GeoDict

The Digital Material Laboratory

Generation of Cylindrical Pleated Structures for Optimization of Digital Filter Flow Performance

Over the last years, developments in the digital design of new geometries to optimize filtration relevant parameters at the micro-scale have gained significant importance. Also on larger scales, as when simulating flow and filtration on filter elements including housing, the use of Computer-Aided-Design (CAD) is of keen interest. However, performing systematic digital experiments on varying geometrical setups requires the generation of these structures as CAD individually and importing each sample one by one. Here, we present our newest software development within the PleatGeo module, that makes possible to generate a wide variety of cylindrical pleat structures with changing pleat count and pleat thickness, as well as the number of porous layers.

Suitable cylindrical pleats structures are created easily, and the resulting filters may be digitally investigated regarding their pressure drop and other filtration relevant parameters, by solving the Navier-Stokes-Brinkman equation. In this study, we run simulations on a filter structure with different pleat counts and volumetric flow rates. We find find the local minimum of the pressure drop and the ideal configuration between filter area and pleat count. So, the performance of filter prototypes may be tested digitally without relying on expensive producing and testing phases. Only promising prototypes undergo measurements at the testbench. These systematic simulations may be run using cloud applications to increase the productivity. In this way, systematic simulations with varying geometries or flow rates may be run simultaneously.

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Poster to go

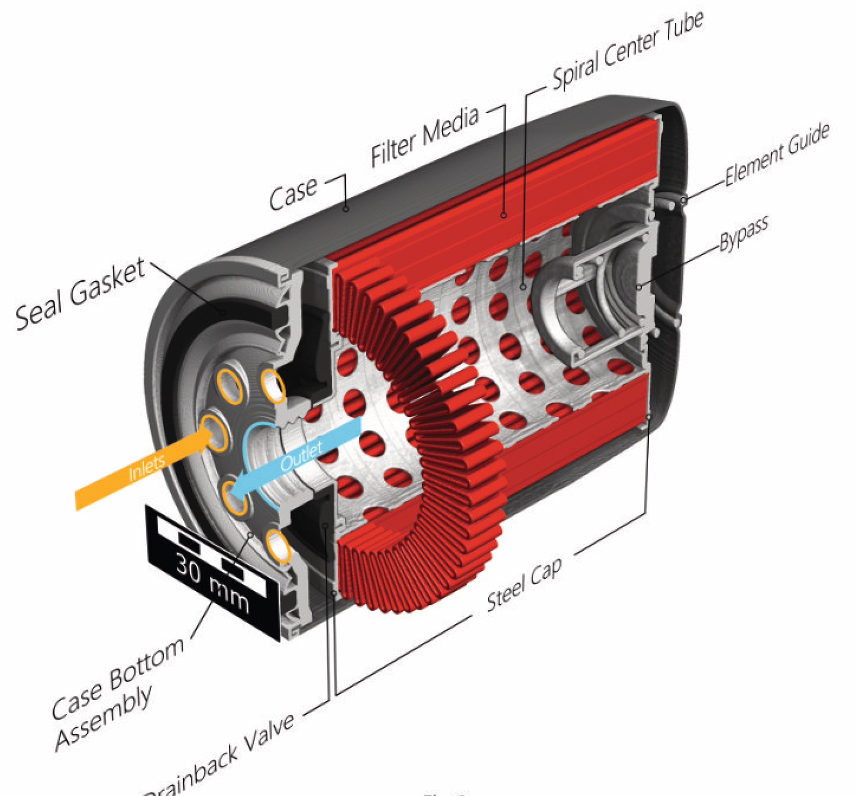


Fig. 1:
Structure of the test filter, imported into GeoDict

Import of the geometry

In this poster, a simple oil filter is used for demonstration. The filter structure, as file in .stl format, is imported into the simulation software GeoDict using the module ImportGeo-CAD.

In this process, each material ID of the imported filter geometry is assigned a different color.

In a consecutive step, each material ID can be assigned to different material parameters through the built-in material database. Additionally, the inlets and outlets - here located in *Fig. 1* at the **case bottom assembly**, marked by the orange (**inlet**) and blue (**outlet**) arrows -, as well as the fluid, need to be specified.

During the import and voxelization step, GeoDict returns feedback regarding the watertightness of the geometry, which is essential for a successful simulation.

