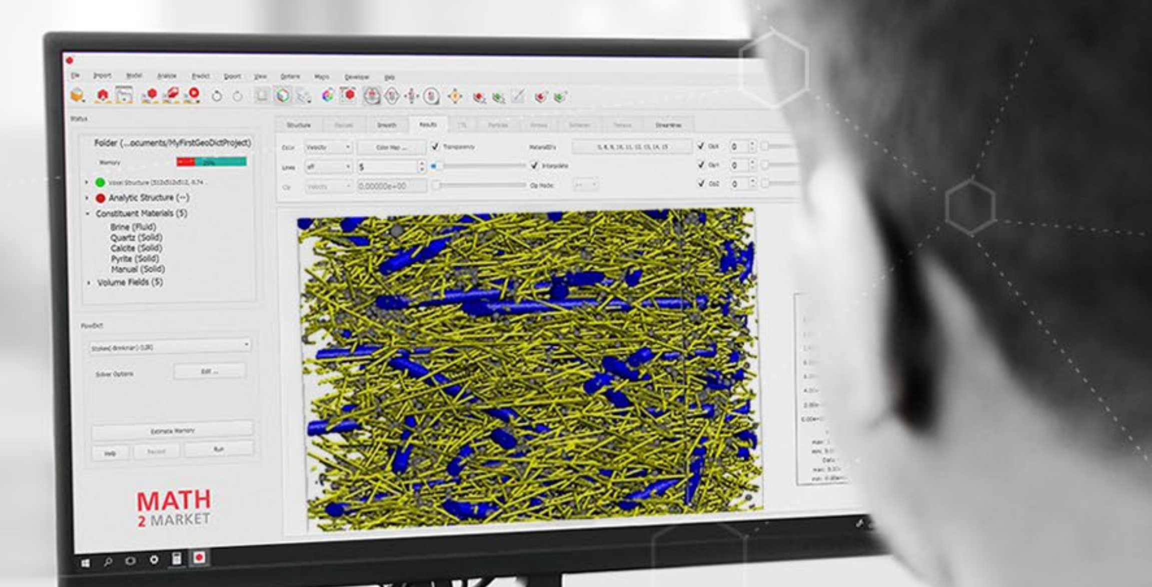
GEODICT



THE INFLUENCE OF SLIP FLOW ON FILTRATION SIMULATIONS ON THE NANO SCALE

FILTECH, October 22 – 24 | Cologne – Germany

Liping Cheng, Sven Linden, Mehdi Azimian, Andreas Wiegmann

Math2Market GmbH, Kaiserslautern, Germany

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Some background information

GeoDict

Math2Market GmbH

- creates and markets the scientific software GeoDict®.
- was spun off in 2011 from Fraunhofer ITWM in Kaiserslautern.
- is a privately-owned company based in Kaiserslautern, Germany.

GeoDict® - The Digital Material Laboratory

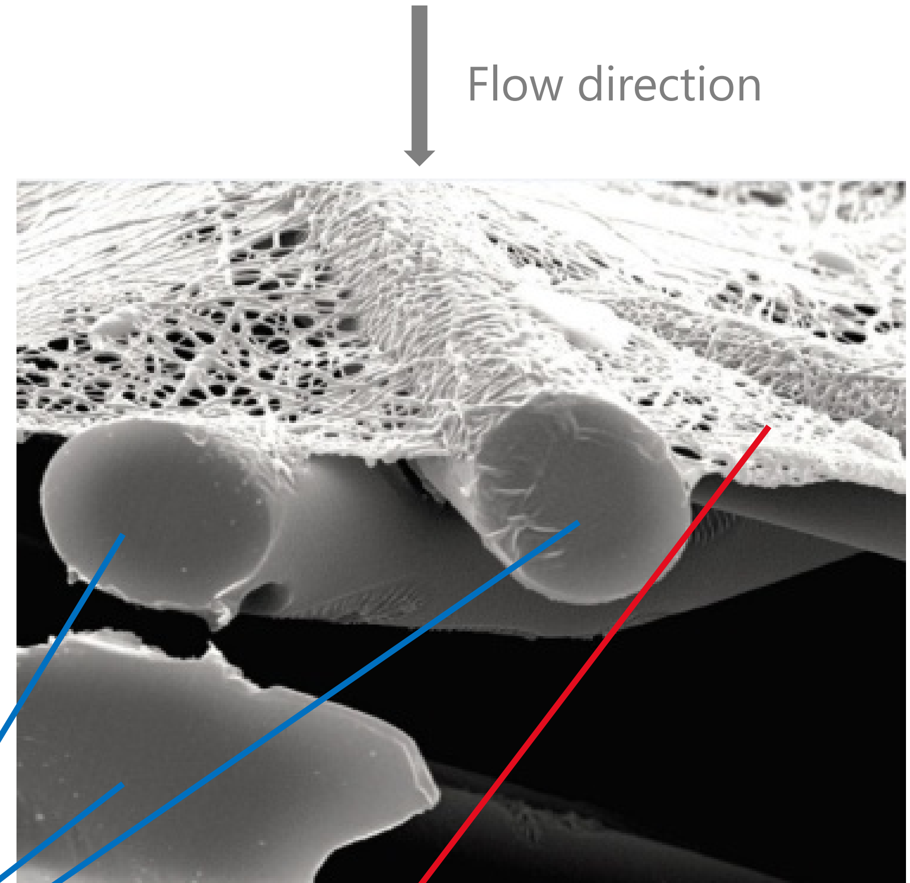
- is a software tool to analyze and design the microstructure of porous media and composites.
- works on
  - µCT and FIB-SEM 3D images or
  - random geometric material models.

MOTIVATION - NANOFIBER

GEODICT

Why nanofiber?

- Higher initial & ongoing efficiency
- Lower pressure drop across the filtration media
- Less compressed air consumption required for pulse-jet cleaned dust collection systems
- Longer filter life
- Flexibility in filter configuration



[source: www.donaldson.com]

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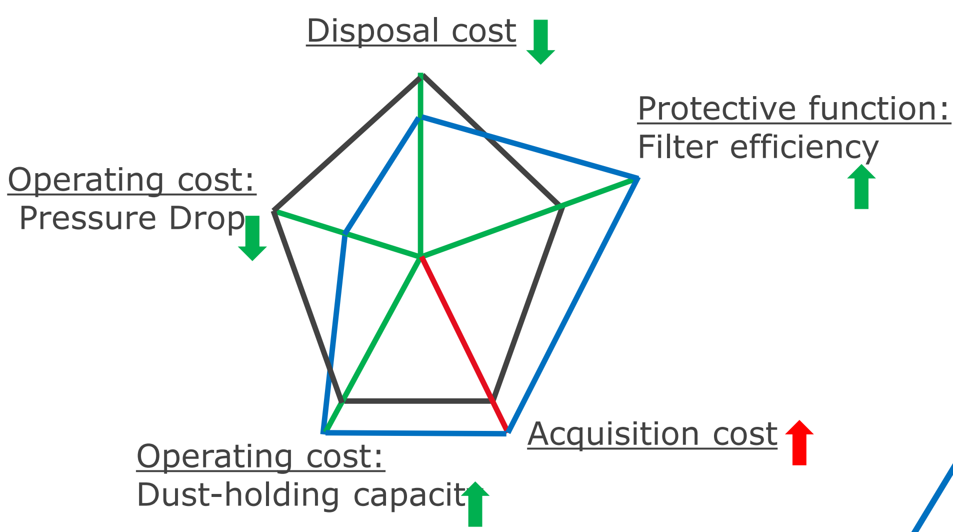
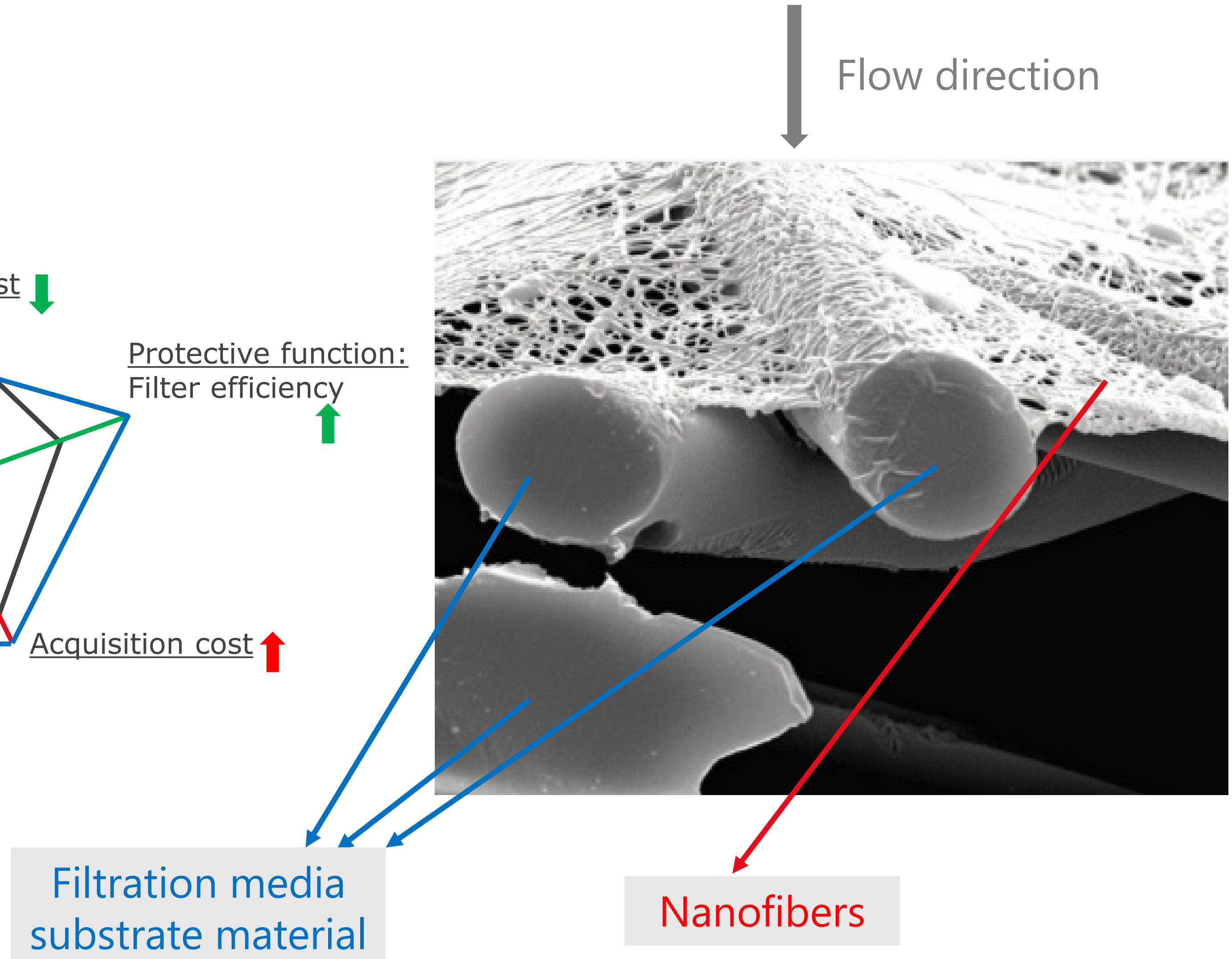
Motivation - Nanofiber

Why nanofiber?





