FILTER ELEMENT SIMULATION (IDENTIFICATION OF PARAMETERS)

Estimate max. particles packing density & max. flow resistivity

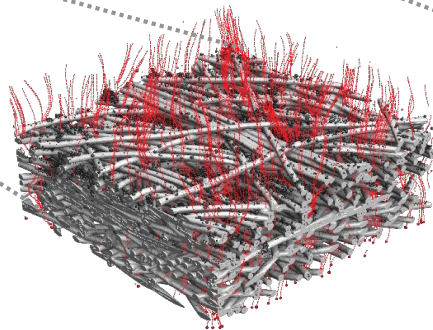


Particles deposited in/on pleated filter element

Simulation requires:

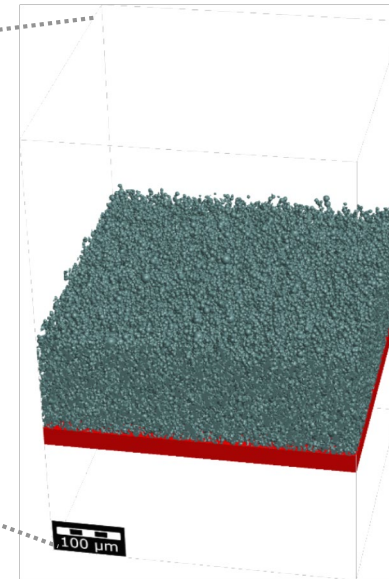
f_{max} : max. particles packing density

σ_{max} : corresponding flow resistivity



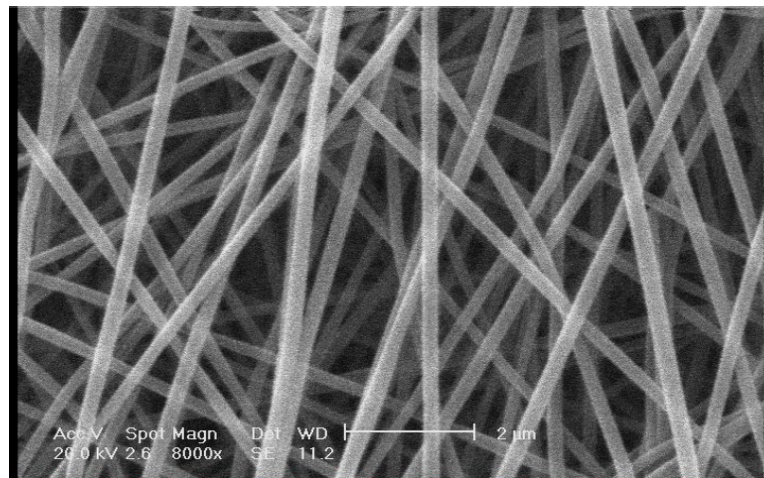
Particles deposited through the micro-structure

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



Particles deposited on a grid frame
high resolution simulation to identify:
 f_{max} & σ_{max} for cake filtration

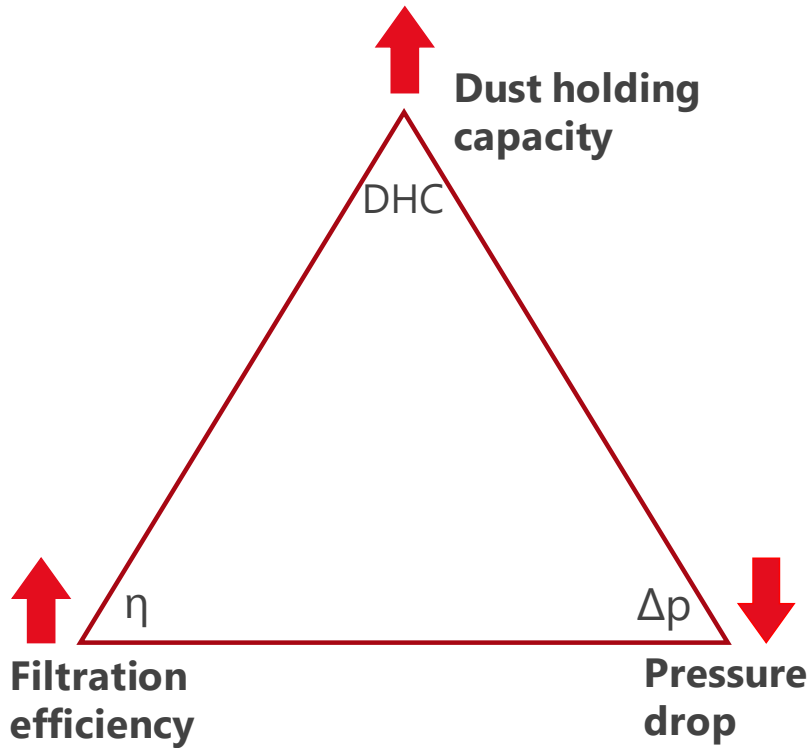
- 1 Introduction
- 2 Simulation of slip flow and filtration through nano-fibrous media**
- 3 Simulation of filters (complete filter with housing)
- 4 Simulation of cross-flow filtration



