Improved Modeling of Filter Efficiency in Life-Time Simulations on Fibrous Filter Media

Jürgen Becker, Andreas Wiegmann
Math2Market GmbH, Kaiserslautern, Germany

Friedemann Hahn, Martin J. Lehmann
MANN+HUMMEL GMBH, Ludwigsburg, Germany
Math2Market GmbH

- Software GeoDict and FilterDict were developed at Fraunhofer Institute for Industrial Mathematics (ITWM) in Kaiserslautern since 2001.
- In 2011, the three main developers spun off Math2Market GmbH, Kaiserslautern, with the support of the department and the whole institute.
- Math2Market and ITWM continue to closely collaborate with joint projects and joint personnel.
- Collaboration with MANN+HUMMEL was also started while at ITWM.
Overview

1. Motivation – strange effects observed in experiments
2. Possible explanations
3. General approach to filtration simulations with FilterDict
4. Numerical results
5. Enhanced numerical results
1. Experimental Observations
The Multipass Test (ISO 4548)

Contamination circuit
- Storage vessel
- Qinj
- Particle injection

Testing circuit
- Qp
- Pump
- Pressure sensor
- Filter
- Online particle counter 1

Dilution system
- Online particle counter 2
The Multipass Test (ISO 4548)

Decreasing fractional filter efficiencies observed in testing of depth filter media!
2. Possible Explanations for Decreasing Efficiencies
Possibility A: Re-Entrainment
Possibility B: Lingering
Possibility C: Flow Pathways
3.
General Approach to Filtration Simulations with FilterDict*

*FilterDict is a module of the software GeoDict.
Filter Simulation: Efficiency

Basic idea:
1. Filter media model
2. Determine flow field
3. Track particles (filtered or not?)

Randomness:
- Starting positions
- Brownian motion

Result:
- Percentage of filtered particles
Tracking the Particles

- Particles do not interact
- Moving particle does not change Flow field

- Modeled effects:
  - Inertia
  - Brownian motion
  - Electrostatic attraction or repulsion
Adhesion Models

What happens when a particle touches the filter material?

a) sticks to material (deposited)

b) bounces off

Particles always stick => Caught on first touch

Particles stick if kinetic energy cannot overcome adhesive forces => Hamaker

Particles do not stick => Sieving

(Particles loose energy when touching => Restitution factor)
Comparison

Caught on first touch  Hamaker constant $= 1e-21$
Restitution $= 0.5$  Sieving
Filter Simulation: Life Time

1. Filter Model
2. Flow Field
3. Track Particles
4. Deposit Particles
5. Flow Field
6. Repeat ...

© Math2Market GmbH
4. Numerical Simulations
Improvements to FilterDict

- Global time concept: particles can continue to the next batch
  => allows lingering particles
  => needed for re-entrainment

- Enabled Re-Entrainment
  - Compare surface forces from adhesion and shear stress

- More accurate particle tracking
  - Previously:
    flow solver uses staggered grid but writes cell-centered result file
    particle tracking uses cell-centered file
    => accuracy lost (especially at no-slip boundary)
  - New in 2012:
    flow solver uses staggered grid and writes staggered grid result file
    particle tracking uses staggered grid
FilterDict Simulations on 3D Tomography

- Tomography cut-out
- Oil filtration
- Particle size distribution as in experiment
Decrease is visible, but:
- unreliable statistics
  (very few large particles per batch)
- large fluctuations
5.
Enhanced Numerical Results
Introducing *Ghost Particles*

Motivation:

- Test dust typically contains very few large particles and many small particles (by count!)
- To get statistically reliable results:
  - simulate large filter area => high numerical costs
  - use large time steps => lower accuracy
=> no solution !!

New idea: *Ghost Particles*
Introducing *Ghost Particles*

Example:
In the next time interval 5 particles of diameter 35 µm will arrive at the filter.

Classical solution: simulate 5 particles.
New solution: simulate 1000 particles.
(5 real, 995 ghost particles)

- Real particles count for efficiency and get deposited / clog the filter
- Ghost particles count for efficiency and disappear
Enhanced Simulated Filter Efficiency

Grey: without ghost particles
Red: with ghost particles

© Math2Market GmbH
Enhanced Simulated Fractional Efficiency
Summary

- Particle tracking
  - Enhanced features: re-entrainment, lingering
  - Higher accuracy by improved interpolation

- Numerical results agree with experimental observations

- New approach of ghost particles
  - More reliable and representative efficiency
  - Detailed analysis on smaller virtual domains

- Input and model setup critical for good quality of results
Thank You!

GEO DICTION
The Virtual Material Laboratory
www.geodict.com