Prediction of Filter Efficiency and Filter Life Time in Different Regimes

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GeoDict User Meeting 2012

Filter Efficiency

Basic idea:

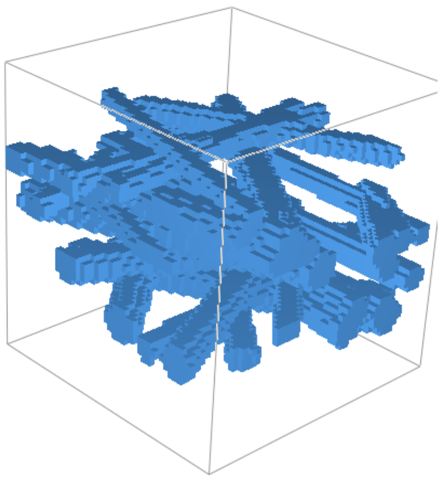
1. Filter model
2. Determine flow field
3. Track particles (filtered or not?)

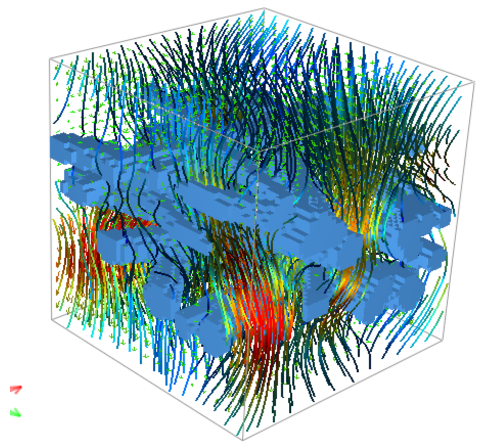
Randomness:

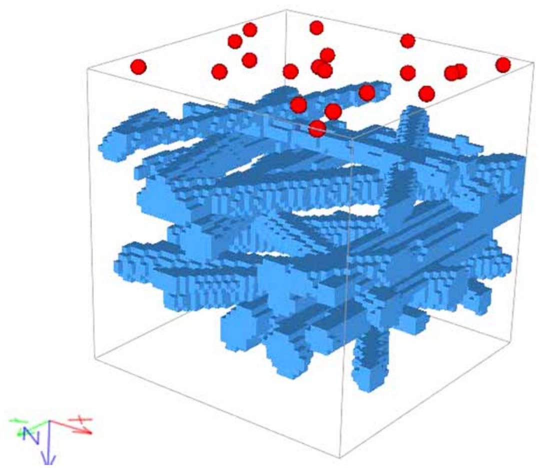
- Starting positions
- Brownian motion

Result:

- Percentage of filtered particles







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Tracking the Particles

- No interaction between particles
- Flow field is not changed by a moving particle

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

Adhesion Model

What happens when a particle hits the filter material?

a) sticks to material (deposited)

b) bounces off

Particles always stick => ***Caught on first touch*** model

Particles always bounce off => ***Sieving*** model

Particles loose energy when bouncing => ***Restitution*** factor

Hamaker Model

Adhesive forces: $F_{vdW} = \frac{Hd}{12a^2}$

(van-der-Waals forces between spherical particle and flat surface)

H Hamaker constant [J]
d Particle diameter
a Distance between particle and surface

Escape velocity:

1. Integrate from a0 (min distance = 4e-10) to infinity
2. Compare with kin. energy of particle

$$v^2 = \frac{H}{4\pi\rho a_0 r^2}$$

Particle sticks for smaller velocities v.

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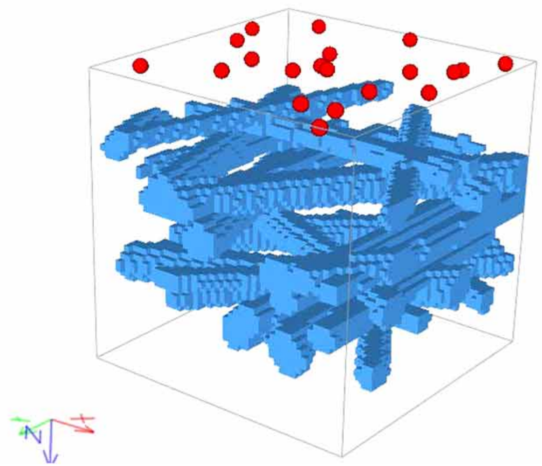
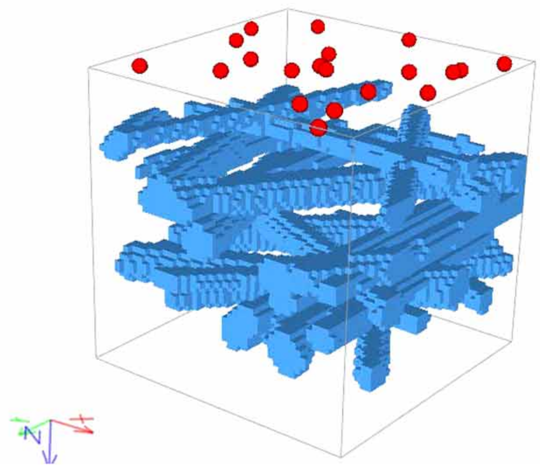
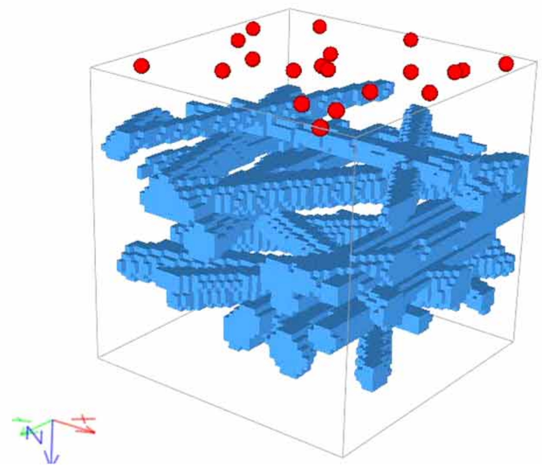
Comparison