FLOW AND FILTRATION SIMULATION THROUGH NANO-FIBROUS MEDIA

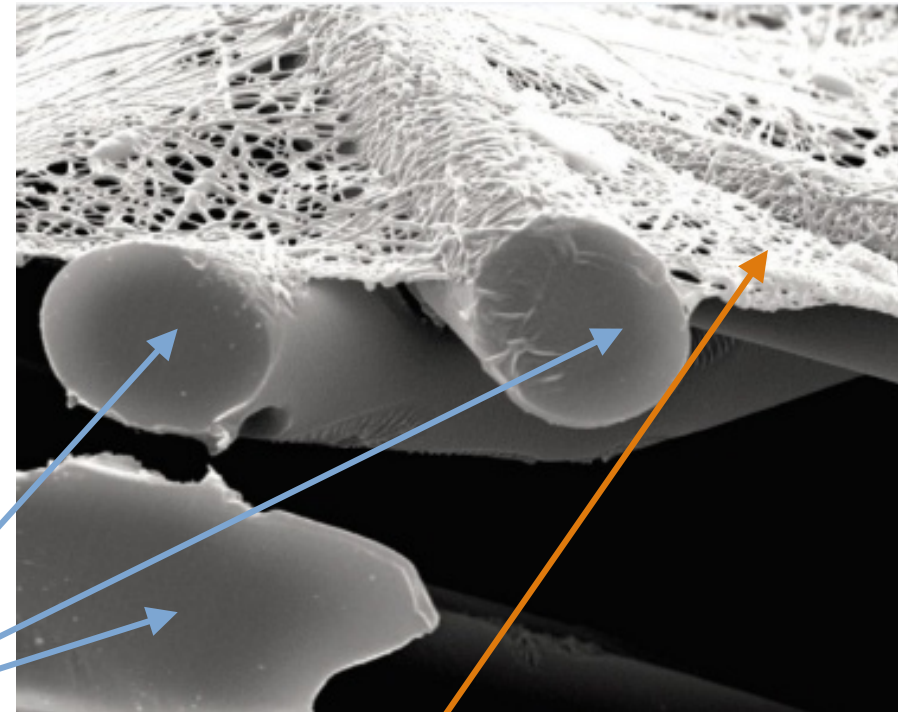
GEODICT

Why nanofibers?



Filtration media
substrate material
(microfibers)

↓ Flow direction



Source: www.donaldson.com

Nanofibers

SIMULATION OF SLIP FLOW AND FILTRATION FOR NANO-FIBROUS MEDIA

For microfiber

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

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

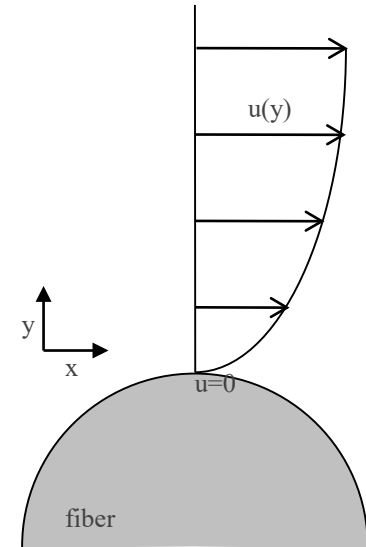
$$\vec{u} = 0 \quad \text{on } \Gamma \quad (\text{no-slip on fiber surfaces})$$

$$P_{in} = P_{out} + c \quad (\text{pressure drop is given})$$

μ : fluid viscosity,

\vec{u} : velocity, periodic,

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



SIMULATION OF SLIP FLOW AND FILTRATION FOR NANO-FIBROUS MEDIA

For microfiber

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

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

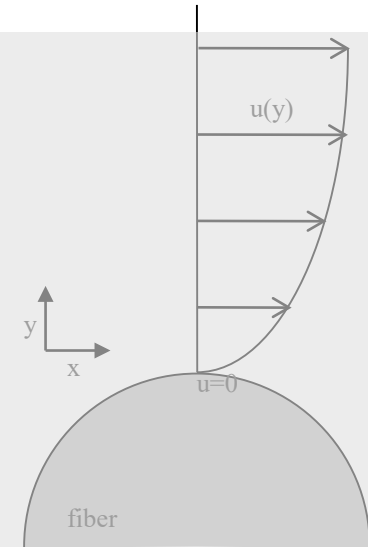
$$\vec{u} = 0 \quad \text{on } \Gamma \quad (\text{no-slip on fiber surfaces})$$

$$P_{in} = P_{out} + c \quad (\text{pressure drop is given})$$

μ : fluid viscosity,

\vec{u} : velocity, periodic,

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



For nanofiber

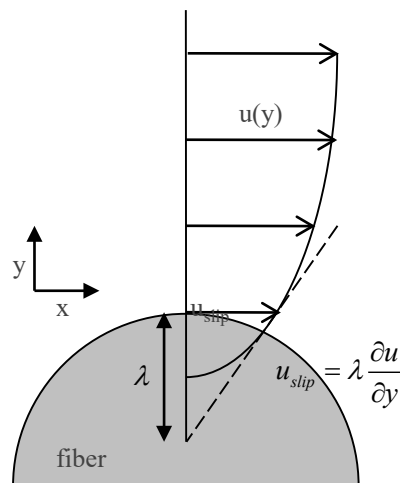
$$-\mu \Delta \vec{u} + \nabla p = 0 \quad (\text{momentum balance})$$

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

$$\vec{n} \cdot \vec{u} = 0 \quad \text{on } \Gamma \quad (\text{no flow into fibers})$$

$$\vec{t} \cdot \vec{u} = -\lambda \vec{n} \cdot \nabla (\vec{u} \cdot \vec{t}) \quad \text{on } \Gamma \quad (\text{slip flow along fibers})$$

$$P_{in} = P_{out} + c \quad (\text{pressure drop is given})$$



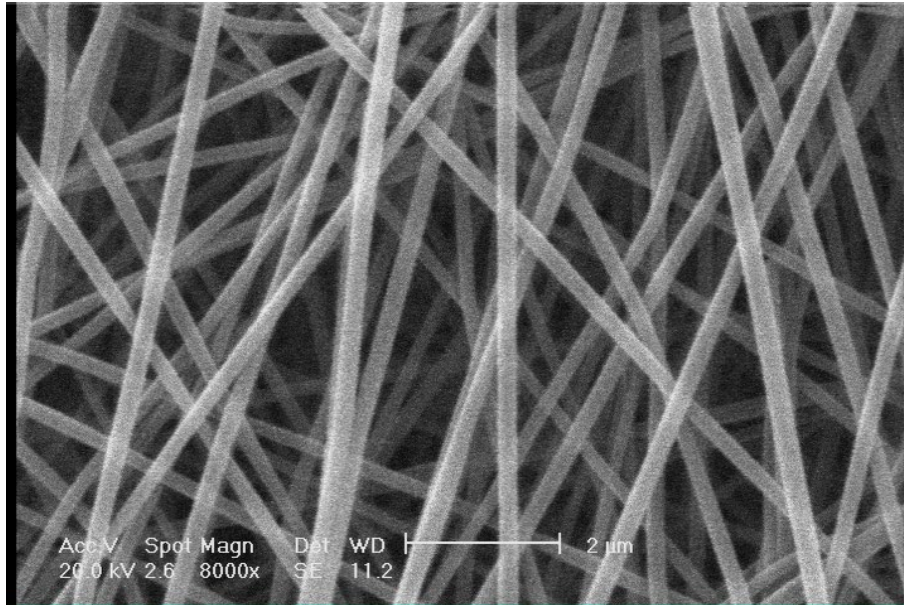
\vec{n} : normal direction to the fiber surface,