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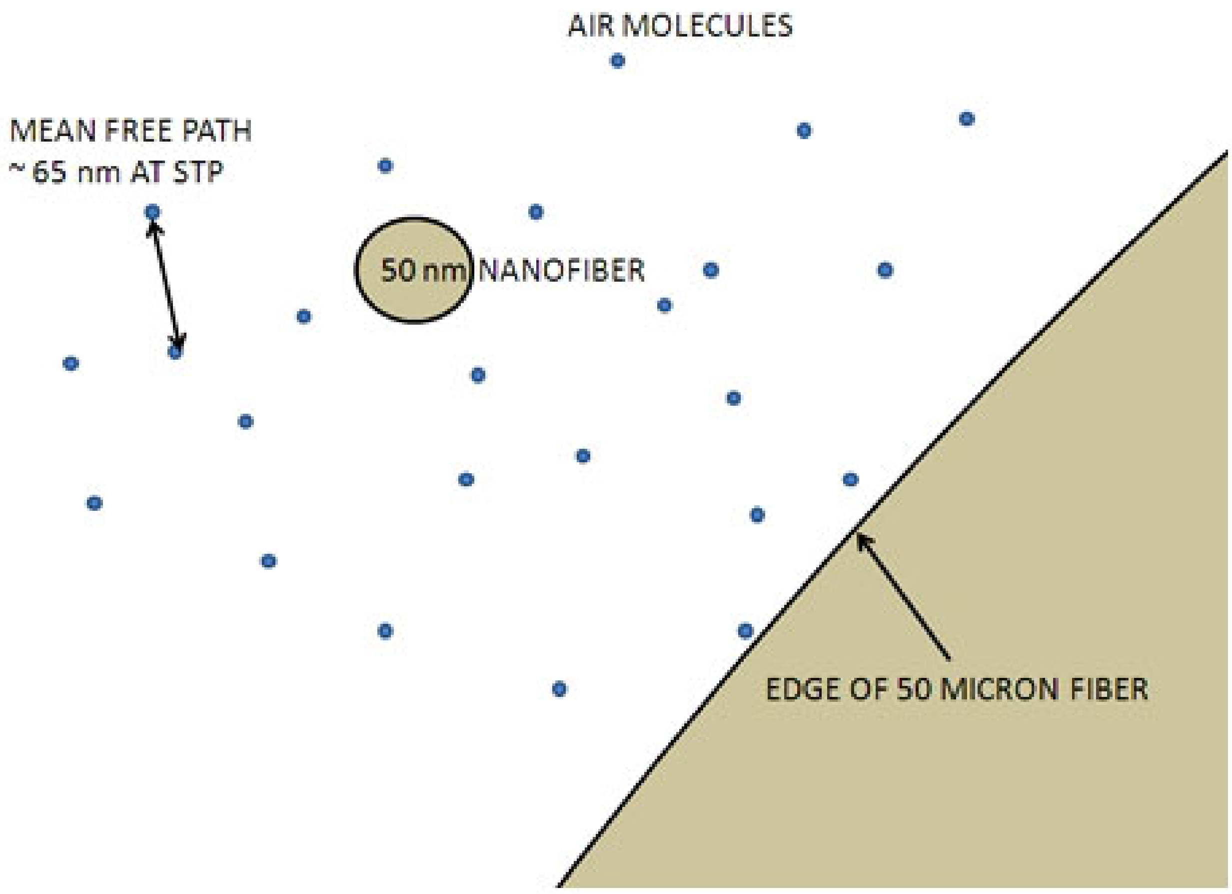
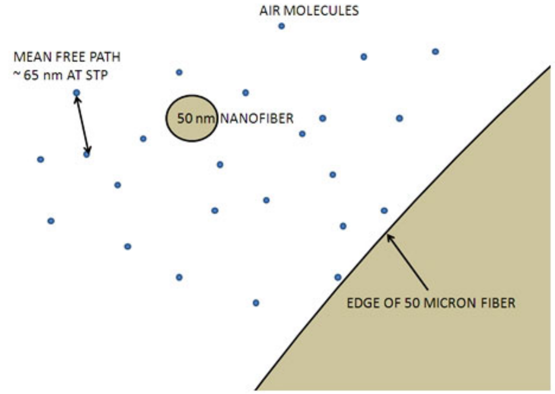
Motivation - Nanofiber

What is slip-flow?



[source: www.afssociety.org]

MOTIVATION - NANOFIBER



GEODICT

What is slip-flow?

- Microfiber
  - Air molecules collide with the fiber and stick to the surface
  - They acquire the velocity of the microfiber plus Brownian motion
  - The motion of a continuum is the average of all the molecules in a volume element, which is zero here.
- Nanofiber
  - Only a fraction of the air molecules collide.
  - The remaining retain the bulk flow motion.
  - The continuum velocity near the nanofiber surface is not zero.
- slip flow results in
  - lower pressure drop for the flow through nanofiber than microfibers when the fiber length is equal.
  - improves the single fiber capture efficiency of small particles on the nanofibers

[source: www.afssociety.org]

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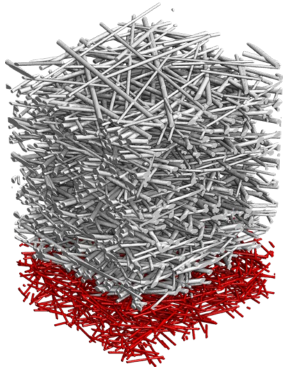
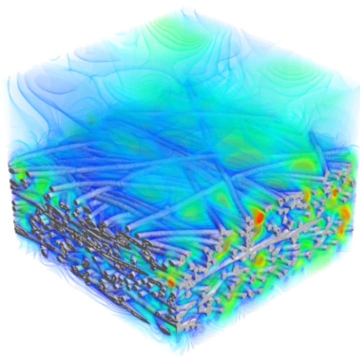
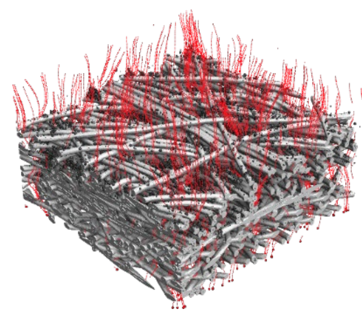
GeoDict® Workflow: Digital Filter Media Design

GeoDict

Import	Analyze	Model	Design	Next Generation Material







Import

Begin with an idea: a new material with ideal properties.

Design a material from scratch or import images from a real material to create a digital material model.

→ **Digital Material**

Analyze

Analyze geometric properties and compute physical properties of designed or real materials.

Extract statistical data to create a Digital Twin.

→ **Statistical Model**

Model

A Digital Twin is the statistical representation of the real material.

Modify the Digital Twin to create Digital Prototypes and begin the design process.

→ **Digital Twin**

Design

Digital prototypes are easily and rapidly created.

Design, simulate, and predict in a loop to find the material with the desired properties.

→ **Digital Prototypes**

Next Generation Material

The materials of the future are within reach and we help you develop them faster.

This is innovation through simulation.

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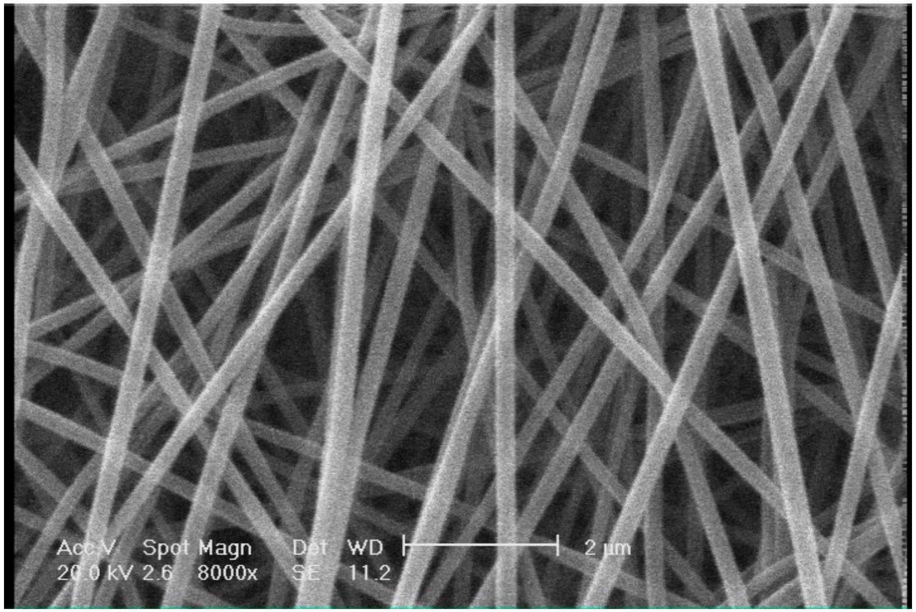
Filtration Simulation

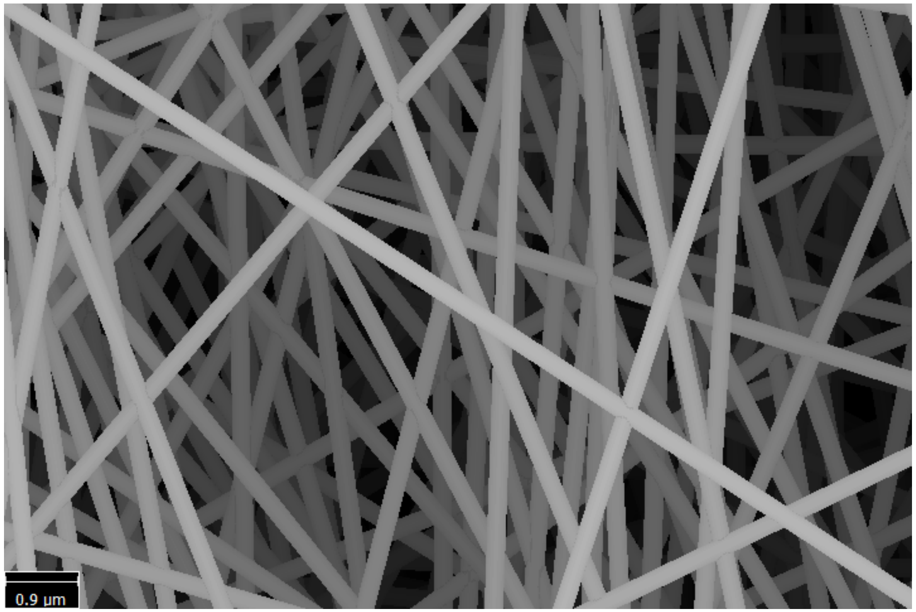
MODELLING OF NANOFIBER MEDIA FROM SEM IMAGE

GeoDict

Real Media (SEM)*



GeoDict 3D Model based on SEM



Voxel Length:	16 nm (GeoDict measured on SEM)	Orientation:	Diag. (0.27, 0.73, 0.00)
Fiber Diameter:	280 nm ± 40 nm (GeoDict measured on SEM)	Porosity:	82%
Size 2D:	720 x 480 Pixels	Size 3D:	720 x 480 x 328 Voxels

