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

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FILTER MEDIA AND FILTER ELEMENT

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:
\( f_{\text{max}} \): max. particles packing density
\( \sigma_{\text{max}} \): corresponding flow resistivity

Particles deposited on a grid frame
high resolution simulation to identify:
\( f_{\text{max}} & \sigma_{\text{max}} \) for cake filtration

Particles deposited through the micro-structure
high resolution simulation to approximate:
\( f_{\text{max}} & \sigma_{\text{max}} \) for depth filtration

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FLOW AND FILTRATION SIMULATION THROUGH NANO-FIBROUS MEDIA

Why nanofibers?

- Higher initial & ongoing efficiency
- Lower pressure drop across the filtration media → lower energy consumption
- Less compressed air consumption required for pulse-jet dust removal
- Longer filter life
- Flexibility in filter configuration

Source: www.donaldson.com

Filtration media substrate material (microfibers)

Filtration efficiency

Dust holding capacity

Pressure drop

$\eta$

$\Delta p$

DHC

Nanofibers

Source: www.donaldson.com

Flow direction
SIMULATION OF SLIP FLOW AND FILTRATION FOR NANO-FIBROUS MEDIA

For microfiber

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

\(\mu\) : 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

\[-\mu \Delta \vec{u} + \nabla p = 0 \text{ (momentum balance)}\]
\[\nabla \cdot \vec{u} = 0 \text{ (mass conservation)}\]
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\[P_{in} = P_{out} + c \text{ (pressure drop is given)}\]

\[\mu : \text{ fluid viscosity,}\]
\[\vec{u} : \text{ velocity, periodic,}\]
\[p : \text{ pressure, periodic up to pressure drop in flow direction.}\]

For nanofiber

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

\[\vec{n} : \text{ normal direction to the fiber surface,}\]
\[\lambda : \text{ slip length,}\]
\[\vec{t} : \text{ any tangential direction with } \vec{t} \cdot \vec{n} = 0.\]
# Modelling of Nano-Fibrous Media from SEM Image

**Real media (SEM)**

- **Voxel length**: 16 nm (measured on SEM with GeoDict)
- **Fiber diameter**: 280 nm ± 40 nm (measured on SEM with GeoDict)
- **Size 2D**: 720 x 480 Pixels

**GeoDict 3D model based on SEM**

- **Orientation**: Diagonal (0.27, 0.73, 0.00)
- **Porosity**: 82%
- **Size 3D**: 720 x 480 x 328 Voxels
### Comparison of Velocity Distribution

<table>
<thead>
<tr>
<th>Slip length</th>
<th>Average flow velocity (cm/s) at 50 Pa</th>
<th>Permeability (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (no-slip)</td>
<td>0.86</td>
<td>1.67e-14</td>
</tr>
<tr>
<td>50 nm</td>
<td>1.45</td>
<td>2.80e-14</td>
</tr>
<tr>
<td>100 nm</td>
<td>2.04</td>
<td>3.94e-14</td>
</tr>
<tr>
<td>150 nm</td>
<td>2.62</td>
<td>5.06e-14</td>
</tr>
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</table>
Settings of filter life-time single-pass simulations

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Air</th>
</tr>
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<tbody>
<tr>
<td>Temperature</td>
<td>22 °C</td>
</tr>
<tr>
<td>Mean flow velocity</td>
<td>0.1 m/s</td>
</tr>
<tr>
<td>Solver</td>
<td>Stokes (LIR)</td>
</tr>
<tr>
<td>Batches</td>
<td>Each batch 2 s, in total 20 batches (40 s filtration)</td>
</tr>
<tr>
<td>Particles</td>
<td>10 different particle size classes from 100 nm to 460 nm</td>
</tr>
<tr>
<td>Test dust concentration</td>
<td>1 g/m³</td>
</tr>
<tr>
<td>Particle density</td>
<td>2650 kg/m³</td>
</tr>
<tr>
<td>Particle shape</td>
<td>Spherical</td>
</tr>
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**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*)
Make sure that the pleats are well resolved, otherwise use a smaller voxel length!
ASSIGN CONSTITUENT MATERIALS AND PERMEABILITY
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

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.]

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Fr Sep 13 2019 (2020 Build 36420)

Domain: 581 x 400 x 1237 Voxel: 500 μm

Load Structure

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
Filtration simulation settings

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

![GEODict Filter Element Life Time](image)
Filtration Simulation

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

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

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.]

Velocity / (m/s):
- max: 2.85e0
- min: 0.0

Data Range:
- max: 3.09e0
- min: 0.0

Fr. Aug. 2 2019 (2020 Build 35313)
Domain: 684 x 128 x 176  Voxel: 10 μm

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 ---
THANK YOU FOR YOUR ATTENTION.