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

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Filtech 2007
Designing filter pleats via simulation

Filter design objectives:
- Minimize Space Requirements
- Minimize Pressure Drop
- Maximize Filter Efficiency
- Maximize 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.
What is a pleat, how does the modelling work?

A pleat is defined by its shape, the media thickness and the media permeability.

The shape defines inflow and outflow regions. The inflow regions contain more dirt particles than the outflow region because the porous region “filters” the dirt.

Very simple model: Discretize as little cubes called voxels, Complexity possible due to very large models, here typically 60 x 60 x 400 cells.
I Pleat design parameters

Fixed number of 2.5 mm pleats

Vary:
- Pleat radii
- Pleat length
- Media Thickness
- Media Permeability

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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 Flow: Stokes-Brinkmann equations

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

\[\begin{align*}
\frac{d\vec{v}}{dt} &= -\gamma \times (\vec{v}(\vec{x}) - \vec{v}_0(\vec{x})) dt + \sigma \times d\vec{W}(t) \\
\frac{d\vec{x}}{dt} &= \vec{v} \\
\gamma &= 6\pi \rho \mu \frac{R}{m} \\
\sigma^2 &= \frac{2k_BT\gamma}{m} \\
\left\langle dW_i(t), dW_j(t) \right\rangle &= \delta_{ij} dt
\end{align*}\]

Same approach as on the micro scale!

\begin{itemize}
  \item $t$: time
  \item $\vec{x}$: particle position
  \item $\vec{v}$: particle velocity
  \item $R$: particle radius
  \item $m$: particle mass
  \item $T$: ambient temperature
  \item $k_B$: Boltzmann constant
  \item $d\vec{W}(t)$: 3d probability (Wiener) measure
  \item $\vec{v}_0$: fluid velocity
  \item $\rho$: fluid density
  \item $\mu$: fluid viscosity
\end{itemize}
At the moment, particles are collected as they enter the porous media.
III Stream lines for transparent media, and particle “media entrance” positions

At the moment, particles are collected as they enter the porous media.
III Particle “entrance” location over the pleat for uniform and non-uniform permeability.

![Graphs showing particle deposition and collisions over layers.]

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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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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

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# GeoDict development teams

<table>
<thead>
<tr>
<th>The GeoDict Team</th>
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| The WeaveGeo & PleatGeo   |                                        |                                        |                                    |
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| The Lattice Boltzmann     |                                        |                                        |                                    |
| Team                     |                                        |                                        |                                    |
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Find out more:

www.geodict.com

Thank you for attending this presentation.