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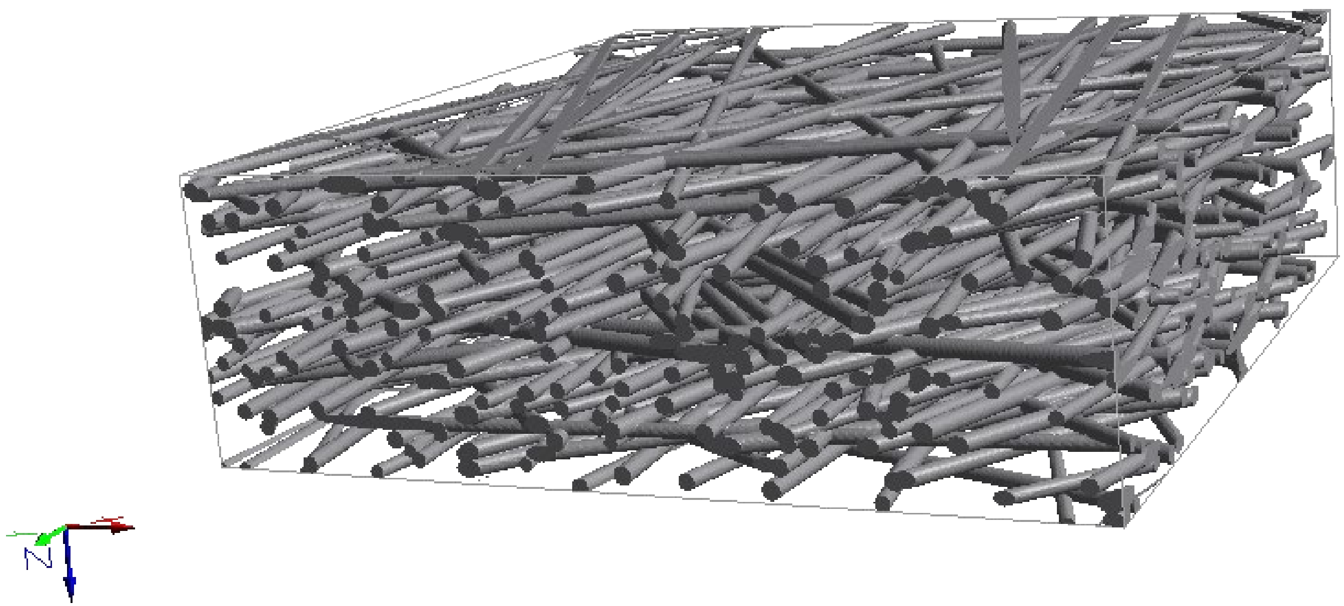
MODELLING OF NANOFIBER MEDIA FROM SEM IMAGE

GeoDict



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Simulation of slip flow and filtration for nano-fibrous media

GeoDict

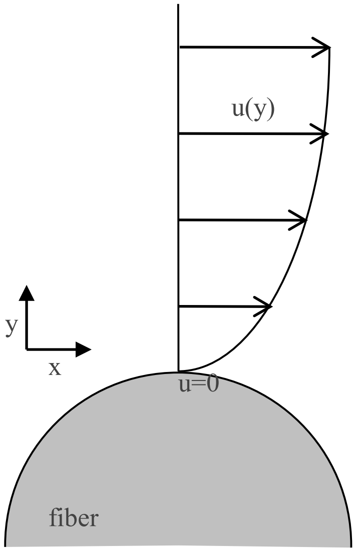
For Micro fiber:

$$
\begin{aligned}
-\mu\Delta\vec{u}+\nabla p &= 0 \text{ (momentum balance)}\\
\nabla\cdot\vec{u} &= 0 \text{ (mass conservation)}\\
\vec{u} &= 0 \text{ on } \Gamma \text{ (no-slip on fiber surfaces)}\\
P_{in} &= P_{out}+c \text{ (pressure drop is given)}
\end{aligned}
$$

μ : fluid viscosity,

$\vec{u}$: velocity, periodic,

p : pressure, periodic up to pressure drop in flow direction.



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SIMULATION OF SLIP FLOW

GEODICT

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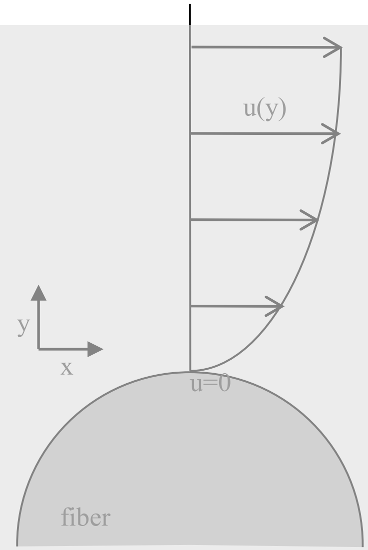
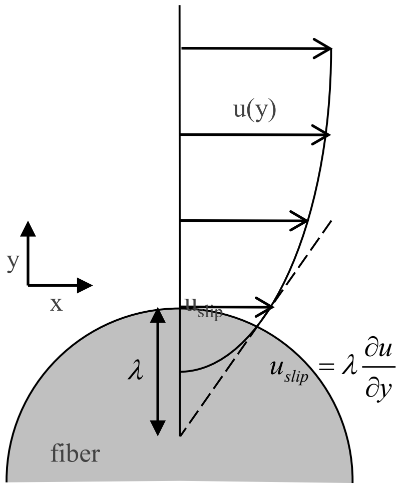


For Nano fiber:



$$
\begin{aligned}
-\mu\Delta\vec{u} + \nabla p &= 0 \text{ (momentum balance)}\\
\nabla\cdot\vec{u} &= 0 \text{ (mass conservation)}\\
\vec{n}\cdot\vec{u} &= 0 \text{ on } \Gamma \text{ (no flow into fibers)}\\
\vec{t}\cdot\vec{u} &= -\lambda\vec{n}\cdot\nabla\left(\vec{u}\cdot\vec{t}\right) \text{ on } \Gamma \text{ (slip flow along fibers)}\\
P_{in} &= P_{out} + c \text{ (pressure drop is given)}
\end{aligned}
$$

$\vec{n}$: normal direction to the fiber surface,

λ : slip length,

$\vec{t}$: any tangential direction with $\vec{t}\cdot\vec{n} = 0$.

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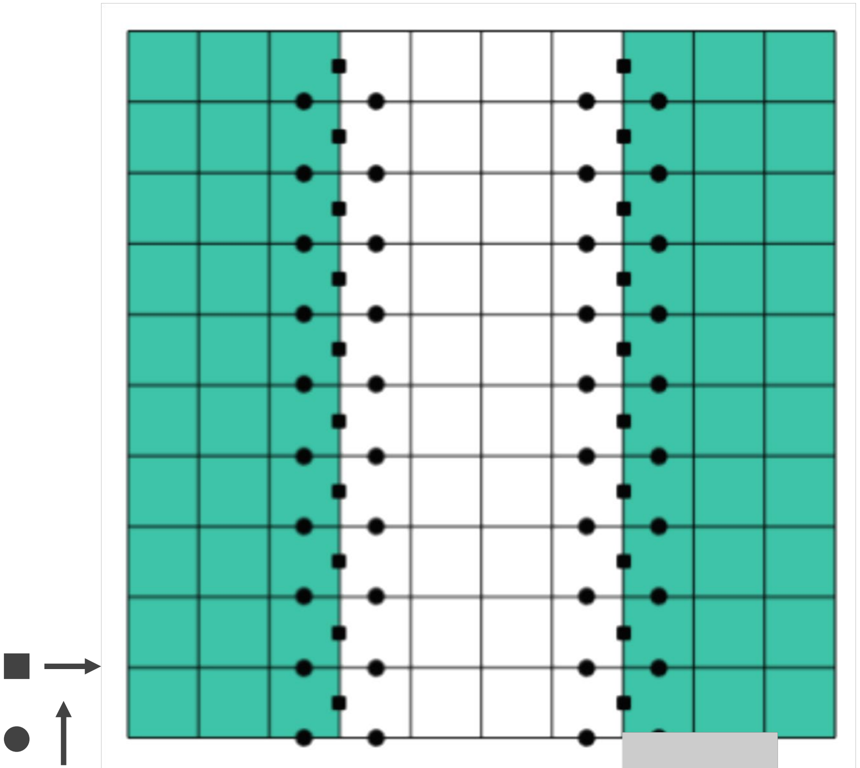
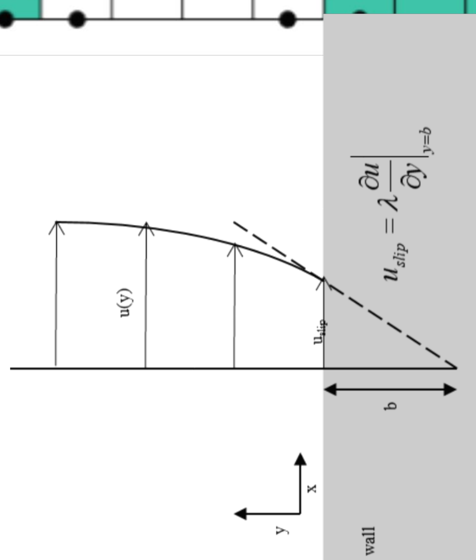
SIMULATION OF SLIP FLOW

