DIGITAL OPTIMIZATION OF HYDRAULIC FILTER MEDIA

Tutorial

GeoDict release 2024 SP3

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GEODICT

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DIGITAL HYDRAULIC FILTER MEDIA OPTIMIZATION

MOTIVATION

The performance of any filter is defined by three properties: pressure drop, filter efficiency, and dust holding capacity (DHC). The **pressure drop** defines in which way the pressure increases during the loading of the filter. The **filter efficiency** reflects how efficient the filter can trap particles of different sizes. The **DHC** measures the number of particles which a filter can trap and hold before the maximum allowable pressure drop is reached.

The ideal filter has a large DHC and a high filter efficiency while maintaining a low pressure drop. Those three properties usually influence each other, meaning that improving one or two of them will usually diminish the third property.

The pressure drop is important because it defines the amount of energy that is needed to operate the filter.

The filter efficiency e can be quantified also by the so-called β-ratio, the ratio between the numbers of particles upstream and downstream of the filter.

$$\beta_d = \frac{n_{d,U}}{n_{d,D}} = \frac{100}{100 - e}$$

The DHC is important because it specifies how long a filter can operate before it must be replaced or cleaned.

The aim of this tutorial is to optimize the filter media by increasing the dust holding capacity (DHC), while maintaining the pressure drop and β-ratio. Concretely, these side conditions are ensured by modelling all media in this tutorial to have initially nearly the same pressure drop (i.e. in the clean state) and the same β-ratio of 200 for particles with diameter of 22 µm or larger. The media thus is 99.5% efficient in removing particles larger than 22 µm.

Reference:

M. Azimian, C. Kühnle, A. Wiegmann. *Design and optimization of fibrous filter media using lifetime multipass simulations*, Chemical Engineering & Technology, 2018, Vol 41(5), pp. 1-9

STATISTICAL PARAMETERS FOR STRUCTURE GENERATION

All three generated 3D structure models in this tutorial consist of thick and thin fibers (dual phase). The distribution of the thick fibers is homogeneous over the media thickness (height) and the same for all generated filter media models. In contrast, the distribution of the thin fibers is variable over the thickness of the filter media.

The names given to the three models are due to the variable distribution of the thin fibers: homogeneous model, linear increasing model, and exponentially increasing model. The following table gives an overview of the properties of these fibers:

Fiber type	Function	Diameter	Material	Orientation	Total volume
Thin	Filtration & separation of particles	4 µm	Glass	Anisotropic / XY plane	~40%
Thick	Stiffness	20 µm	Glass	Anisotropic / XY plane	~60%

To make the three models comparable to each other, they were modelled to have the same initial pressure drop and ß-ratio in the clean state. To ensure this, FlowDict simulations were used to guide the choice of geometric model parameters.

GEODICT MODULES USED IN THE TUTORIAL

In this tutorial, several modules of GeoDict are used in this order:

FiberGeo	to create and generate the fibrous filter media
FlowDict	to find important flow parameters such as pressure drop, permeability and flow resistivity of the clean media
FilterDict	to get information about the efficiency of the filter and its lifetime performance.

INTRODUCTION - FILES APPENDED TO THE TUTORIAL

Several files are appended to this tutorial. Those files are the results and the .gps files of the simulations. When unzipping the tutorial folder, three folders with the names **Input-Data, Results_M2M, and Results_User** are found. The **Input-Data** folder contains input data needed in the simulation. The **Results_User** folder is empty and will be filled with the users' results. The **Results_M2M** folder further contains subfolders called **Small** and **Medium**:

We appended two different simulation dimensions in the .zip file. The reason for this is the simulation time. To give you the chance to follow this tutorial in a decent amount of time, we also ran simulations on a smaller scale. We advise you to run this tutorial **to learn the procedure** with the small domain size, due to simulation times.

Disclaimer:

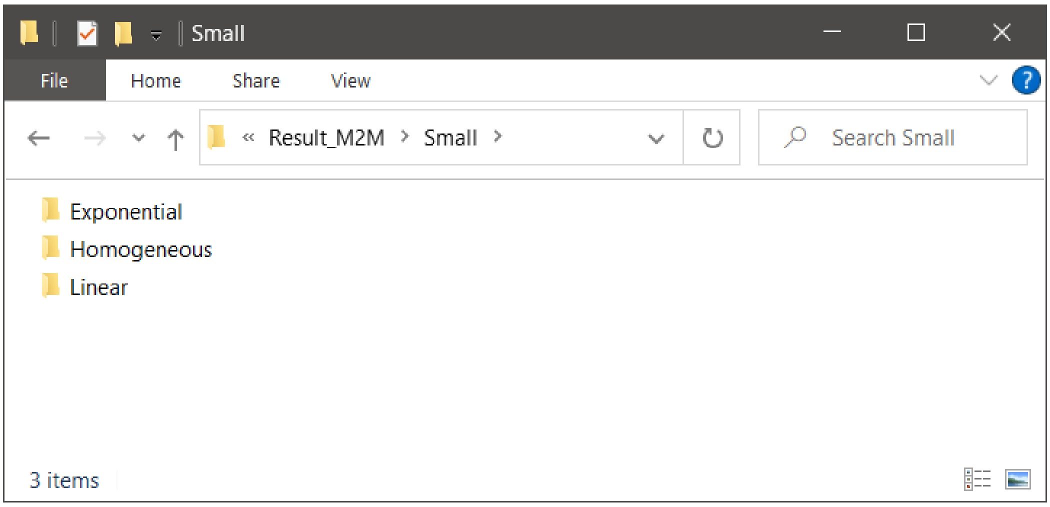
The simulations on smaller scales are not representative of the material. Results from small structures may not give enough accuracy! We actively searched for cases where the results on small structures match the results on large structures. To get representative results, the user needs to run simulations on representative domain-sizes! We tested domain-sizes of 600x600 µm and 1000x1000 µm and the results do not differ much. This means that for this specific case simulations of 600x600 µm are representative when the voxel size is 1 µm.

All simulations in the **Small** folder were run with a domain-size of 128x128x1000 voxel, using 1.5 µm as the voxel length.

All simulations in the **Medium** folder were run with a domain-size of 600x600x1500 voxel, being the voxel length 1 µm.

The **Small** and the **Medium** folders contain three subfolders with identical file structures:

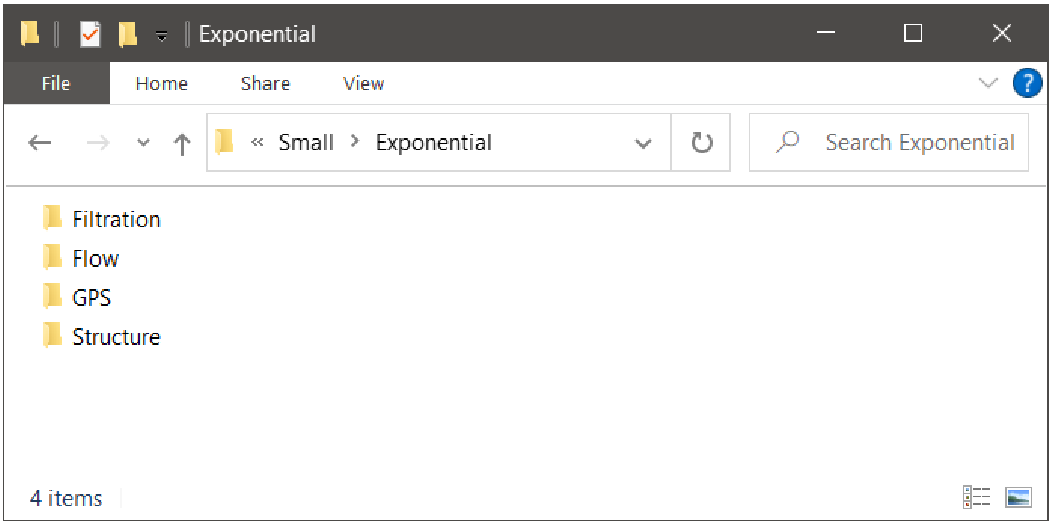
- Exponential
- Homogeneous
- Linear



We take **Exponential** as an example. All files for the **Exponential** microstructure (see below, page 15) can be found in in the **Exponential** folder.

Each of these three subfolders contain subfolders with identical built:

- The **Filtration** folder contains all files of the filtration results
- The **Flow** folder contains every file of the flow simulation
- The **GPS** folder contains the .gps settings files
- The **Structure** folder includes the files for the used microstructure



Those files are the results created by Math2Market for this tutorial.

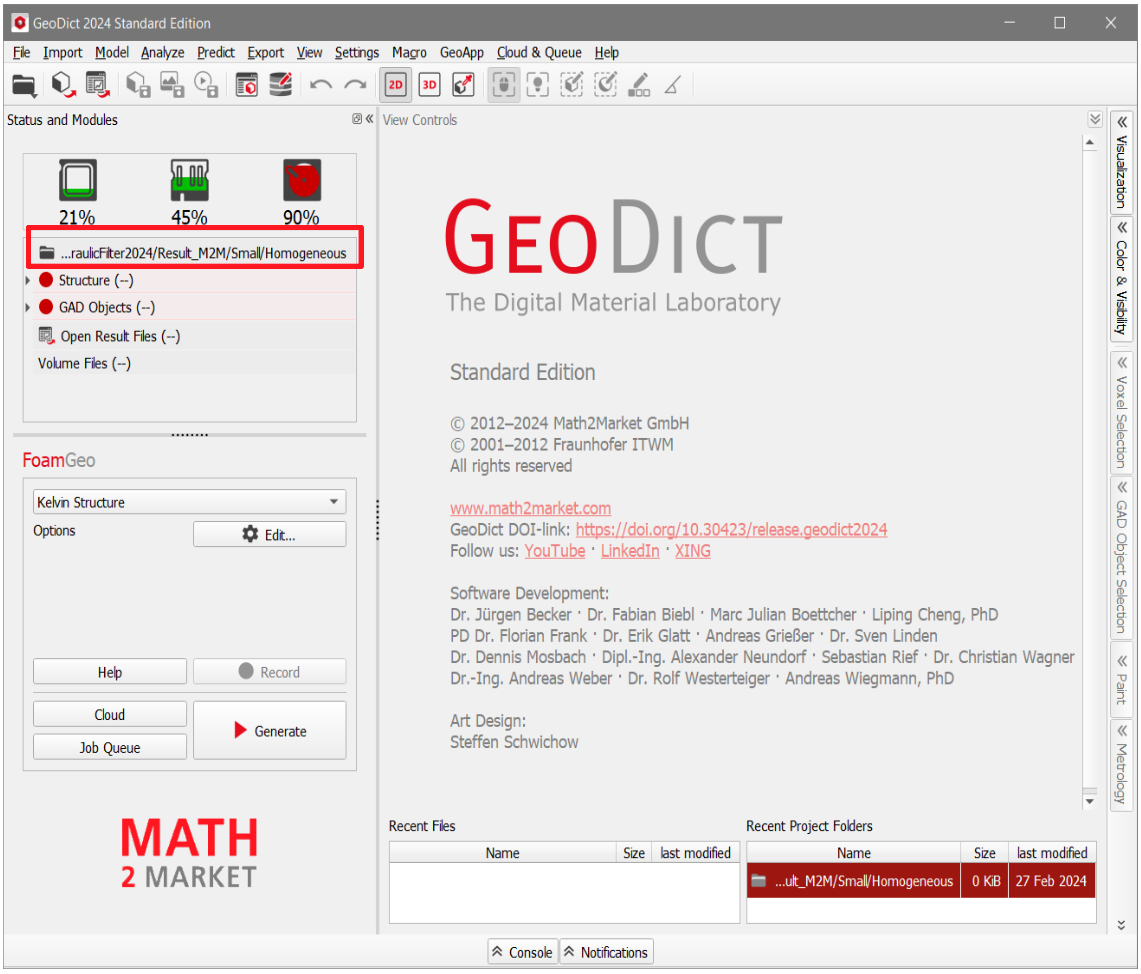
To avoid confusion, we advise the user to use the **Results_User** folder built for the simulations and not to overwrite the files that have been sent with the tutorial.

MICROSTRUCTURE MODELING AND FINDING REPRESENTATIVE DIMENSIONS

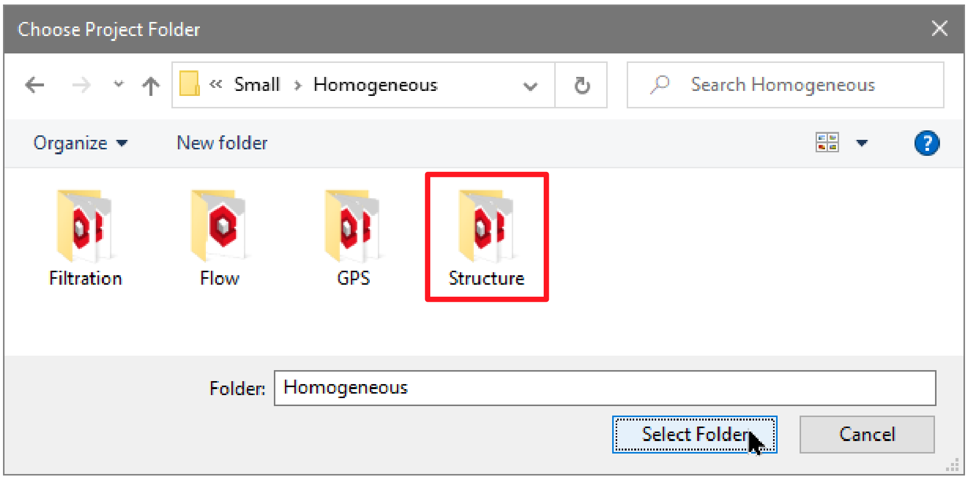
Start this tutorial by doing the following:

1. Create a folder within the **Results_User** folder called **Small**.
2. Inside of the **Small** folder create 3 subfolders with the names:
   - Exponential
   - Linear
   - Homogeneous
3. Inside of each of these 3 folders create 3 subfolders with the names:
   - Flow
   - Filtration
   - Structure
4. Start GeoDict 2024
5. At the beginning it is advisable to select the project folder. After selecting it, GeoDict looks there to load and save files. Navigation through all folders and to saved structures is of course still possible, but the default starting point is the selected project folder. To change the project folder, select **File** → **Choose Project Folder** from the menu bar.

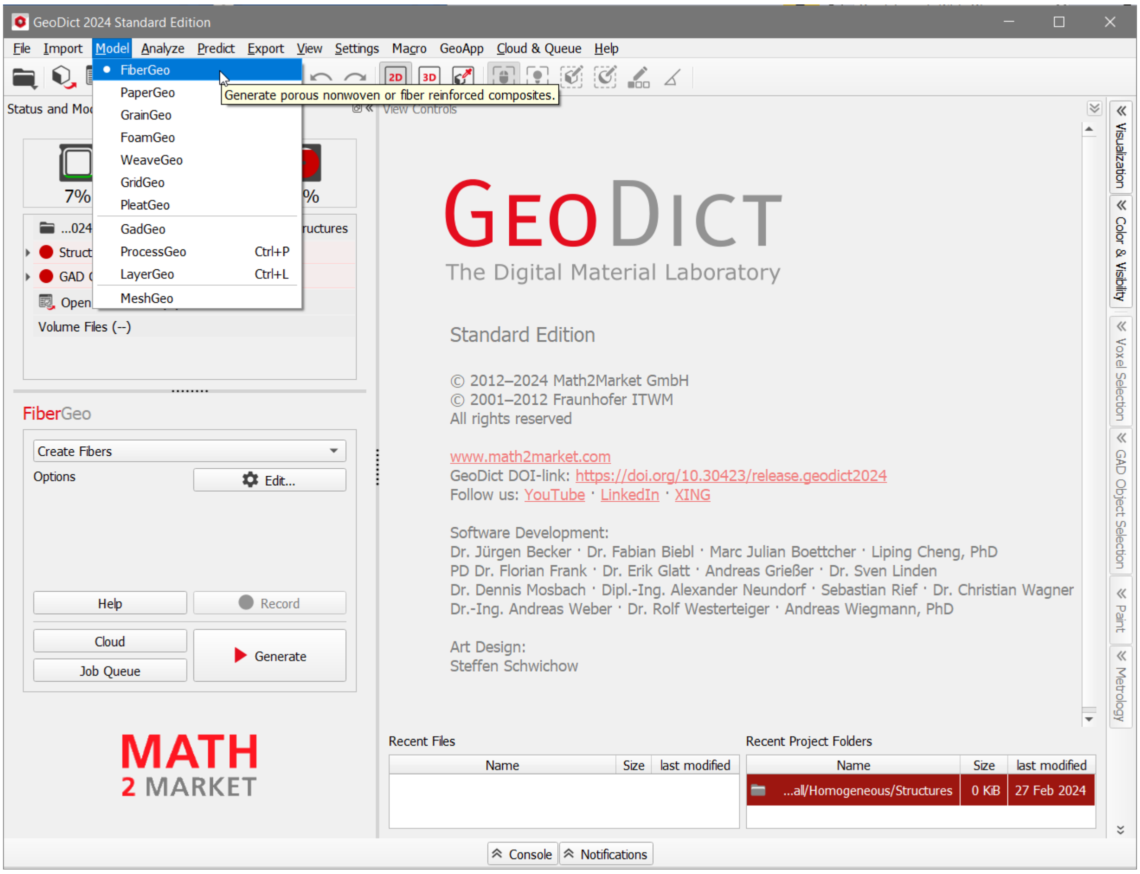
   Alternatively, click the icon in the toolbar.



6. For the first step of creating a homogeneous structure, navigate to the created **Homogeneous** folder, find the **Structure** subfolder, and select it as the project folder. When creating the other structure types (Linear, Exponential) change the project folder to the corresponding folder and subfolder.



7. For the three structures, we want to make the distribution of the thick fibers all the same but only vary the distribution of the fine fibers. To do that, we first generate a common coarse fiber structure used for all structures. Select **Model** → **FiberGeo** from the menu bar.

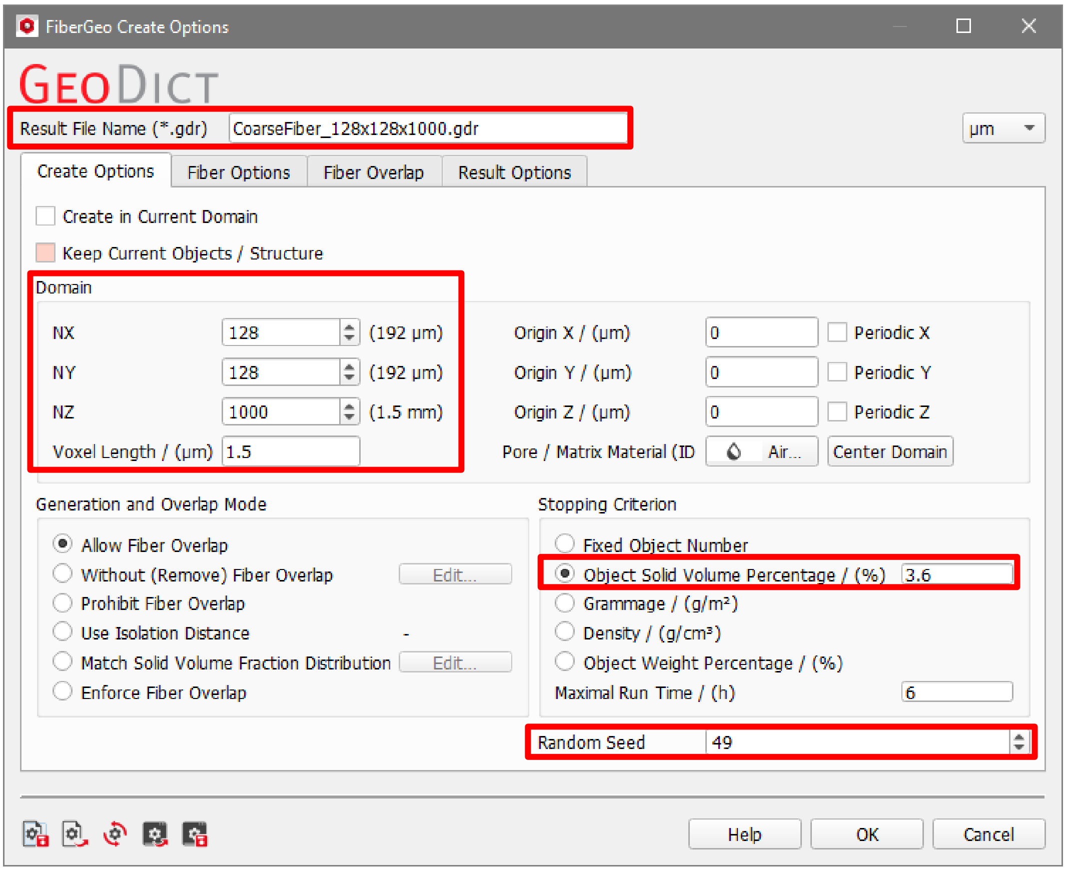


8. In the **FiberGeo** section, on the left of the GeoDict GUI, select **Create Fibers** from the pull-down menu and click **Edit ...** to modify the statistical parameters used for the generation.