Caught on first touch



Hamaker
H =1e-21
Restitution = 0.5



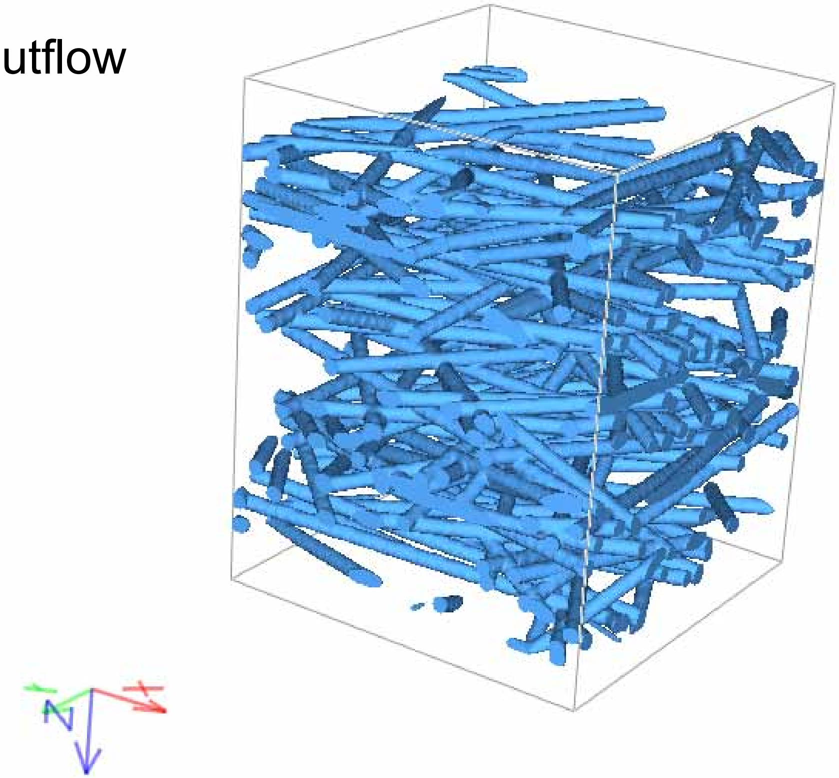
Sieving

Example

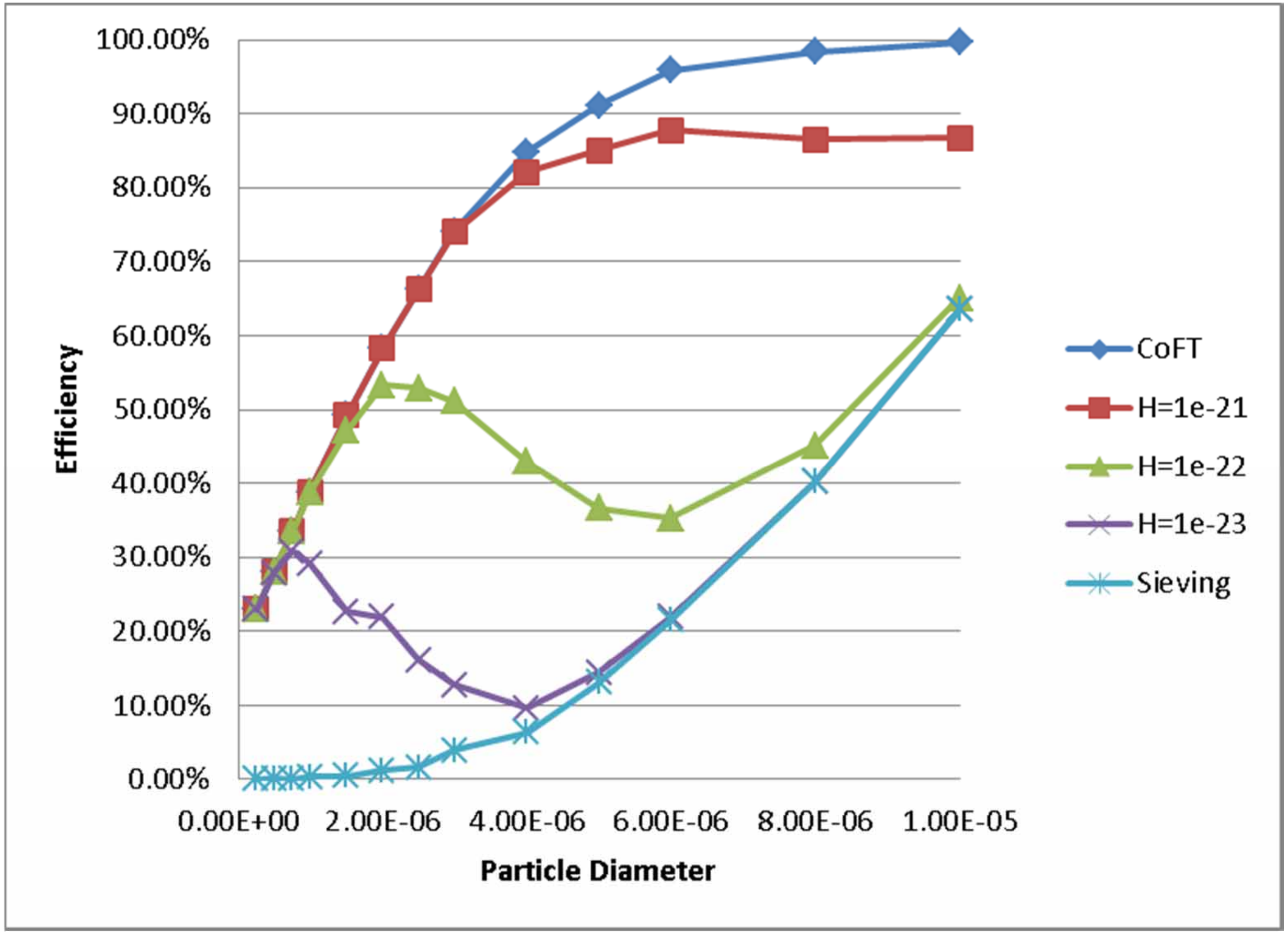
- 200^3 voxels + 30 inflow, 20 outflow
- Voxel length 0.95 µm
- 90 % porosity
- Fiber diameter 6 µm