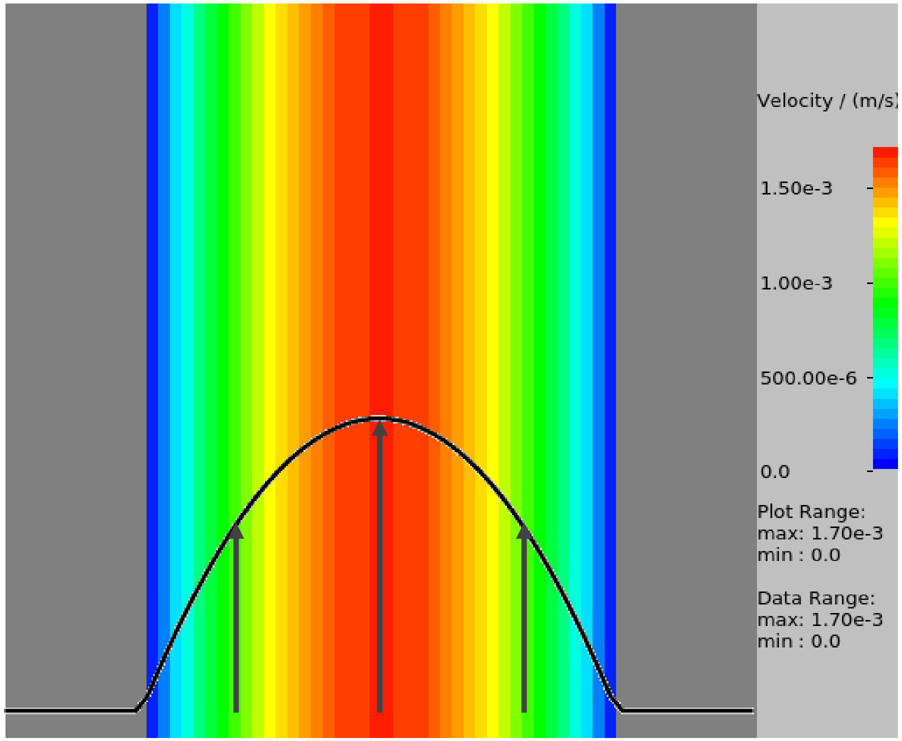


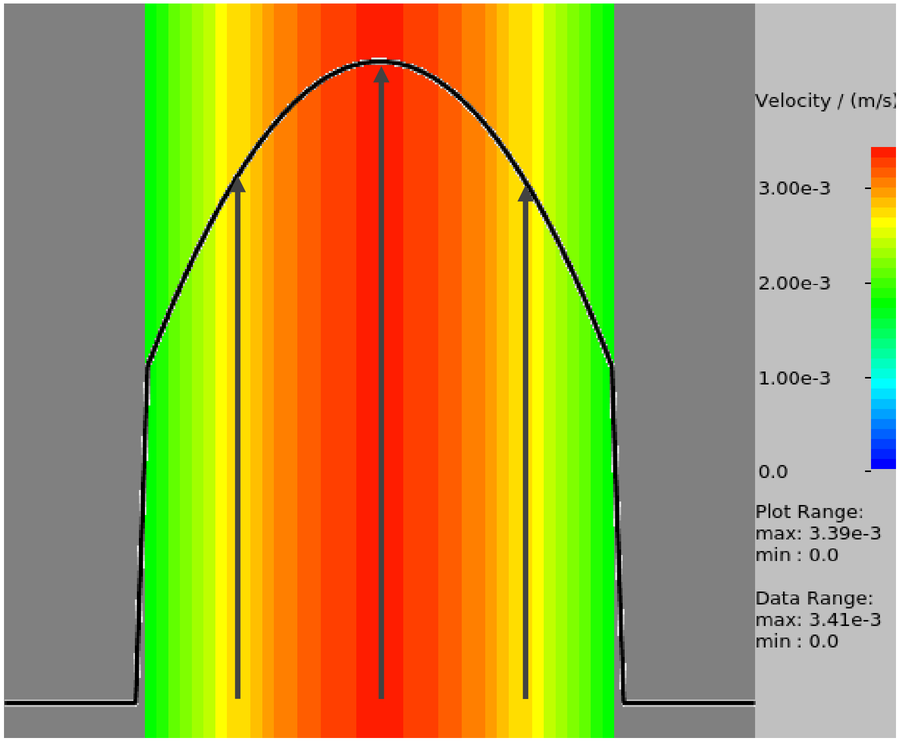


$$u_{slip} = \lambda \left.\frac{\partial u}{\partial y}\right|_{y=b}$$

Simulation of Slip Flow

GeoDict





Validation: Poiseuille flow

- No-slip boundary condition for channel in axial direction possible since 2001
- Slip boundary condition for channel in axial direction possible since 2008 or earlier

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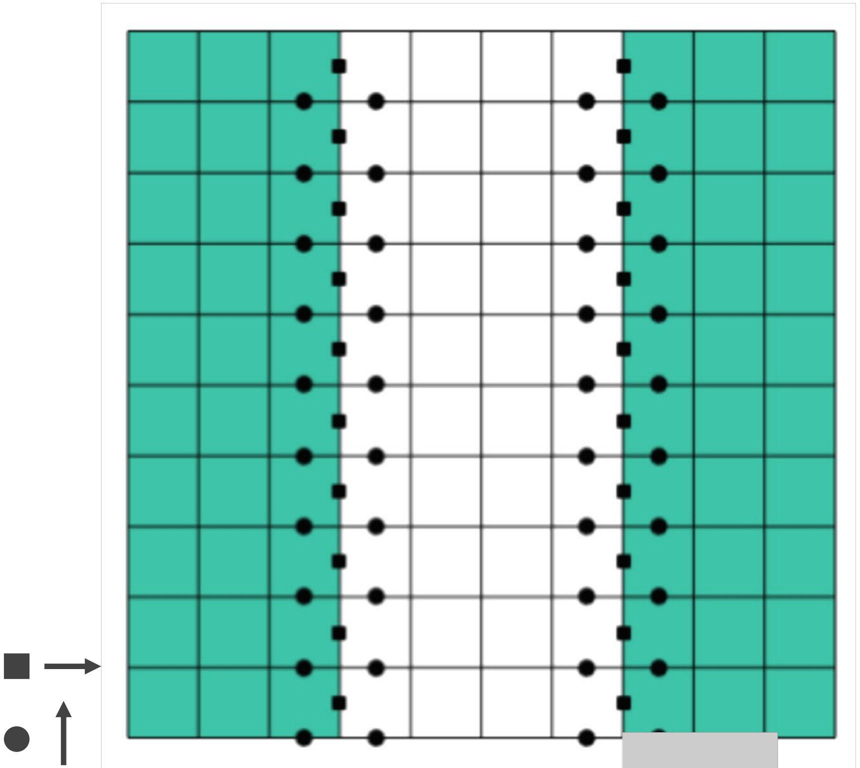
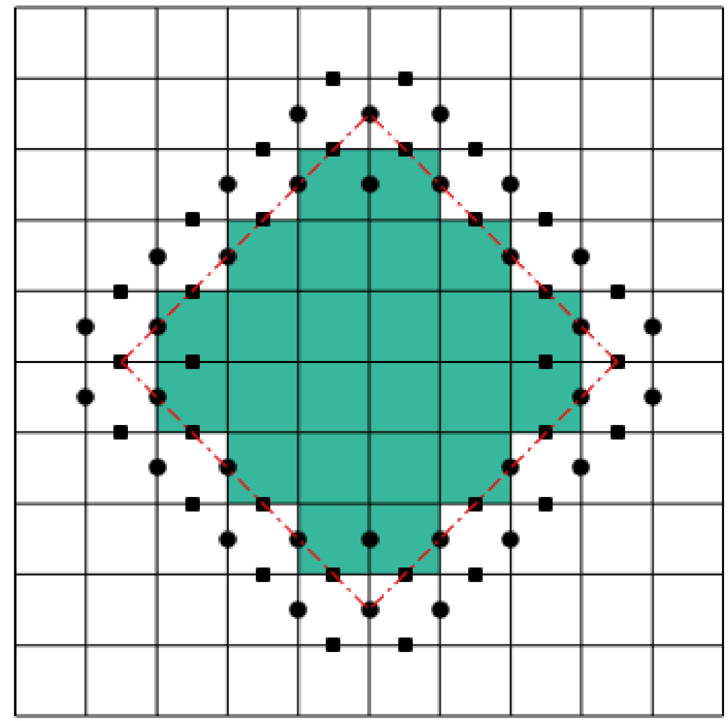
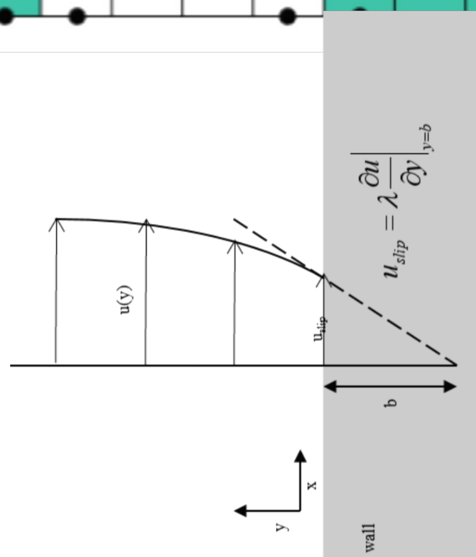
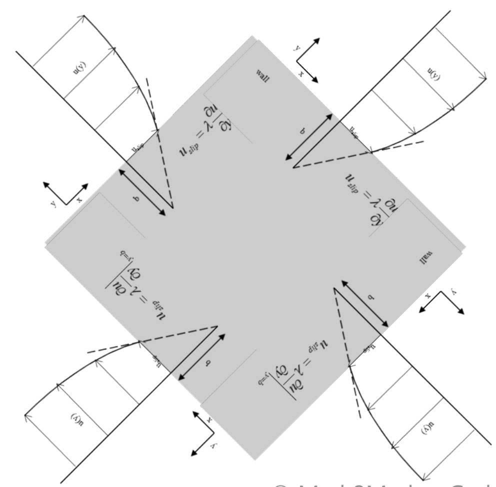
Simulation of slip flow