λ : slip length,

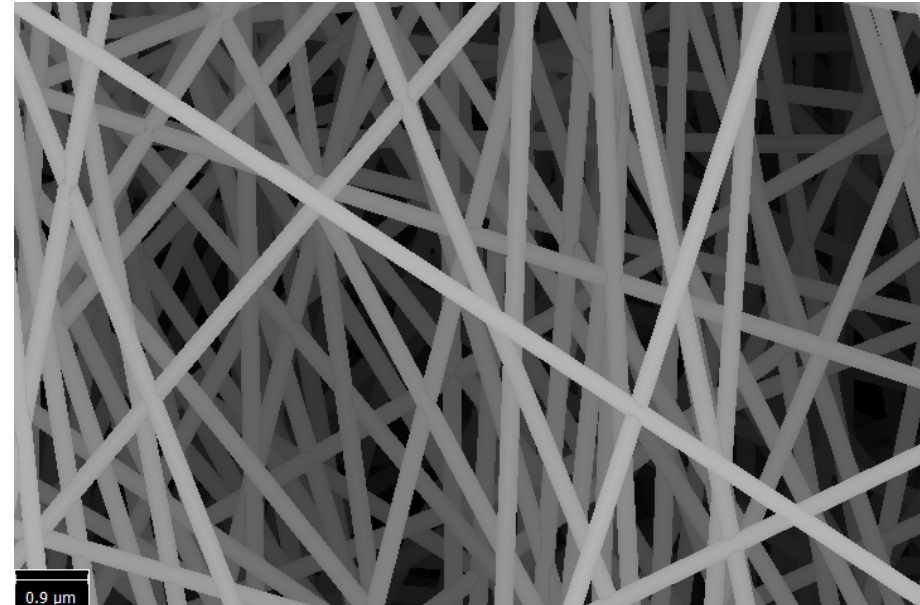
\vec{t} : any tangential direction with $\vec{t} \cdot \vec{n} = 0$.