Flow field:
- Water at 20° C
- v = 0.008 m/s

- Restitution = 0.5



Efficiency



100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Efficiency
0.00E+00
2.00E-06
4.00E-06
6.00E-06
8.00E-06
1.00E-05
Particle Diameter
CoFT
H=1e-21
H=1e-22
H=1e-23
Sieving

Comments

- Results are dependent on fluid velocity and viscosity.
- Parameters need to be fitted to experiments (by the user!).
  - Need: tomogram of the clean filter
  - Need: efficiency measurement for this filter
- FilterDict UDF allows full access to adhesion model.

Filter Life Time Simulations

Basic idea:

1. Filter model
2. Determine flow field
3. Track particles
4. Deposit particles (change structure)
5. Determine flow field (consider deposited dust)
6. Track particles (consider deposited dust)

(Steps 4–6: time step: batch)

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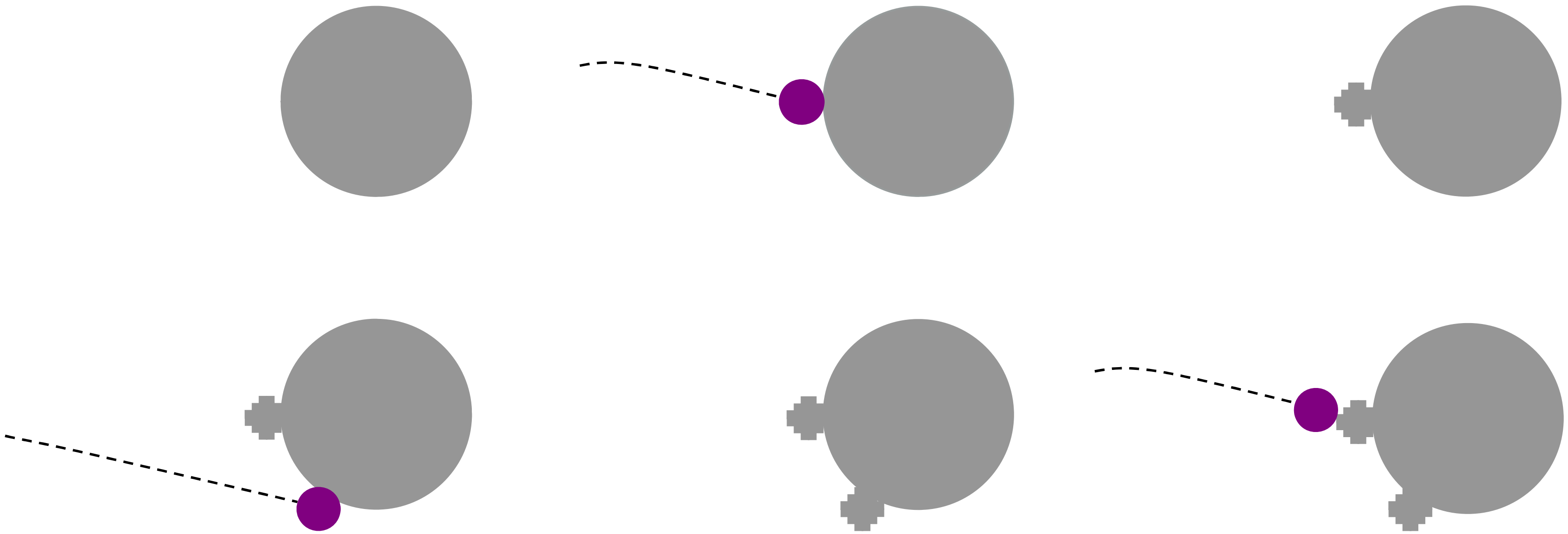
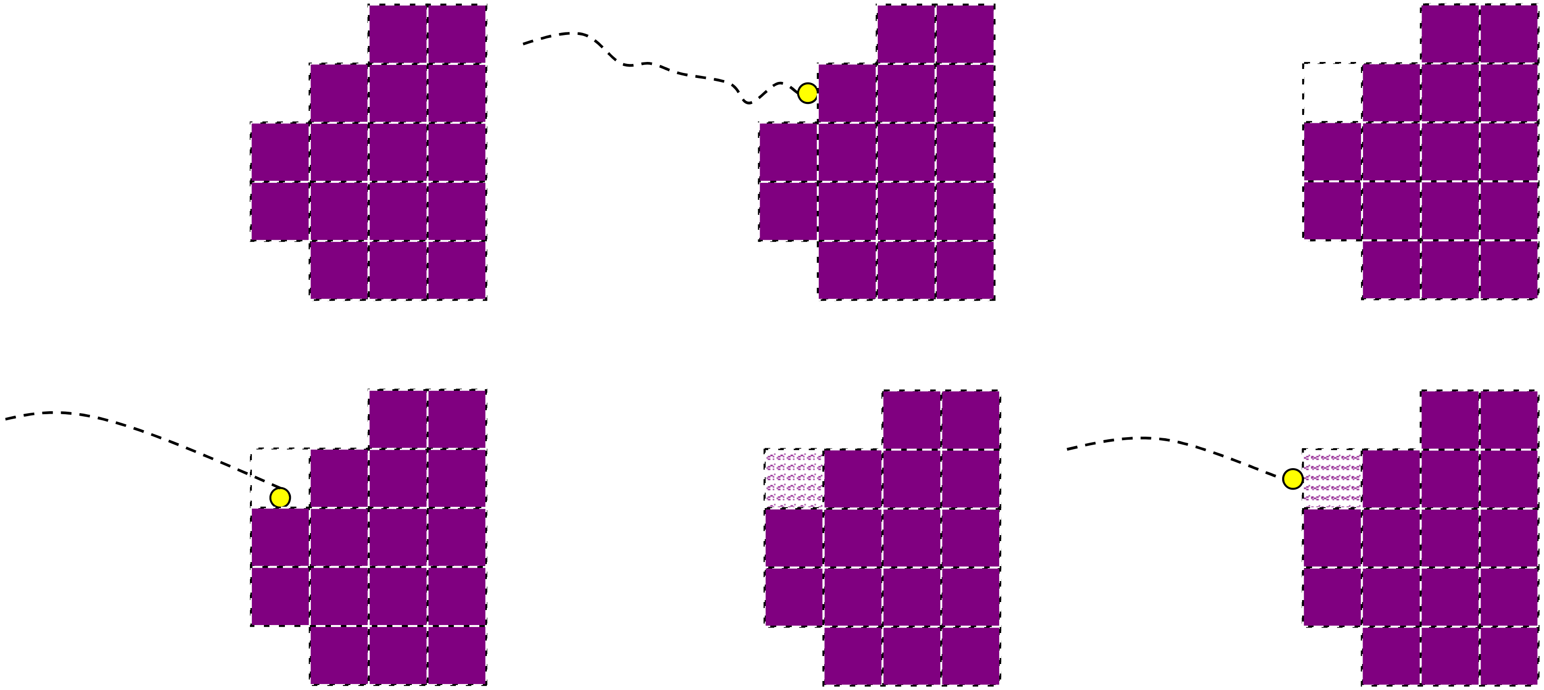
Solid/Empty Model



- Particle diameter > voxel length
- Flow modeled with Stokes equation

Partially Filled Voxels



- Particle diameter < voxel length
- Flow modeled with Stokes-Brinkman equation
  (porous voxels: local flow resistivities)

Local Flow Resistivity

Particle Deposition: fill a (volume) fraction of a voxel *0<f<1*

Volume Fraction	Particle Collision	Flow Resistivity
$0 < f \leq f_{min}$	empty	0 (empty)
$f_{min} < f < f_{max}$	empty	$\frac{f-f_{min}}{f_{max}-f_{min}}\sigma_{max}$ (linear)
$f_{max} \leq f$	solid	σ_{max}
$f = 1$	solid	∞ (solid)

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Choice of Parameters

f_{min}: should be slightly > 0, no big influence on results

f_{max}: solid volume fraction inside of dust agglomerations (or the filter cake)

σ_{max}: flow resistivity of dust agglomerations (or the filter cake)

How can f_{max} and σ_{max} be found ?