If the structure is initially not entirely enclosed, it is possible to seal the geometry with built-in functions of GeoDict, which saves time, instead of fixing the initial input data separately.

For further simulations or parametric studies, the filter structure geometry can be saved to a file, to avoid having to reimport the .stl file for each additional simulation.

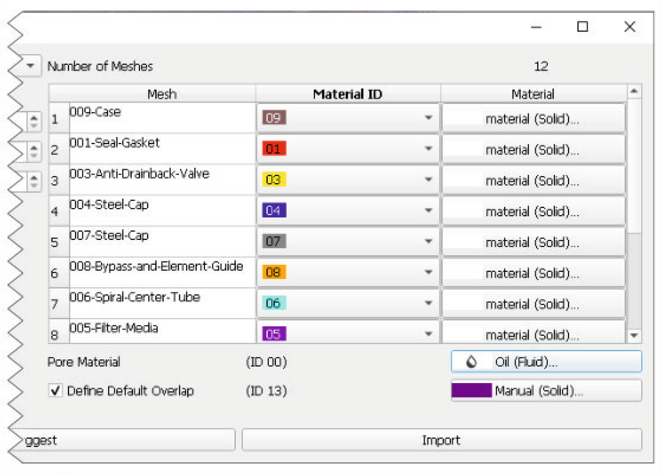


Fig. 2:
ImportGeo-CAD import interface

Step 1: Model generation

Files in .obj, .stl and .stp format can be imported into the GeoDict software using the ImportGeo-CAD module. This is necessary to use the precise digital model for the simulation and optimization process.

In an additional step, the inlet and outlets are specified as well as flow relevant parameters for the filter element, such as permeability of the filter media of the pleats.

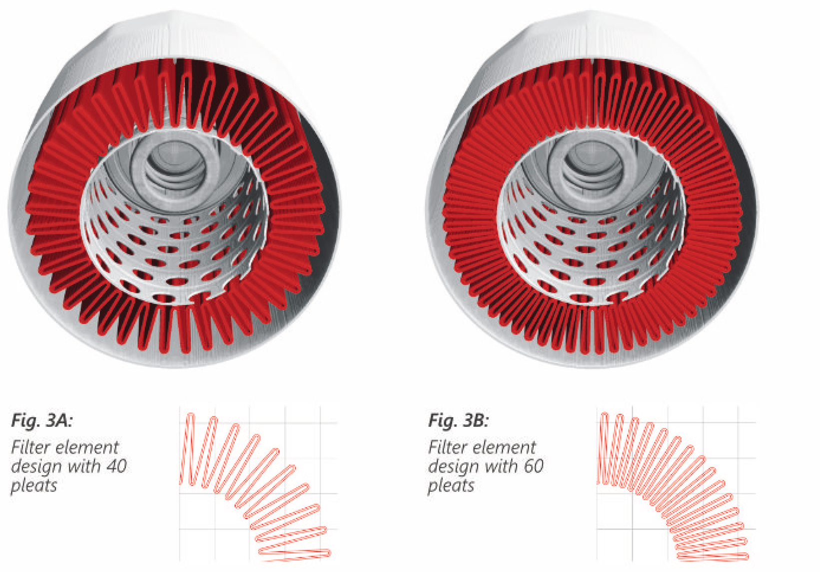


Fig. 3A:
Filter element design with 40 pleats

Fig. 3B:
Filter element design with 60 pleats

Generation of cylindrical pleat structures using PleatGeo

To perform systematic tests or to optimize the filter flow performance, several sets of pleated filter media are used to find the local minimum of the pressure drop which describes the ideal configuration between the filter area and pleat count. For this, several pleat counts configurations are generated using the new feature of PleatGeo to model cylindrical pleats (see *Fig. 3A* and *Fig. 3B*) [3][5]. The input parameters are the inner and outer diameter, the pleat count and the height of the pleat, as well as the inner radius at the pleat valley and tip. After entering these values into the software, the geometry is modeled within seconds and the structure is saved as .stl. In a second step, the .stl structure is imported and voxelized to be inserted digitally at the correct location within the filter geometry. *Fig. 4* shows the PleatGeo interface to enter the input parameters for the pleat generation.