MODELLING OF NANO-FIBROUS MEDIA FROM SEM IMAGE

Real media (SEM)*

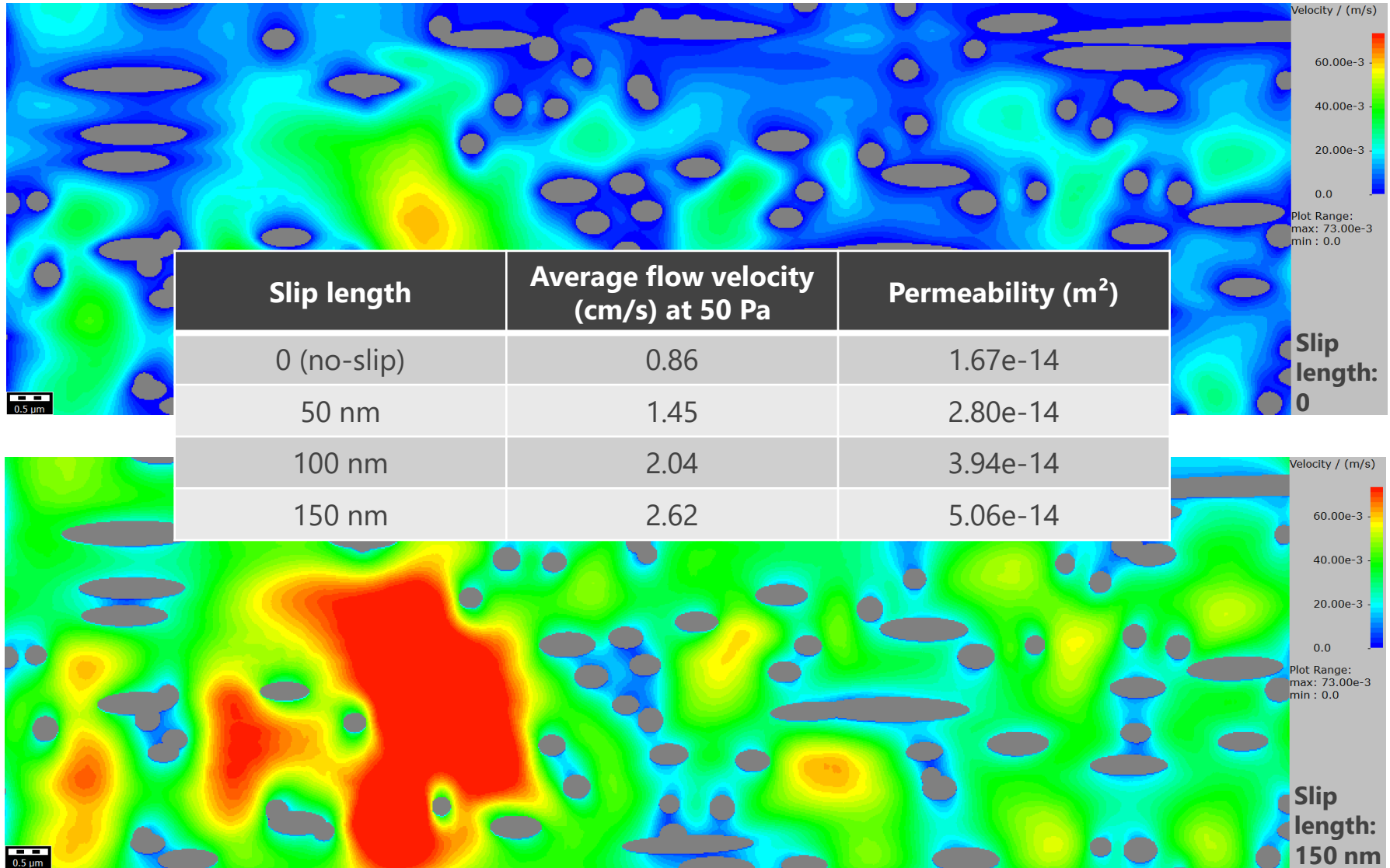


GeoDict 3D model based on SEM



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

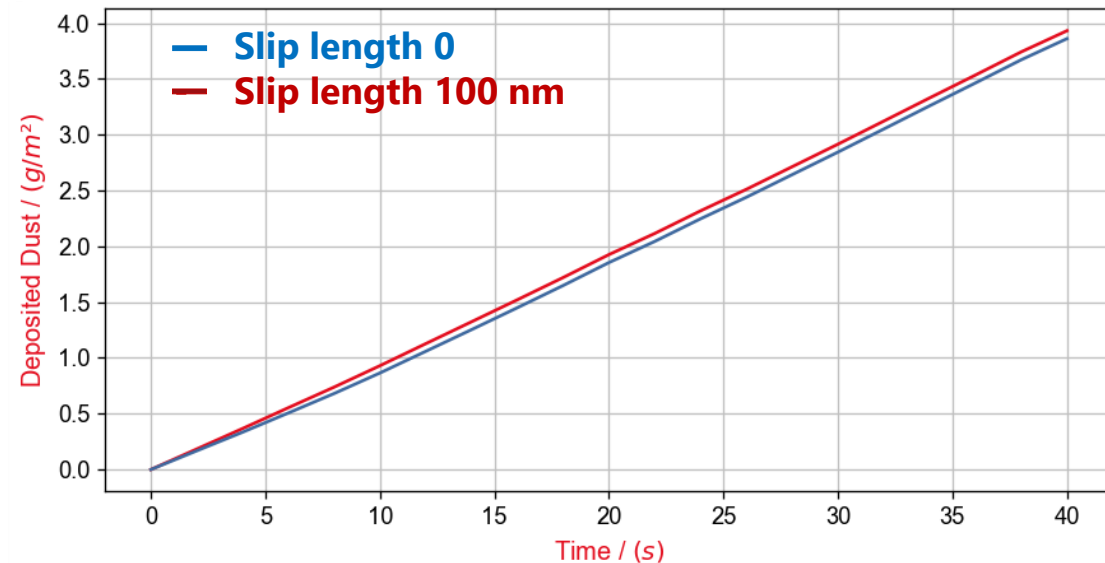
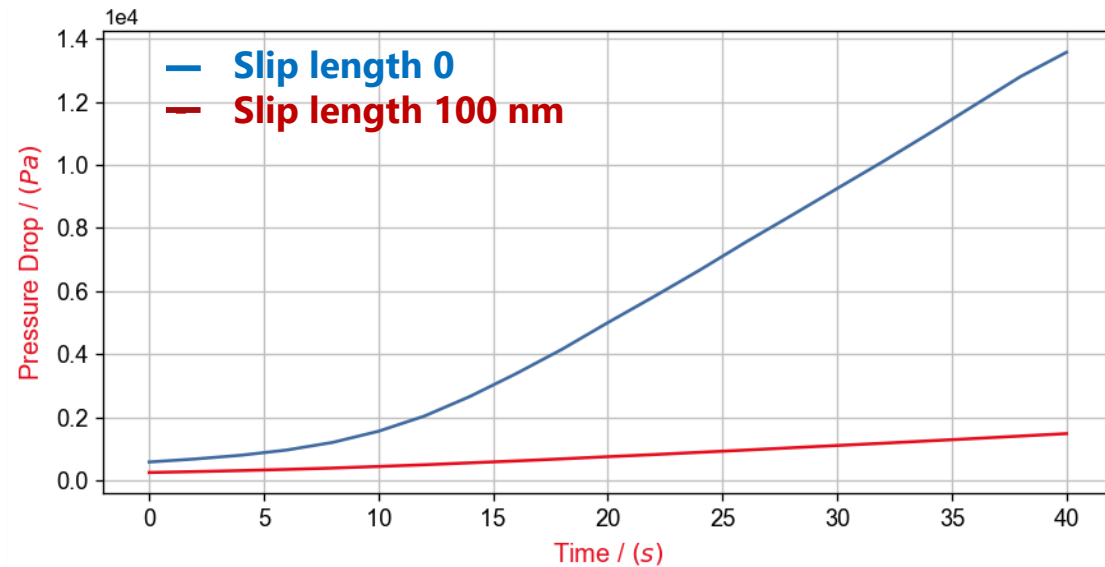
COMPARISON OF VELOCITY DISTRIBUTION



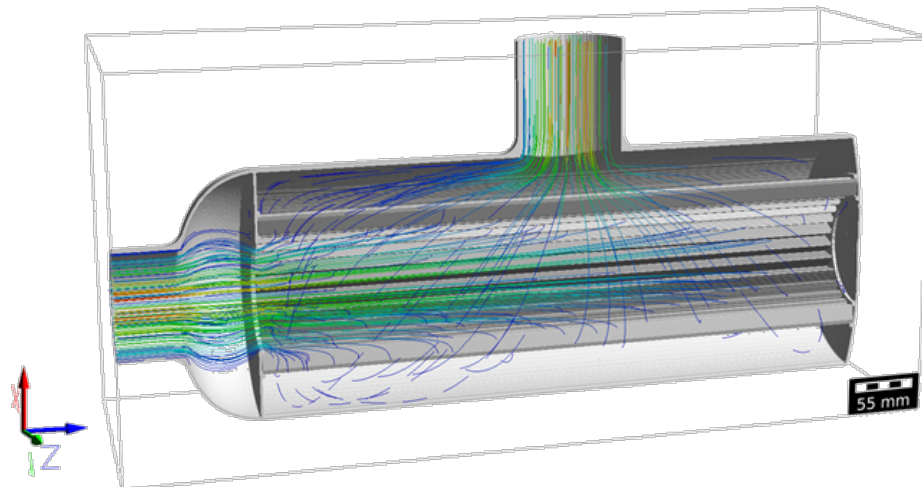
COMPARISON OF FILTRATION SIMULATION RESULTS

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



- | | |
|---|---|
| 1 | Introduction |
| 2 | Simulation of slip flow and filtration through nano-fibrous media |
| 3 | Simulation of filters (complete filter with housing) |
| 4 | Simulation of cross-flow filtration |



