Improved Modeling of Loading Kinetics in Detailed Filter Media Simulations with GeoDict

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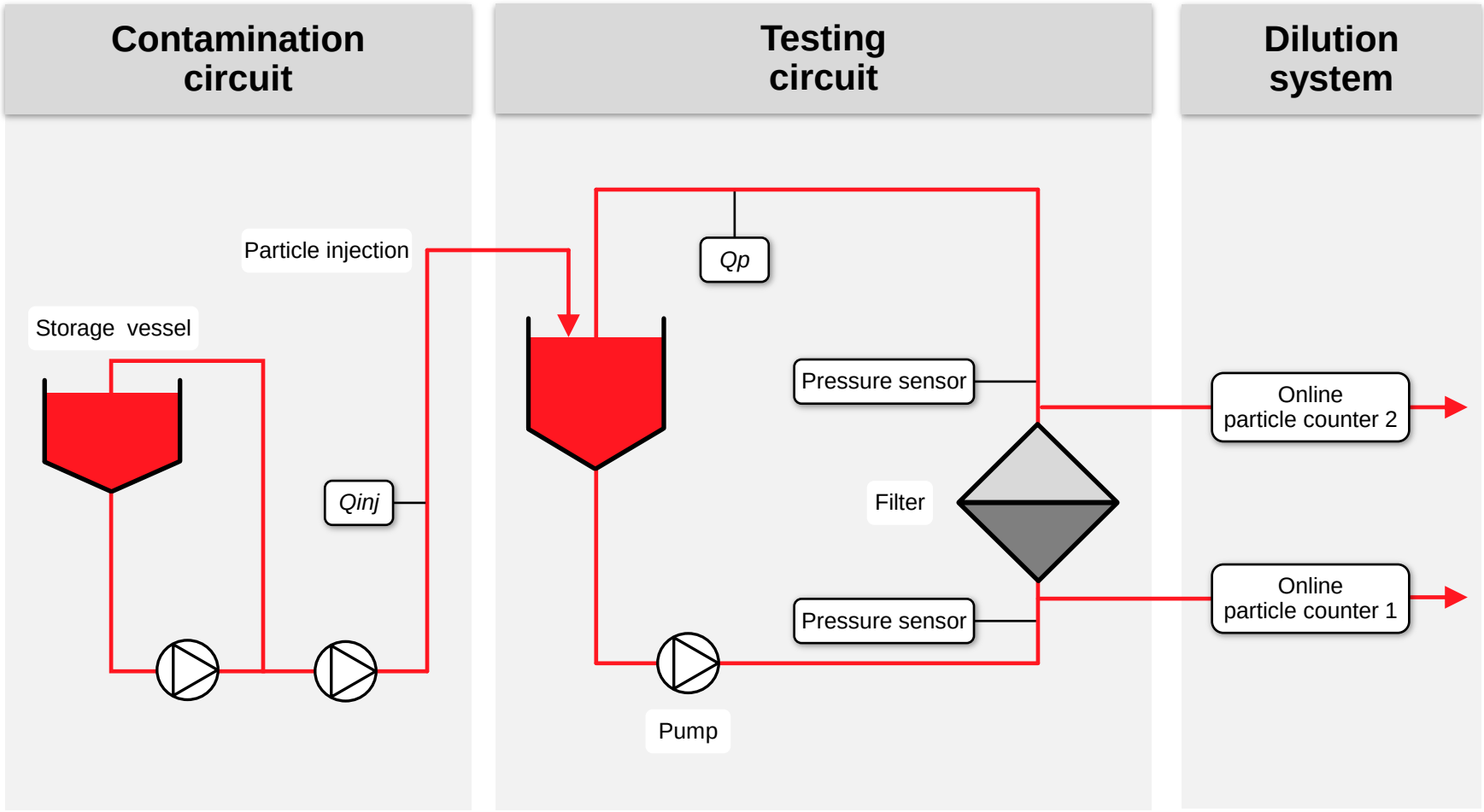
Overview

1. Motivation - peculiar effects observed in experiments
2. Hypothetical explanations
3. Filtration simulation with GeoDict
4. Results