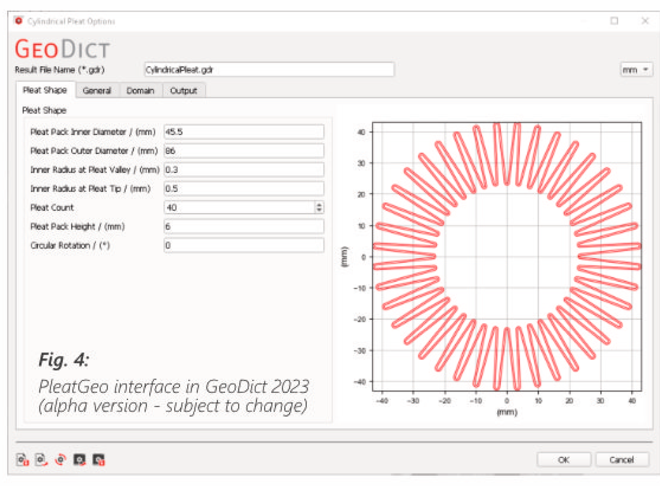


Fig. 4:
PleatGeo interface in GeoDict 2023 (alpha version - subject to change)

Step 2: Simulate filter performance

The well-known Navier-Stokes-Brinkman equations are solved to simulate the velocity and pressure distribution in the filter geometry using the fast and memory-efficient LIR solver.

For larger simulations or parametric studies, the software is ready for computations in the cloud. This is especially beneficial as all needed simulations can be run simultaneously to increase productivity and, therefore, reduce the time-to-market performance.

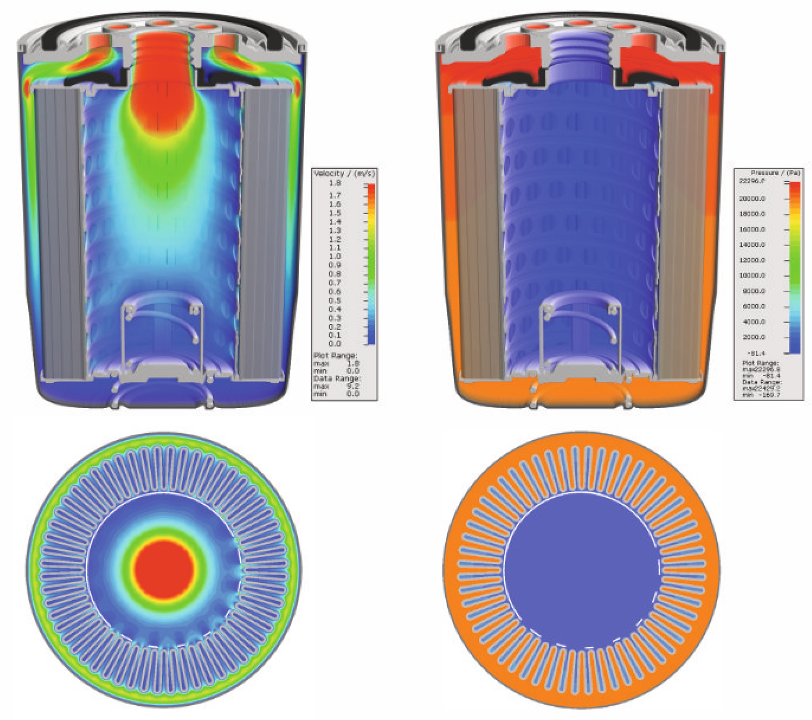


Fig. 5:
Determination of flow and pressure characteristics in a filter with 56 pleats

Simulation of the filter flow performance

After the generation of several filter geometries with changing pleat counts, computations of pressure and velocity are performed by using the FlowDict module. The (Navier-)Stokes-Brinkman equations used read as:

$$\nabla \cdot u = 0$$

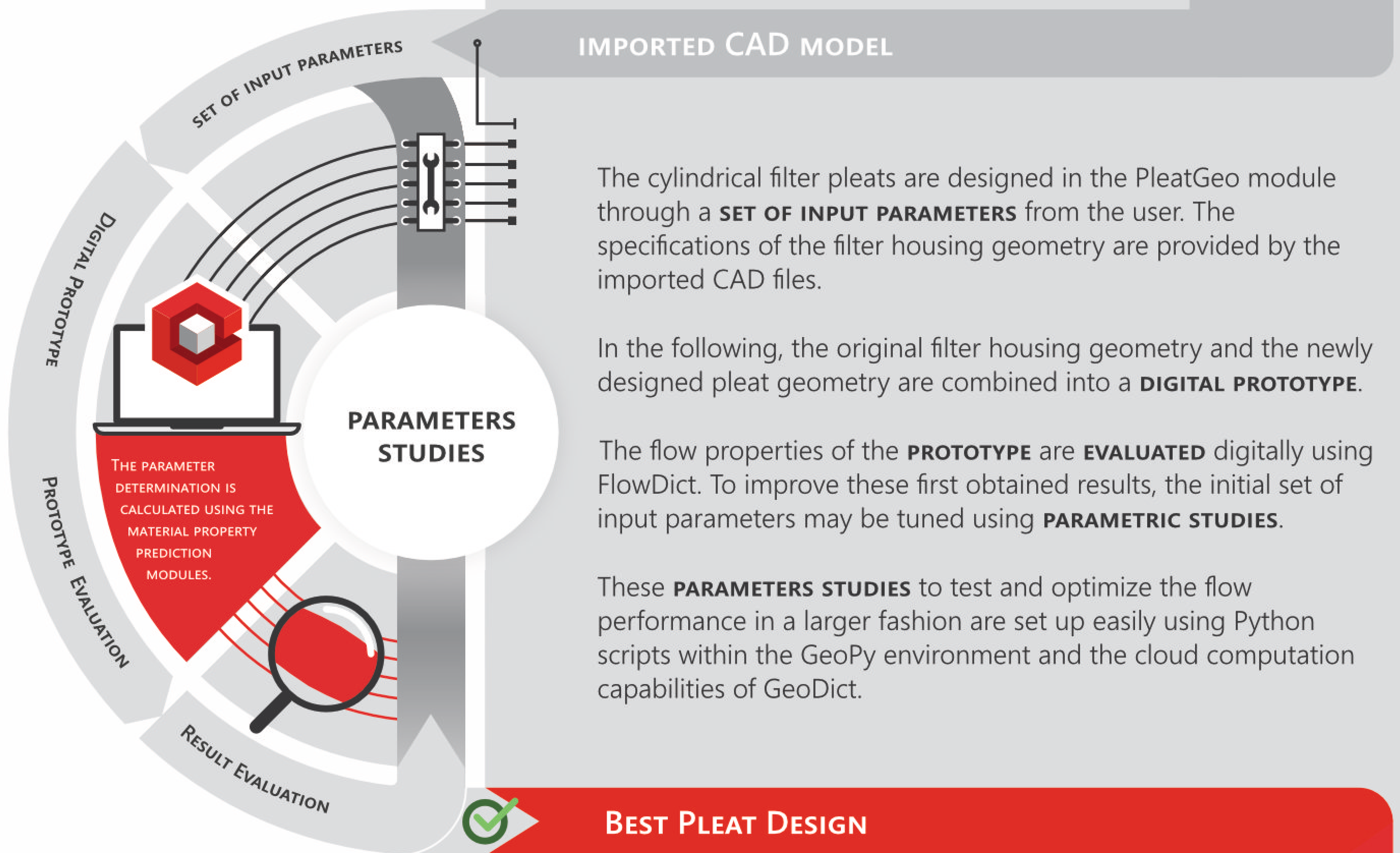
$$\mu\Delta u - \rho(u \cdot \nabla)u - \mu K^{-1}u = \nabla p$$

where, **u** is the velocity vector, **μ** is the dynamic viscosity, **ρ** is the density, **K** is the permeability and **p** is the pressure. These equations are solved applying the fast and memory-efficient LIR solver [1] shipped with GeoDict. The LIR solver applies adaptive meshing, which coarsens the numerical resolution in the far field and refines the resolution close to surfaces on a staggered grid scheme [2]. Furthermore, the numerical efficiency is improved by using state-of-the-art numerical methods such as multigrid and Krylov solving schemes. The Brinkman term is associated for the filter pleats, which are modelled as a porous layer with a specified material permeability, that can be obtained from measurements or simulations on the filter media scale [4]. The porous layer is necessary since, for complete filter simulations, the numerical resolution is too large to resolve individual features of the filter media.

Fig. 5 shows the velocity distribution from a 2D perspective, highlighting the flow of oil through the pleats and inner netting and the cross-sectional 3D view of the entire filter. In detail, the velocity distribution shows zones of high velocity and therefore, a larger pressure loss in between the filter element and housing of the filter.