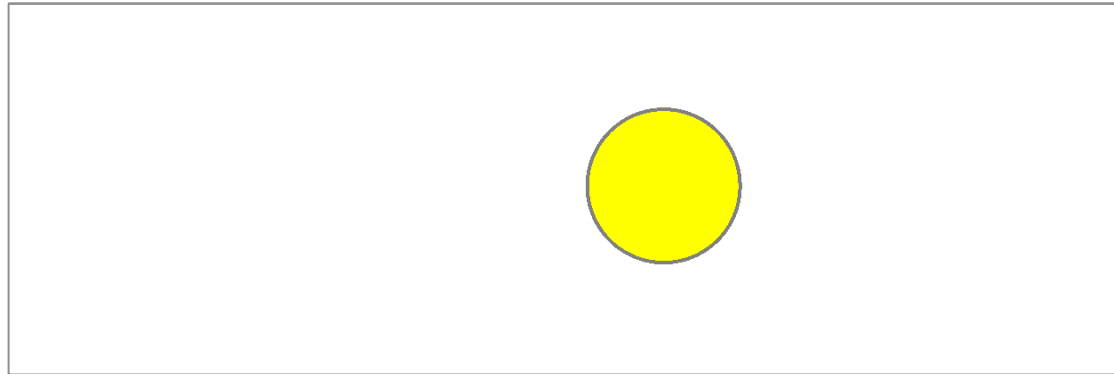


Goals

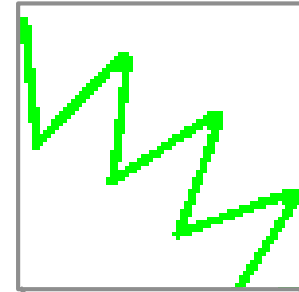
- Import geometric model of a filter (ImportGeo-CAD, ProcessGeo, editing tools)
- Predict pressure drop, efficiency, and life-time for this filter (FilterDict-Element)

REVIEW OF FILTER IMPORT

2D Top View



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



Ambient void

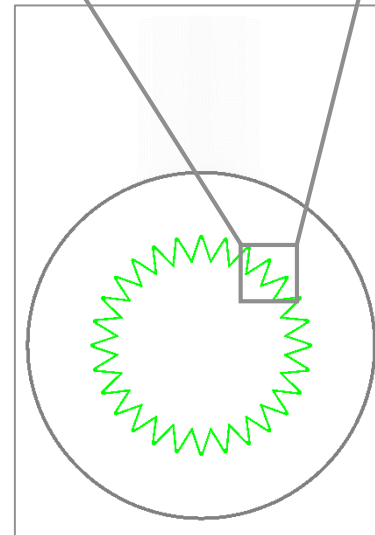
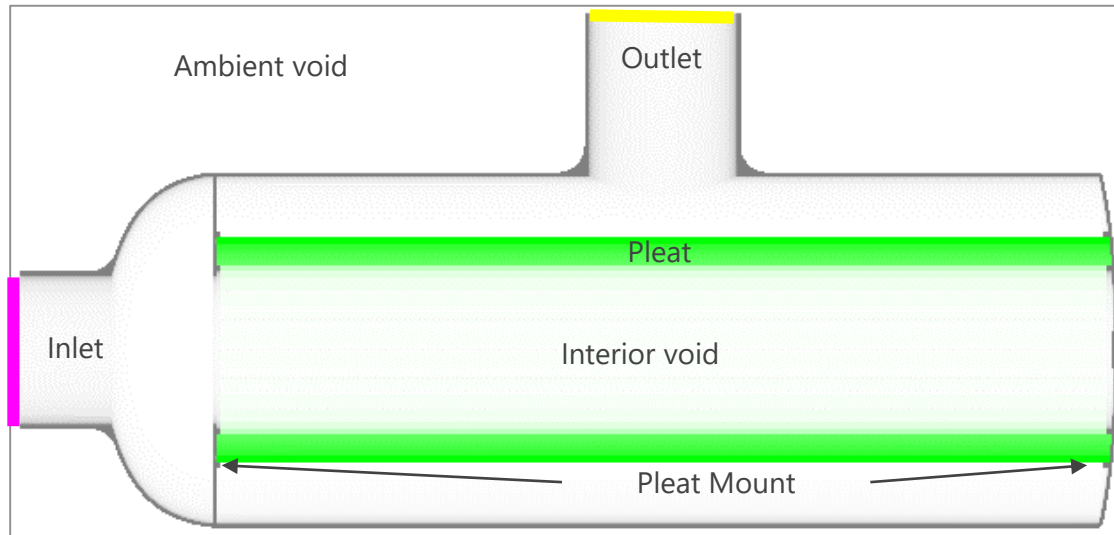
Outlet

Pleat

Interior void

Inlet

Pleat Mount



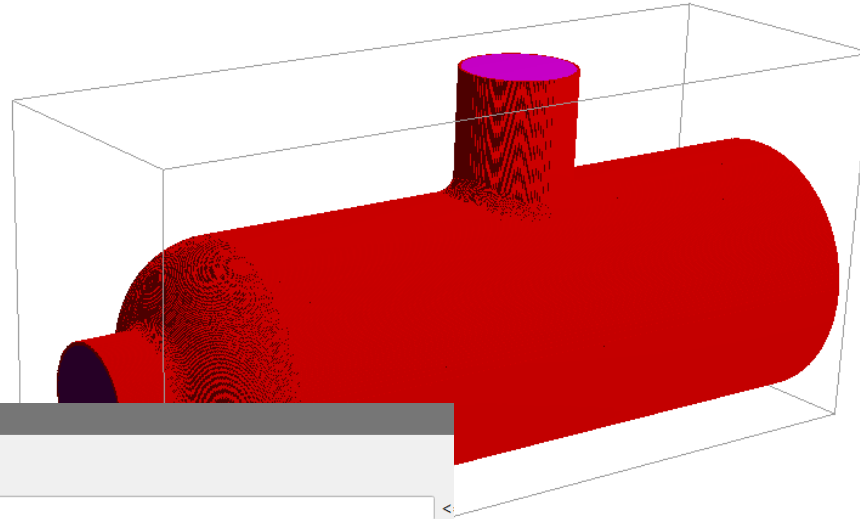
2D Front View

2D Side View

2D Interior View

ASSIGN CONSTITUENT MATERIALS AND PERMEABILITY

Material Information:
 ID 00: Oil [invis.]
 ID 01: Steel (A36) [Casing]
 ID 02: Oil in Porous [Overlap]
 ID 03: Steel (A36) [Interior Support]
 ID 04: Oil [Inlet]
 ID 05: Oil [Outlet]
 ID 15: Aluminum [Ambient void] [invis.]