In the **FiberGeo Create Options** dialog, under the **Create Options** tab, enter the parameters shown in the screenshot below. More information on these parameters can be found in the FiberGeo handbook of the User Guide.

The **Domain**-size of the smaller structures is 128x128x1000 voxels. In this case, NX represents the domain-size in X-direction. To achieve the domain-size of 128x128x1000 the value for NX needs to be 128.

The **Voxel Length** represents the size of one single voxel in any direction (X, Y, or Z). A voxel length of 1.5 µm indicates, that 1 voxel represents 1.5 µm.



Since there is no reason to change the object's origin in any specific direction, keep the origin at 0.

Allow Fiber Overlap is checked because fiber overlap leads to intersecting fibers, which is a suitable for highly porous, fibrous structures.

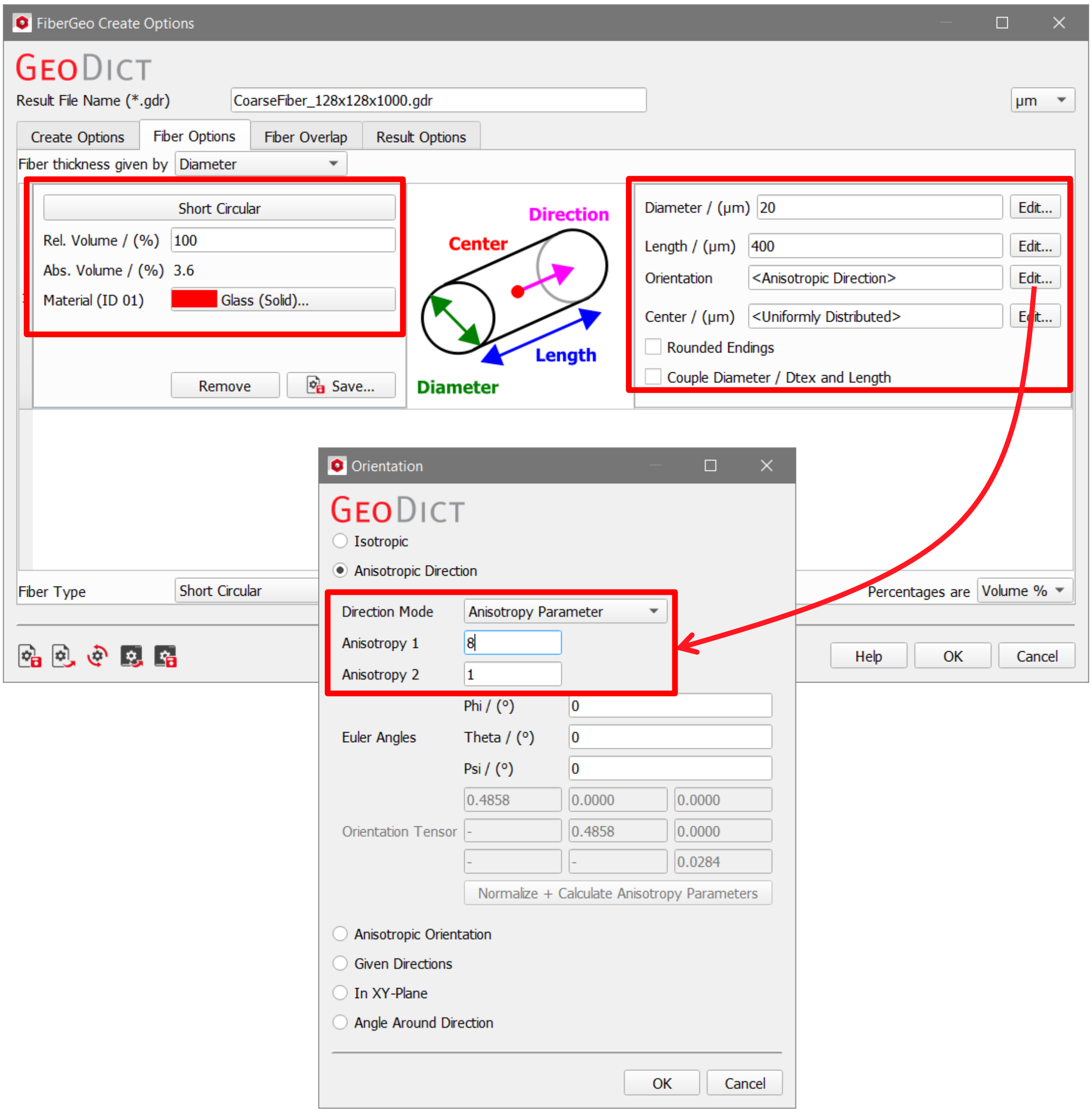
The **Object Solid Volume Percentage** influences the flow resistivity, the permeability and the pressure drop. A higher solid volume percentage increases the pressure drop. A solid volume fraction of 3.6% for the coarse fiber is chosen.

9. Select the **Fiber Options** tab and delete the existing fiber types by clicking **Remove** in their panels.

   At the bottom left of the dialog, select **Short Circular** as **Fiber Type** and click **Add** to add a new fiber type.

   Enter the parameters shown below or take a shortcut by loading a .gps settings file. The .gps is provided by Math2Market and contains all parameters.

   Load the .gps file by clicking on the icon at the bottom left corner of the dialog ( ) and navigating to ../Small/Homogeneous/GPS/CoarseFiber_Creation.gps in the Results_M2M folder.

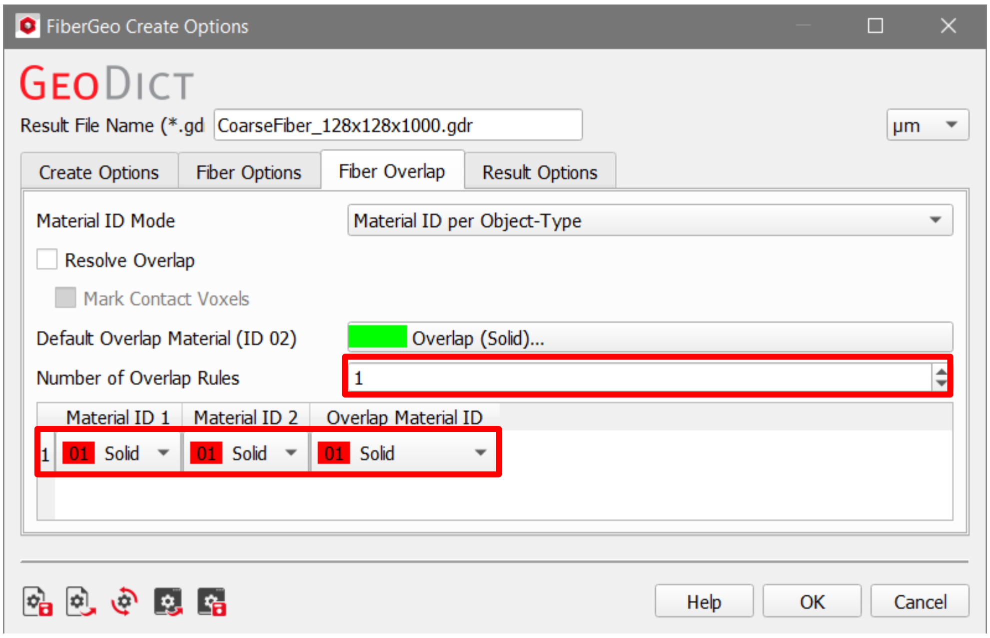


Here, the parameters shown produce **thick** short circular fibers. The function of the thick fibers is mainly to support the thin fibers and give the filter its needed stiffness. More information on adding fibers can be found in the [FiberGeo handbook] of the User Guide.

The thick fibers have a diameter of 20 µm and a length of 400µm. The **Orientation** of the fibers are set to have an **Anisotropic Direction**, instead of isotropic, where no specific direction is preferred. The anisotropy describes the relative direction towards the XY-Plane. By changing the anisotropy values to 8/1 the XY-Plane is preferred. To change this parameter, click **Orientation**, check **Anisotropic Direction** and change it to 8/1 for the thick and, later, for the thin fibers.

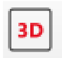
To create a homogeneous distributed structure, distribute the **Center** of the fibers uniformly through the height of the structure by choosing **Uniformly Distributed**.

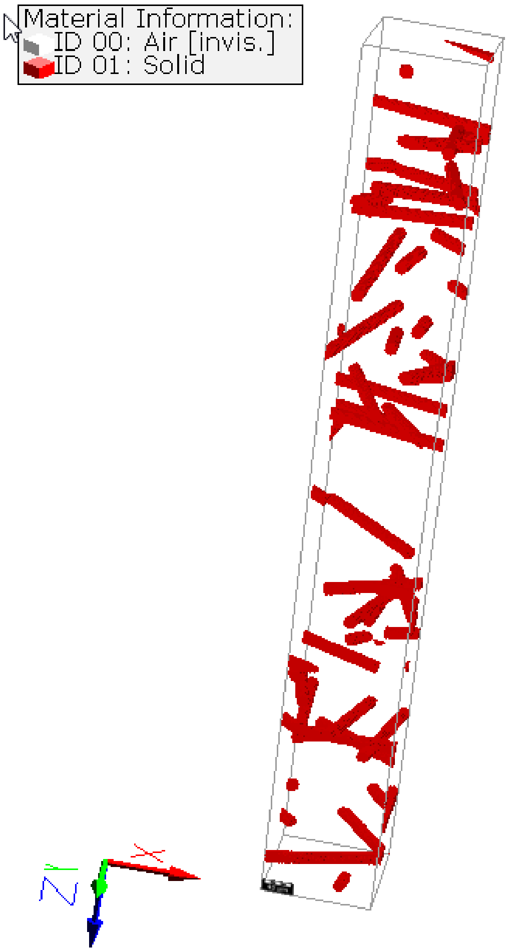
10. The overlap of the coarse fibers is taken as the same material. To do that, go to **Fiber Overlap**, set 1 to **Number of Overlap Rules**, and make the **Overlap Material ID** as Material 01.

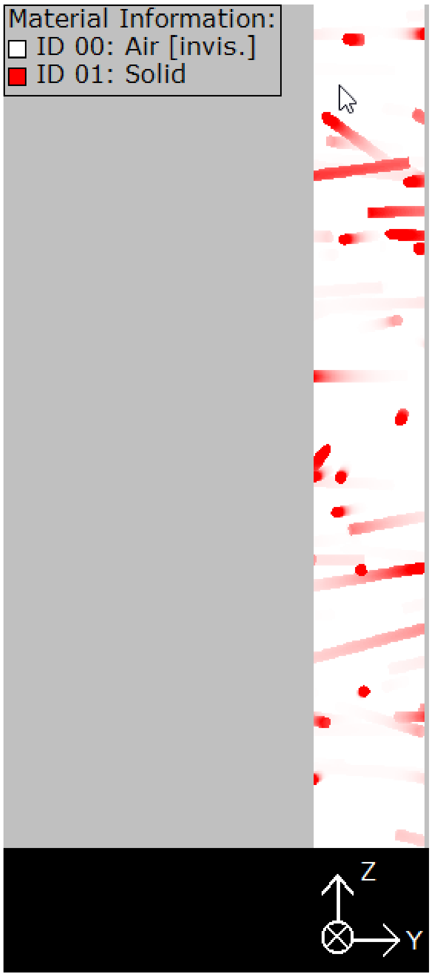


11. Click **OK** to close the **FiberGeo Create Options** dialog. Click **Generate** in the **FiberGeo** section to generate the structure.

    The microstructure resulting from the entered parameters is generated and displayed in the Visualization area in 2D.

    To visualize it in 3D Rendering, click on the  icon in the toolbar. To save the structure click **File** → **Save Structure as...** in the menu bar.





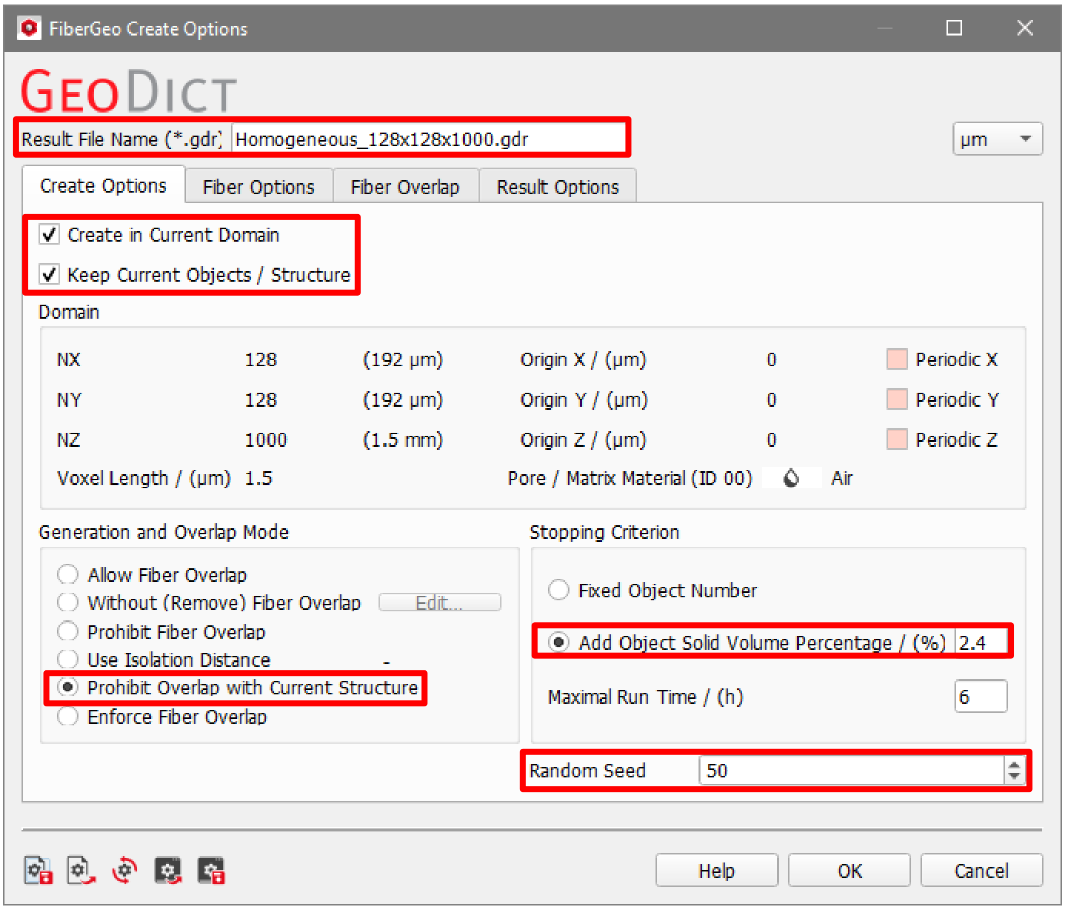
12. As the thick (coarse) fiber structure is generated, thin fibers can then be added by keeping the current structure. Let's see first the homogenous case of thin fibers.

    Again, use the **Create** command in the FiberGeo section. Click **Edit …** to modify the parameters used for the generation.

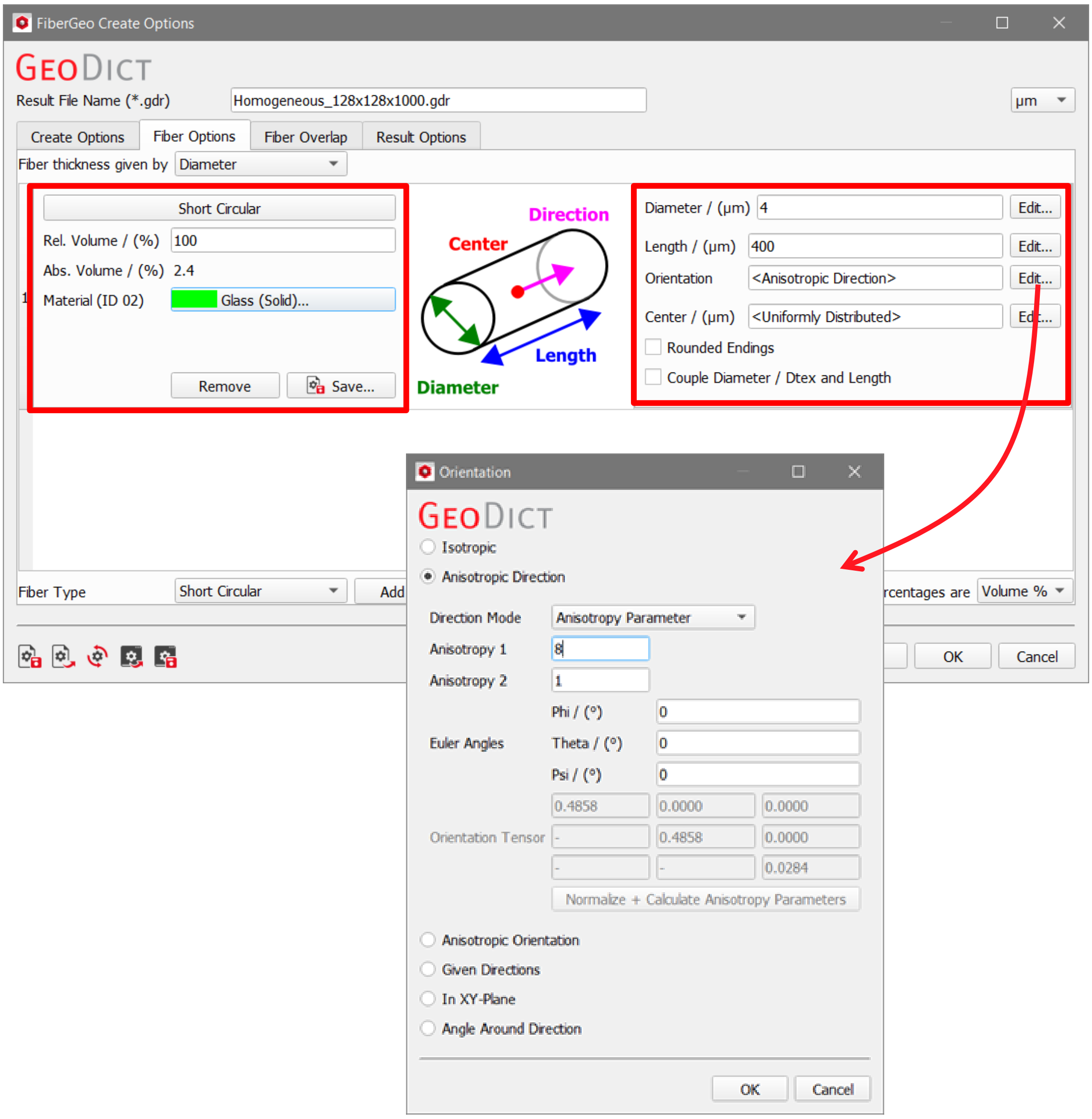
    Do not forget to check **Create in Current Domain** and **Keep Current Objects / Structure** so that the newly generated fibers are added to the current structure.

    Select **Prohibit Overlap with Current Structure**.

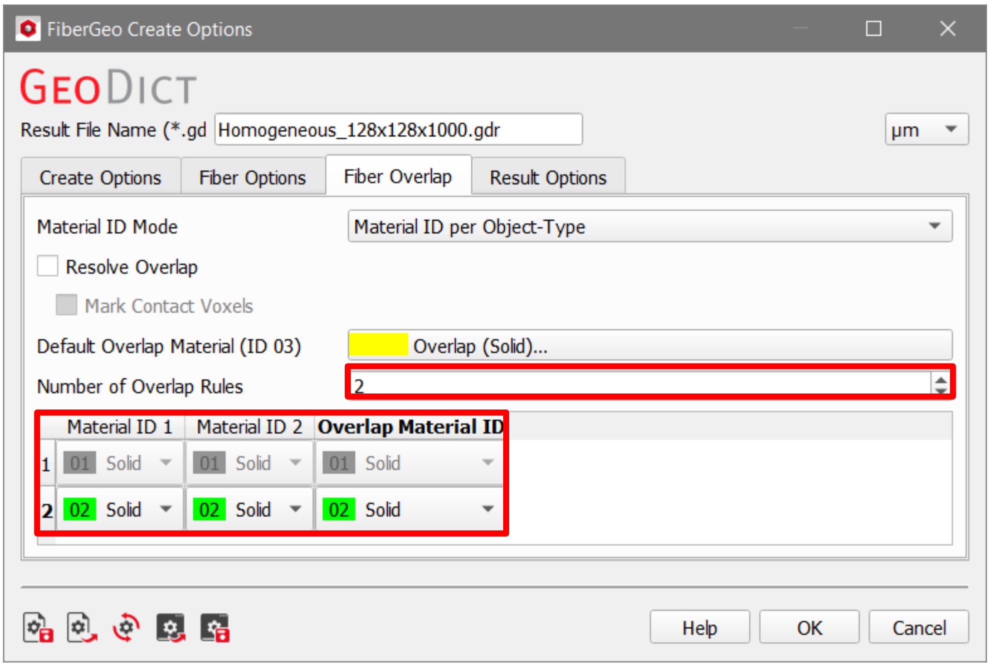
    To create structures with nearly the same initial pressure, the **Solid Volume Percentage** was adjusted such that it matches to experimental results. A fitting parameter for the homogeneously distributed thin fibers is 2.4 %.