I. Fit to measurements

II. Numerical simulations on a sub-scale (i.e. particle diameter > voxel length)

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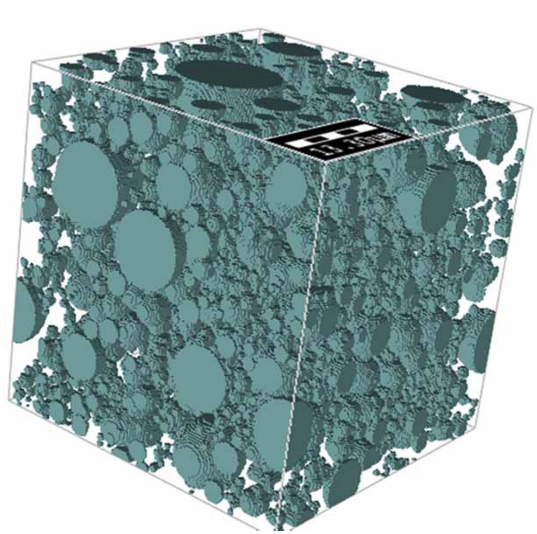
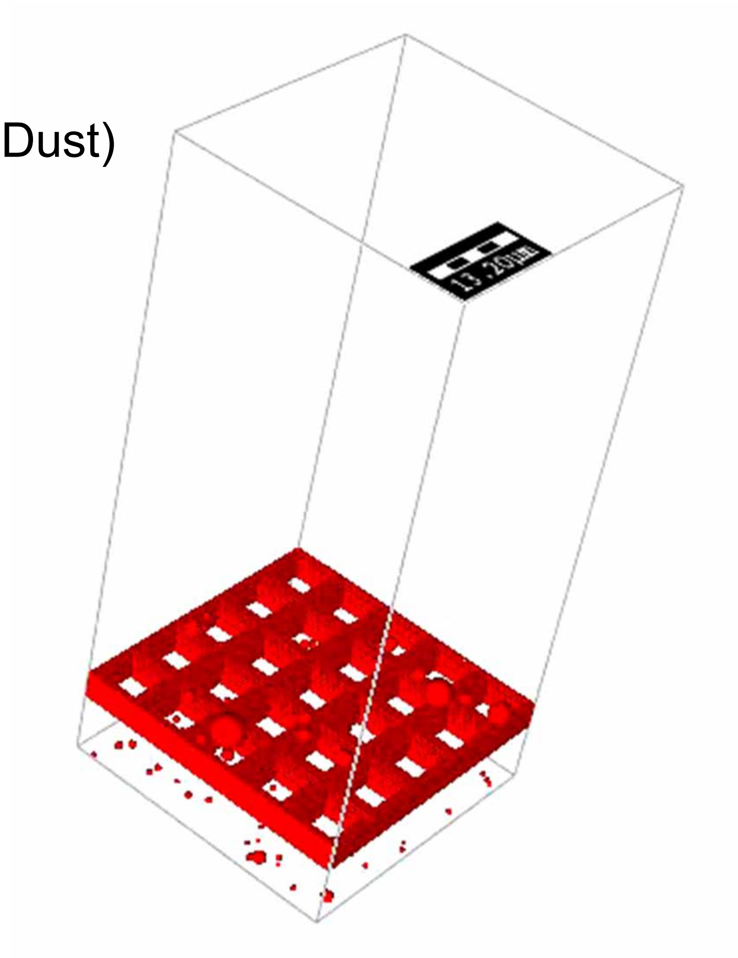
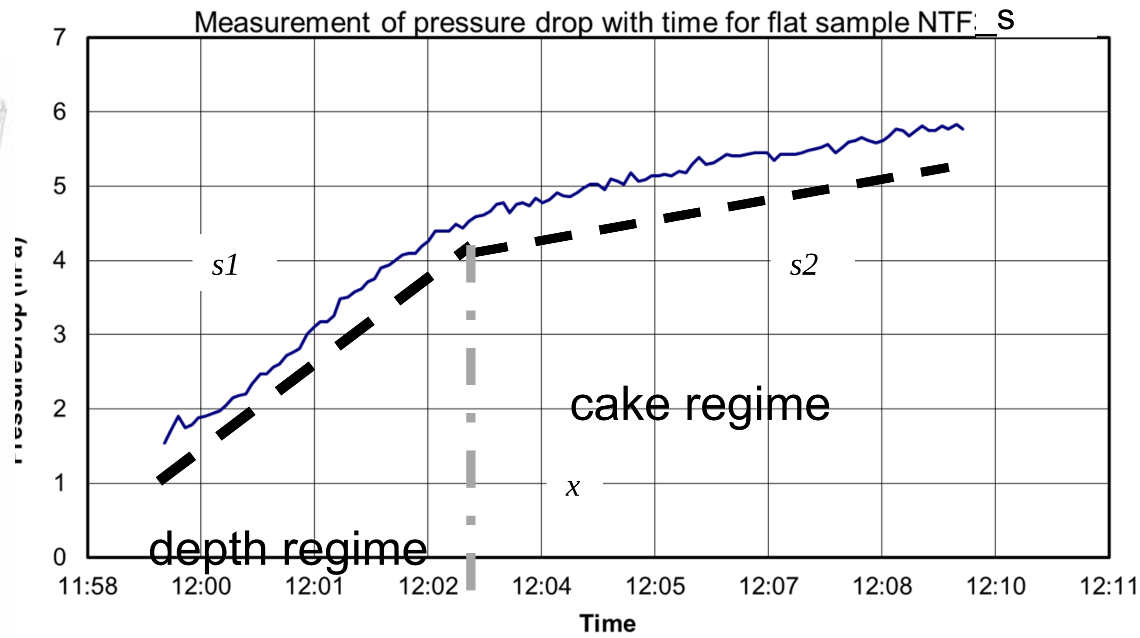
II. Numerical Simulations on a Sub-Scale

1. Model deposition (here: SAE Fine Dust)
2. Take a piece of cake
3. Porosity: 73.5 % => f_{max} = 0.265
4. Use FlowDict-EJ Stokes:
   Flow resistivity: σ_{max} = 6.8 e+7