Select Constituent Materials

GEODICT

Temperature -273.15 <= 22

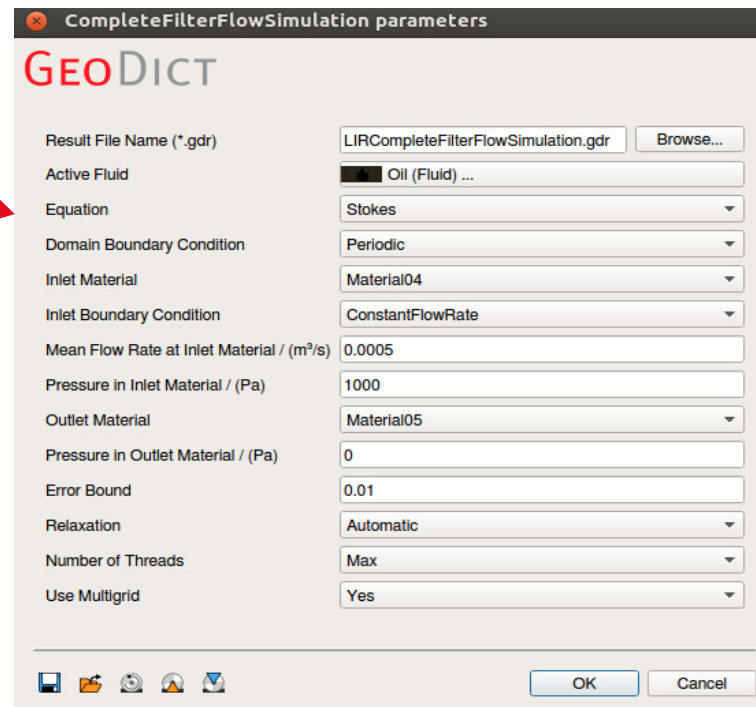
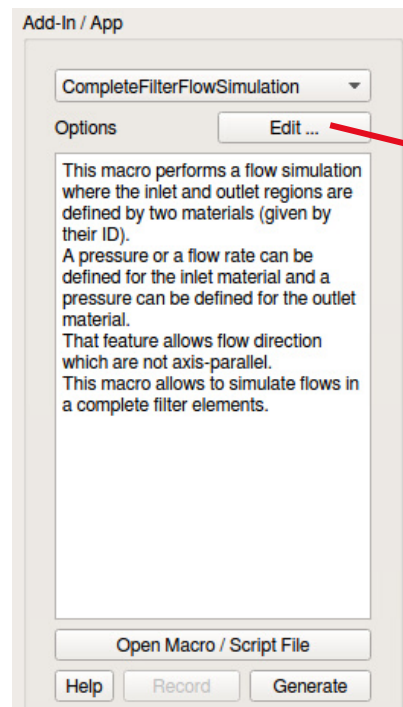
Material	Solid Density	Fluid Density / Viscosity		Permeability			Mechanical Prop.	Thermal Conductivity
				Perm. X / (m ²)	Perm. Y / (m ²)	Perm. Z / (m ²)		
ID Name								
00 Oil (Fluid) ...								
01 Steel (A36) (Solid) ...								
02 Oil in Manual (Porous) ...								
03 Steel (A36) (Solid) ...								
04 Oil (Fluid) ...								
05 Oil (Fluid) ...								
06 Aluminum (Solid) ...								
07 Undefined ...								
08 Undefined ...								
09 Undefined ...								
10 Undefined ...								
11 Undefined ...								
12 Undefined ...								
13 Undefined ...								
14 Undefined ...								
15 Aluminum (Solid) ...								

Permeability details for ID 02 (highlighted):

Permeability Type	Perm. X / (m ²)	Perm. Y / (m ²)	Perm. Z / (m ²)	Temp. Range / (°C)
Isotropic	0	0	0	-
Isotropic	1e-12	1e-12	1e-12	-
Isotropic	0	0	0	-

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

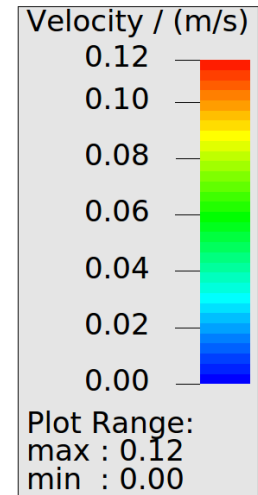
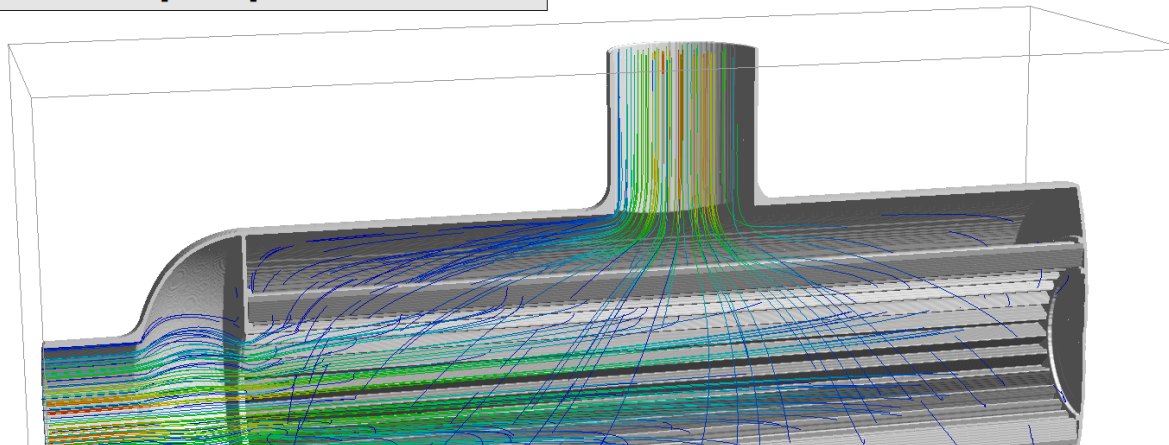


FILTER FLOW SIMULATION RESULTS

GEODICT

Material Information:

-  ID 00: Oil [invis.]
-  ID 01: Steel (A36) [Casing]
-  ID 02: Oil in Porous [Pleats]
-  ID 03: Steel (A36) [Interior Support] [invis.]
-  ID 04: Oil [invis.]
-  ID 05: Oil [invis.]
-  ID 15: Aluminum [invis.]