    Under the **Fiber Option** tab, also choose **Short Circular Fiber** for the thin fibers. The thin fibers have a diameter of 4 µm and a length of 400µm



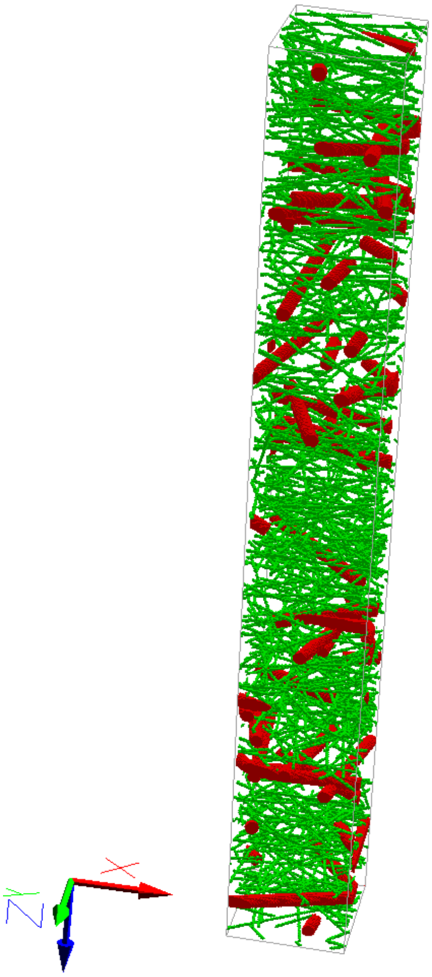
13. For **Fiber Overlap**, set the overlap of the thin fibers as Material 02.

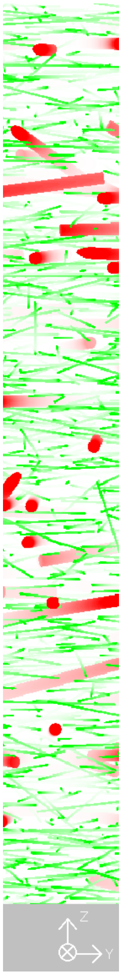


14. The settings in the dialog above may be loaded from the file

    ../Small/Homogeneous/GPS/Homogeneous_Creation.gps.

    Click **Generate** in the FiberGeo section to generate the structure. The microstructure resulting from the entered parameters is generated and displayed in the visualization area in 2D or in 3D.





15. For the next step, creating the **Linear** microstructure and the **Exponential** microstructure, change the project folder to their folders:

    - **Results_User\Small\Linear\Structure** for the Linear microstructure
    - **Results_User\Small\Exponential\Structure** for the Exponential microstructure.

    All files produced during the creation of a Linear microstructure and an Exponential microstructure are saved in these folders.

    The difference between the homogeneous, exponential, and linear microstructures is the distribution of the thin fibers.

    The parameters for the **Orientation** stay the same for all three microstructures and were shown above (Anisotropic Direction).

    The parameters **Object Solid Volume Percentage** and **Random Seed** vary for each structure (Linear and Exponential). The values are shown below in the screenshots of the FiberGeo Create Options dialog – Create Options tab for the Linear and for the Exponential microstructure.

The different distribution of the thin fibers in the Linear and the Exponential microstructures is achieved by choosing a **Density Distribution**. These parameters for the **Center** distribution for microstructures can be found in their .gps settings files (Linear_Creation.gps and Exponential_Creation.gps). The values for the center parameters are shown below in the screenshots of the FiberGeo Create Options dialog – Fiber Options tab.

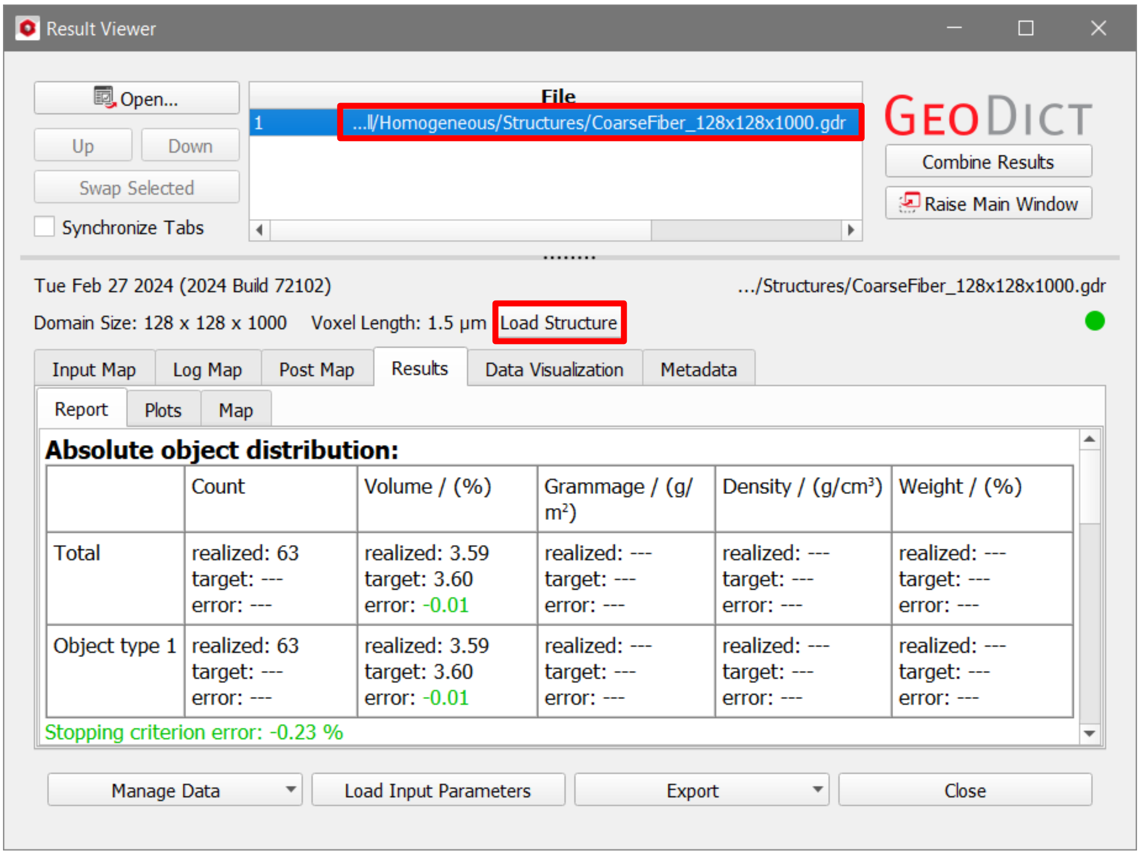
There are 2 different options to select the values for the density distribution:

- The first option is to enter the values in as **absolute position**, which means that 0µm corresponds to the bottom of the microstructure and the absolute height of the microstructure corresponds to the top.
- The second option is to use **Relative Position** and, in this case, 0 corresponds to the bottom of the structure, while 1 indicates the top. The density is always relative to the lowest value, excluding 0, which means that if the lowest value for density is 1 and the highest value is 20, the density for that specific slice is 20 times higher than the lowest. A density of 0 represents no fibers starting in that area.

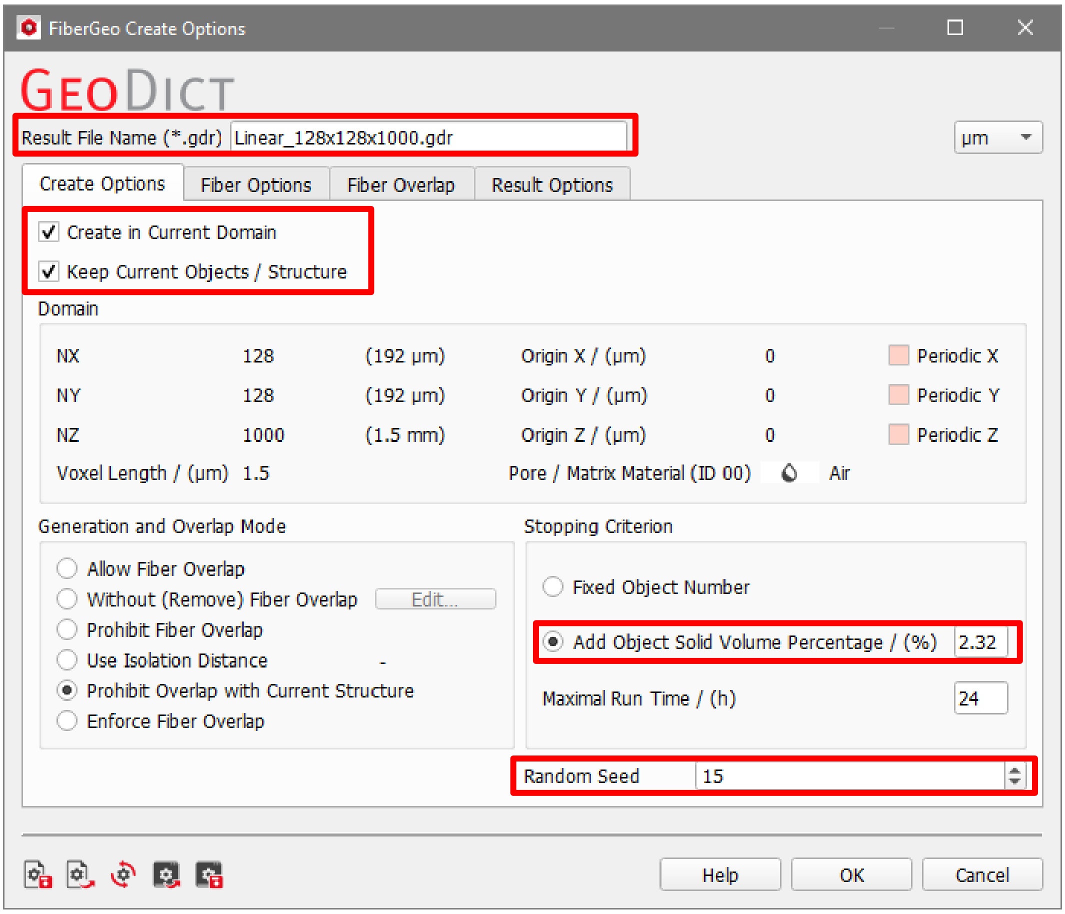
More information on density distribution can be found in pages 61-64 of the FiberGeo handbook of the User Guide.

16. To create the **Linear** microstructure, navigate to the created **Linear** folder, find the **Structure** subfolder, and select it as the project folder. The first step is to get the same thick fiber structure as for the homogeneous case. Since it has been generated for the **Homogeneous** microstructure, we can simply load it into memory.

From the **File** menu, choose **Open Results (*.gdr) ...**, find the **CoarseFiber_128x128x1000.gdr** in **..\..\Homogeneous\Structure** folder. Click **Load Structure**.



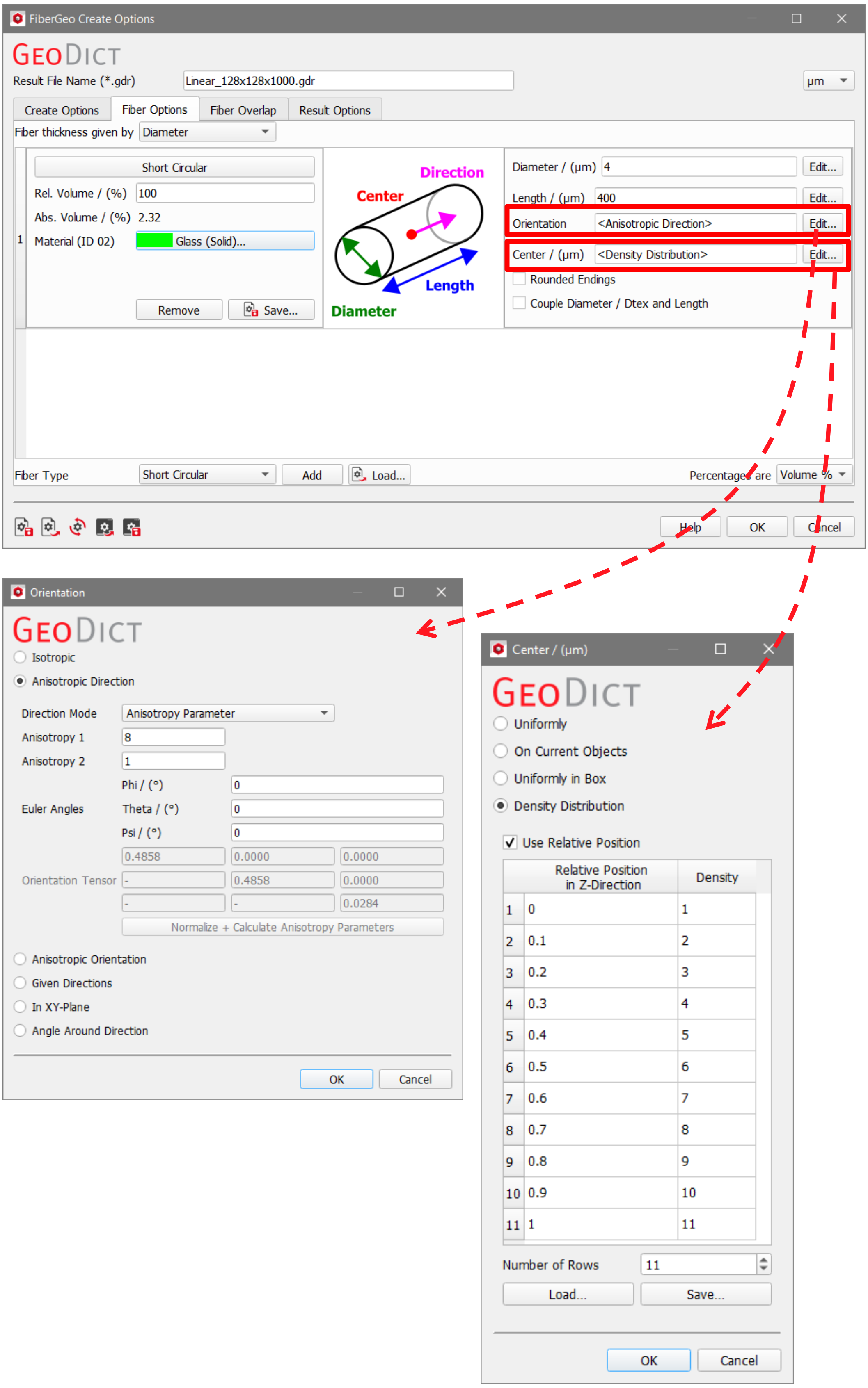
17. Again, select **Create Fibers** in the FiberGeo section, and click the Edit… button. In the opening dialog, **Create in Current Domain** and **Keep Current Objects / Structure** are checked. The Solid Volume Percentage for the **Linear** microstructure is 2.32%.



In the **Fiber Options** tab, keep fiber type, diameter, length, and orientation the same as for the homogenous structure.

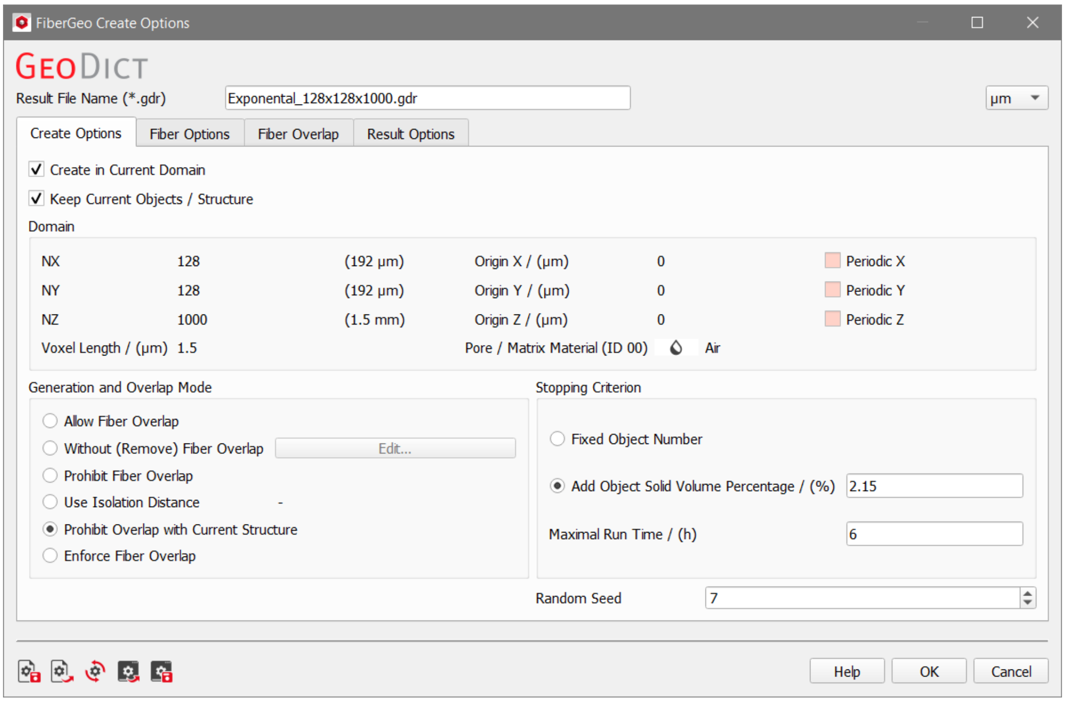
The difference lies in the density distribution of the centers. The easiest way to create a **linear** microstructure is to use a **Relative Position** while increasing the density linearly over the height.

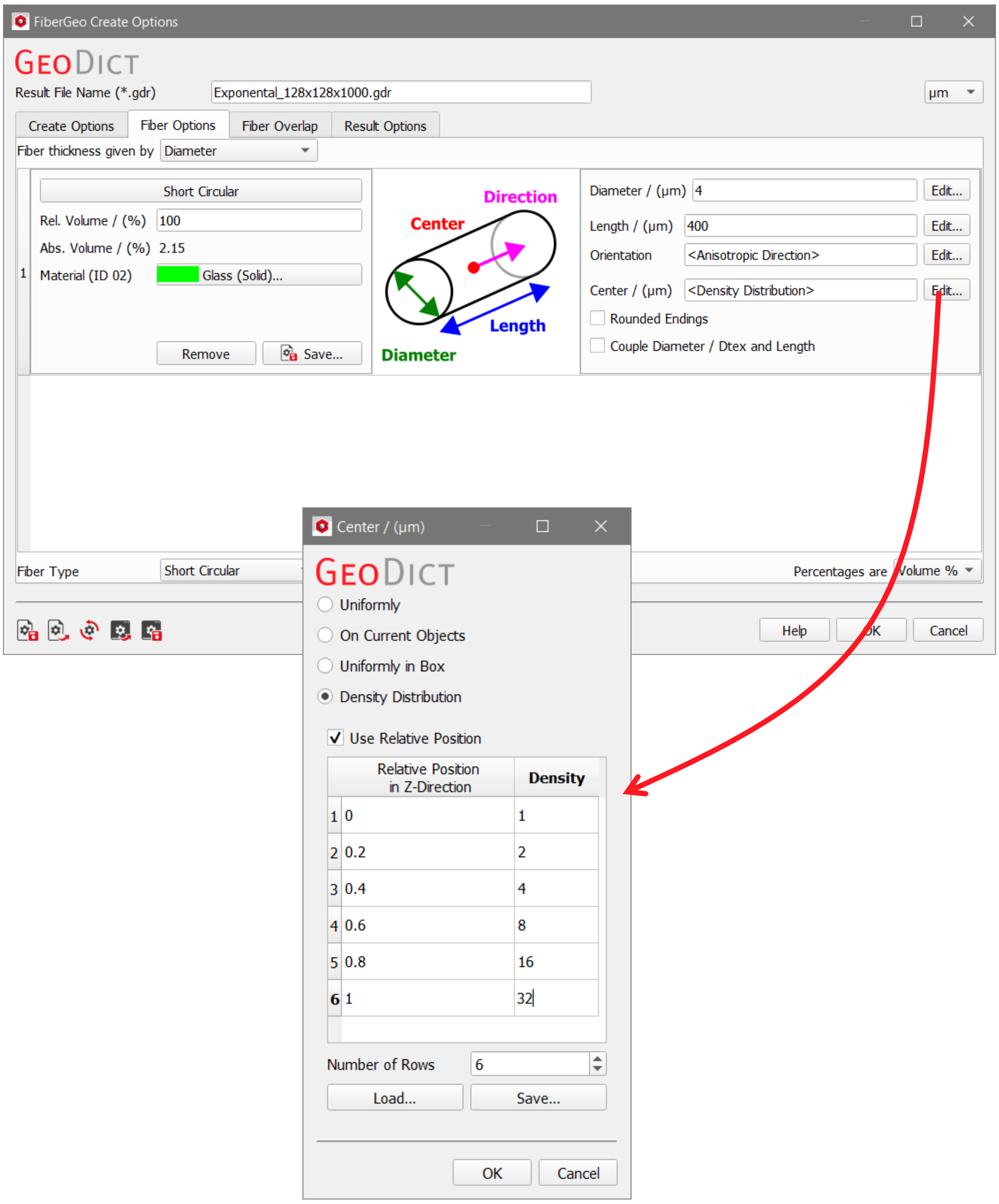
Because it was decided that the distribution of the thick fibers is the same in all three microstructures, only the distribution of the thin fibers needs to be changed. The chosen values for the density distribution are shown in the following images.