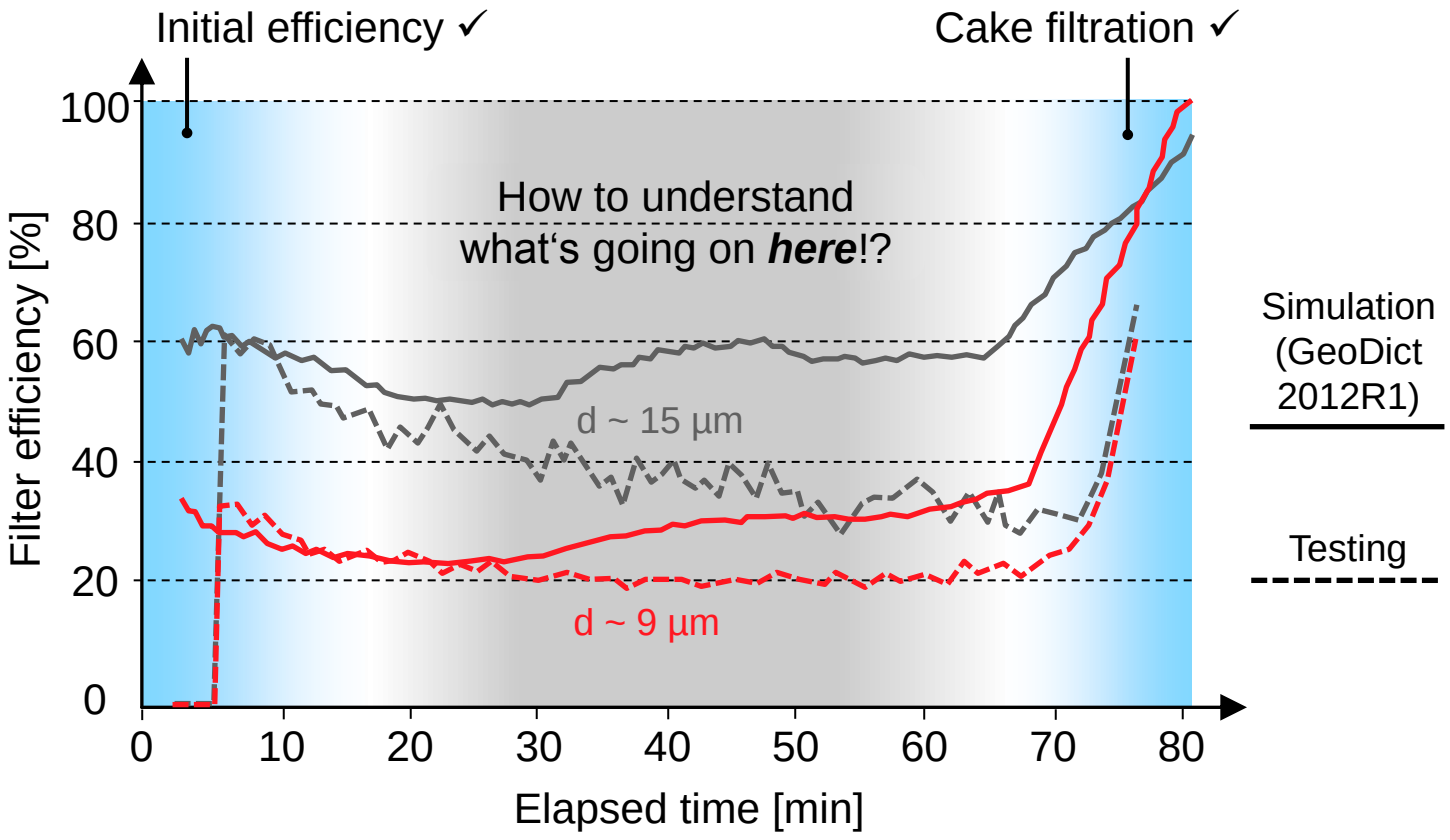
1. Experimental Observations

The Multipass Test (ISO 4548)



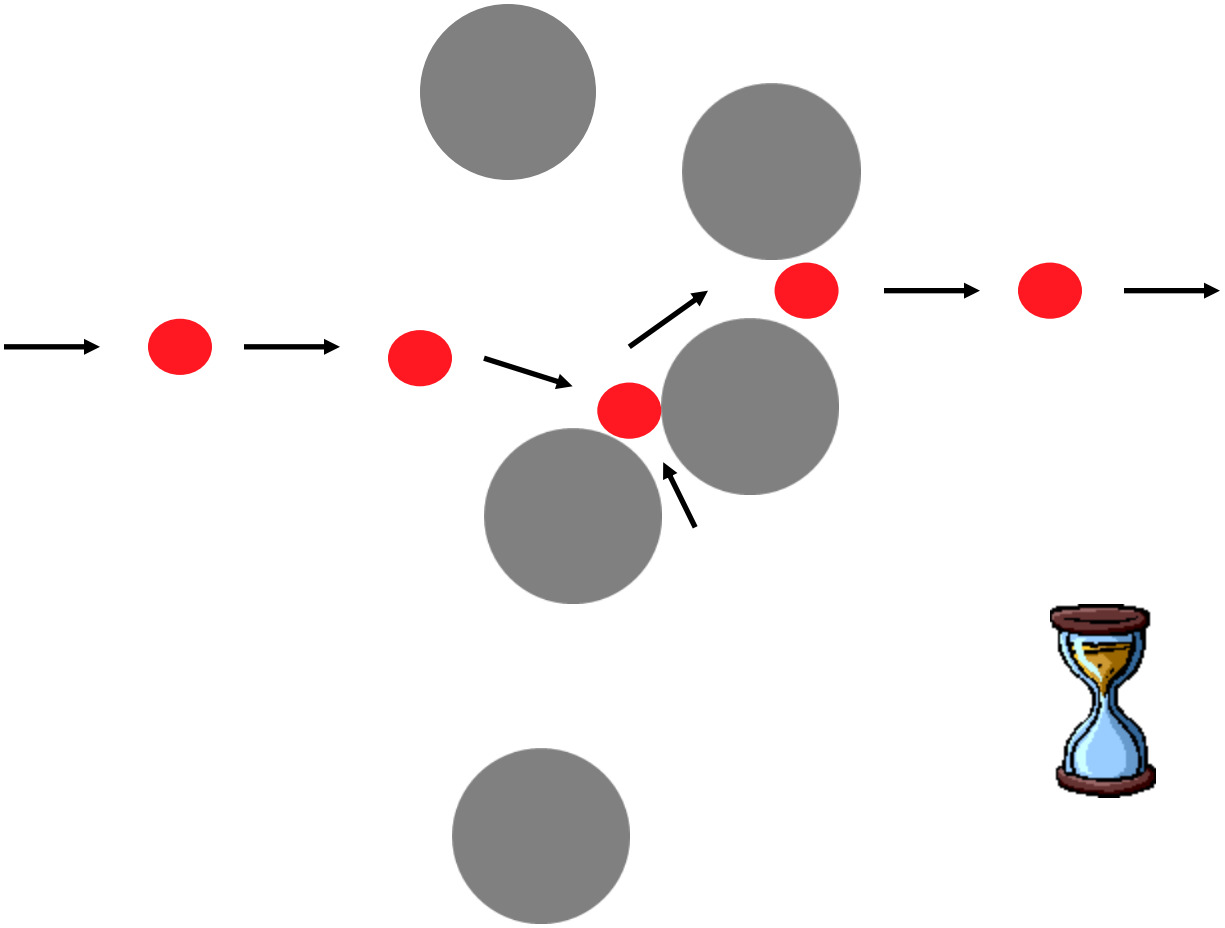
The Multipass Test (ISO 4548)