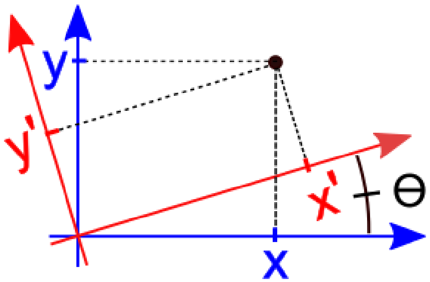






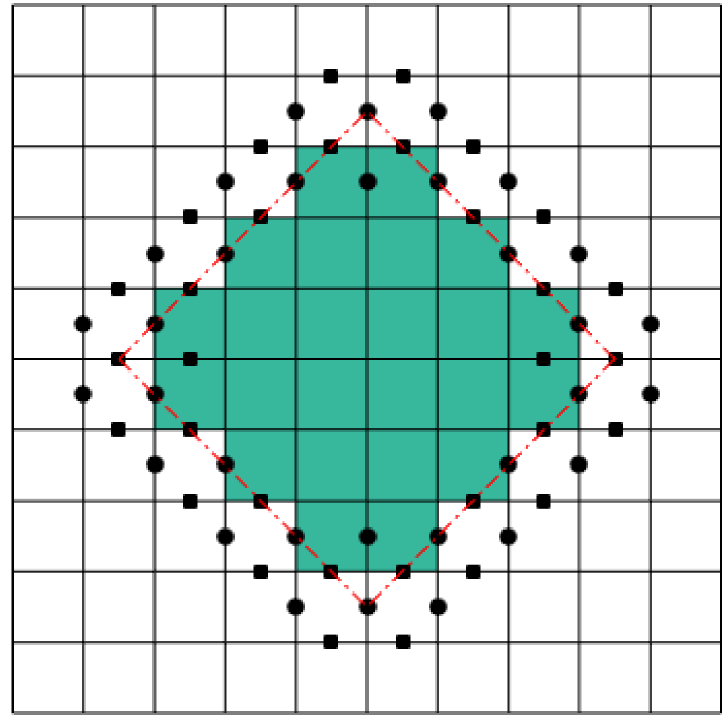


Simulation of Slip Flow



$$u = u' cos\theta$$

$$v = u' sin\theta$$

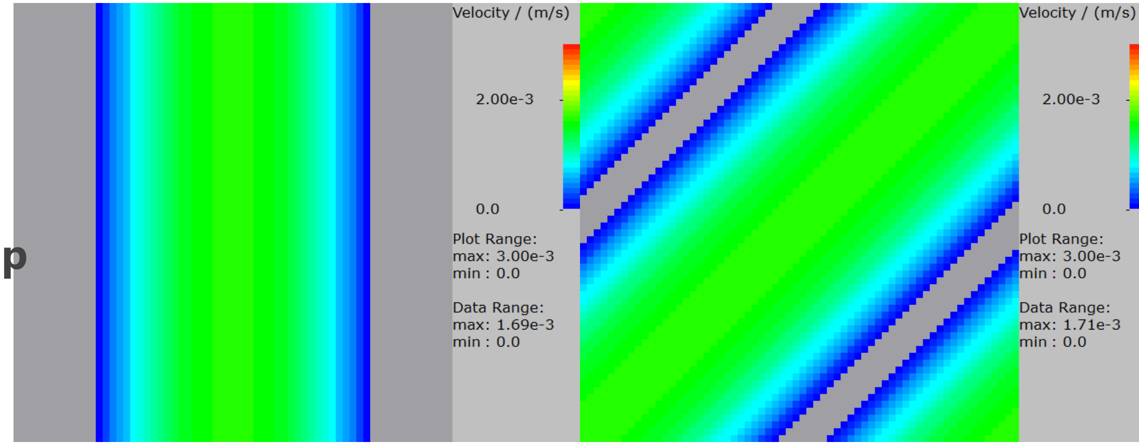


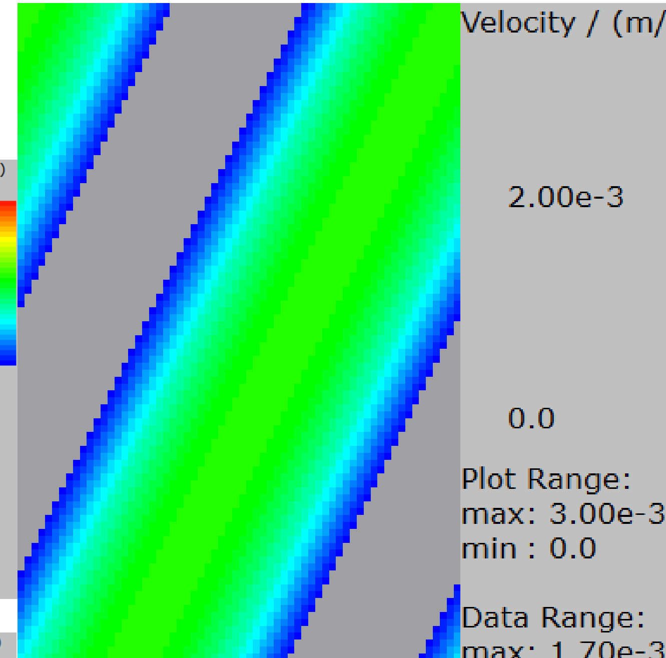
$$u\Big|_{x=0,y=0} = \frac{\lambda}{cos\theta}\frac{\partial u}{\partial x}\Big|_{x=0,y=0} = \frac{\lambda}{sin\theta}\frac{\partial u}{\partial y}\Big|_{x=0,}$$

$$v\Big|_{x=0,y=0} = \frac{\lambda}{cos\theta}\frac{\partial v}{\partial x}\Big|_{x=0,y=0} = \frac{\lambda}{sin\theta}\frac{\partial v}{\partial y}\Big|_{x=0,y=0}$$