18. The **Exponential** microstructure is created in the same way as the linear structure.

The screenshots below show the values entered under the **Create Options** tab (Result File Name, Object Solid Volume Percentage, Random Seed) and under the **Fiber Options** tab (Center) for the density distribution of the thin fibers.


FiberGeo Create Options
GeoDict
Result File Name (*.gdr)
Exponental_128x128x1000.gdr
µm
Create Options
Fiber Options
Fiber Overlap
Result Options
Create in Current Domain
Keep Current Objects / Structure
Domain
NX 128 (192 µm) Origin X / (µm) 0 Periodic X
NY 128 (192 µm) Origin Y / (µm) 0 Periodic Y
NZ 1000 (1.5 mm) Origin Z / (µm) 0 Periodic Z
Voxel Length / (µm) 1.5
Pore / Matrix Material (ID 00) Air
Generation and Overlap Mode
Allow Fiber Overlap
Without (Remove) Fiber Overlap
Edit...
Prohibit Fiber Overlap
Use Isolation Distance
Prohibit Overlap with Current Structure
Enforce Fiber Overlap
Stopping Criterion
Fixed Object Number
Add Object Solid Volume Percentage / (%) 2.15
Maximal Run Time / (h) 6
Random Seed 7
Help
OK
Cancel

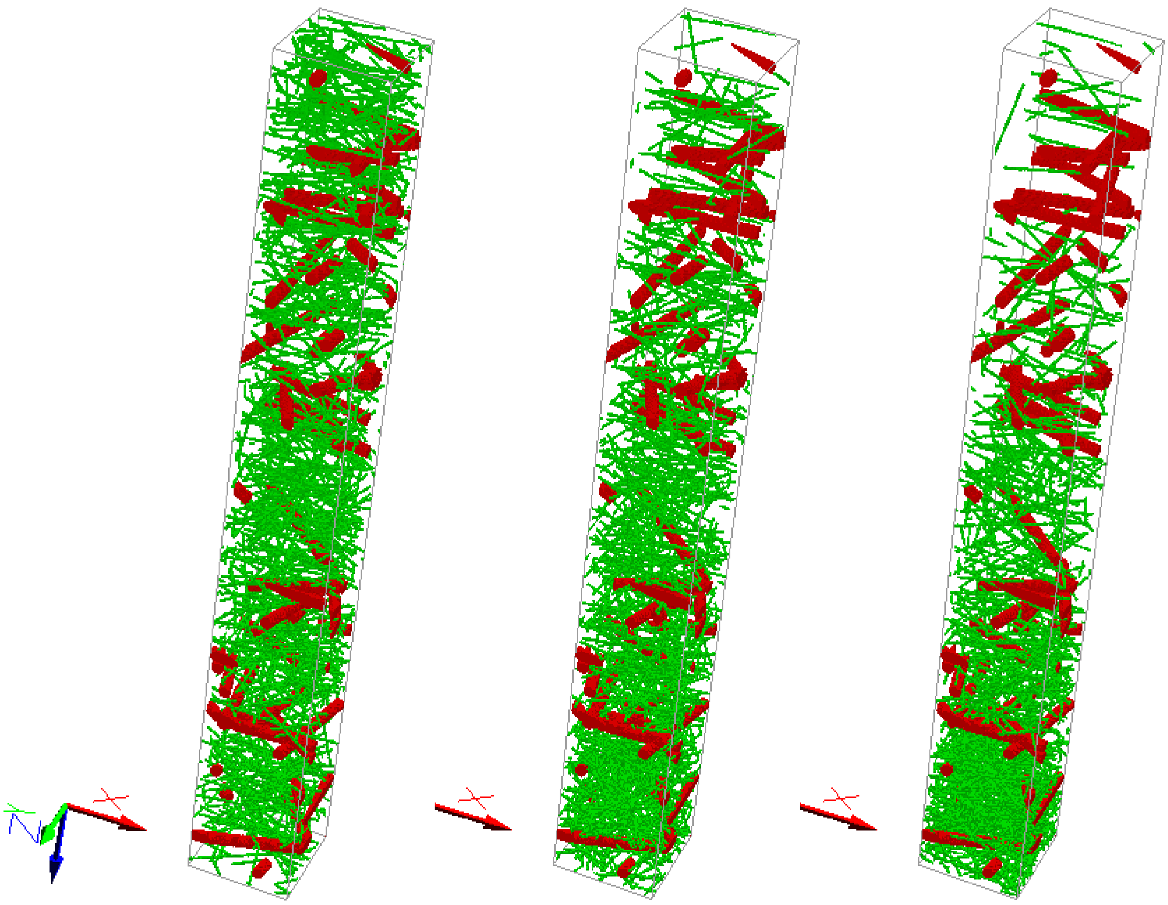

FiberGeo Create Options
GeoDict
Result File Name (*.gdr)
Exponental_128x128x1000.gdr
µm
Create Options
Fiber Options
Fiber Overlap
Result Options
Fiber thickness given by Diameter
Short Circular
Rel. Volume / (%) 100
Abs. Volume / (%) 2.15
Material (ID 02) Glass (Solid)...
Remove
Save...
Direction
Center
Length
Diameter
Diameter / (µm) 4
Length / (µm) 400
Orientation <Anisotropic Direction>
Center / (µm) <Density Distribution>
Edit...
Rounded Endings
Couple Diameter / Dtex and Length
Fiber Type Short Circular
Percentages are Volume %
Help
OK
Cancel
Center / (µm)
GeoDict
Uniformly
On Current Objects
Uniformly in Box
Density Distribution
Use Relative Position
Relative Position in Z-Direction
Density
1 0 1
2 0.2 2
3 0.4 4
4 0.6 8
5 0.8 16
6 1 32
Number of Rows 6
Load...
Save...
OK
Cancel

Creating the **Linear** and **Exponential** microstructures was an iterative process. The boundary fixed for this process was that the initial pressure drop had to match. In each case, the SVFs (Solid Volume Fractions) were varied until the initial pressure drop agreed with the pressure drop calculated for the homogeneous microstructure. Initially, entering the same SVF for all microstructures lead to different initial pressure drops, and so they were varied to achieve the fixed initial pressure drop.

If this is the case, changing the parameters of the **Linear/Exponential** structure will lead to a different filtration performance and permeability. By changing different parameters such as **Fiber Distribution** and **Object Solid Volume Percentage** a better filter performance can be achieved, while keeping the initial permeability and initial pressure drop.

Reminder: the microstructures in the **Small** folder are not representative, which means that the pressure-drop and filter lifetime of real media would depend heavily on the individual choice of filter media cutout. However, they are used here to showcase how to improve filtration efficiency through simulation.

The created homogeneous, linear, and exponential microstructures are shown below in a 3D Rendering visualization. The color of the fibers has been changed from the default GeoDict colors (Settings → Color & Visibility Settings in the menu bar)



Homogeneous **Linear** **Exponential**

COMPUTING PERMEABILITY AND FLOW RESISTIVITY WITH FLOWDICT

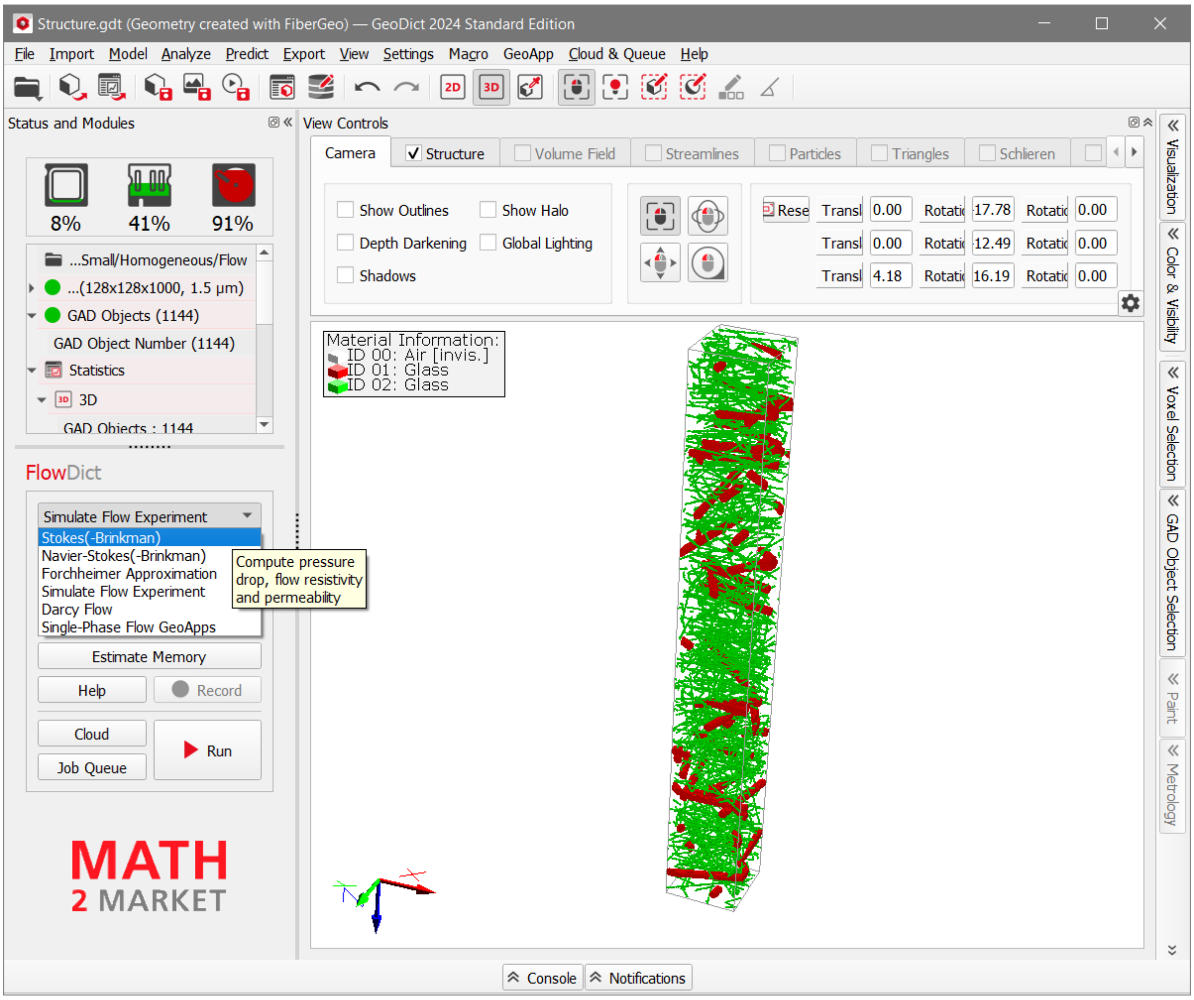
A FlowDict simulation through a given microstructure calculates the initial pressure drop, the flow resistivity, the permeability, the Reynolds number, and more flow parameters. For more details, see the FlowDict handbook of the User Guide.

After generating the three microstructures as shown above, a FlowDict simulation reveals the initial pressure drop and the flow resistivity of the given microstructure. Because the objective was to start with matching the initial pressure drop for all three microstructures, this value had to be compared.

A comparison between the three initial pressure drop values for the generated microstructures proves that their values are very similar. This is done as follows:

1. Choose the project folder for the flow simulations as indicated above in page 5. For the homogeneous microstructure, the folder created by the user is located at **Results_User/Small/Homogeneous/Flow**.
2. Load the created homogeneous microstructure by selecting **File → Open Structure (*.gdt, *.gad)...** from the menu bar or clicking the icon and navigating to

   Results_User/Small/Homogeneous/Structure/
3. To set up the FlowDict simulation, select **Predict → FlowDict** from the menu bar. In the **FlowDict** section, at the left of the GeoDict GUI, select **a suitable solver** from the pull-down menu and click **Edit...**

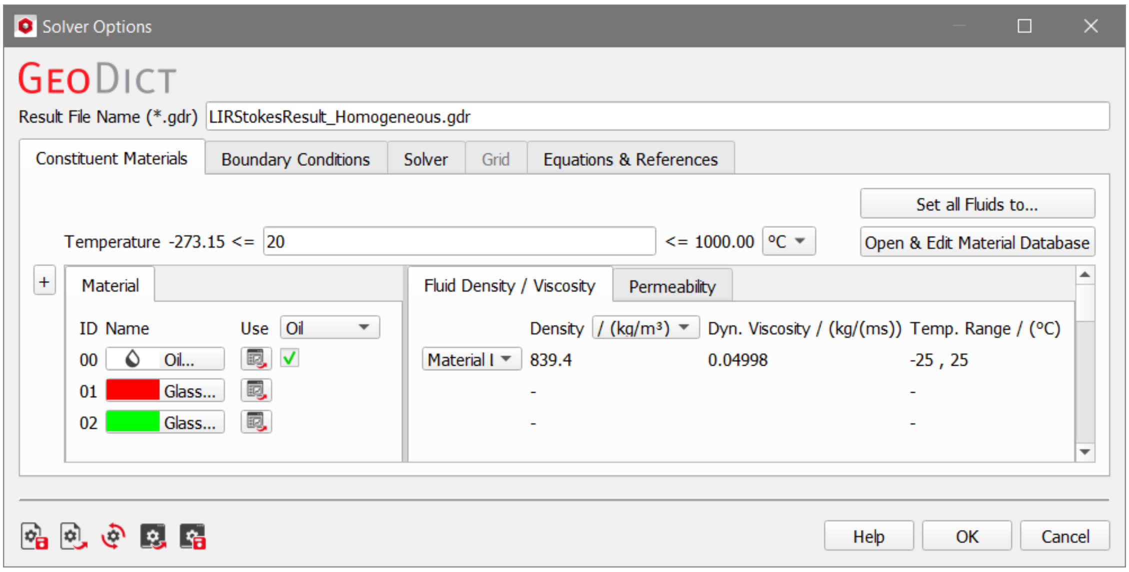


If you are sure that the flow is laminar and slow (creeping), choose **Stokes(-Brinkman)**. Otherwise run **Navier-Stokes(-Brinkmann)** simulations. When the flow is creeping, the only difference between using the **Stokes(-Brinkmann)** or the **Navier-Stokes(-Brinkmann)** is the longer calculation time for the second.

If you are unsure, it is possible to run a **Stokes(-Brinkman)** simulation and a **Navier-Stokes(-Brinkmann)** simulation and compare the results. If the difference between those results is insignificant, the flow is creeping and **Stokes(-Brinkman)** can be chosen for the rest of the simulations.

More information on the individual solvers can be found in the FlowDict handbook of the User Guide.

4. In our tutorial case, oil is selected as a fluid, therefore the flow is creeping and **Stokes(-Brinkmann)** was chosen.
5. After selecting **Stokes-(Brinkmann)** from the pull-down menu and clicking **Edit…**, the **Solver Options** dialog opens. Set the simulation environment to be at a temperature of **20°C** and the fluid to be **Oil** under the **Constituent Materials** tab. Also choose the **Result File Name**.



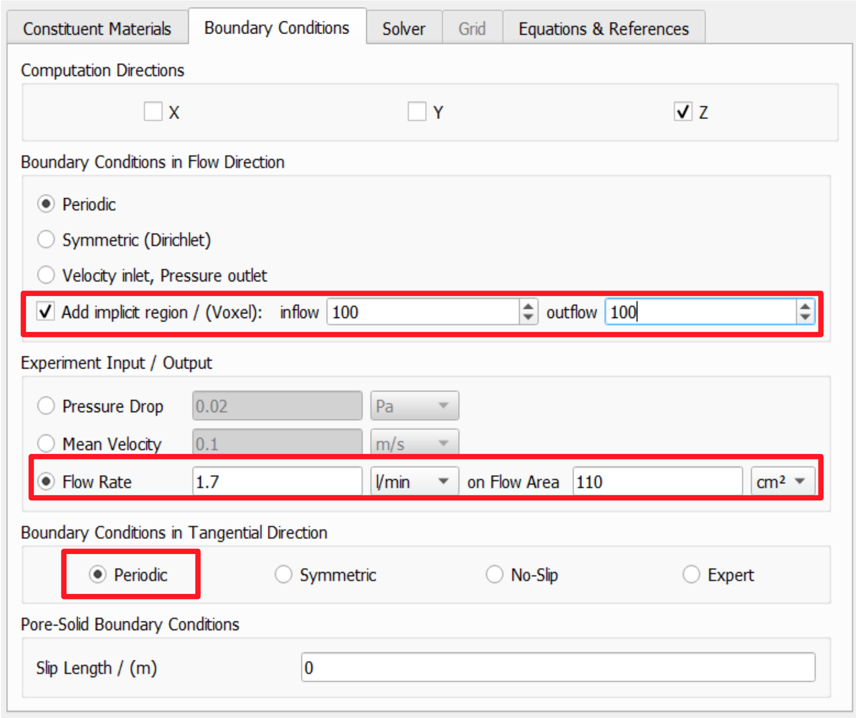
6. Now, click the **Boundary Conditions** tab and later the **Solver** tab.

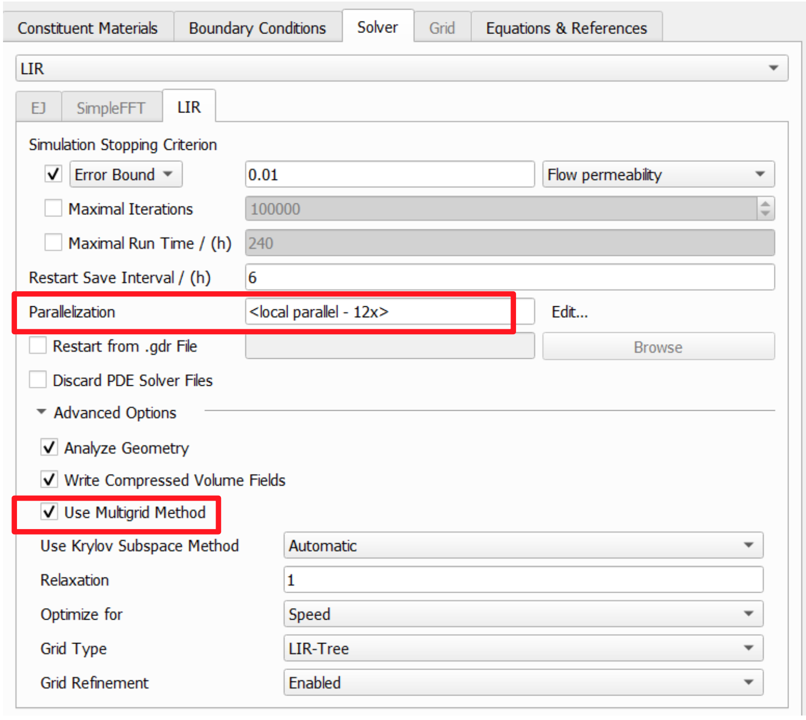
In the **Boundary Conditions in Flow Direction**, check **Add implicit in-flow region** and enter a value of 100 voxel for the **inflow** and for the **outflow** to normalize the flow. This is necessary to ensure that the flow is stabilized through the whole structure and does not start at only one specific area above the structure.

In the **Experiment Input/Output** panel, check the option **Flow Rate** on **Flow Area** and enter 1.7 l/min for the **Flow Rate** and 110 cm² for the **Flow Area**. The boundary conditions for this specific structure are periodic. More information on these values can be found in the FlowDict handbook of the User Guide.

Choose **Periodic** for the **Boundary Conditions in Tangential Direction**.