Fr Sep 13 2019 (2020 Build 36420)

Domain: 581 x 400 x 1237 Voxel: 500 μm

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** ---



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

The screenshot shows the 'Filter Element Life Time' window in the GEO DICT software. The window has a title bar with a red icon and standard window controls. Below the title bar is the GEO DICT logo. A text field for 'Result File Name' contains 'FilterElementLifeTimeCompleteFilterBatch100s.gdr'. A tabbed interface shows 'Single Pass', 'Constituent Materials', 'Model' (selected), 'Particles', 'Process', 'Solver', and 'Output'. The 'Model' tab is active, displaying three sections: 'Particle Initial Position', 'Particle Motion', and 'Particle End Position'. In the 'Particle Initial Position' section, 'Particle Start Position' is set to 'Chosen Material IDs' (highlighted with a red box), 'Start Position Material IDs' is set to '4', 'Random Seed' is '42', 'Particle Multiplicity' is checked, 'Max. Number of Trajectories per Type' is '1000', and 'Reflect particles at inflow plane' is checked. The 'Particle Motion' section has 'Simulate Brownian Motion' and 'Cunningham Correction' unchecked, and 'Cunningham Lambda / (m)' is set to '6.6e-8'. The 'Particle End Position' section has 'Particle End Position' set to 'Chosen Material IDs' (highlighted with a red box) and 'End Position Material IDs' set to '5'.

Filter Element Life Time

GEODICT

Result File Name: FilterElementLifeTimeCompleteFilterBatch100s.gdr

Single Pass | Constituent Materials | **Model** | Particles | Process | Solver | Output

Particle Initial Position

Particle Start Position: Chosen Material IDs

Start Position Material IDs: 4

Random Seed: 42

☒ Particle Multiplicity

Max. Number of Trajectories per Type: 1000

☒ Reflect particles at inflow plane

Particle Motion

☐ Simulate Brownian Motion

☐ Cunningham Correction

Cunningham Lambda / (m): 6.6e-8

Particle End Position

Particle End Position: Chosen Material IDs

End Position Material IDs: 5

Change flow direction from "z" to "From Particle Inflow to Outflow".

Filter Element Life Time

GEODICT

Result File Name:

Single Pass | Constituent Materials | Model | **Particles** | Process | Solver | Output

Simulation Stopping Criterion

- ☒ Max. pressure drop increase: Pa
- ☐ Max. pressure drop: Pa
- ☒ Max. time reached: s
- ☐ Max. total deposited dust: kg/(m²)
- ☒ Inflow region filled

Flow Direction: From Particle Inflow to Outflow

Flow Motion:

Boundary Conditions

- in Flow Directions:
- in Tangential Directions:

Batch Settings

- Batches per Flow Field:
- Time Step Mode:
- Time per Batch / (s):
- Particles per Batch:

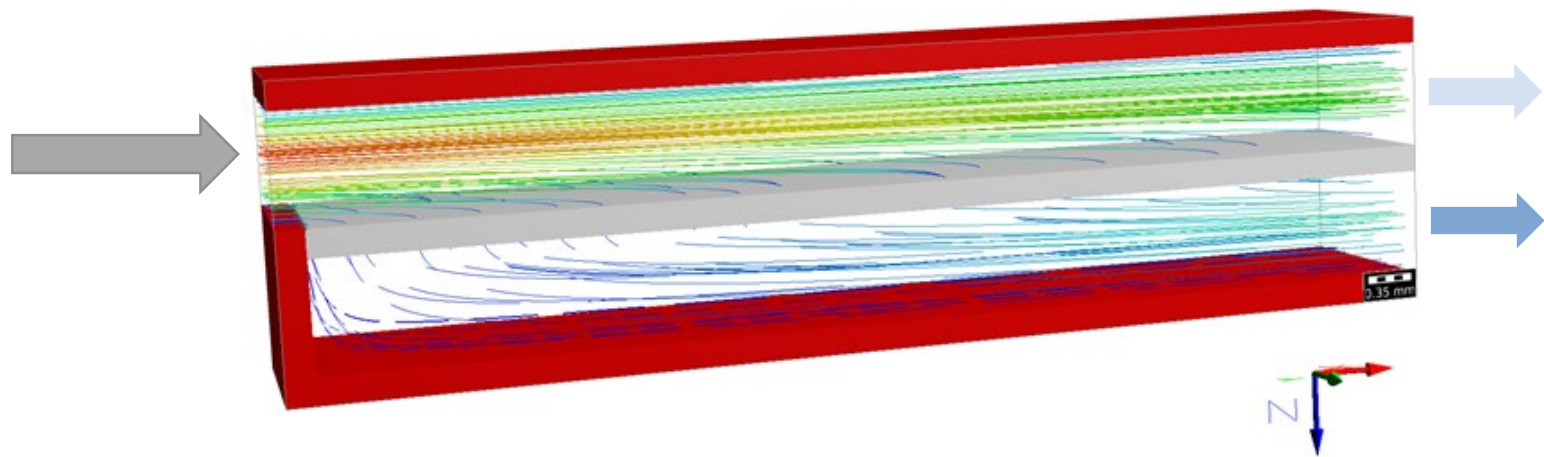
- Movement of particles can be animated
- Simulation and analysis of depth and cake filtration
- Particles are shown 50 times larger here (for better visualization)



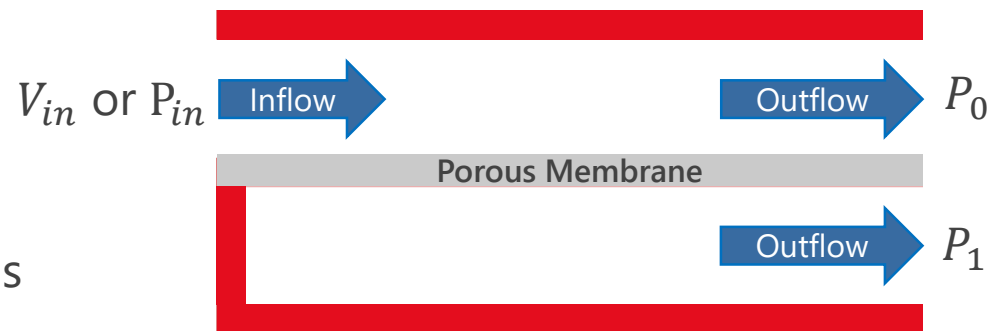
- Particles are trapped inside a vortex
- Filter design not optimal
 - Increased pressure drop
 - Increased simulation runtime



- 1 Introduction
- 2 Simulation of slip flow and filtration through nano-fibrous media
- 3 Simulation of filters (complete filter with housing)
- 4 Simulation of 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!