Fig. 6 presents a plot of the calculated pressure drop for several pleat count configurations. In this plot, we observe that the 56-pleats configuration shows the lowest pressure drop and therefore, a good ratio between pleat count and filter area.

Simulations performed in this study used a standard workstation featuring 16 cores. The simulations needed about 67 GB of RAM and a simulation time of around 1.4 hours each. A set of simulations or an entire parametric study may simply be run simultaneously using the new built-in "Run-in-cloud"- button, which is shipped with the upcoming GeoDict 2023 release. This unlocks new possibilities to increase productivity and dramatically improve the time-to-market performance, especially toward deadlines and for larger systematic studies.



Imported CAD model

The cylindrical filter pleats are designed in the PleatGeo module through a **set of input parameters** from the user. The specifications of the filter housing geometry are provided by the imported CAD files.

In the following, the original filter housing geometry and the newly designed pleat geometry are combined into a **digital prototype**.

The flow properties of the **prototype** are **evaluated** digitally using FlowDict. To improve these first obtained results, the initial set of input parameters may be tuned using **parametric studies**.

These **parameters studies** to test and optimize the flow performance in a larger fashion are set up easily using Python scripts within the GeoPy environment and the cloud computation capabilities of GeoDict.

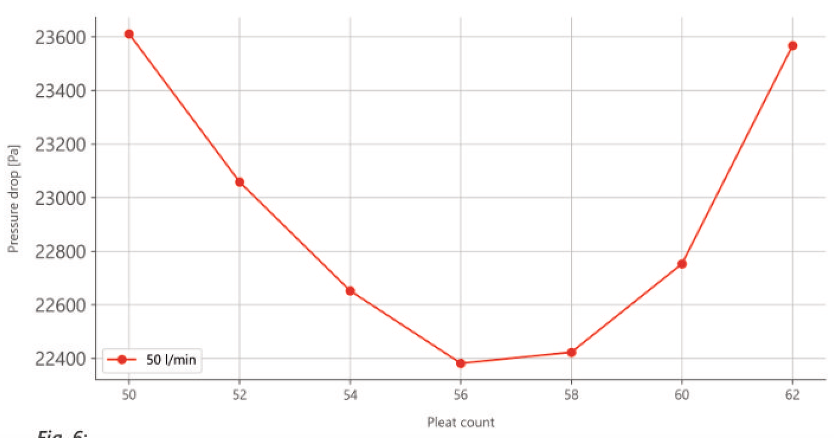


Fig. 6:
Results of the parameter study to determine the optimal number of filter pleats for this filter

Best Pleat Design

Digitally design, test, and optimize the filters of tomorrow

In this poster, we show a novel feature in GeoDict to generate cylindrical pleats for filter geometries and test or optimize these regarding their filter flow performance. This enables the user to digitally test the influence of varying filter pleat count configurations efficiently. Thus, costly and time-consuming measurements at the test bench could be limited only to the promising prototypes.

To further optimize the time-to-market performance, the software is ready to be run in the Cloud and may be used to perform parametric studies including changing pleat count, volumetric flow velocities, or various fluid viscosities. For this feature, the upcoming GeoDict 2023 release includes a "Run-in-cloud"-button, which directly sends the simulation with all its settings into the Cloud.

[1] S. Linden, A. Wiegmann, H. Hagen, The LIR Space Partitioning System applied to the Stokes Equations, Graphical Models, Vol. 82 (2015) 58-66.

[2] F. H. Harlow and J. E. Welch. Numerical Calculation of Time-Dependent Viscous Incompressible Flow of Fluid with Free Surface. The Physics of Fluids, 8(12):2182|2189, 1965.

[3] A. Wiegmann, S. Rief, and D. Kehrwald. Computational Study of Pressure Drop Dependence on Pleat Shape and Filter Media. In Filtech 2007 International Conference for Filtration and Separation Technology, volume I, pages 79|86, October 2007.

[4] A. Wiegmann. Computation of the permeability of porous materials from their microstructure by FFF-Stokes. Technical Report 129, Fraunhofer ITWM Kaiserslautern, 2007.

[5] A. Wiegmann, L. Cheng, E. Glatt, O. Iliev and S. Rief. Design of pleated filters by computer simulations. In Berichte des Fraunhofer-Instituts für Techno- und Wirtschaftsmathematik (ITWM Report), Fraunhofer ITWM, Vol. 155, 2009.