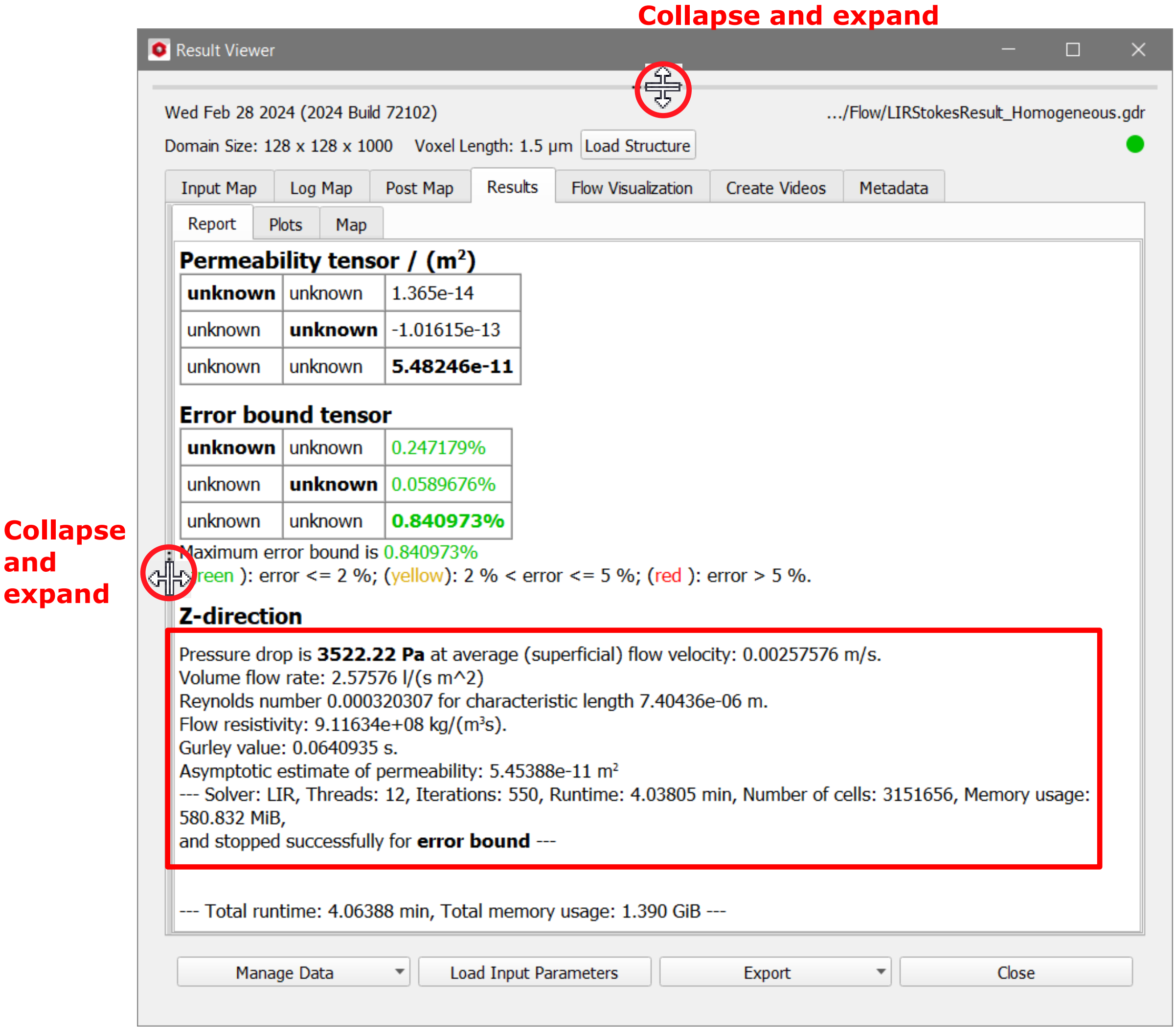
Under the **Solver** tab, choose **LIR** as the solver. For fibrous structures, the LIR solver is often faster than the SimpleFFT solver. Specify the **stopping criterion** of the solver and its parallelization options. We advise using the available **Parallelization** possibilities and **Multigrid** to speed up the simulation.





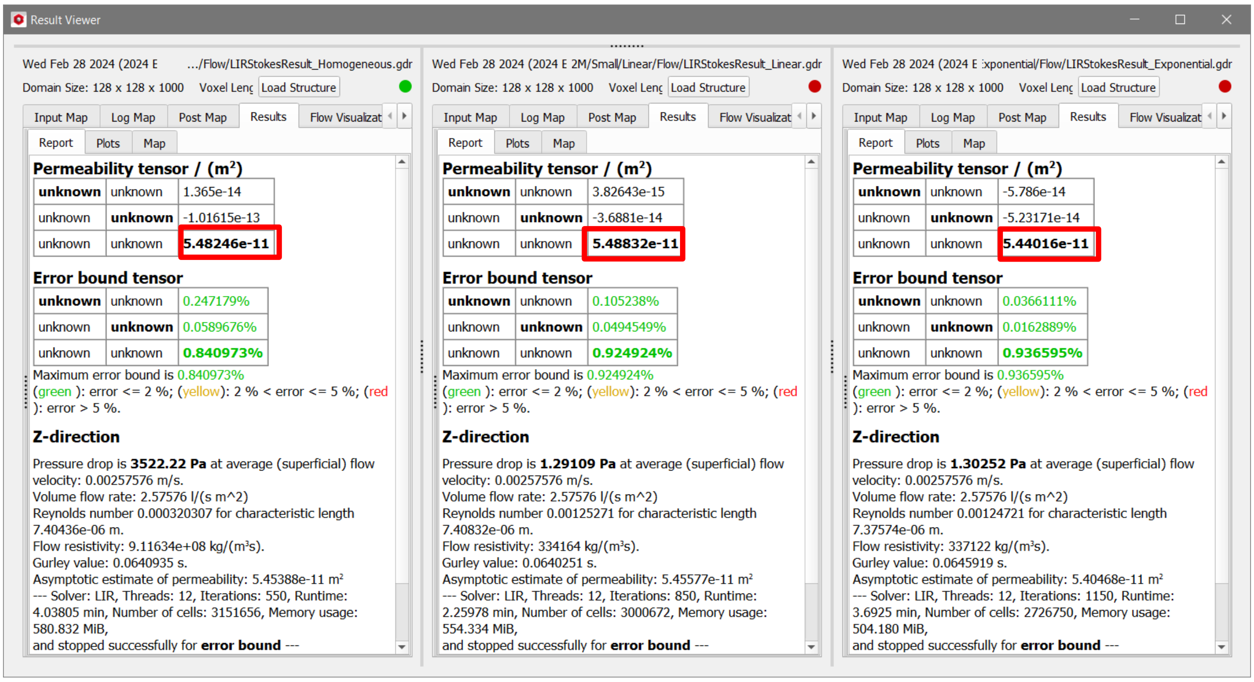
7. After entering those parameters close the dialog by clicking **OK**, and then click **Run** in the **FlowDict** section to start the simulation.

   When the simulation is finished the Result Viewer of the result file (*.gdr) opens automatically. The quantity of interest is in this case the **initial pressure drop** as shown here:



8. Now, start the flow simulations for the **Linear** and the **Exponential** microstructures by changing to their project folders and loading the corresponding structures.
9. In this way, obtain the other two initial pressure drop values and compare them.

   We found that the initial pressure drop values nearly match and, therefore, continue with the **Filter-Lifetime-Simulation.**



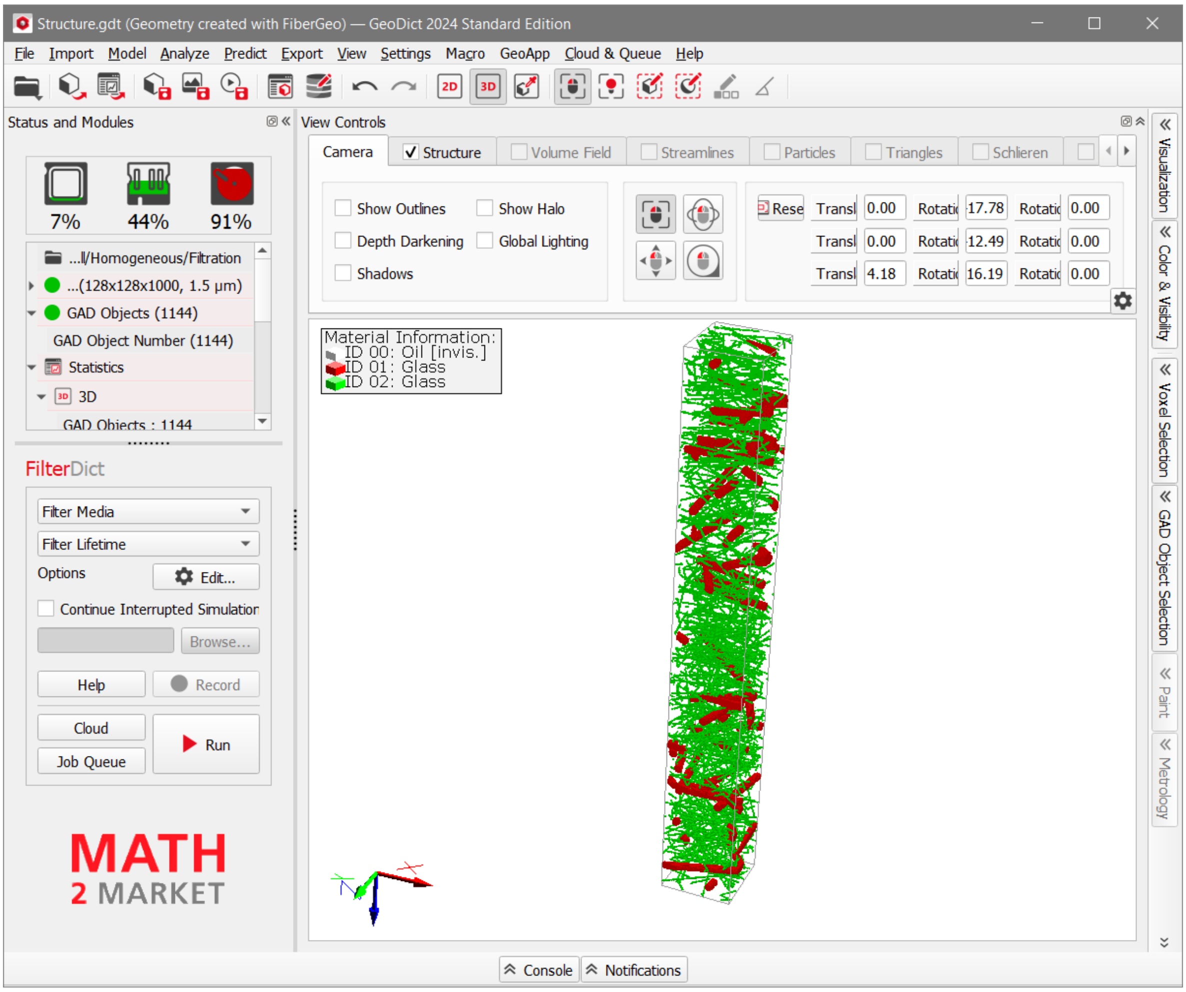
Suggestion: If the computational domain size is divisible by a power of 2 (ideally in every direction), it is more efficient to choose the number of processes for parallelization also as a power of 2.

FILTER LIFETIME SIMULATION WITH FILTERDICT

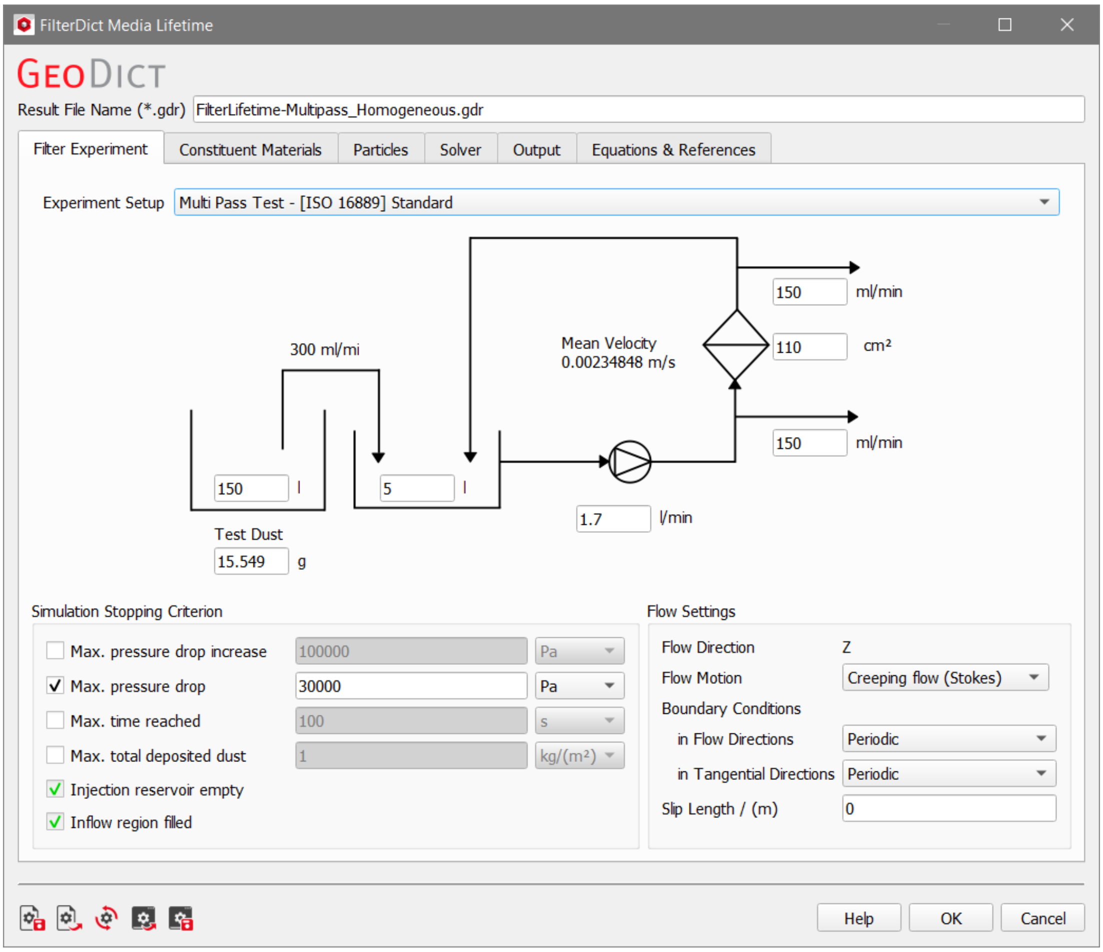
After finding structures and making sure that their initial pressure drops match, the next step is to run a **Filter Lifetime** simulation with FilterDict. This is done as follows:

1. Choose the project folder for the filtration simulations as indicated above in page 5. For the homogeneous microstructure, the folder created by the user is located at **Results_User/Small/Homogeneous/Filtration**.
2. Load the created homogeneous microstructure by selecting **File → Open Structure (*.gdt, *.gad)…** from the menu bar or clicking the icon and navigating to Results_User/Small/Homogeneous/Structures.
3. To start the FilterDict simulation, select **Predict → FilterDict** from the menu bar.

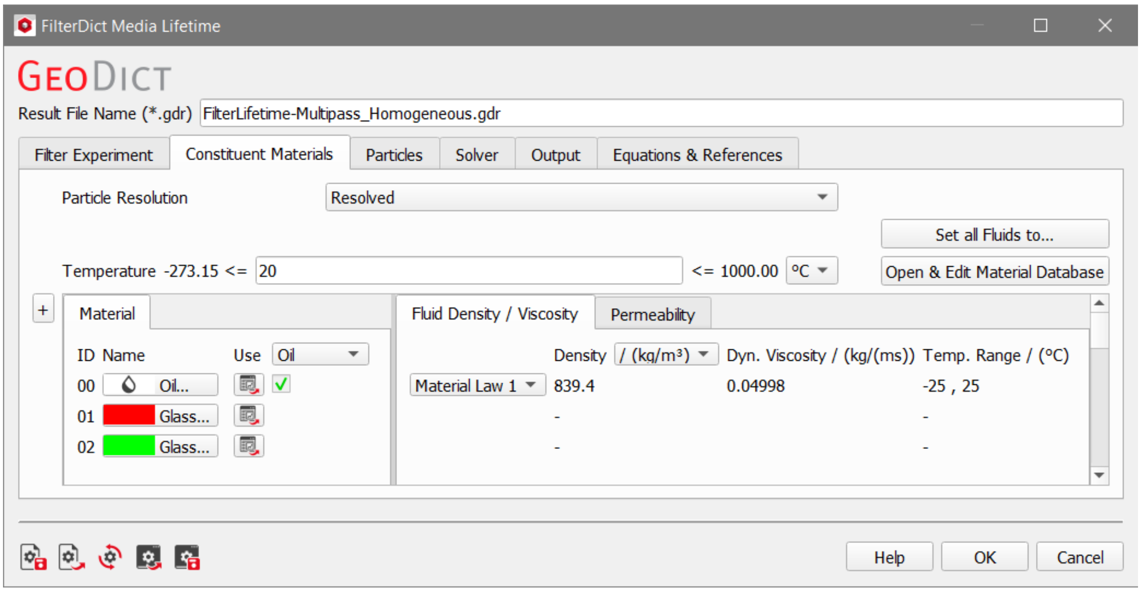
   In the FilterDict section, at the left of the GeoDict GUI, choose **Filter Media** and **Filter Lifetime** from the pull-down menus and click **Edit…**. More information on **Filter Efficiency** and **Filter Lifetime** simulations can be found in the FilterDict handbook of the User Guide.



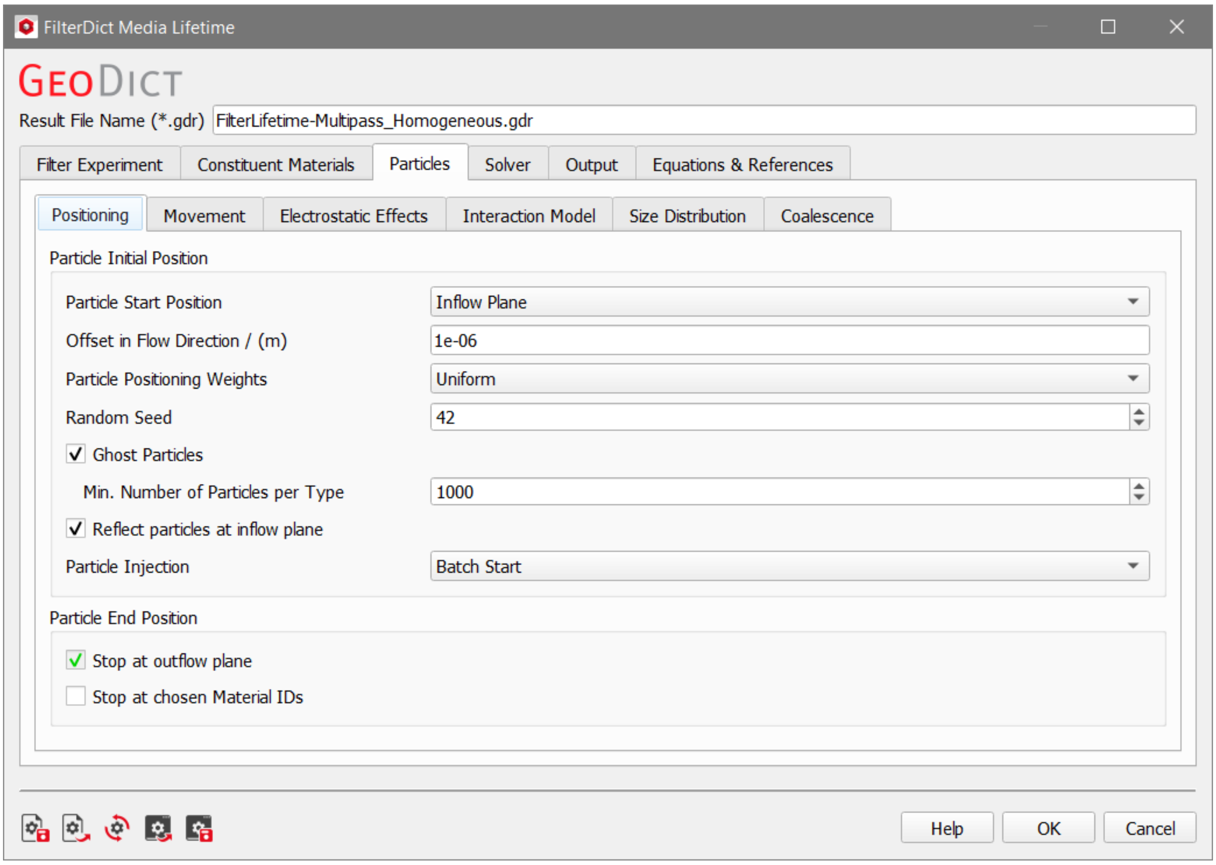
4. In the **FilterDict Media Lifetime** dialog, under the **Filter Experiment** tab, the values used to run the simulation are shown. Set the values as shown below. These values are based on a realistic industrial **Filter Multi Pass** test. Here, check **Max. pressure drop** as the simulation stopping criterion and enter the value of 30000.