Peculiarities observed in testing of depth filter media

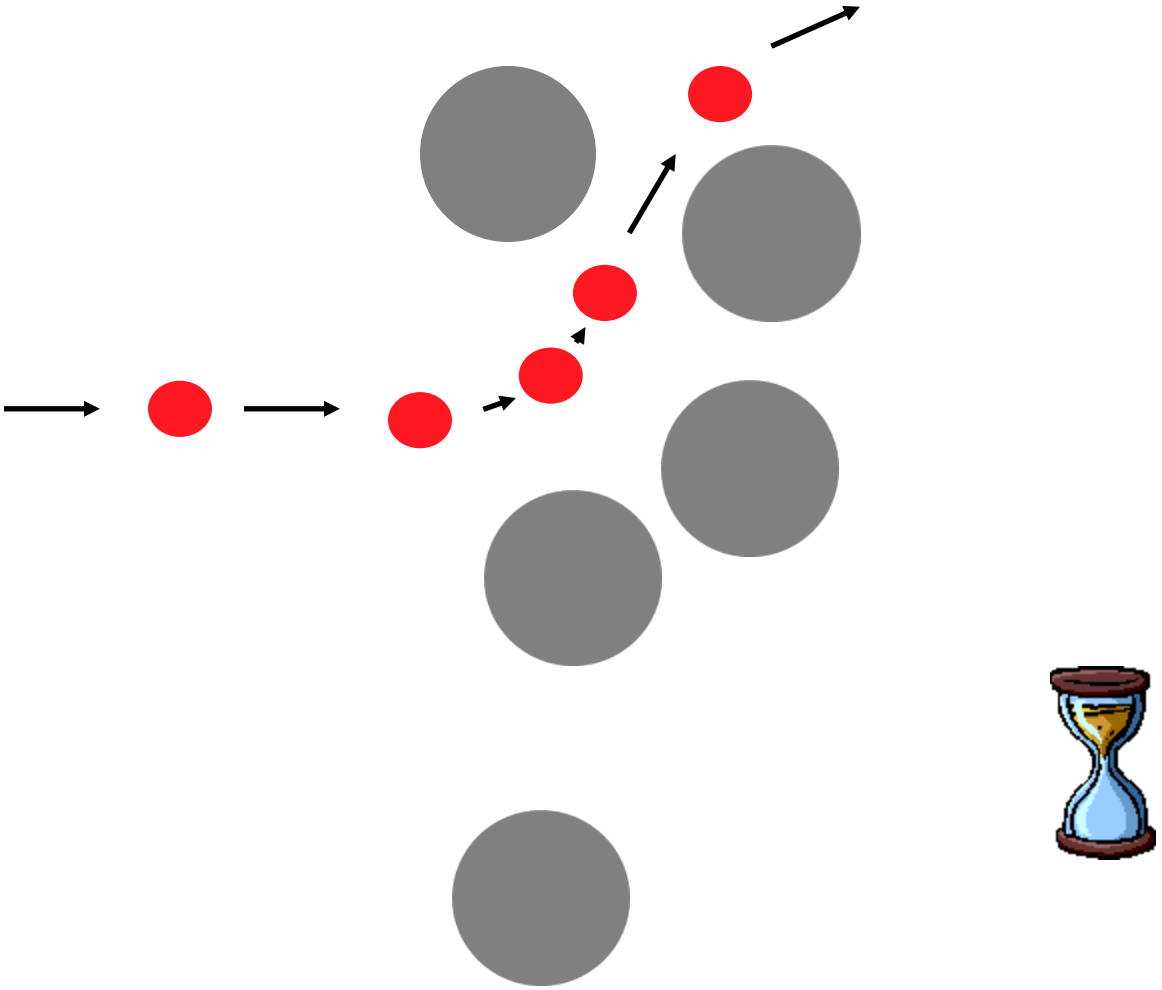


2. Hypothetical Explanations for a Decreasing Efficiency

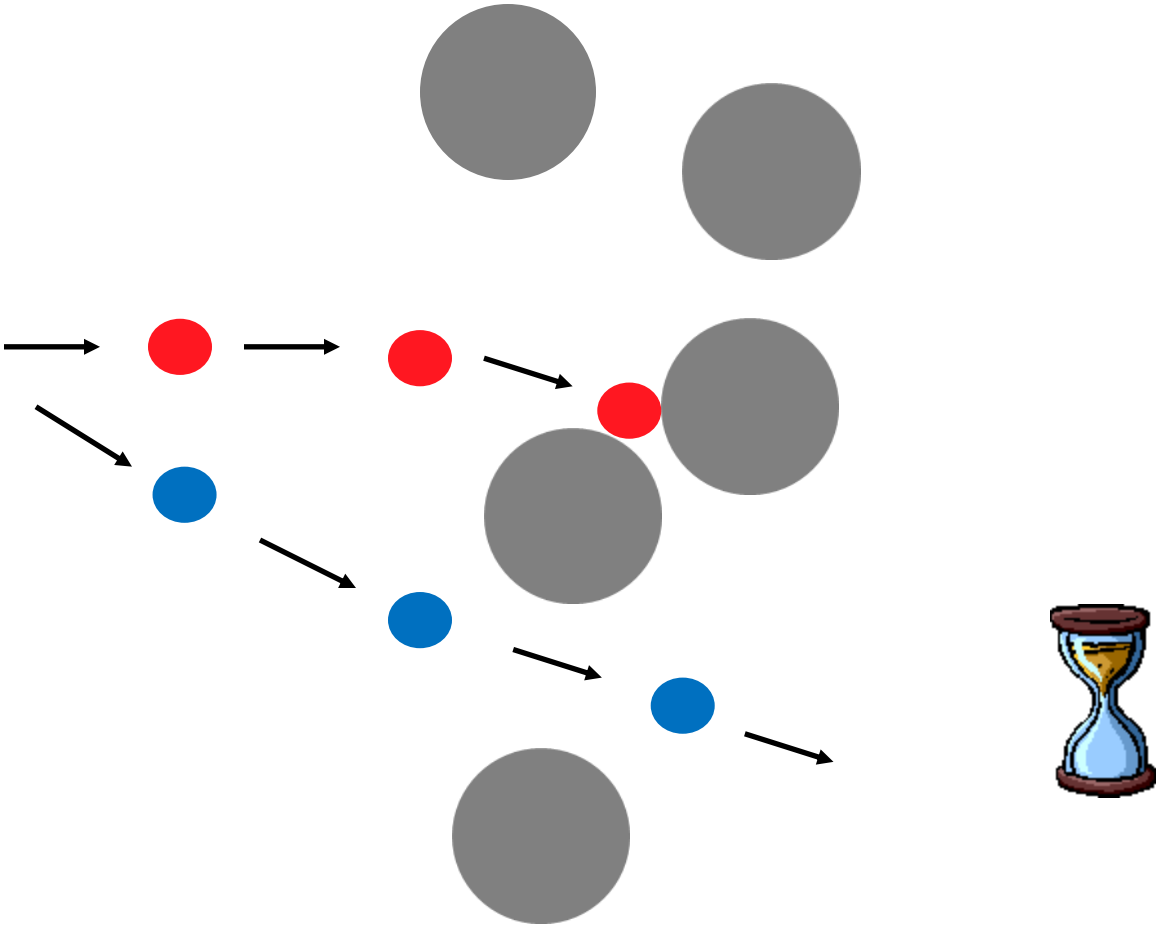
Explanation A: Re-Entrainment



Explanation B: Lingering



Explanation C: Flow Pathways



3. General Approach to Filtration Simulations

Filter Simulation: Efficiency

Basic idea:

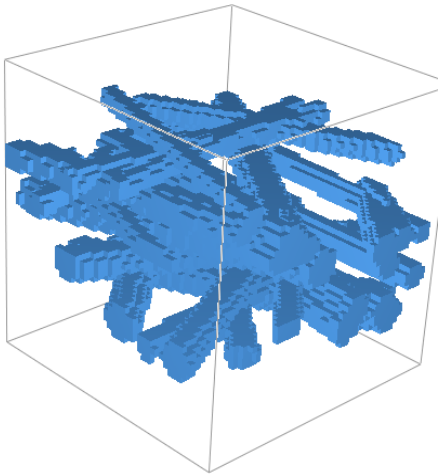
1. Filter model
2. Determine flow field
3. Track particles (filtered or not?)