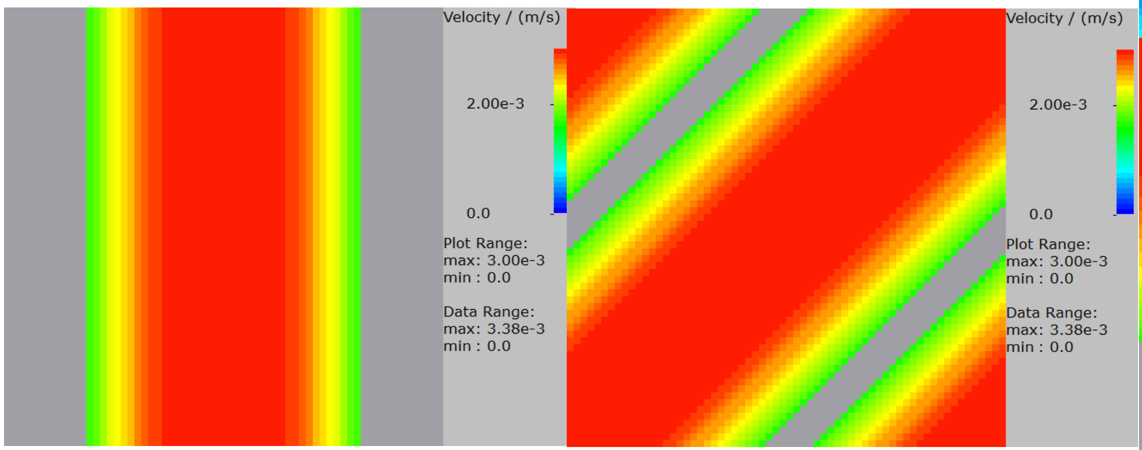
SIMULATION OF SLIP FLOW

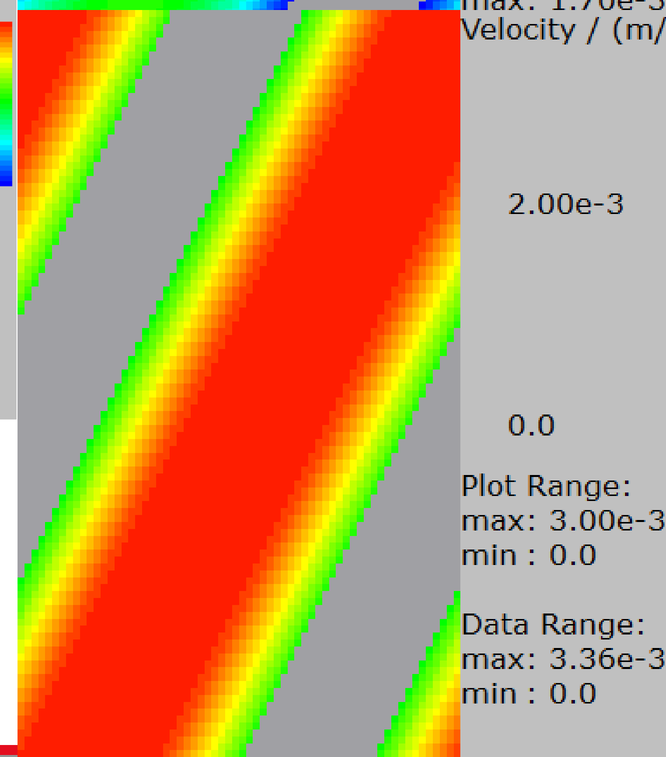
No-slip





Slip



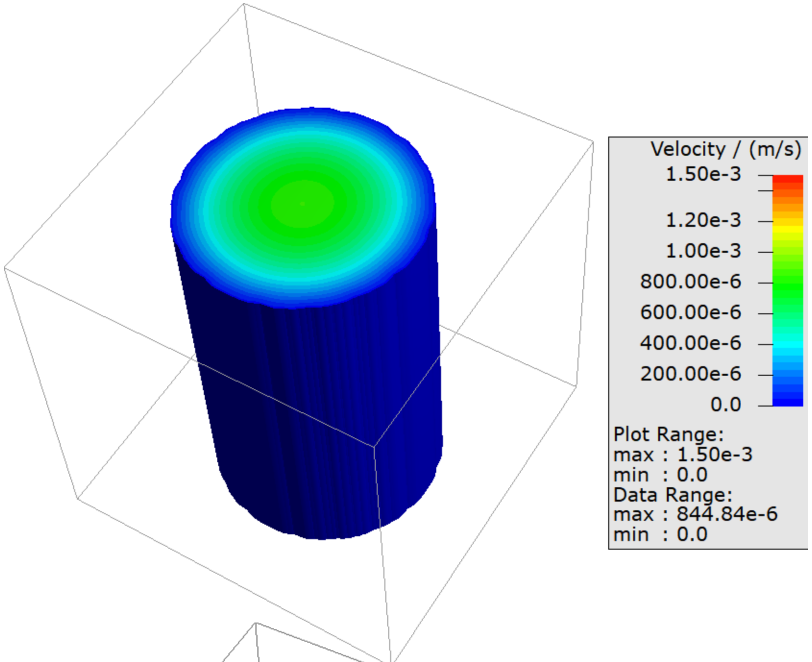


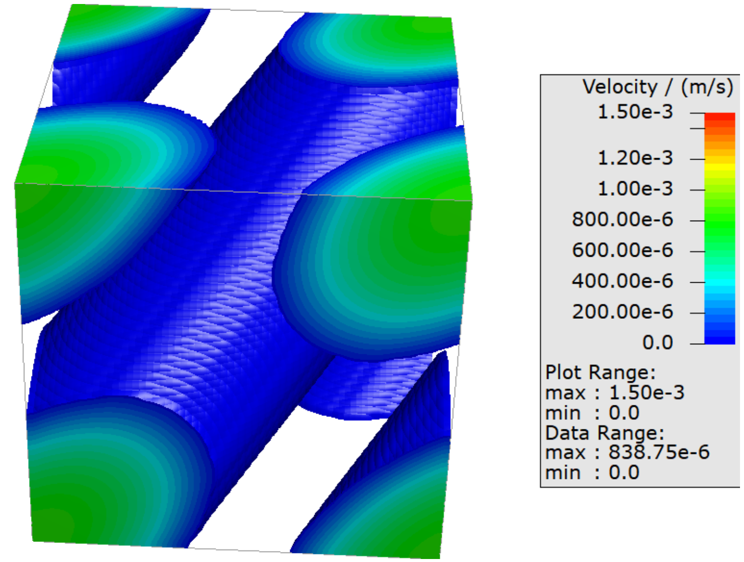
Validation I:
Planar Poiseuille flow

SIMULATION OF SLIP FLOW

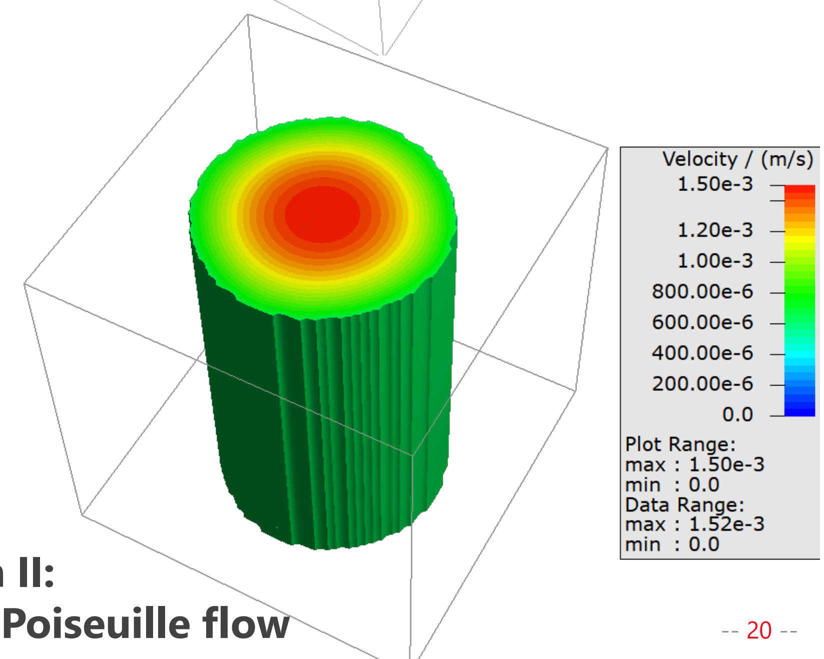
GEODICT

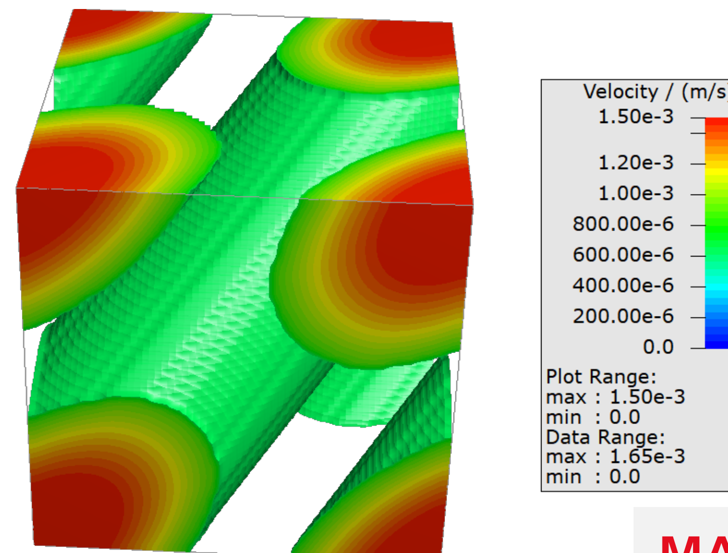
No-slip





Slip





Validation II:
Coutette Poiseuille flow

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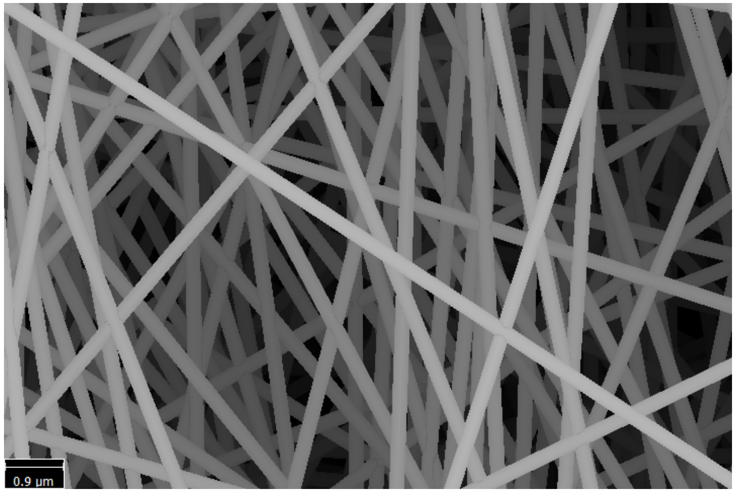
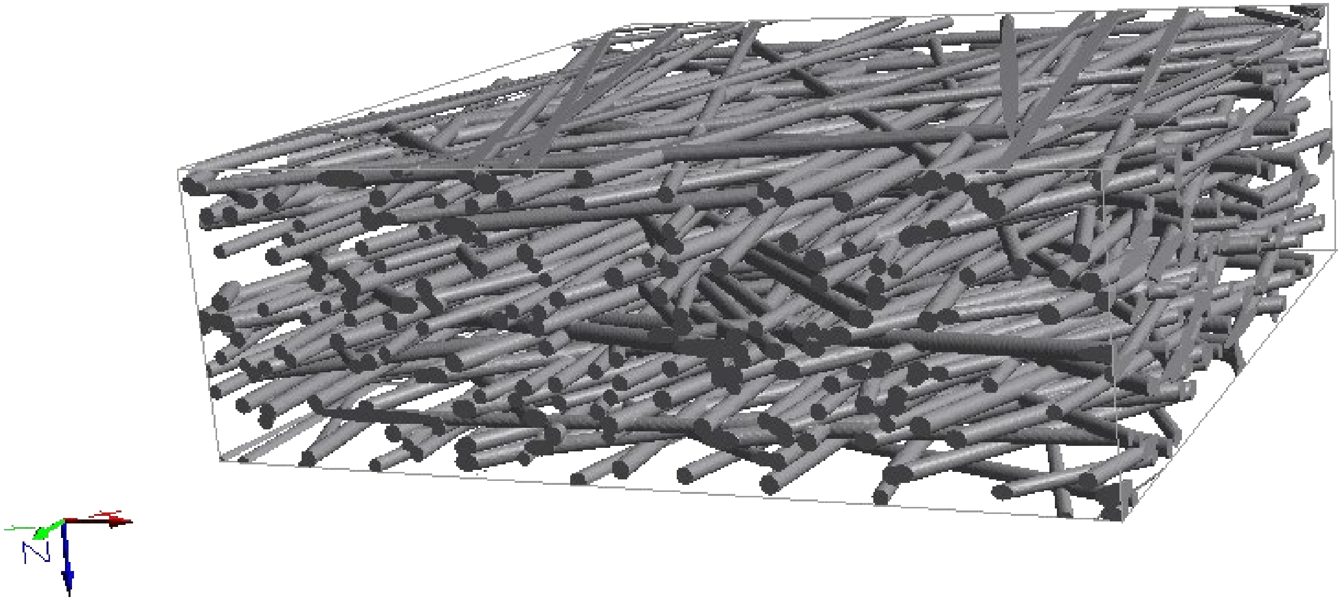
Simulation of slip flow