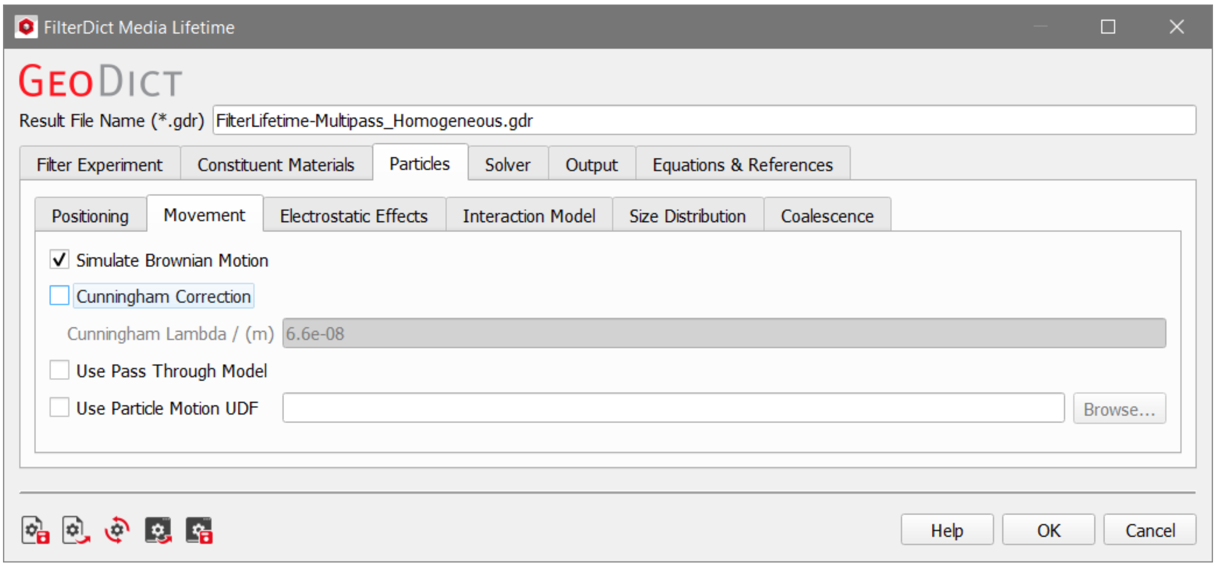
5. Under the **Constituent Materials** tab, change the **Result File Name** to **FilterLifeTime-MultiPass_Homogeneous.gdr** and change the **Material ID 00** to Oil.



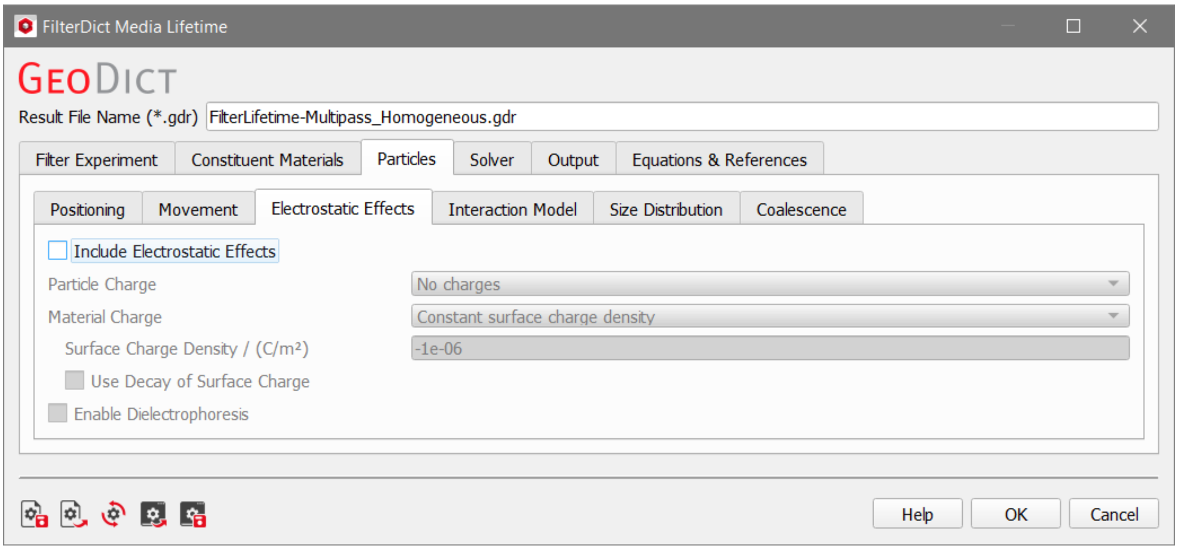
6. Under the **Particles - Positioning** subtab, leave the default values.



7. Under the **Particles - Movement** subtab, check to **Simulate Brownian Motion** and uncheck **Cunningham Correction**.

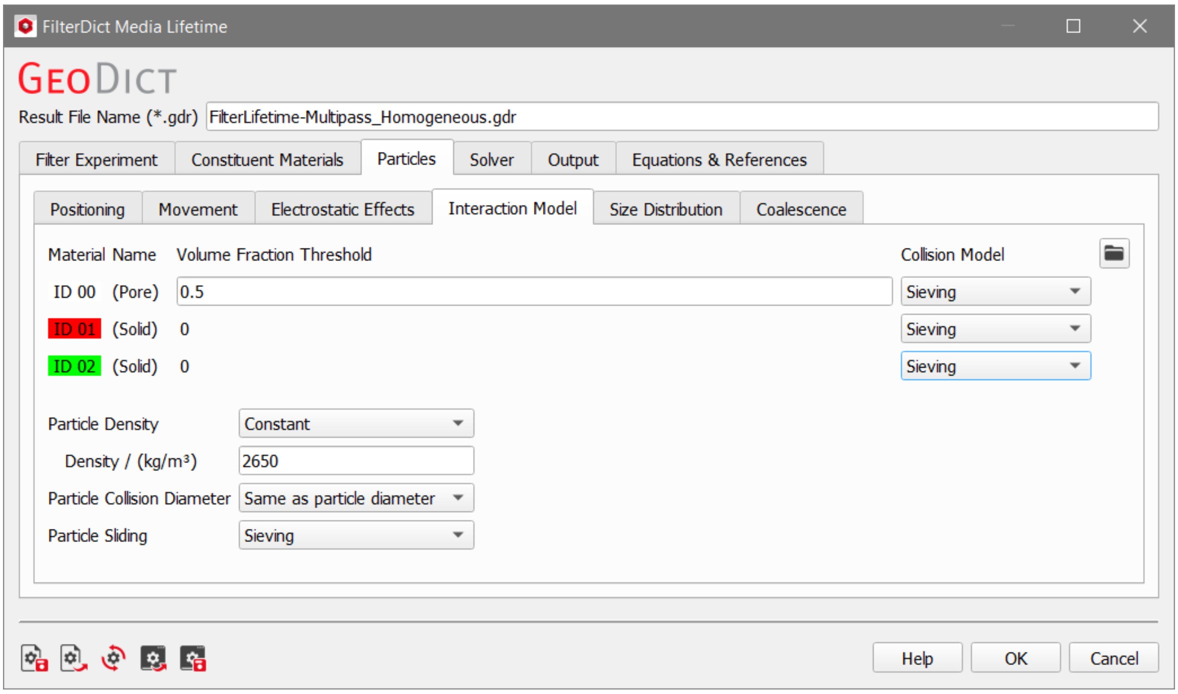


8. Under the **Electrostatic Effects** subtab, we leave **Include Electrostatic Effects** unchecked, since we do not have electrostatic charges on the fibers.

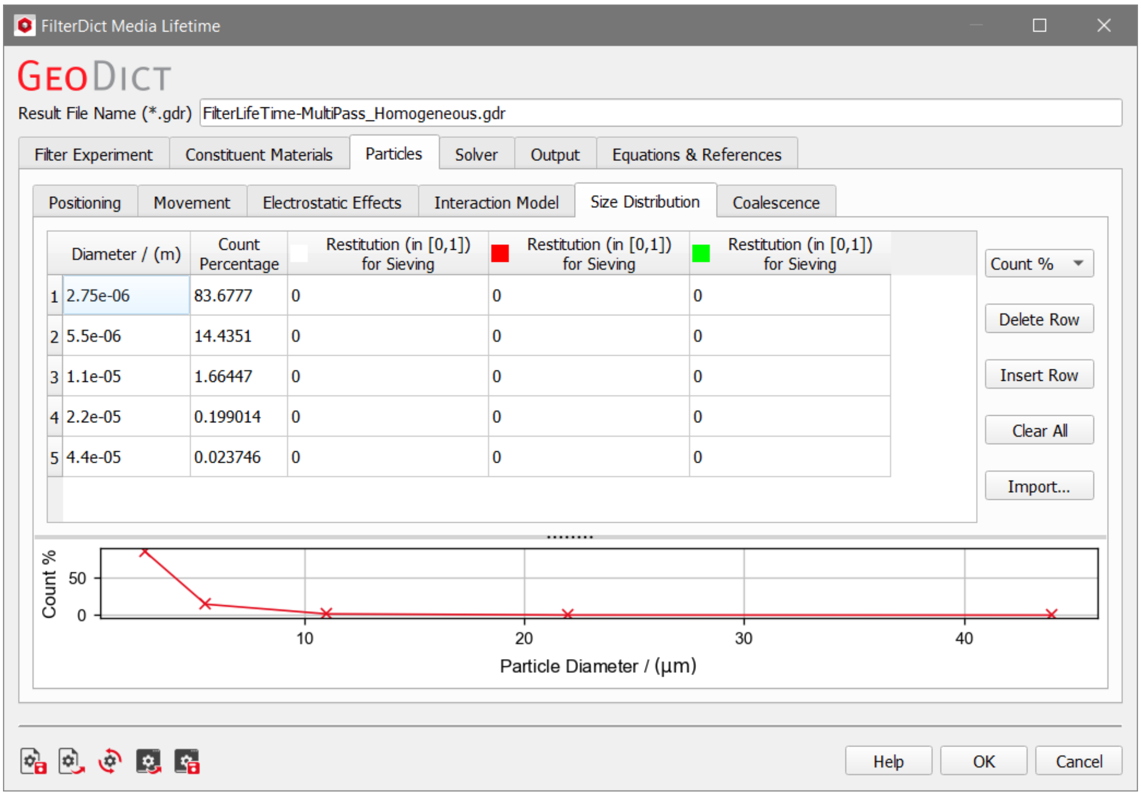


9. Under the **Particles - Interaction Model** subtab, enter a value of 0.5 for the Volume Fraction Threshold of ID 00 and choose the collision model **Sieving for all Material ID's**. Set the **Particle Density** to be **Constant** with a value of 2650 kg/m³.

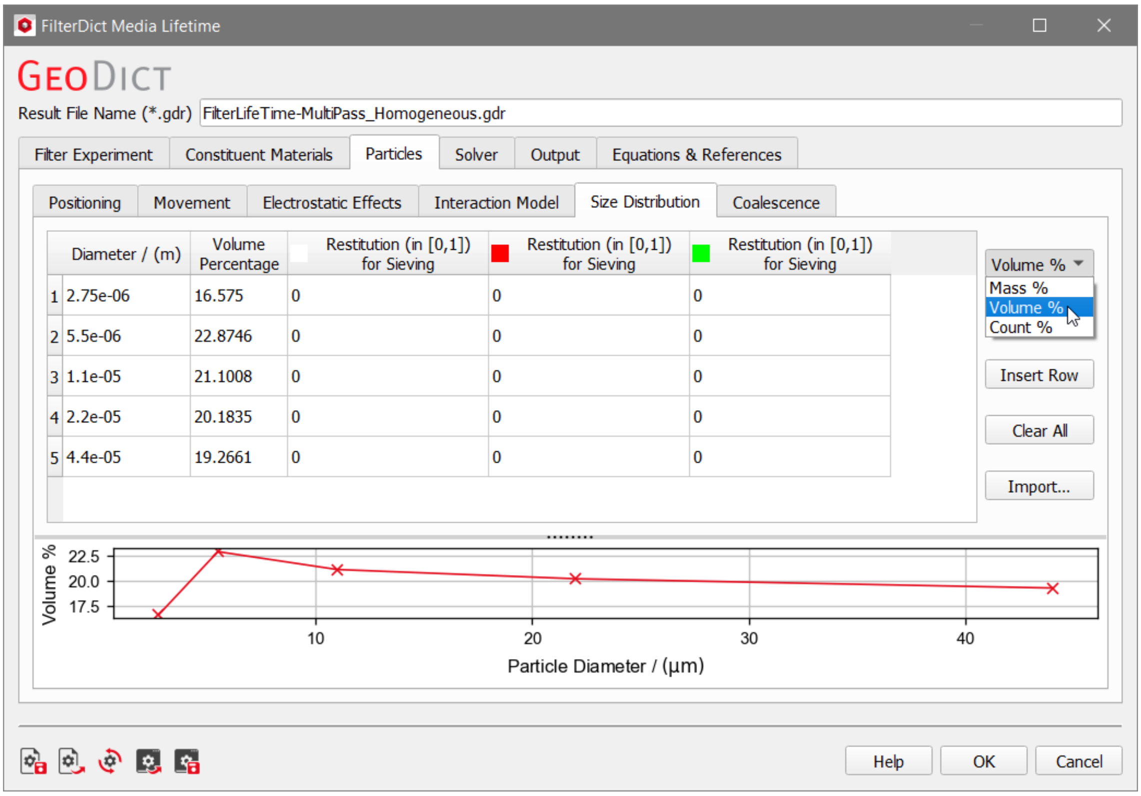
   The particle collision diameter is the **Same as particle diameter**.



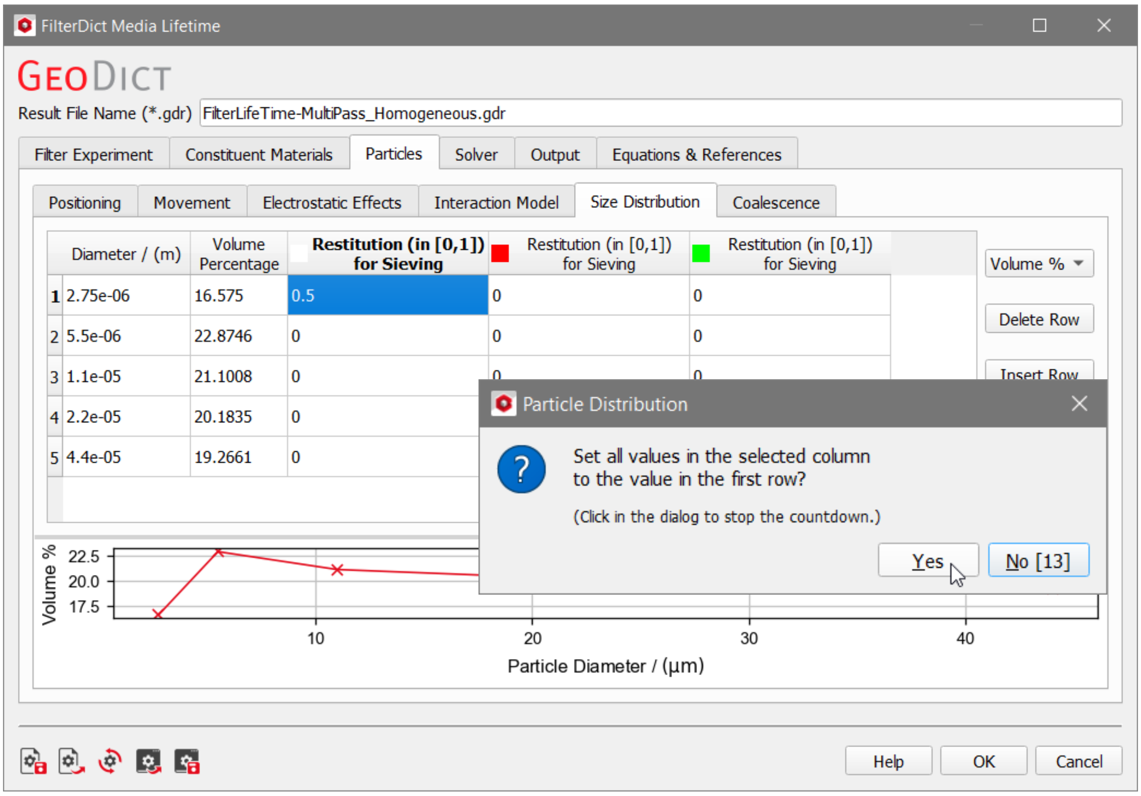
10. Under the **Particles - Size Distribution** subtab, select the particle size distribution by clicking on **Import...** and navigating to **Input-Data\ParticleSizeDistribution_Count.txt**.

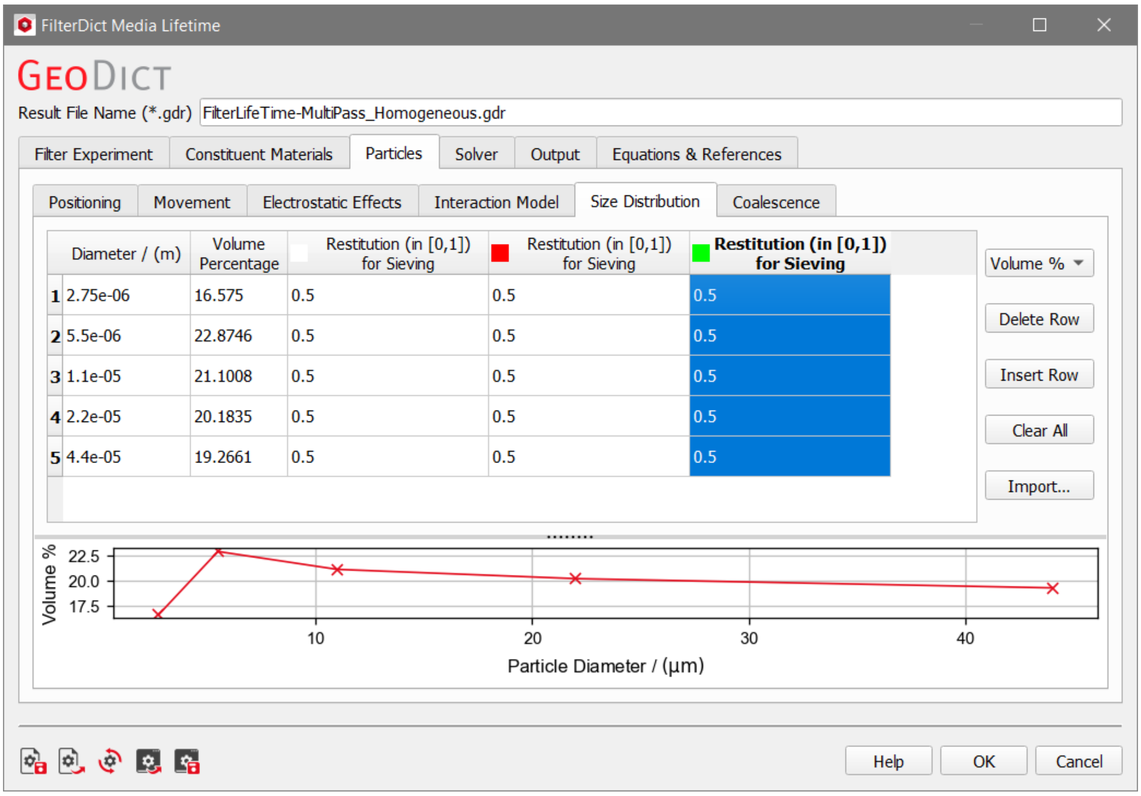


Or if **Volume %** is selected, the particle size distribution in volume percentage is shown:



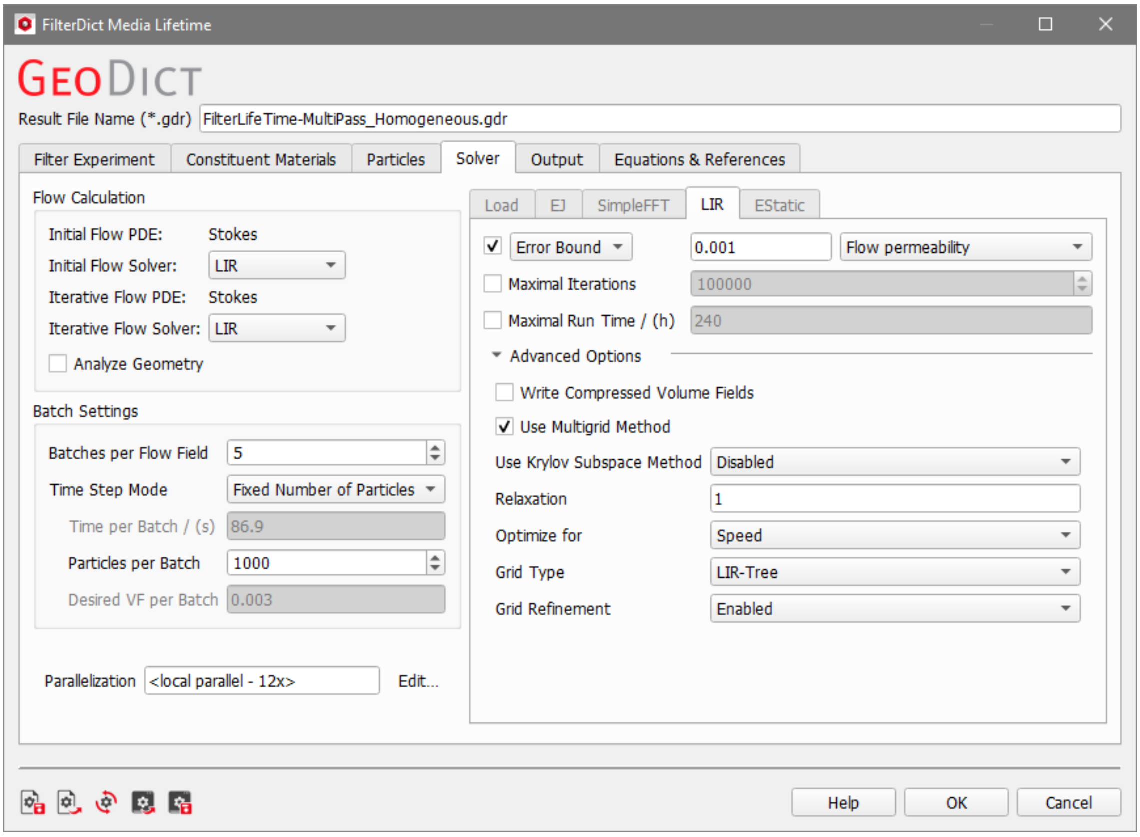
11. Enter a Restitution coefficient of 0.5 for all columns by entering 0.5 in the first cell and clicking on the corresponding title (**Restitution (in [0.1]) for Sieving**). This changes the restitution coefficient for the entire column, as shown below.