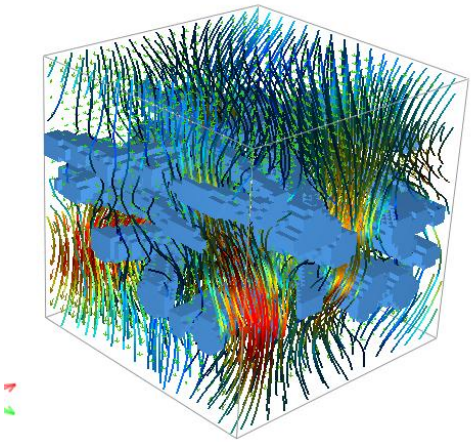
Randomness:

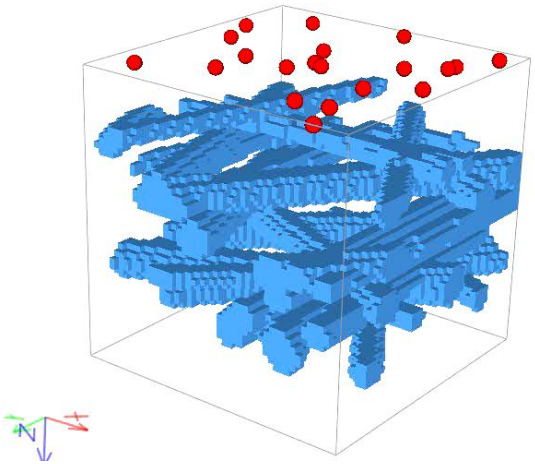
- Starting positions
- Brownian motion

Result:

- Percentage of filtered particles







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

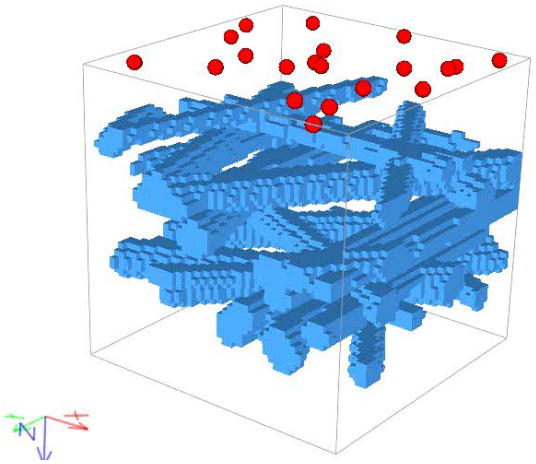
Escape velocity:

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

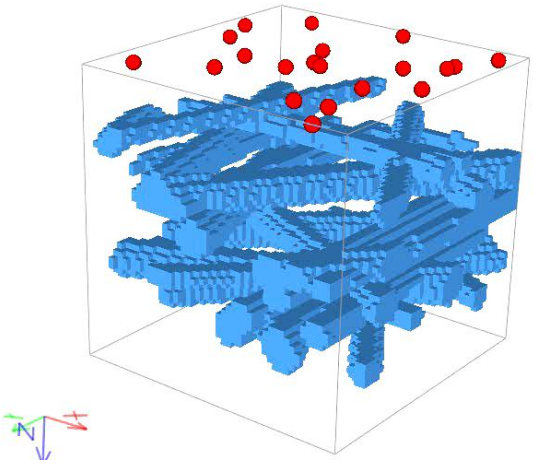
$$v^2 = \frac{H}{4\pi\rho a_0 r^2}$$

Particle sticks for smaller velocities v.