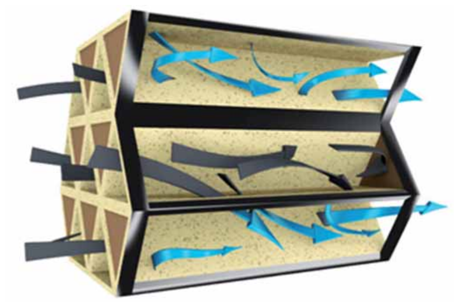
Example: Fit to Measurements



Ceramic **D**iesel **P**articulate **F**ilter media
(Fraunhofer IKTS)

Obervation:

1. fast initial pressure drop increase (depth filtration)
2. long slower pressure drop increase (cake filtration)



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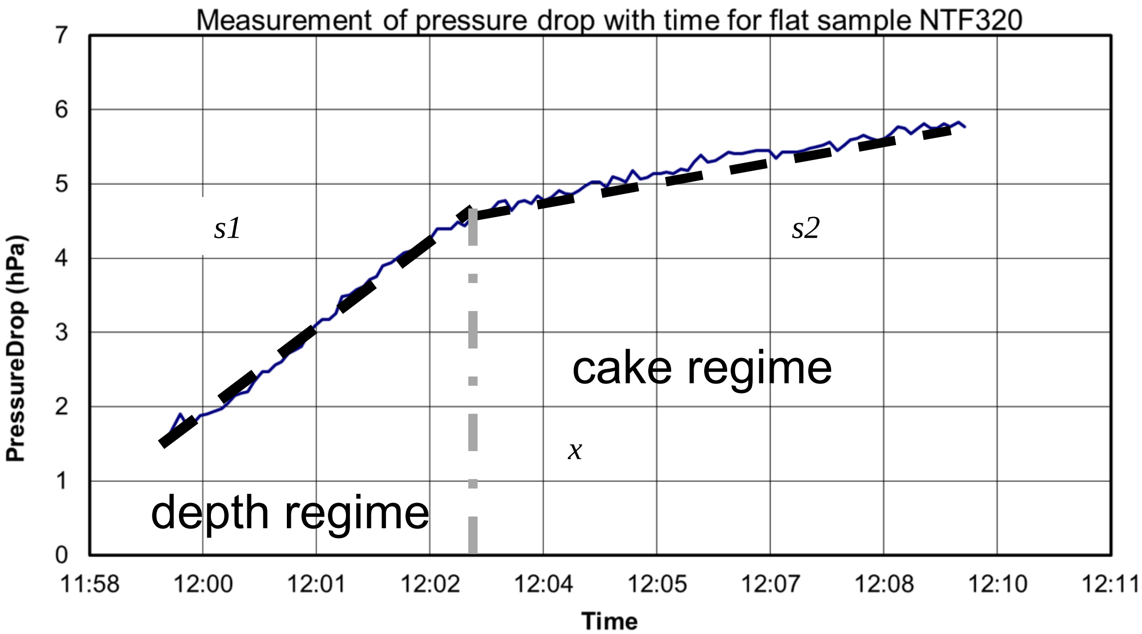
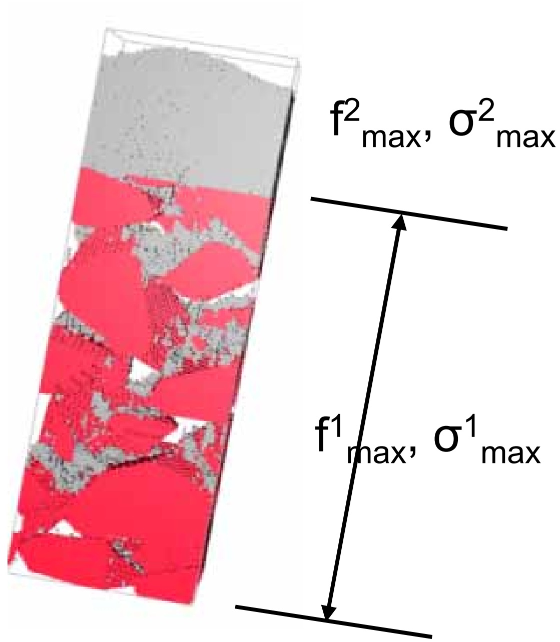
Cake|Depth Model