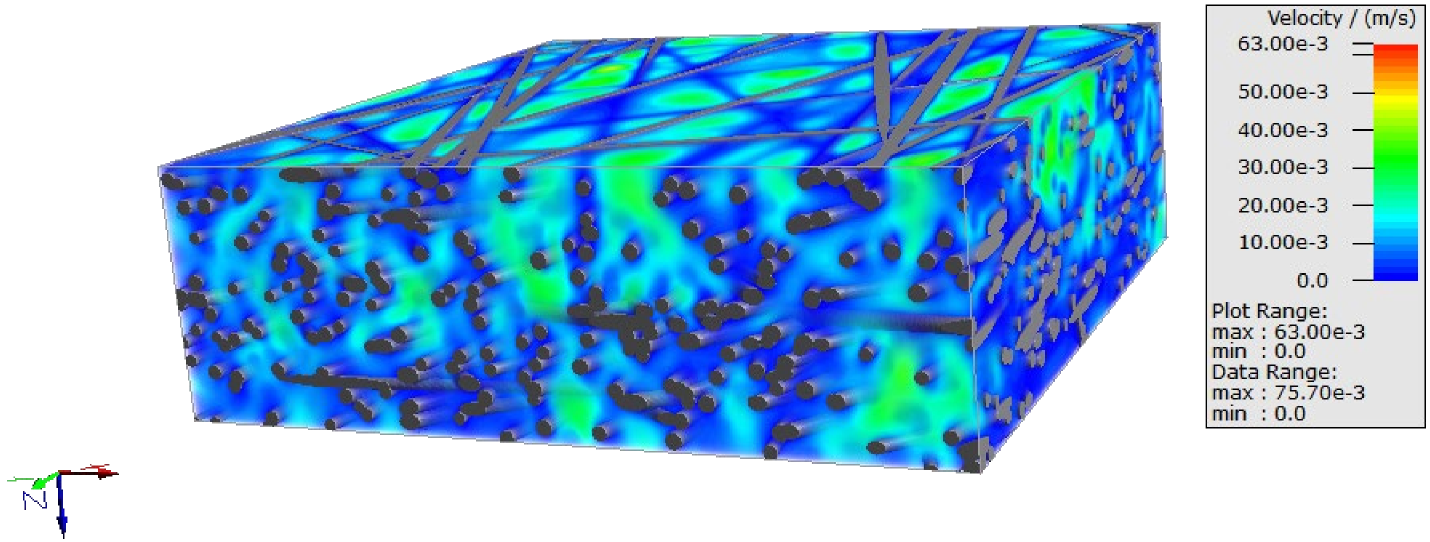




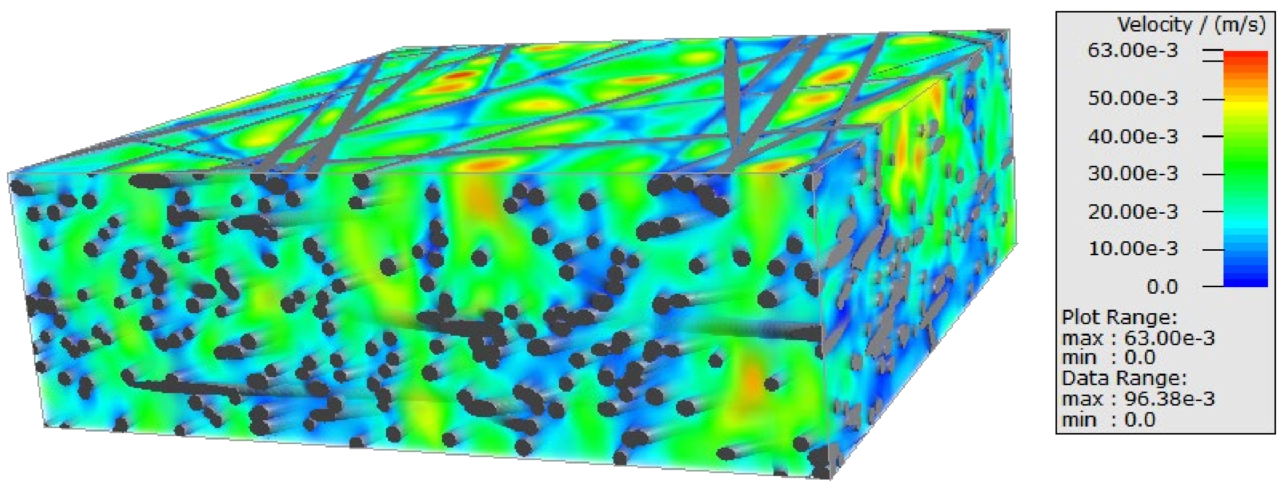
SIMULATION OF SLIP FLOW

GEODICT

No-slip



Slip



Comparison of velocity distribution

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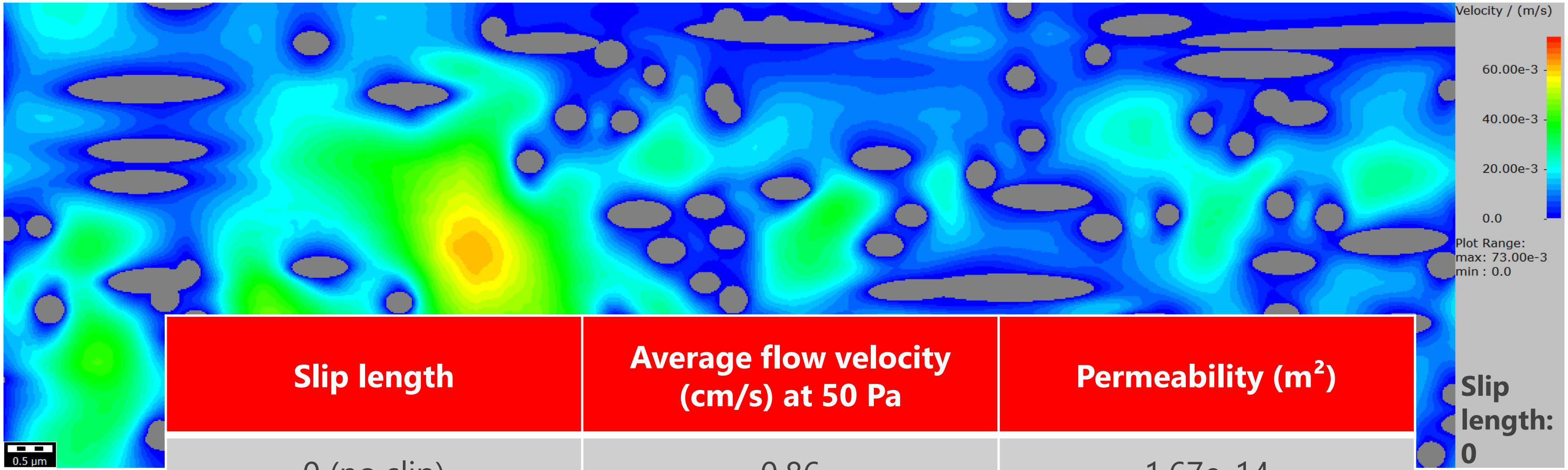
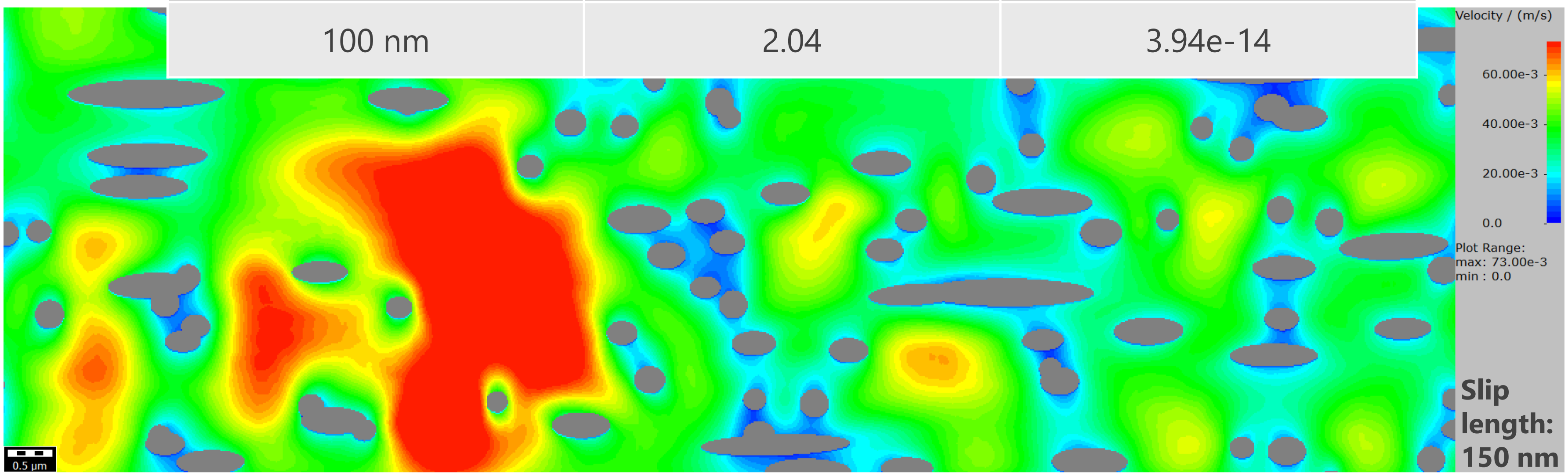
COMPARISON OF VELOCITY DISTRIBUTION

GeoDict



Slip length	Average flow velocity (cm/s) at 50 Pa	Permeability (m^2)
0 (no slip)	0.86	1.67e-14
100 nm	2.04	3.94e-14



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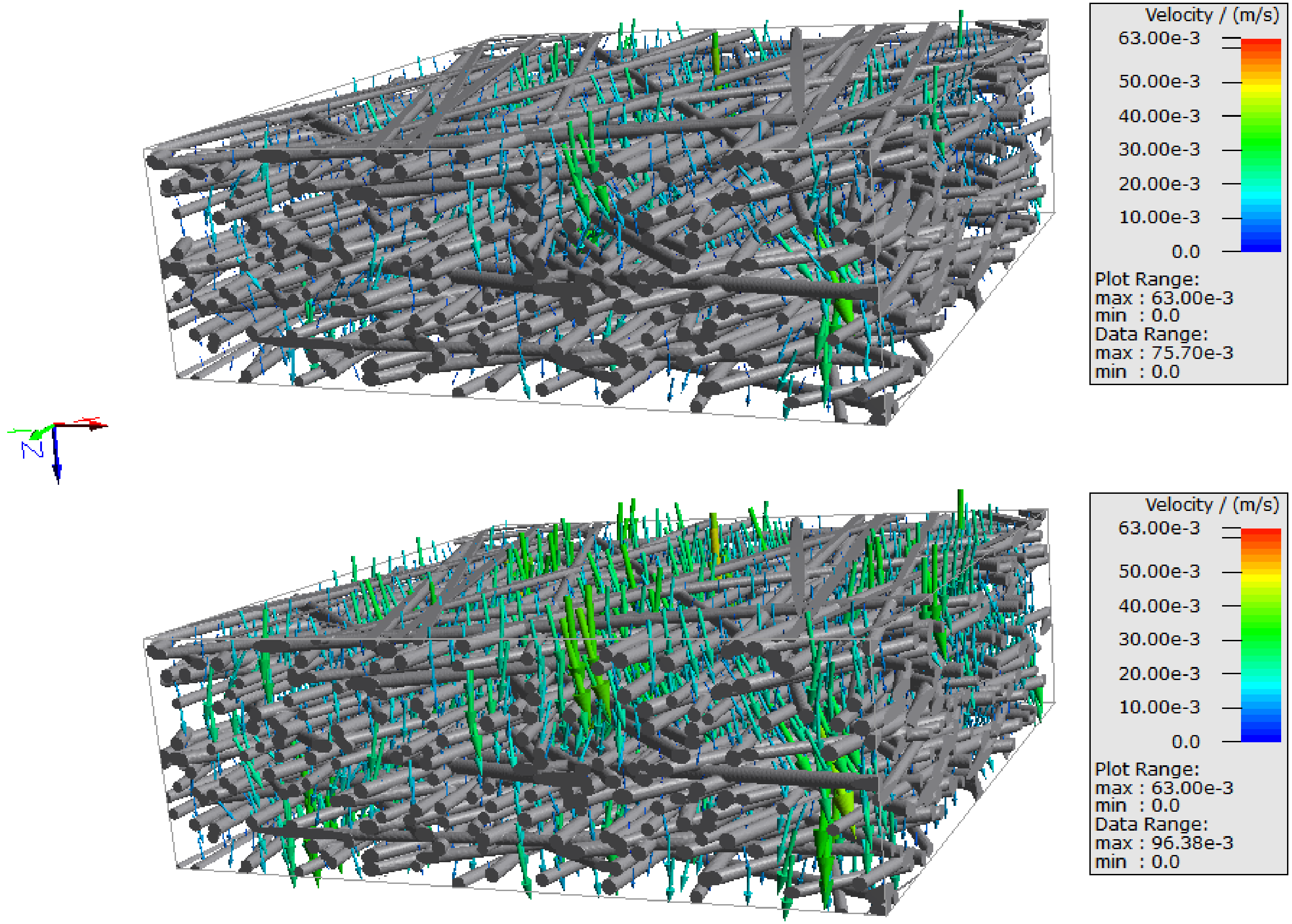
Simulation of slip flow