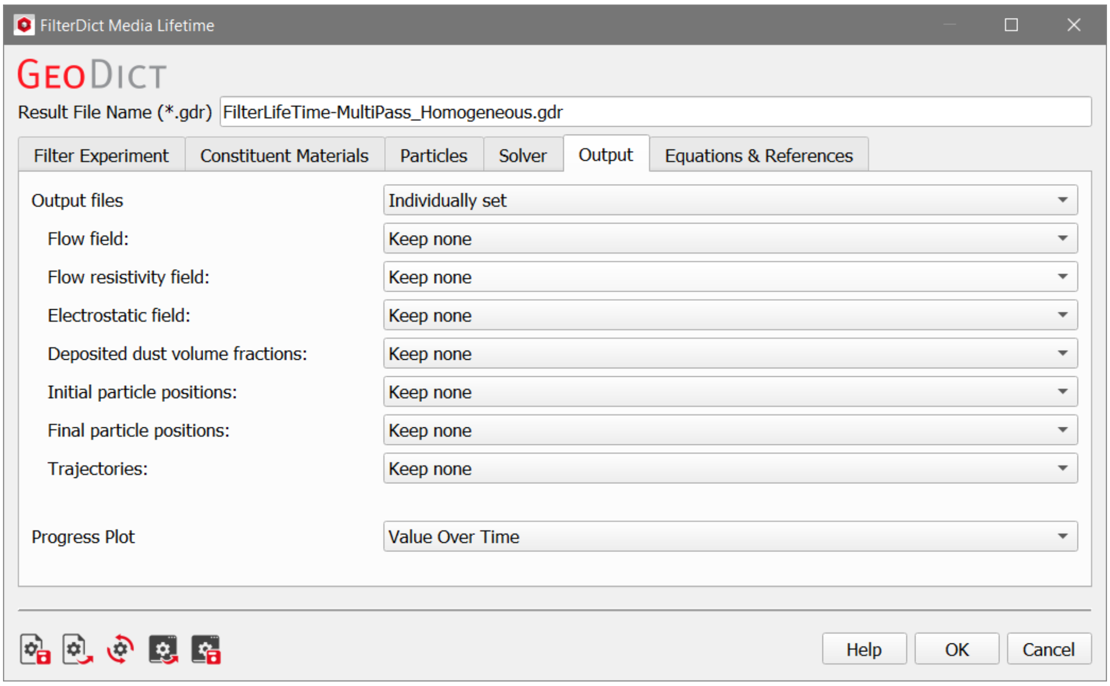


12. To choose the solver settings, click on the **Solver** tab and select **LIR** as the **Initial Flow Solver** and the **Iterative Flow Solver**.

    For the **Batch settings**, enter **5** for **Batch per Flow Field**. As the **Time Step Mode**, select **Fixed Number of Particles** with a value of **1000**. Use the maximum **Parallelization** option to speed up the simulation time. Choose **Error Bound** as the simulation stopping criterion and activate **Use Multigrid Method** under the **Advanced Options**.



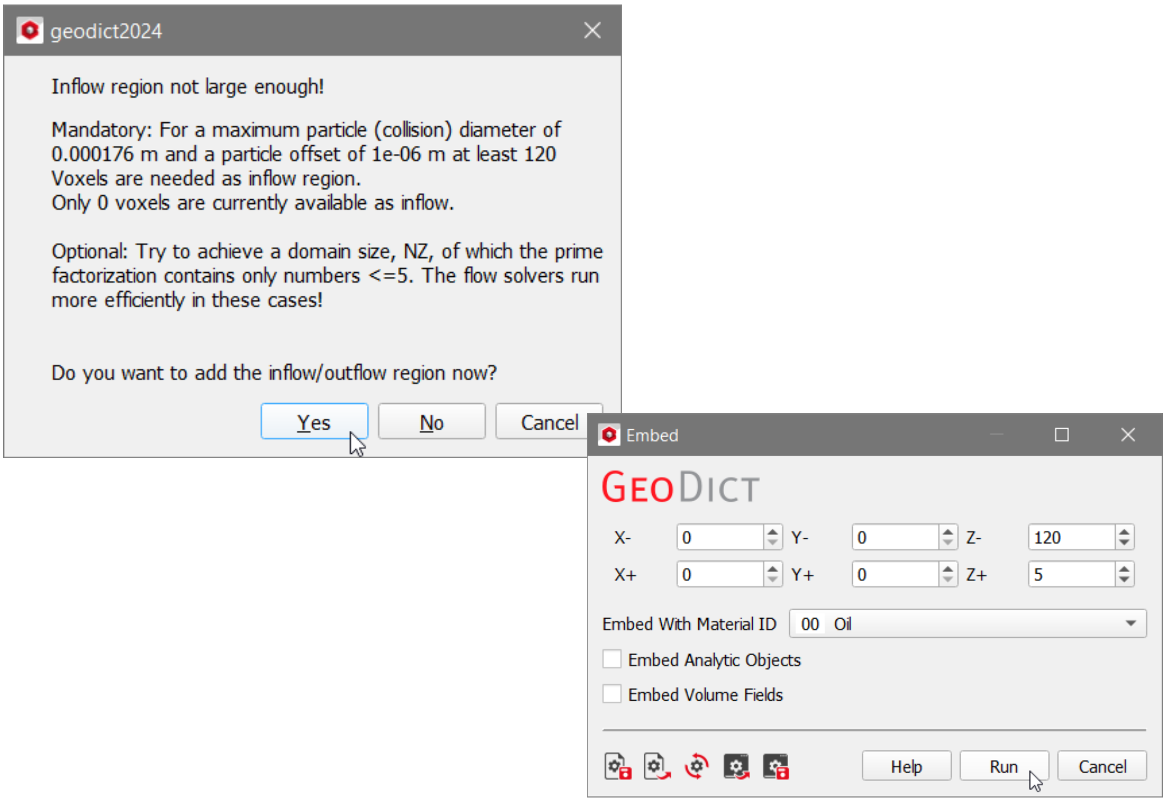
13. Under the **Output** tab, choose the files that should be saved during the simulation.



Choose **Keep none** for all the output files since we do not need them for visualization in this tutorial. You can also just replace **Individually set** with **Keep none** for **Output files**. If you want compare, for example, changes of the flow field, you can set **Keep first and last** for **Flow field**. Or, if you want to visualize the deposited particles at intermediate batches, set **Keep first, last, and every nth** for **Deposited dust volume fractions** with the interval you want.

This selection determines how much hard drive space is needed, because those files contain much information and tend to be large. Particle positions and particle trajectories file take an especially large amount of disk space, therefore consider this carefully before choosing the options for the **Initial particle positions**, **Final particle positions**, and **Trajectories**.

14. When clicking **OK**, a message pops-up warning that the inflow region is not large enough. Click **Yes** to agree to add the inflow/outflow region. The Embed dialog shows with suggested numbers, give 120 for the inflow and 5 for the outflow region in Z direction. Click **Run** with the given number.



An alternative to add the inflow and outflow region is to do it with ProcessGeo. More information on this option can be found in the ProcessGeo handbook of the User Guide.

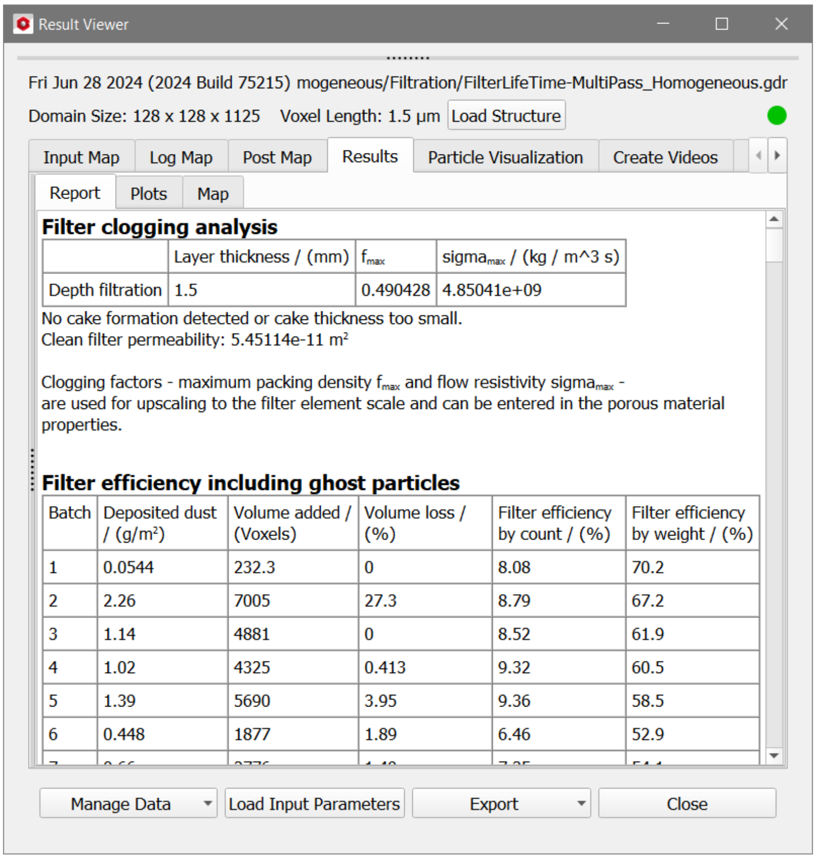
15. After the embedding is done, the structure size becomes 128 x 128 x 1125. Click **Run** in the FilterDict section to start the simulation.

16. Before running the simulation with the same parameters for the other two microstructures (Linear and Exponential) change the project working folder.

    After that, consecutively **Run** the simulation for all these structures too. The small filtration simulations have an average runtime of 6h (machine with 12 cores, max. Number of Threads).

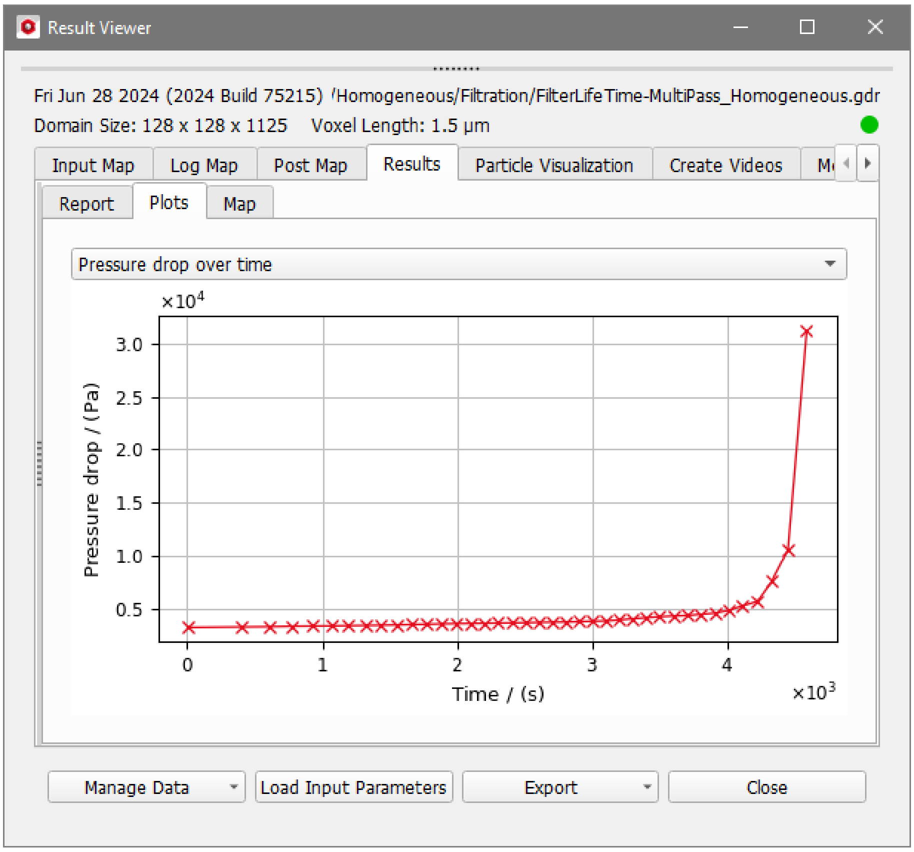
After the simulations have finished, the **Result Viewer** of the result files pops-up automatically.

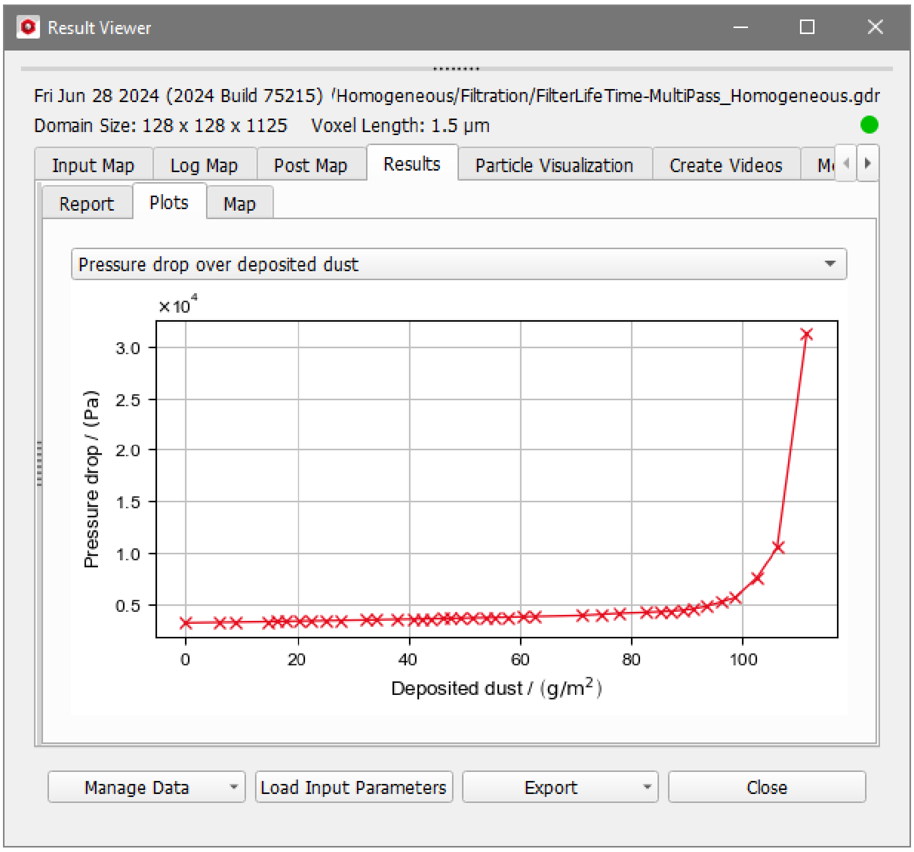
The **Results - Report** subtab of the three result files, for the three FilterDict simulations, display tables with the **Filter Efficiency**, the **Pressure Drop** over time, and the **Filter Efficiencies per Particle Type**.



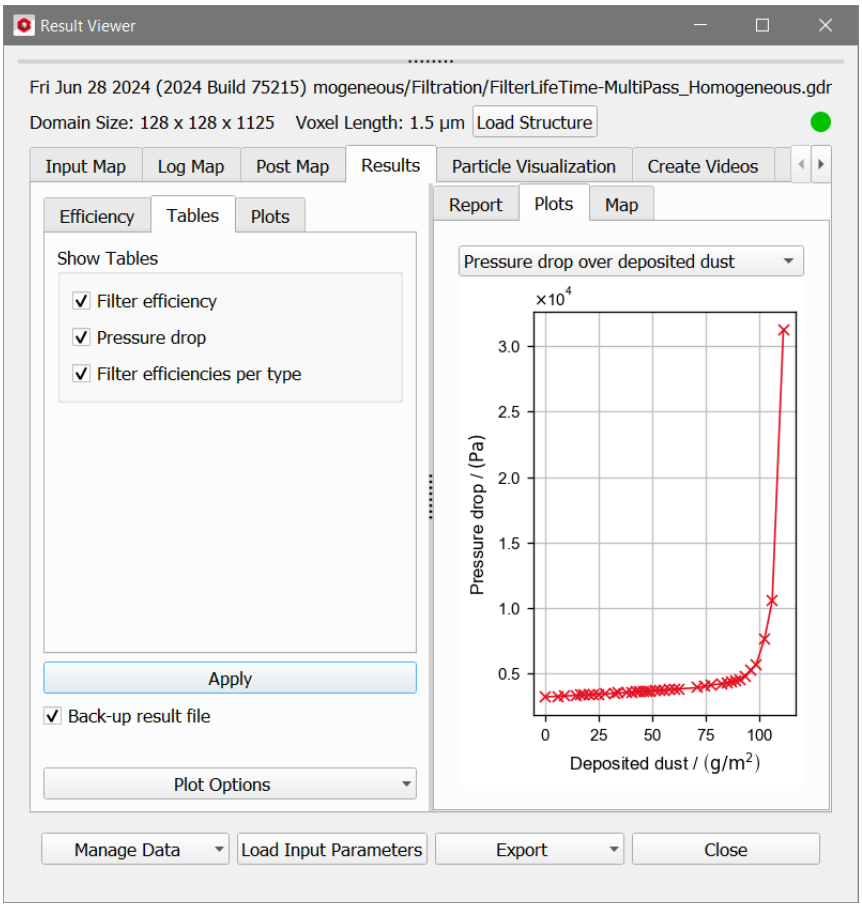
Under the **Results - Plots** subtab, by default, the plots of the **Pressure Drop over Time** and total **Deposited Dust over Time**, **Pressure Drop over Deposited Dust, Fractional Efficiency by Particle Type** are provided.

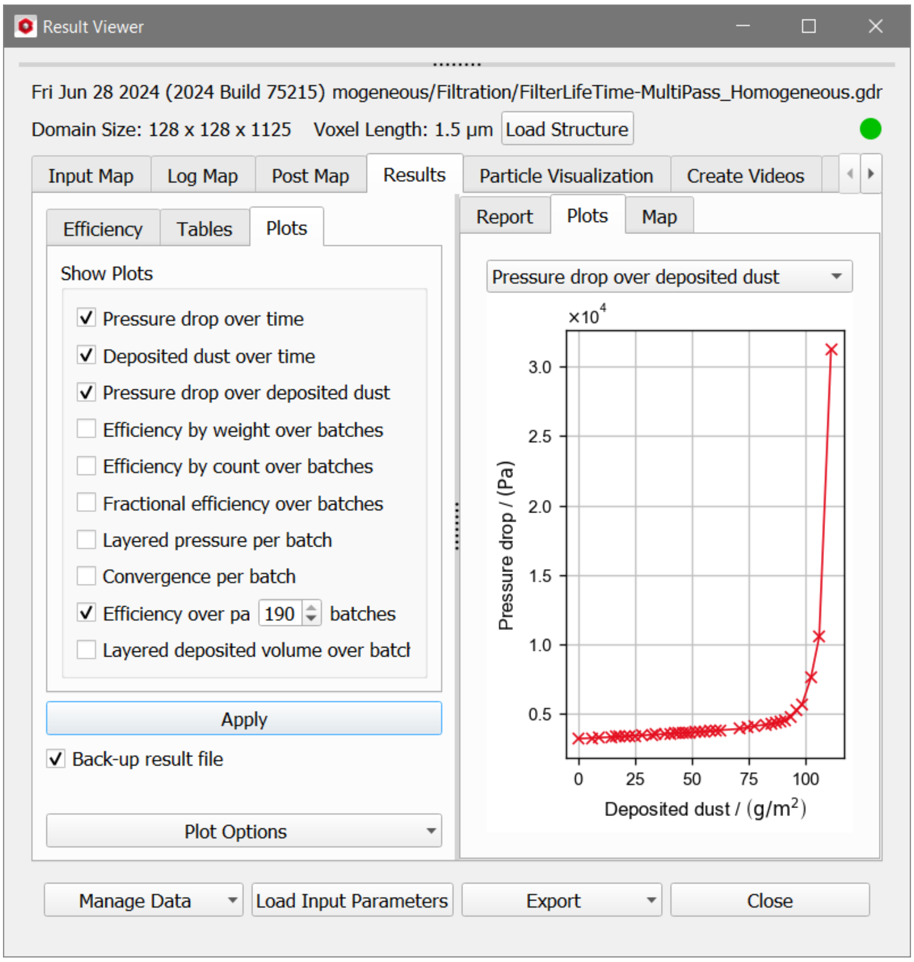
For example, for the homogeneous filter media it looks as follows:





To obtain other tables and plots, a post-processing section with the available settings is displayed on the left side of the **Results** tab after expanding it. The post-processing section can be collapsed and expanded (and accessed), and the options for Tables and Plots are like follows:




Result Viewer
Fri Jun 28 2024 (2024 Build 75215) mogeneous/Filtration/FilterLifeTime-MultiPass_Homogeneous.gdr
Domain Size: 128 x 128 x 1125   Voxel Length: 1.5 µm
Load Structure
Input Map
Log Map
Post Map
Results
Particle Visualization
Create Videos
Efficiency
Tables
Plots
Show Plots
Pressure drop over time
Deposited dust over time
Pressure drop over deposited dust
Efficiency by weight over batches
Efficiency by count over batches
Fractional efficiency over batches
Layered pressure per batch
Convergence per batch
Efficiency over pa 190 batches
Layered deposited volume over batcl
Apply
Back-up result file
Plot Options
Report
Plots
Map
Pressure drop over deposited dust
×10^4
Pressure drop / (Pa)
Deposited dust / (g/m^2)
Manage Data
Load Input Parameters
Export
Close

COMPARING PERFORMANCE OF DIFFERENT FILTER MEDIA

Finally, the **Pressure Drop over Time** and the total **Pressure Drop over Deposited Dust** is compared for each microstructure to evaluate the performance of the three filter media types. A low pressure drop over time, while accumulating more dust, indicates a better performance of the filter. For this reason these results characterize the performance of the filter.