f^1_{max} : max soot concentration per *depth* voxel determines x

σ^1_{max} : max flow resistivity for (full) *depth* voxel determines s1

f^2_{max} : max soot concentration per *cake* voxel determines cake height

σ^2_{max} : max flow resistivity for (full) *cake* voxel determines s2

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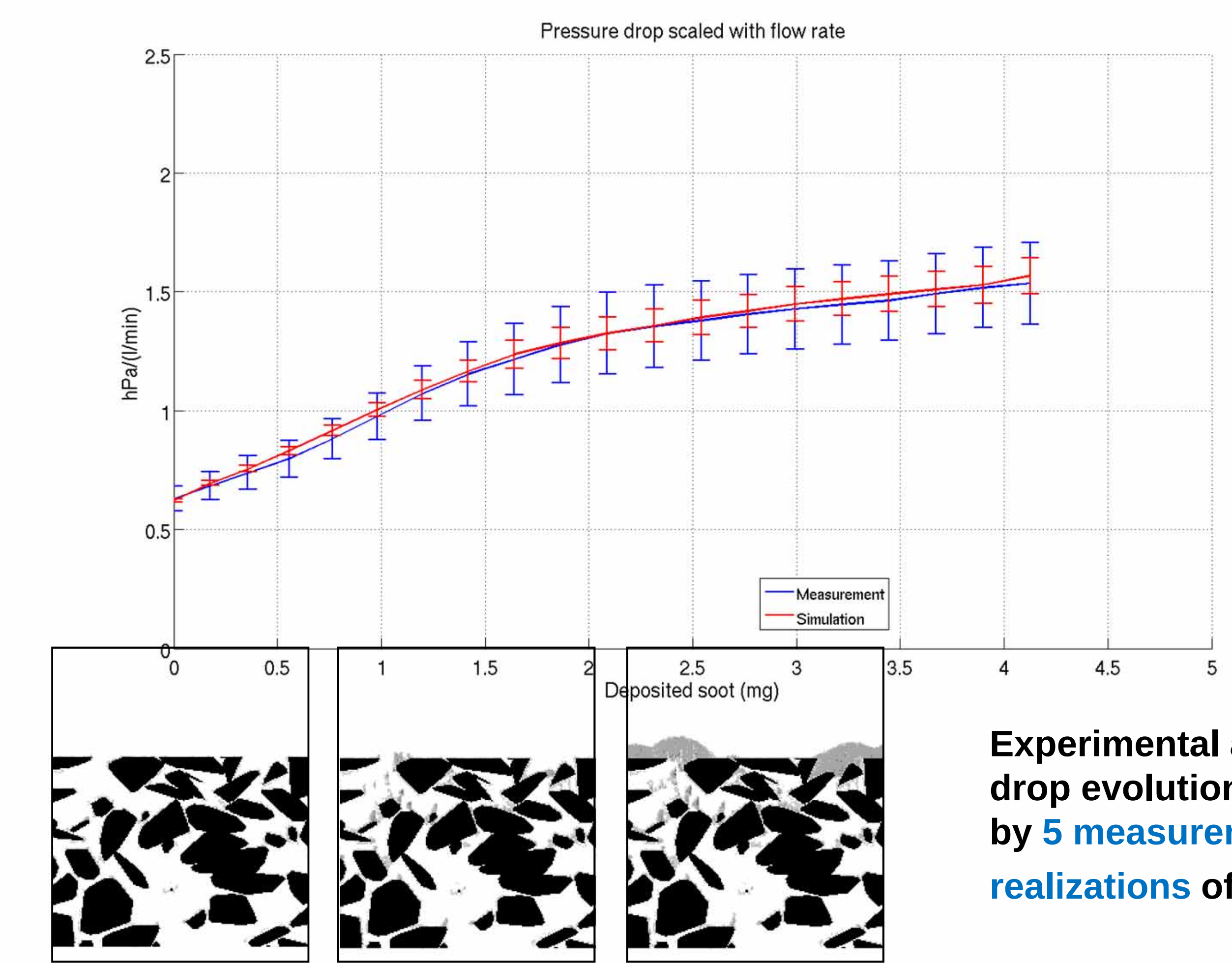
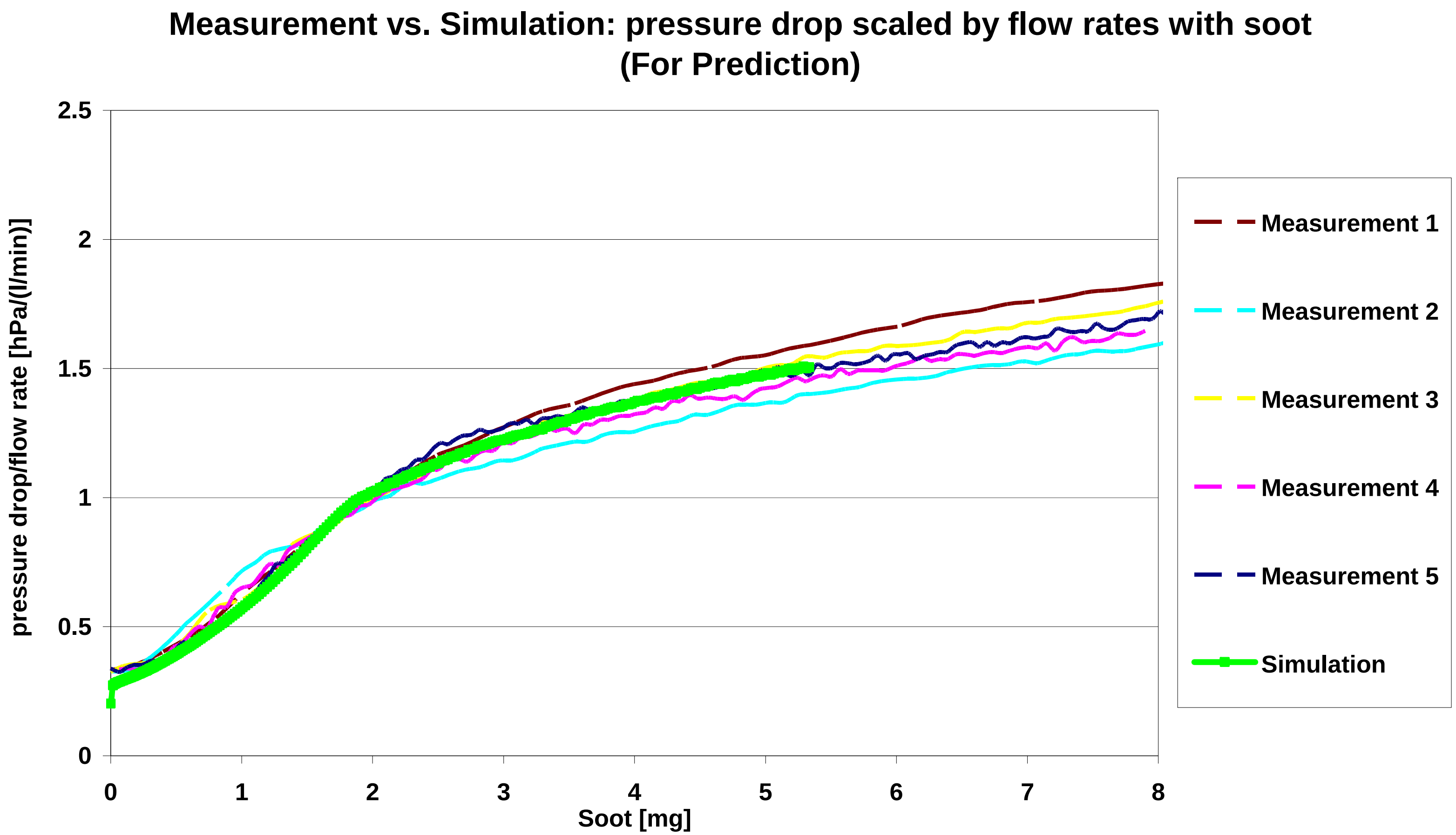
Simulations with Fitted Parameters