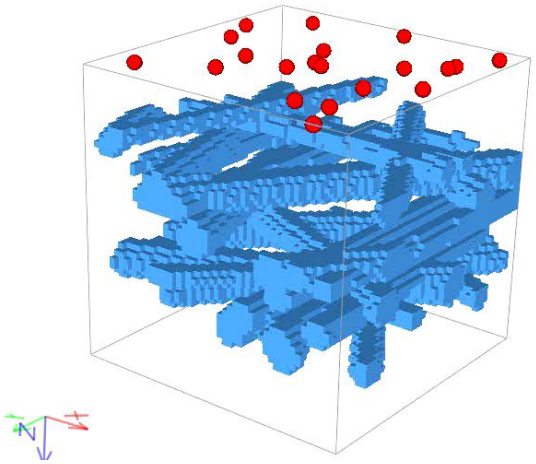
Comparison



Caught on first touch

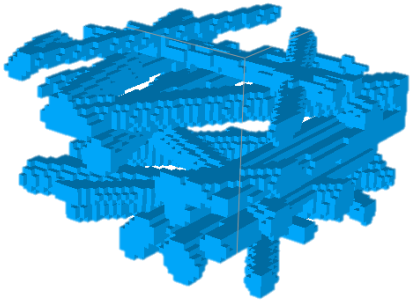


Hamaker
H =1e-21
Restitution = 0.5

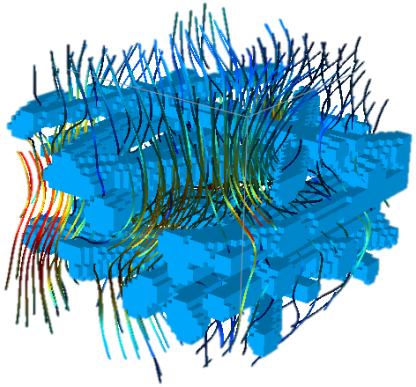


Sieving

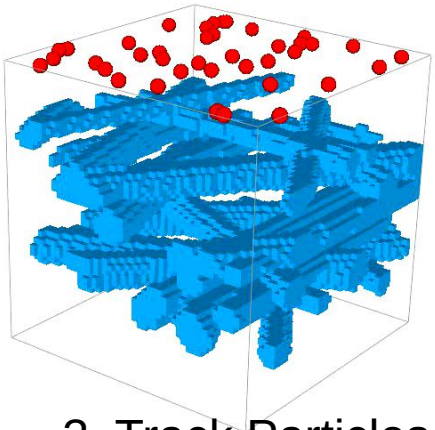
Filter Simulation: Life Time



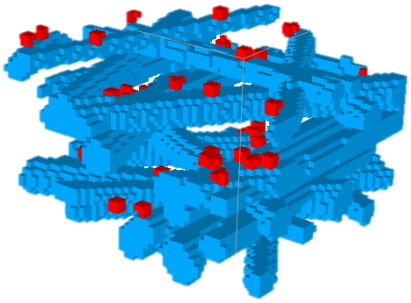
1. Filter Model



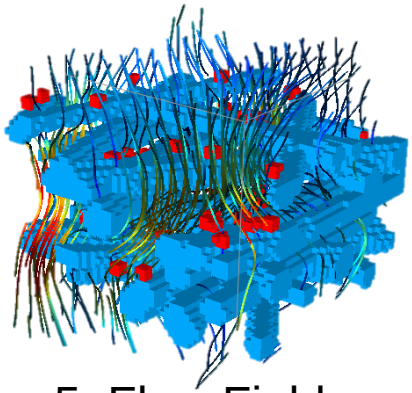
2. Flow Field



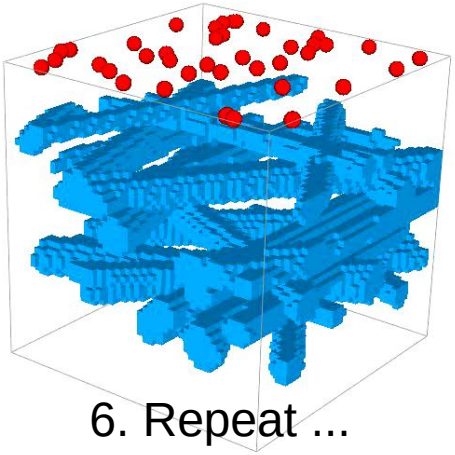
3. Track Particles



4. Deposit Particles



5. Flow Field



6. Repeat ...

Improvements to FilterDict

- Global time concept: particles can continue to the next batch
  => allows lingering particles
  => needed for re-entrainment
- More accurate particle tracking
  - 2012R1:
    flow solver uses staggered grid but writes cell-centered result file
    particle tracking uses cell-centered file
    => accuracy lost (especially at no-slip boundary)
  - 2012R2:
    flow solver uses staggered grid and writes staggered grid result file
    particle tracking uses staggered grid
- ...

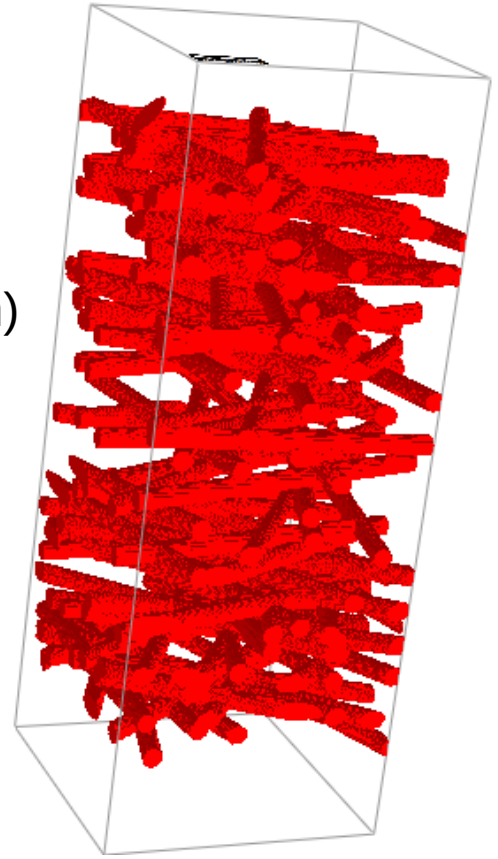
Effect of Higher Accuracy: MPPS Simulation Example

Structure:

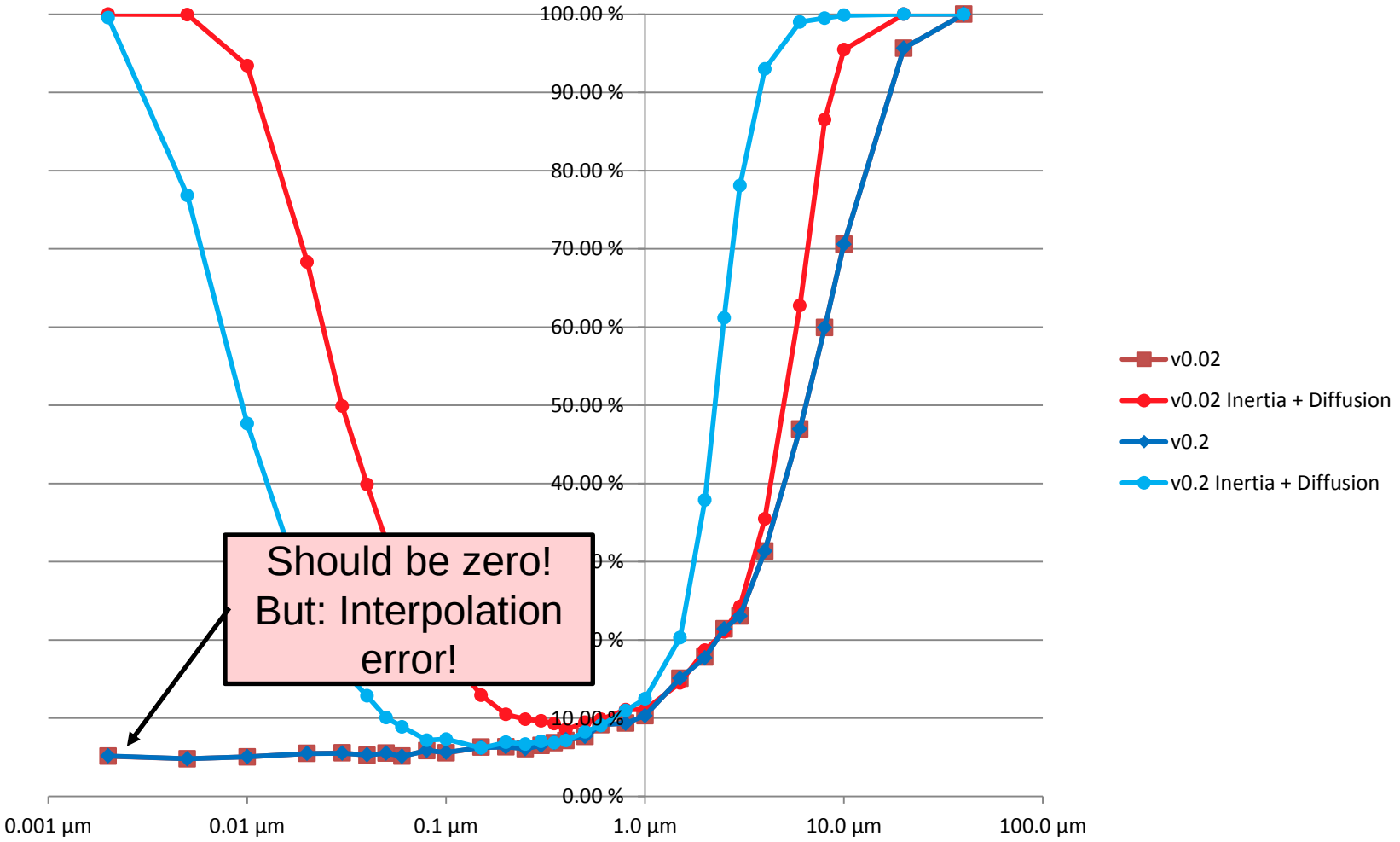
- Fibers with diameter 20 µm
- Different porosities
- Different resolutions (voxel length 1 µm – 4µm)