No-slip

Slip



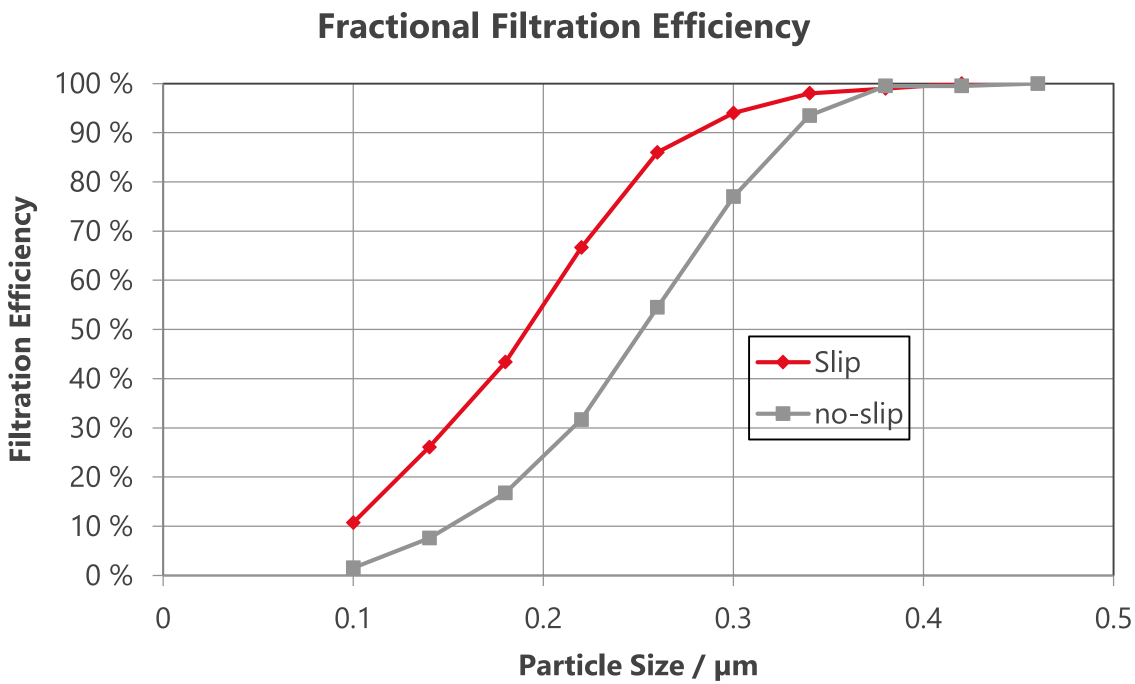
Comparison of velocity arrow field

Simulation of Nanofiber Filtration

GeoDict

Settings of filter life-time single-pass simulations

Fluid	Air
Temperature	22 °C
Mean flow velocity	0.1 m/s
Flow	Darcy (Stokes)
Filtration duration	40 s
Particles	10 different particle size classes from 100 nm to 460 nm
Test dust concentration	1 g/m³
Particle density	2650 kg/m³
Particle shape	Spherical



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SIMULATION OF NANOFIBER FILTRATION

GEODICT

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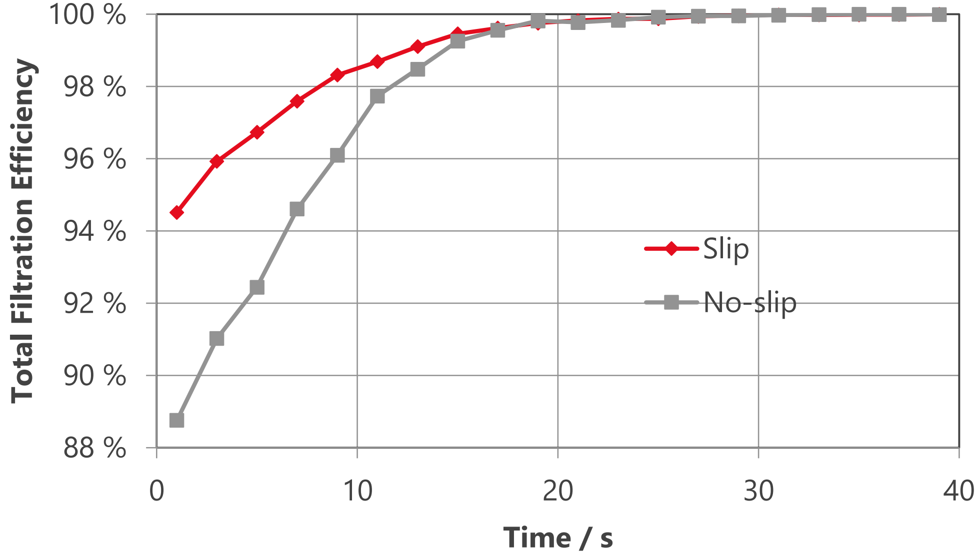

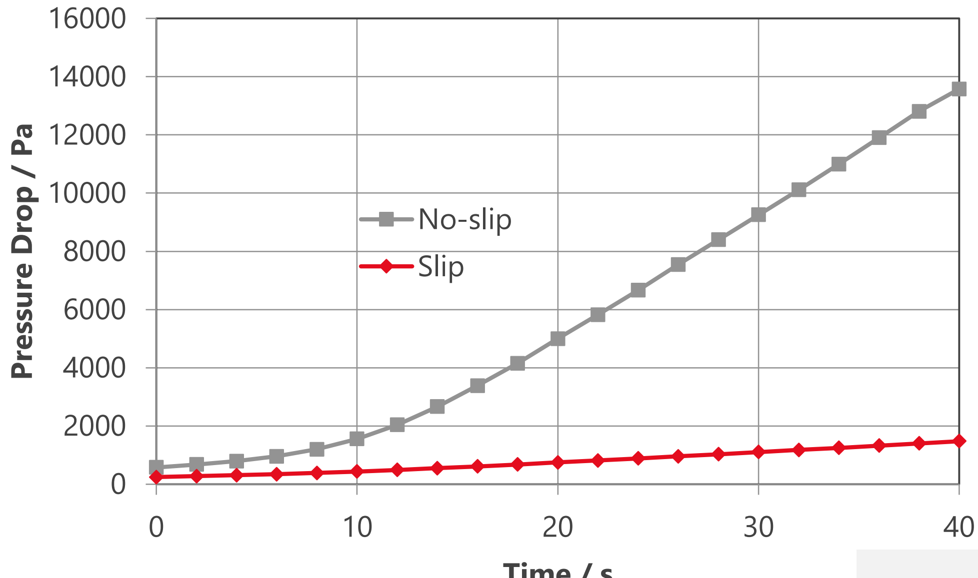

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SUMMARY

GEODICT

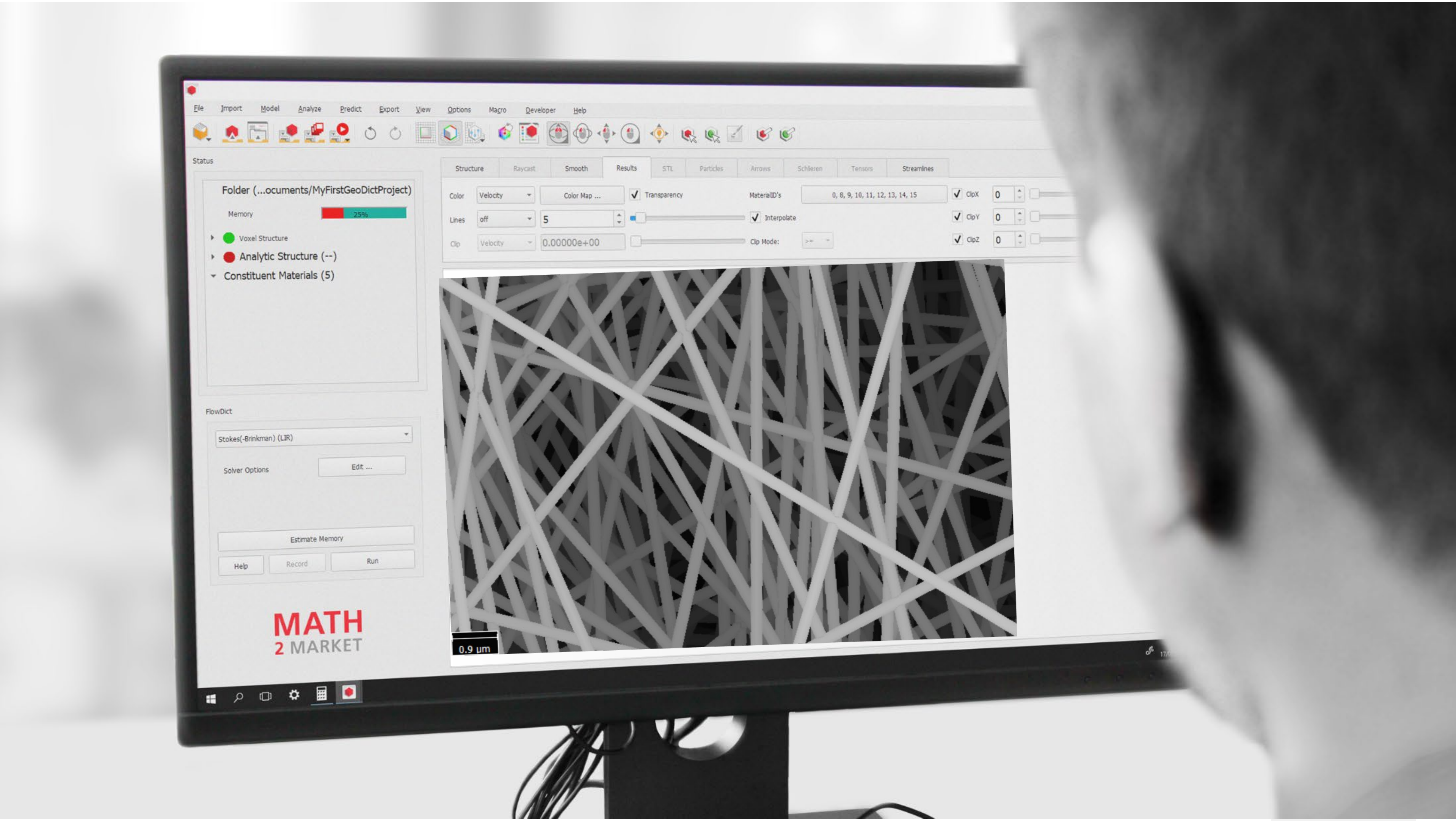
- Slip flow plays an important role in nanofiber filtration.
- Slip boundary condition has been implemented in GeoDict.
- The slip flow effects in nanofiber filtration can be observed by comparing to no-slip flow.

OUTLOOKS

- To improve the automatic detecting of orientation of each fiber
- Extensive validation by comparing with experiments
- ……

Visit us at Hall 11.1, Booth #A11

GeoDict



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