Optimization of Nonwoven Filter Media Characteristics

Mehdi Azimian, Christopher Kühnle, Andreas Wiegmann

Math2Market GmbH, Kaiserslautern, Germany

4/24/2018
GeoDict (The Digital Material Laboratory)

**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
The GeoDict® Workflow

- **IMPORT**: Diverse ways to import materials for modeling
- **MODEL**: Detailed material models created in 3D
- **ANALYZE**: Extensive analysis and evaluation of structural material properties
- **PREDICT**: In-depth analysis and prediction of material behavior
- **OPTIMIZE**: GeoDict models made available for standard workflows

**Export**
- ExportGeo-Base
- ExportGeo-CAD
- ExportGeo-Fluent
- ExportGeo-Abaqus
Modeling, simulation & optimization of micro-structure of filter media
Simulate filtration at different scales

Pleated element

Flat sheet (micro structure)
Simulation on the micro-structure of the filter media
Particulate flow simulations

1. Filter model
2. Flow field
3. Track particles
4. Deposit particles
5. Flow field
6. Repeat...
Modeling of three various filter media structures

Homogeneous

Linear

Exponential
Modeling of three various filter media structures

**Thick glass fibers**
- Homogeneous

**Thin glass fibers**
- Homogeneous
- Linear
- Exponential

**Three various structures**
- Same initial pressure-drop
- Same β ratio

**Thick fibers (blue):**
- Diameter: 20 µm
- Orientation: Anisotropic 8/1
- Material: Glass
- Vol. ratio: 60%

**Thin fibers (Yellow):**
- Diameter: 4 µm
- Orientation: Anisotropic 8/1
- Material: Glass
- Vol. ratio: 40%

$$\beta_d = \frac{n_d,U}{n_d,D} = \frac{100}{100 - e}$$

Anisotropic Orientation: The material is compressed in the Z-direction & the fibers are isotropic in the XY-plane (Z-slice). The higher the value of the first component of Anisotropy, the stronger is the anisotropy.
## Structural comparison of the three various filter media

<table>
<thead>
<tr>
<th>Structure</th>
<th>Homogeneous</th>
<th>Linear</th>
<th>Exponential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size [µm]</strong></td>
<td>600x600x1600</td>
<td>600x600x1600</td>
<td>600x600x1600</td>
</tr>
<tr>
<td>Distribution of coarse fiber / fine fiber</td>
<td>Uniform / Uniform</td>
<td>Uniform / 1,2,3,4,5,6,7,8,9,10,11</td>
<td>Uniform / 1,2,4,8,16,32</td>
</tr>
<tr>
<td><strong>Permeability [m²]</strong></td>
<td>5.47E-11</td>
<td>5.48E-11</td>
<td>5.53E-11</td>
</tr>
<tr>
<td>$\beta_{22\mu m}$</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td><strong>Object solid volume in domain [%]</strong></td>
<td>6.11</td>
<td>5.9</td>
<td>5.43</td>
</tr>
<tr>
<td>(porosity [%])</td>
<td>(93.89)</td>
<td>(94.1)</td>
<td>(94.57)</td>
</tr>
<tr>
<td><strong>Volume coarse fiber / Volume fine fiber</strong></td>
<td>60/40</td>
<td>60/40</td>
<td>60/40</td>
</tr>
</tbody>
</table>
Homogeneous media

Coarse fibers: Homogeneous
Fine fibers: Homogeneous

Z-Layers [micron]
SVF through plane Z

Flow direction

Domain
600x600x1600 µm
Linear media

Coarse fibers: Homogeneous
Fine fibers: 1,2,3,4,5,6,7,8,9,10,11

Flow direction

Domain
600x600x1600 µm
Exponential media

Coarse fibers: Homogeneous
Fine fibers: 1, 2, 4, 8, 16, 32

Flow direction

Domain
600x600x1600 µm
Particulate oil flow parameters

Used Fluid: Oil
Temperature: 20 °C
Solid particles: ISO Fine A2 test dust
Particle density: 2560 kg/m³
Particle collision model: Sieving
Solver: LIR (Adaptive grids based)
Flow regime: Laminar

Multi-pass filter test schematic based on ISO 4548-12

Iso Fine A2 Test Dust Concentration

Mean Velocity 0.00234848 m/s

Test Dust 15.549 g
Transient filtration simulation (Homogeneous structure)

2650 s → 8733 s → 11340 s
Transient filtration simulation (Homogeneous structure)

2650 s  →  8733 s  →  11340 s
Animation of the transient filtration simulation (Linear structure)
Comparison among the three structures

Homogeneous

Linear

Exponential
Multipass simulation results: Pressure drop over time

- The exponentially increasing media shows the lowest pressure-drop increase through the life-time simulations.
Multipass simulation results: Pressure-drop over total deposited dust

- The exponentially increasing media shows the lowest pressure-drop increase & the highest DHC through the life-time simulations.
## Save in material

<table>
<thead>
<tr>
<th>Structure</th>
<th>Homogeneous</th>
<th>Linear</th>
<th>Exponential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size [µm]</td>
<td>600x600x1600</td>
<td>600x600x1600</td>
<td>600x600x1600</td>
</tr>
<tr>
<td>Distribution of coarse fiber / fine fiber</td>
<td>Uniform / Uniform</td>
<td>Uniform / 1,2,3,4,5,6,7,8,9,10,11</td>
<td>Uniform / 1,2,4,8,16,32</td>
</tr>
<tr>
<td>Permeability [m²]</td>
<td>5.47E-11</td>
<td>5.48E-11</td>
<td>5.53E-11</td>
</tr>
<tr>
<td>$\beta_{22\mu m}$</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Object solid volume percent in domain [%] (porosity [%])</td>
<td>6.11 (93.89)</td>
<td>5.9 (94.1)</td>
<td>5.43 (94.57)</td>
</tr>
<tr>
<td>Volume coarse fiber / Volume fine fiber</td>
<td>60/40</td>
<td>60/40</td>
<td>60/40</td>
</tr>
</tbody>
</table>
Selection of a representative computational domain

Subcakes can form, if there is a gap between high and low solid volume fraction. Such subcakes will lead to a lower DHC.
Conclusions

✓ By modification of the micro-structure of filter media, the macroscopic properties can be optimized.

✓ Computational domain has to be large enough to be representative.

✓ The gradient distribution of fibers through the media thickness, can improve the filtration characteristics.

✓ The exponential media shows the lowest pressure-drop increase & the highest DHC through the life-time simulations.

✓ Results are published recently:

  M. Azimian, C. Kühnle, A. Wiegmann, Design and optimization of fibrous filter media using life-time multi-pass simulations, Chemical Engineering & Technology 41, No. 5, 2018. doi.org/10.1002/ceat.201700585
Thank you for your attention.
Visit us at booth 312 Math2Market