Simulation:

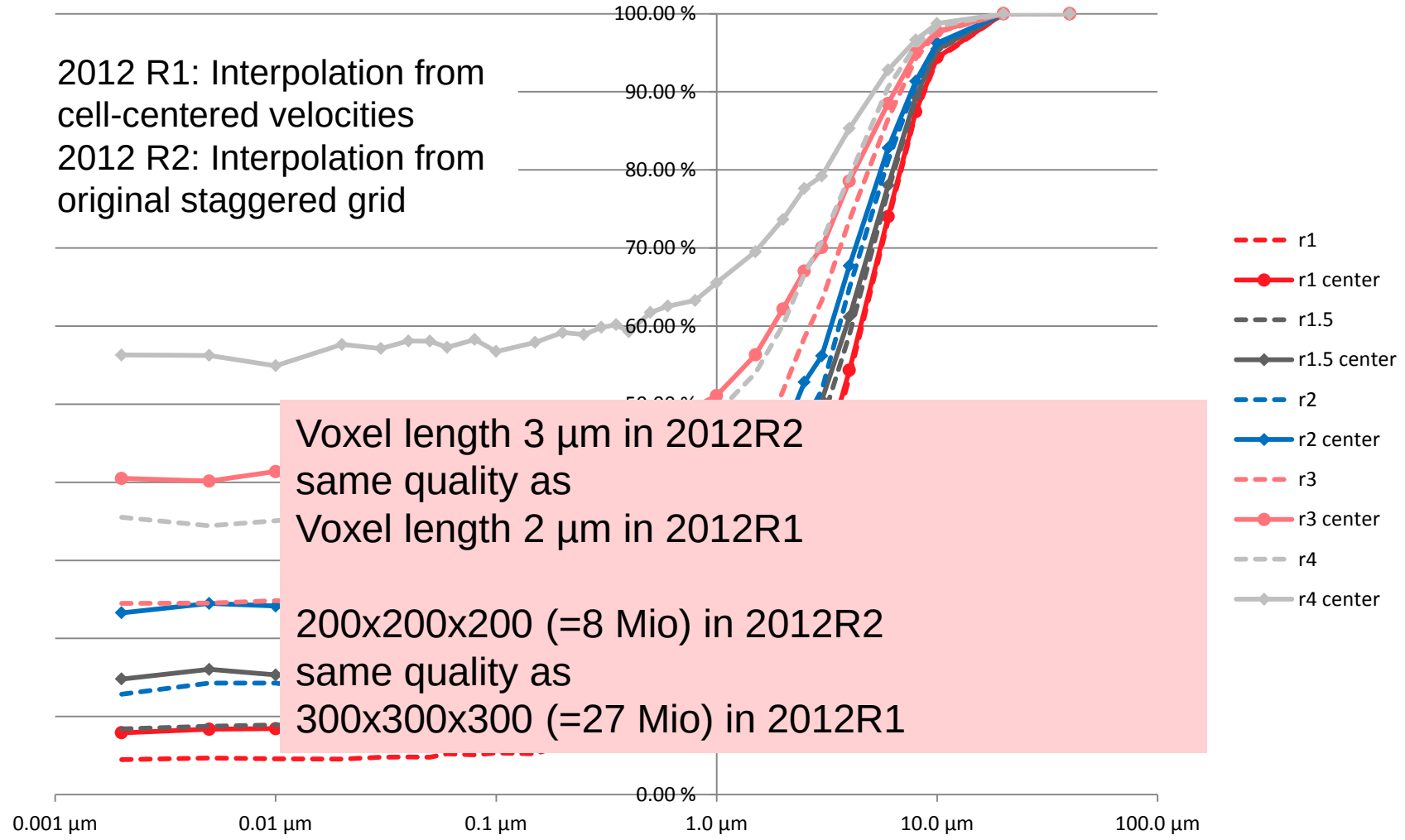
- Find efficiency for all particle diameters (caught on first touch, air filtration)
- Brownian Motion: on/off
- Inertia: on/off (by particle weight)
- Different flow velocities