Comparing the results from the different type of filter media regarding their plots of Pressure Drop over Deposited Dust can easily be done in GeoDict.

For this step, the results of the medium-sized simulation, which are time consuming and therefore have been performed by Math2Market, will be used. To save storage only the result files of the medium-sized simulations are attached to this tutorial. In order to rerun the simulations, use the function **Load Input Map** in the Results Viewer. This loads the input parameters for FilterDict-Media into GeoDict. The used structure can also be loaded from the Results viewer by clicking **Load Structure**.

The simulation is started by selecting FilterDict Media → Filter Lifetime and clicking Run. Here, the simulation time is significantly longer than in the shown smaller case (/Small). To load the .*gdr file, proceed as follows:

1. Select **File → Open Results (*.gdr)...** from the menu bar or click the icon in the toolbar.
2. Consecutively, navigate to:
   a. Results_M2M/Medium/Homogeneous/Filtration and select to open

      FilterLifeTime-MultiPass_Homogeneous.gdr

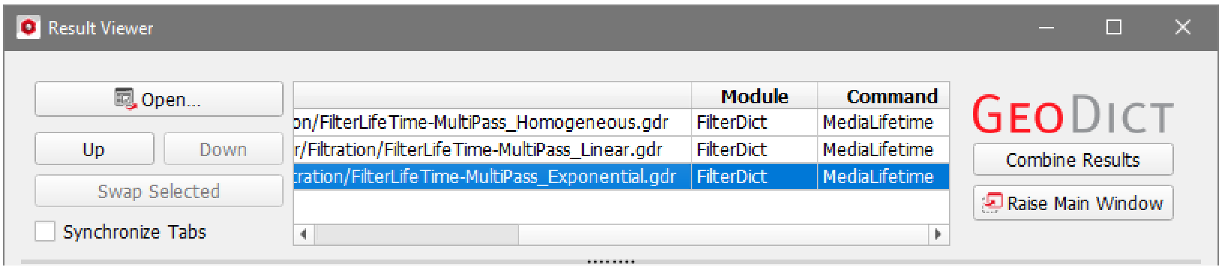
   b. Results_M2M/Medium/Linear/Filtration and select to open

      FilterLifeTime-MultiPass_Linear.gdr

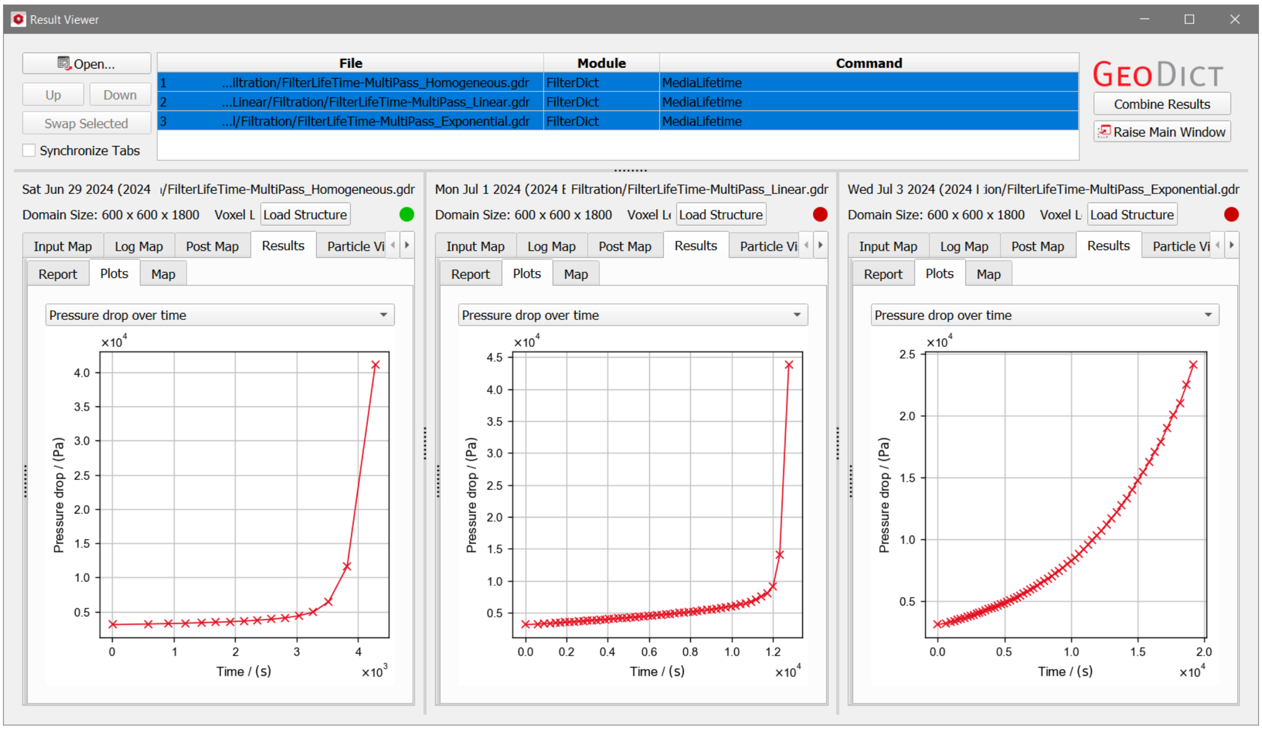
   c. Results_M2M/Medium/Exponential/Filtration and select to open

      FilterLifeTime-MultiPass_Exponential.gdr
3. The three result files are now open in the **Result Viewer**. The names of the three files with the paths to them, the name of the module that created the file, and the command name of currently opened results are listed in the box in the Header Section.

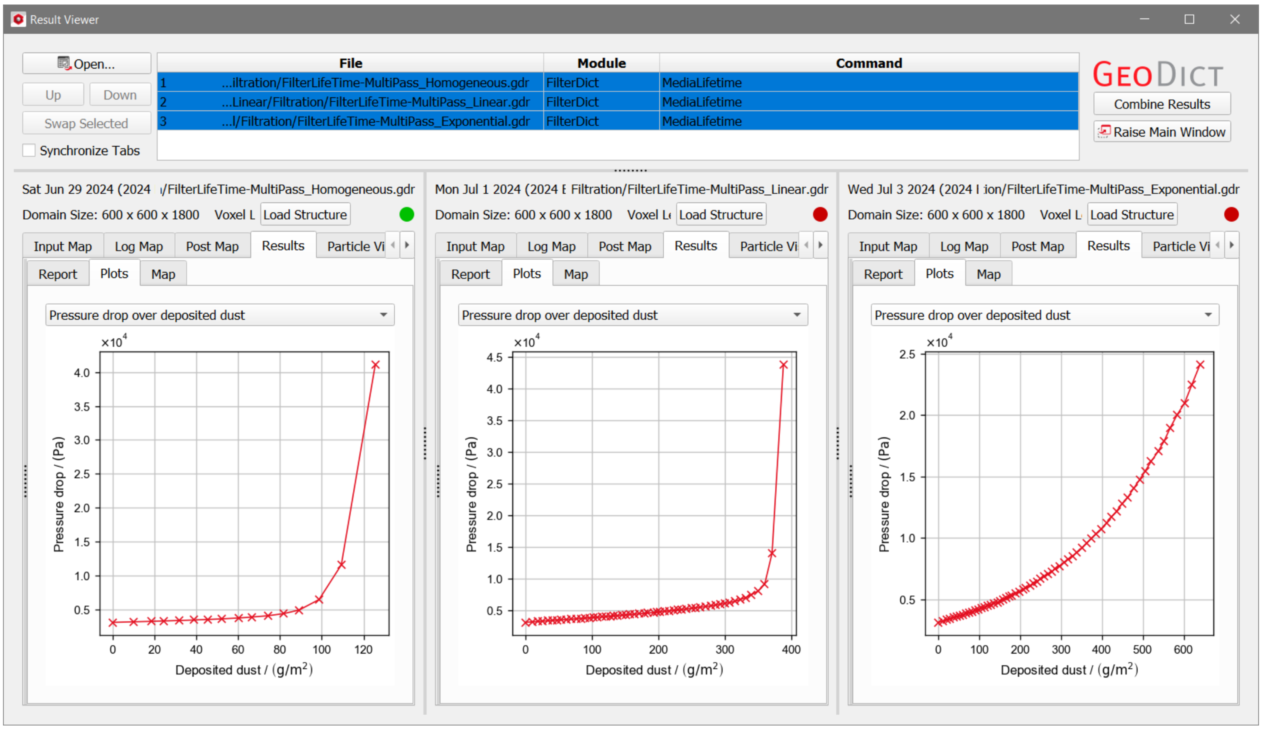
   Only the content of a highlighted result file is visible below in the Result section.



4. Select and highlight all three result files by using **Shift+click** on the list of entries. The Result section of the three result files appears side-by-side below the header section.
5. Click and go to the **Results – Plots** subtab for all of them.

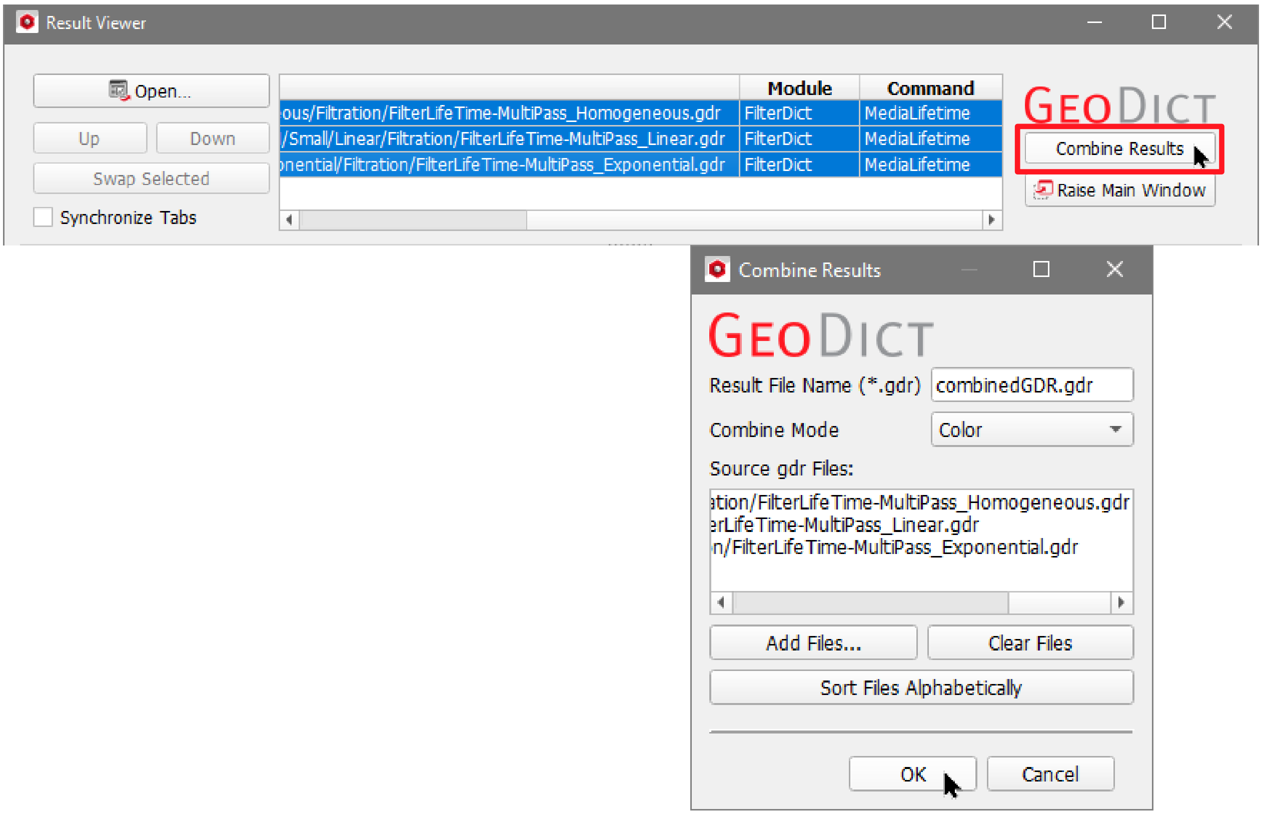


6. Choose **Pressure Drop over Deposited Dust** from the drop-down menu above the plot for all three result viewer panels. Now, the plots are shown as follows:

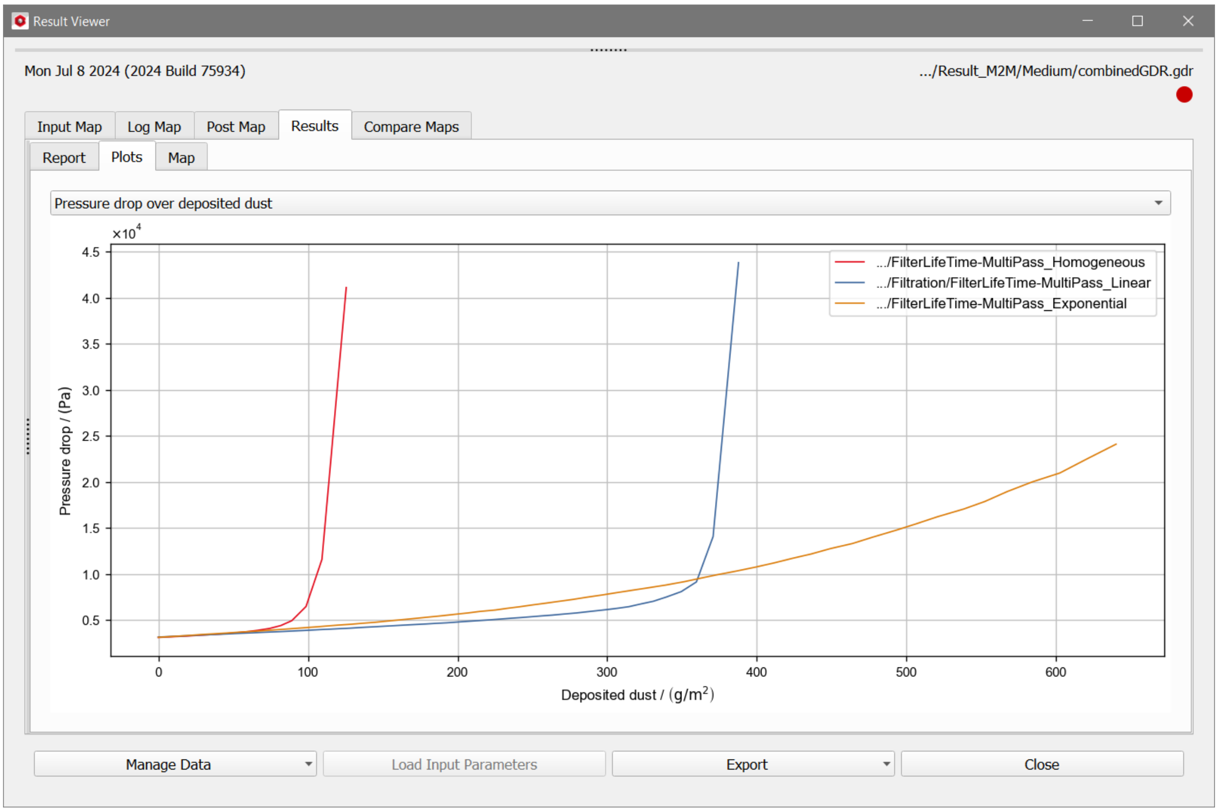


7. To combine the three **Pressure Drop over Deposited Dust** plots into a single plot, click the **Combine Results** button in the header section, as seen in the image above.

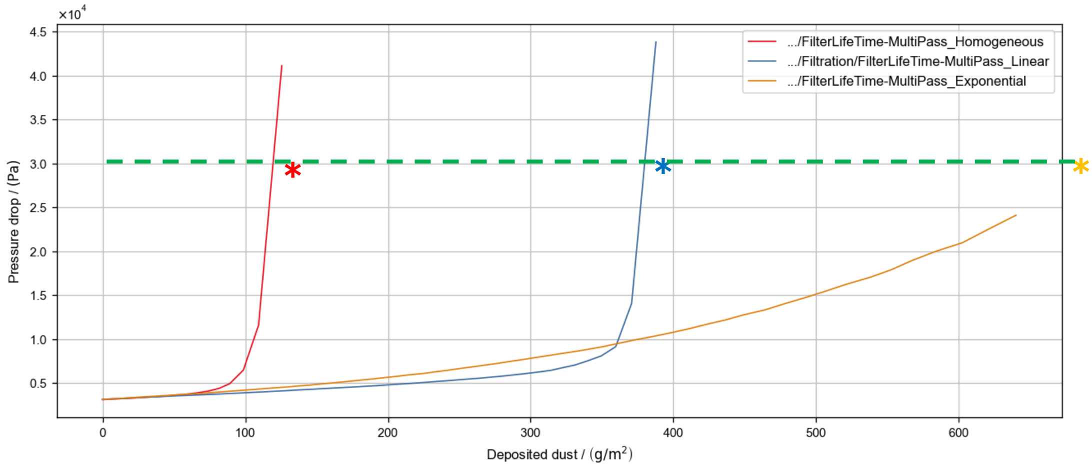
   The **Combine Results** dialog opens, listing the names of the three files to be combined. Click **OK.**



8. The resulting **combinedGDR.gdr** file appears now among the listed result files in the **Result Viewer** and it is already selected.



Click the **Results – Plots** subtab and observe the combined **Pressure drop over deposited dust** plot with three curves, corresponding to the three filter media types.



As seen above in the combined plot, the pressure drop for the exponential structure is lower while exhibiting a higher dust holding capacity. This means that the filter media with the exponential microstructure (orange curve) performs better than the filter media with the linear microstructure (blue curve) and, this one, better than the homogeneous microstructure (red curve).

The presented values are found under the **Results - Report** tab in their corresponding Result Viewer. When the pressure drop reaches $3{\times}10^4$ Pa, the collected dust is approximated in the table:

Microstructure	Dust holding (g/m^2)
Homogeneous	130
Linear	380
Exponential	710

This indicates that the filter media with the exponential microstructure shows, by far, the best performance.

To be able to compare results, the β-ratio needs to be taken into consideration.

When a β-ratio is measured, it provides the efficiency rating of the filter media at its given particle size. The efficiency is calculated by subtracting 1 from the β-ratio, and then dividing by the β-ratio. For example: A ß-ratio of 200 corresponds to (200-1)/200 = 0.995 or the media being 99.5% efficient at removing 3μm particles.

Find more information about β-ratio here.

Therefore, it is relevant to check that the filtration efficiency of all three types of filter media for particles larger than the desired β-ratio is higher than 99.5%.

In our case, observe under **Report** tab – **Filter Efficiencies per Particle Type** table that for all three filter media types, the efficiency for particles larger than 22μm (Type 4) is higher than 99.5%.

If the performance is better and the β-ratio is the same, the newly designed filter media has improved.

Technical documentation:

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