Experimental and simulated pressure drop evolution with error bars induced by 5 measurements and 5 different realizations of the virtual structure

Predicting power of the model



Experimental and simulated pressure drop for a different ceramic, NTF_B, with parameters found by fitting against the measurements of NTF_S.

The difference between S and B lies in grain sizes and consequently pore sizes.

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Summary

Fine-tuning of adhesion and clogging models:

- Efficiency
  - Hamaker constant and restitution
  - FilterDict UDF allows to implement own model

- Life Time
  - Porosity of deposited soot/dust
  - Flow resistivity in a partially filled voxel

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Outlook: FilterDict 2012R2

- Redesign of FilterDict dialogs
- Split efficiency and single pass
- Improvements in models and algorithms

Thank you !

Some Slides for FilterDict Experts...

FilterDict Refactoring Summary (GeoDict 2012R1 Version)

1. Renamed FilterSolver to Tracker
2. Flow solver called from GeoDict, not from FilterSolver
   - allows parallel execution of flow solver and Tracker in Windows
3. Tracker parallelization improved
   - Geometry, flow field and e-field data stored distributed
     (now: each proc only stores a slice,   prev.: full data field on each proc)
   - Flow field stored as float (instead of double), geometry as 4-bit
4. Only small changes in GUI

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Outlook: FilterDict 2012R2

1. Hamaker formula corrected
   - Prev.: $$v^2 = \frac{H}{8\pi\rho a_0 r^2}$$
   - Now: $$v^2 = \frac{H}{4\pi\rho a_0 r^2}$$

v = escape velocity
H = Hamaker constant
ρ = particle density
a_0 = 4e-10
r = particle radius

2. Exact calculation of particle-wall collision points and times.
   - Prev.: test for particle-wall overlap at the end of an ODE time step
   - Now: find place, time and collision normal when particle touches wall
     - changes FilterDict UDF

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Outlook: FilterDict 2012R2

3. Adjustment of "Sieving" criterion
   - Prev.: last 5 collisions close together (particle center did not move much) and particle touches several not directly neighbored voxels.
   - Now: last 5 collisions close together (particle center did not move much) and with different, not directly neighbored voxels.

4. Flow solver files contain physical units (no dimensionless values)
   - removed LB-Solver (ParPac)
   - *.vap instead of *.mom files (Advantage: *.vap has ASCII header, which allows for additional information, e.g. double or float, voxel corner or center)
   - allows to use Navier-Stokes in FilterDict

Outlook: FilterDict 2012R2

5. Enhanced interpolation of velocities
   - Prev.: *.mom file contains values at voxel center (averaged for EJ, EFV)
   - Now: *.vap file contains staggered grid data as used in EJ, EFV

6. "Time per Batch" instead of "Particles per Batch" also in SinglePass
   - Tracker respects batch time interval (prev.: max. # time steps in ODE)
   - Particle is transfered to next batch, if it is still "in flow" at the end of the time interval
     - Changes in visualization and result files
   - *Possible feature: particles starting at different times (currently only in AddiDict)*

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Outlook: FilterDict 2012R2

7. Added FilterDict-Efficiency as new command with new GUI
   - Prev.: use single pass with one batch and many particles for efficiency simulations
   - Now: can get better statistics for non-uniform distributions (e.g. SAE fine dust)
   - Less parameters

8. Miscellaneous
   - Cunningham correction choosable in GUI
   - Additional model available for clogging and flow resistivity (Cake|Depth)
   - 2012R1 macros still run (compatibility mode) if no LB solver was used.

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Question: Single Pass GUI

How should the SinglePass GUI look like ?

What are the input values ?