Fixed: Porosity 90%, Resolution 2 µm
Vary: Velocity



Enhancement of Interpolation in 2012R2

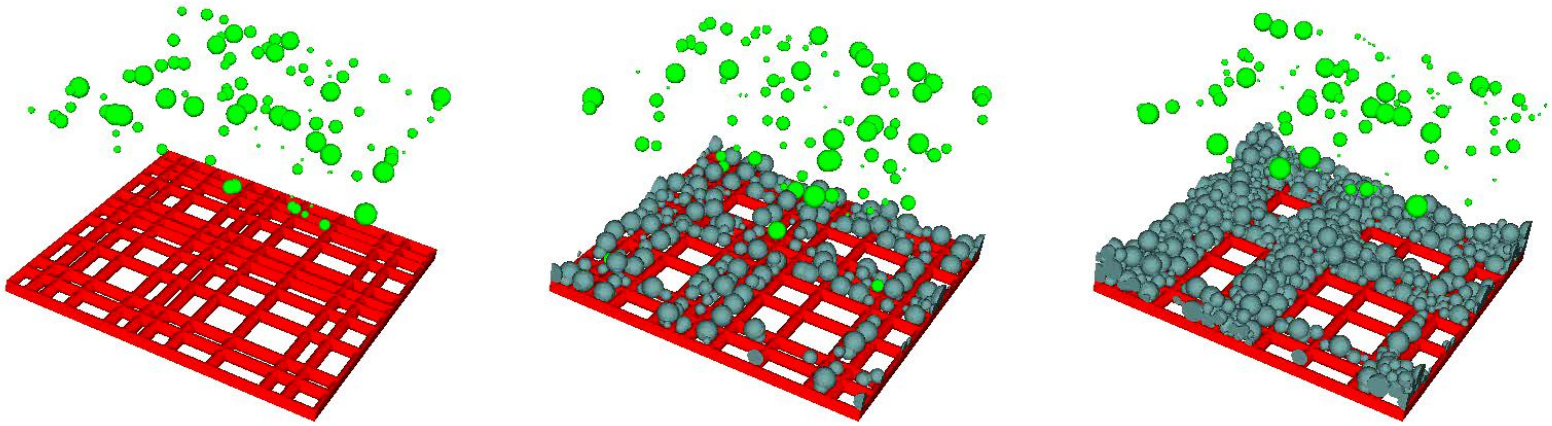


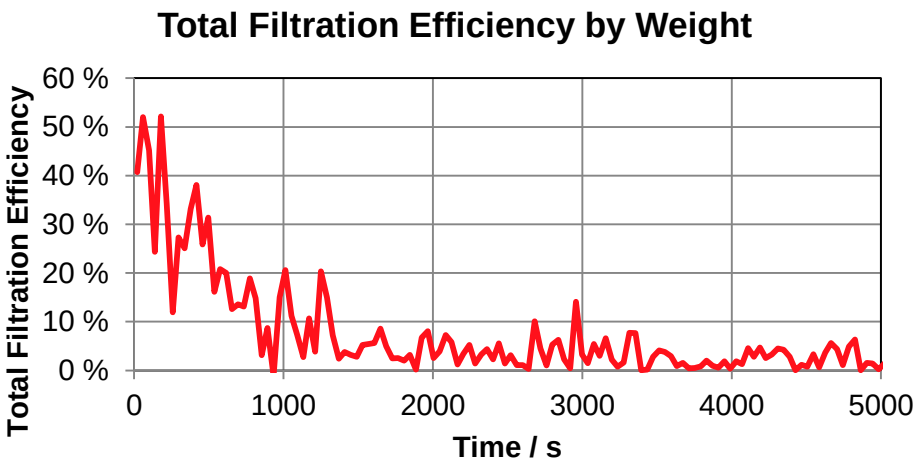
Voxel length 3 µm in 2012R2
same quality as
Voxel length 2 µm in 2012R1

200x200x200 (=8 Mio) in 2012R2
same quality as
300x300x300 (=27 Mio) in 2012R1

4. Results

Decreasing Efficiency by Changed Pathways





=> Effect can explain decreasing efficiencies!

Reentrainment & Lingering

Observations from numerous simulations:

- Larger particles get sieved!
- Local flow field does not flip direction => particles stay sieved.

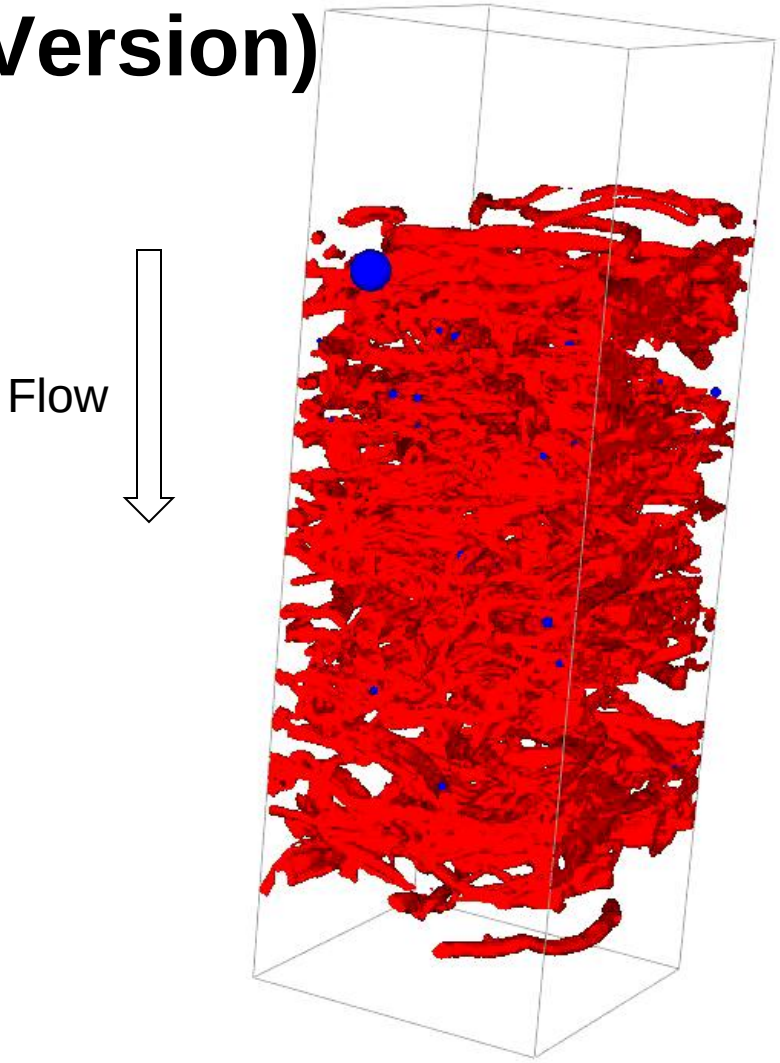
=> Larger particles do not re-entrain (in significant numbers)!

- Initially, particles pass the clean filter quickly.
- Small particles pass through filter cake slowly
  (in later stages of filtration, assuming sieving model)