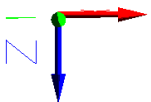
Example of a simple cross-flow filtration setup with an inflow region at the top-left and two pressure outflow boundaries at the top-right and bottom-right

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]

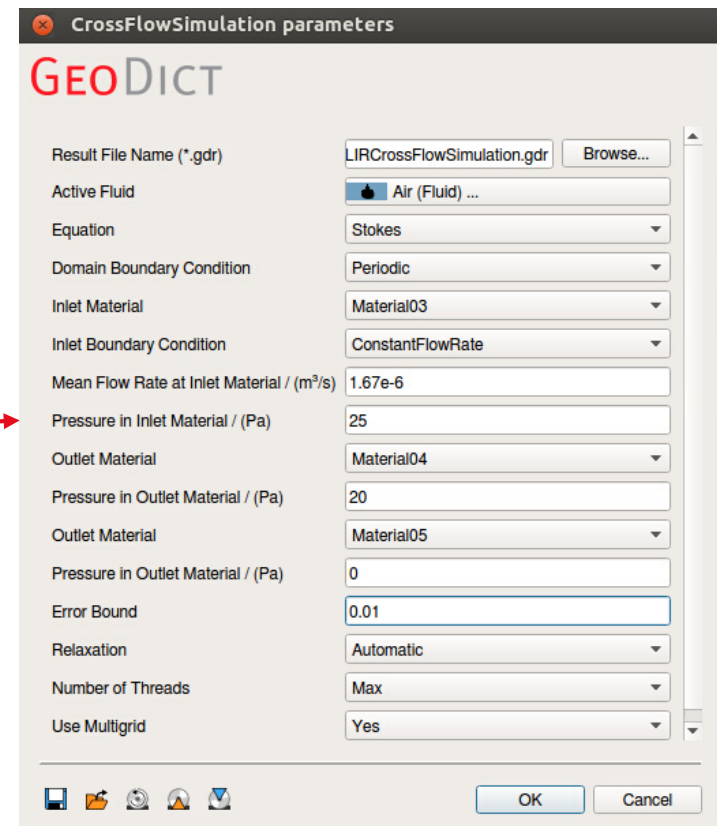
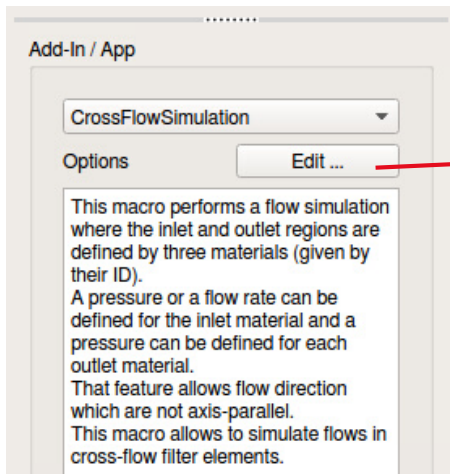
Domain size: 684 x 176 x 128 voxels

Voxel length: 10 μm









RUN A CROSS-FLOW SIMULATION WITH FLOWDict GEODict

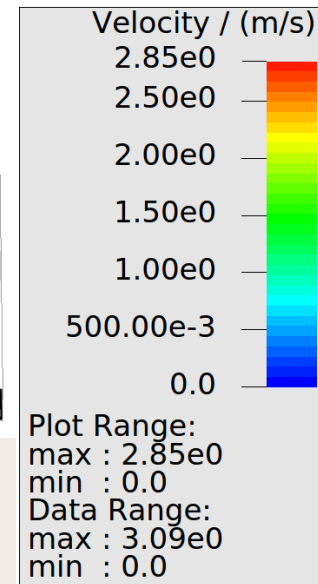
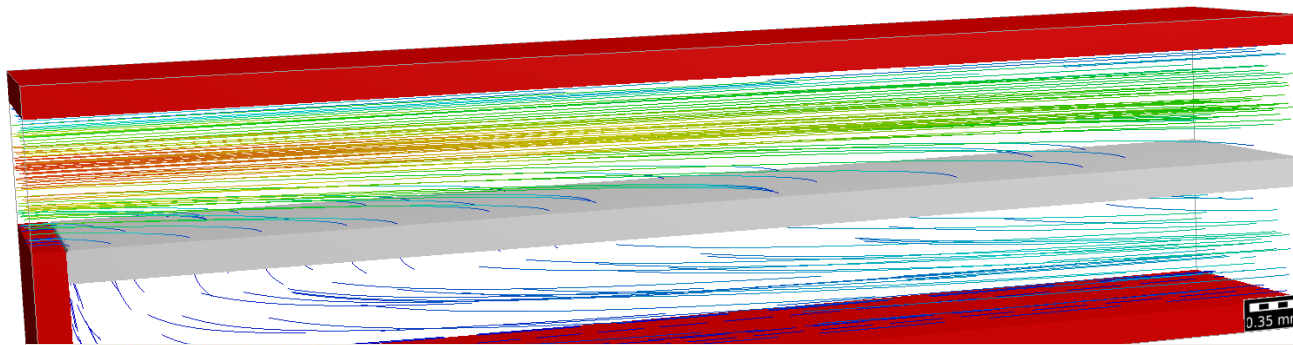
- Select **Add-In/App** → **FilterDict** for a predefined script
- Click Edit... for the **CrossFlowSimulation** predefined script
 - Set the Result File Name
 - Choose inlet material (ID 03) with inlet pressure / or mean flow rate at inlet
 - Choose outlet material (ID 04 and ID05) with outlet pressures



CROSS-FLOW SIMULATION RESULTS

Material Information:

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



Fr. Aug. 2 2019 (2020 Build 35313)

Domain: 684 x 128 x 176 Voxel: 10 μm

Volume flow rate : 0.00167 l/s.
Average flow velocity over $8.192\text{e-}7 \text{ m}^2$ 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** ---





THANK YOU FOR YOUR ATTENTION.

GEOdict