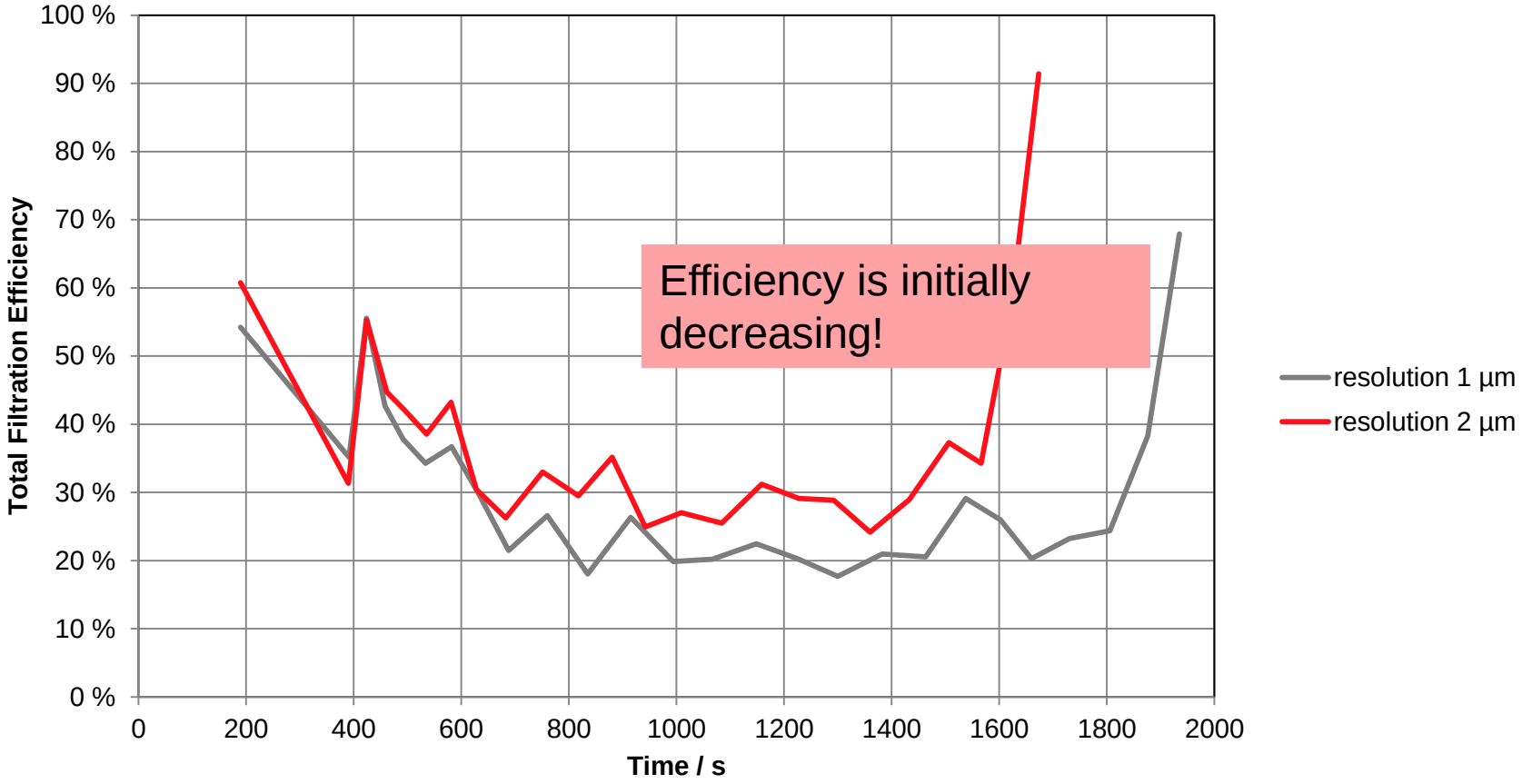
=> This is most likely not the main explanation!

Simulation Results (GeoDict 2012R2 Version)

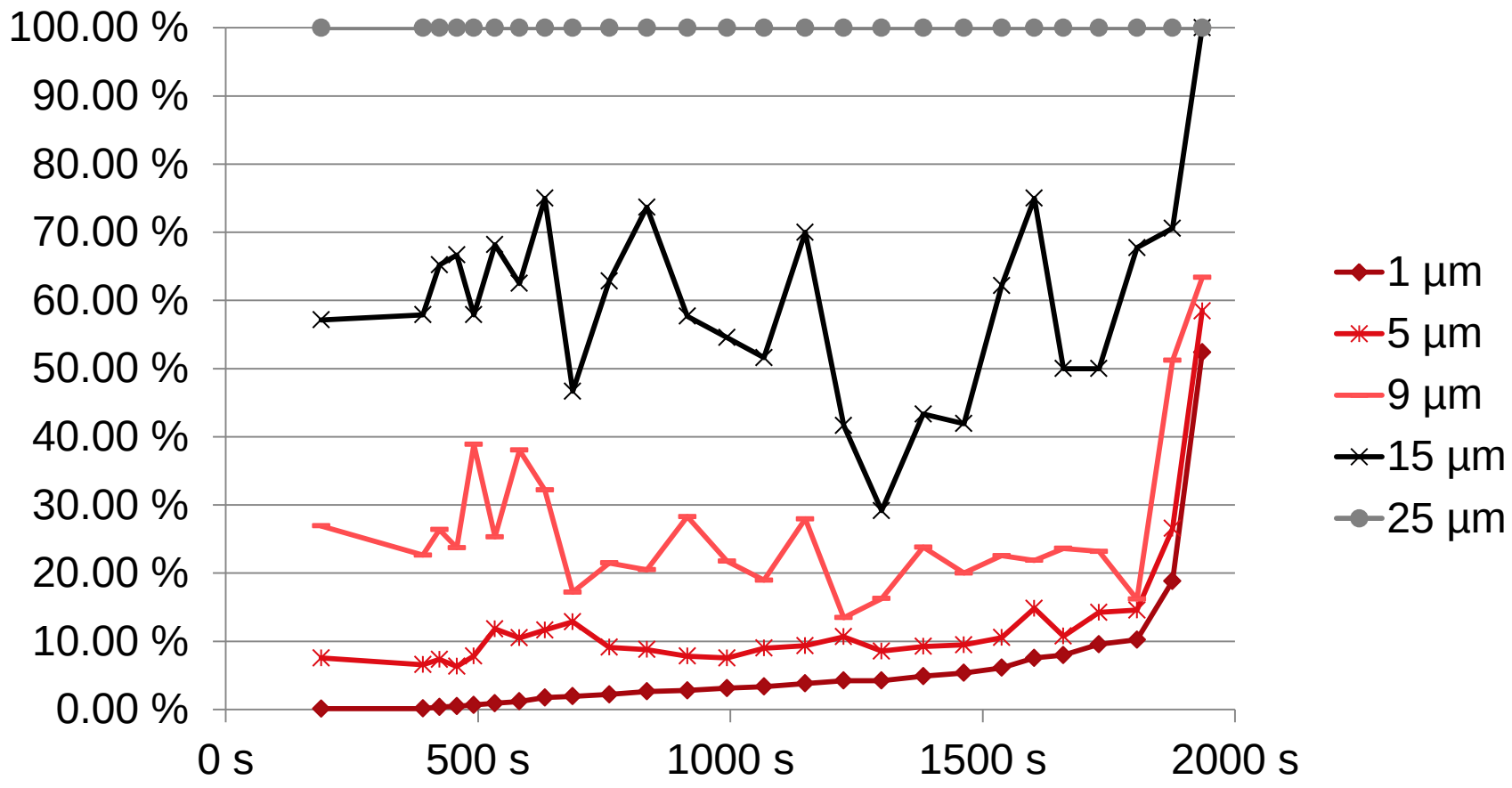
- Tomography cut-out
- Oil filtration
- Adhesion model: sieving
- No re-entrainment



Total Efficiency by Weight



Fractional Filtration Efficiency



Summary and Outlook

Summary:

- Decreasing efficiencies can be explained by simulation
  => No re-entrainment, but explained geometrically

Improvements needed:

- More accurate particle tracking / flow field interpolation
- Global time concept: particles can continue in the next batch

Future improvements:

- Enhance fractional efficiency determination (Filtech 2013)
- Reconsider sieving criterion w.r.t. resolution dependency

Thank You !

GEO DICT

The Virtual Material Laboratory

www.geodict.com

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