AcoustoDict

User Guide

GeoDict release 2022

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GeoDict

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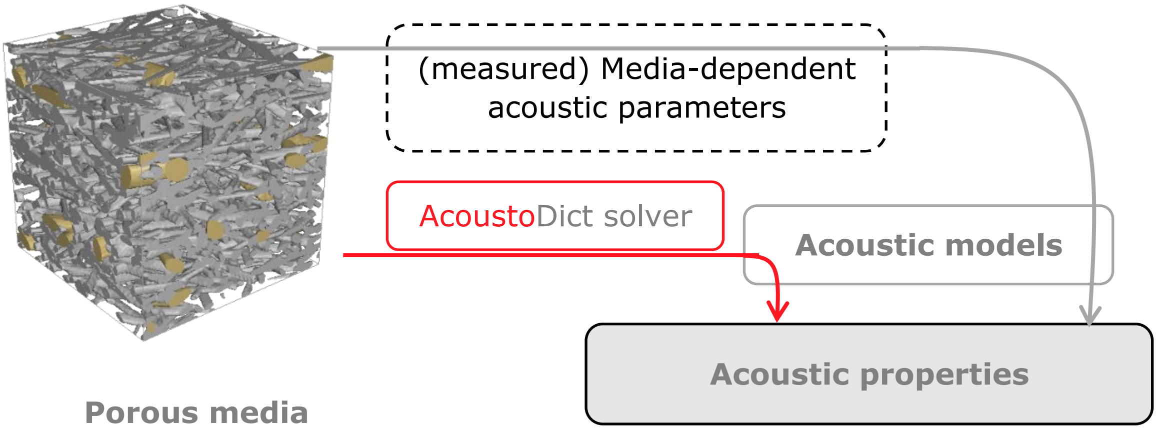
AcoustoDict for the Calculation of Media-Dependent Acoustic Parameters

AcoustoDict determines the effective (acoustic) material parameters by computer simulation, so that a connection between the microscopic structure and the acoustic properties can be identified without the need for time-consuming and expensive measurements of blank parts and prototypes.

The basis is a stochastic model, which represents the microstructure of the material realistically. Based on purely geometrical parameters, the propagation of airborne sound can be simulated by the Delany-Bazley model for highly porous absorbers and by the Allard-Johnson model for stiff absorbers. The calculation of the coupled airborne and solid-borne sound can be done by means of the model of Biot, provided the elastic properties of the material components, like polyurethane (PUR), are given.



AcoustoDict can compute six measurable media-dependent acoustic parameters:

Static air flow resistivity given by Darcy's law	σ	$\sigma \phi \vec{v} = -\nabla p$ $\sigma = \eta / k_0$	1)
Open porosity or volume fraction of the open pores	ϕ		
High frequency limit of the tortuosity	α_∞	$\alpha_\infty = \phi \frac{r_{fluid}}{r_{effective}},$	2)
Low frequency limit of the tortuosity	α_0	$\alpha_0 = \frac{\int_V v \cdot v \, dx}{\left(\int_V v_z dx\right)^2},$	3)
Viscous characteristic length	Λ	$\frac{2}{\Lambda} = \frac{\int_{\partial V_p} \lvert\nabla \psi\rvert^2 dS}{\int_{V_p} \lvert\nabla \psi\rvert^2 dx},$	4)
Thermal characteristic length	Λ'	$\frac{2}{\Lambda} = \frac{\int_{\partial V_p} dS}{\int_{V_p} dx}$	5)

1) where ϕ is the open porosity of the material, and η is the dynamic viscosity of air (~1.84 × 10^{-5} N·s·m^{-2} at ambient temperature and pressure conditions). See the FlowDict module.
2) where r_{fluid} is the resistivity of a conducting fluid and $r_{effective}$ is the effective resistivity of the saturated porous material - as calculated by the DiffuDict module. The high frequency limit is called T_∞ by Norris [3].
3) where $v = (v_x, v_y, v_z)$ is the fluid velocity - as calculated by the FlowDict module. The low frequency limit is called T_0 by Norris [3].
4) where Ψ is the solution of the Diffusion equation with appropriate boundary conditions in the pore space V_p - as calculated by the DiffuDict module.

These media-dependent parameters, obtained from AcoustoDict computations, are used as input for two models of sound propagation in a rigid skeleton (see APMR [2]): the Delany-Bazley model and the Johnson-Champoux-Allard model.

Delany-Bazley model

The **Delany-Bazley Model** encompasses equations for the complex **wave number** and the **characteristic impedance**. This model is applicable for highly porous materials with porosity close to the maximum of 1. AcoustoDict computes the **static air flow resistivity** (σ) of porous materials, the only parameter needed to describe the acoustic behavior of the material through the Delany-Bazley model. The porosity value (ϕ) obtained in AcoustoDict can be used to determine the validity of the model.

The Delany-Bazley [7] model expressions for the complex wave number k and the characteristic impedance Z_c are functions of frequency:

$$k = \frac{\omega}{c_0}(1 + 0.0978 \cdot X^{-0.700} - j\, 0.1890 \cdot X^{-0.595}) \tag{1}$$

$$Z_c = \rho_0 c_0 (1 + 0.0571 \cdot X^{-0.754} - j\, 0.0870 \cdot X^{-0.732}) \tag{2}$$

where the variable X is given by

$$X = \frac{\rho_0 f}{\sigma} \tag{3}$$

Here, ρ_0 is the air density; c_0 is the sound speed in air and f is the frequency in Hertz. $\omega = 2\pi f$ is the angular frequency; σ is the static air flow resistivity of the porous media; and j is the complex unity.

The results predicted by AcoustoDict are in best agreement with experimental results even for low frequencies. To achieve continuous dependence of the absorption on the frequency, the correction of Mechel [4] is used. This modifies the Delany-Bazley formulas to

$$k = \frac{\omega}{c_0} \cdot \begin{cases} 1 + 0.0978 \cdot X^{-0.693} - j\, 0.1890 \cdot X^{-0.618} & \text{for } X > \frac{1}{60} \\ \sqrt{-1.466 + j\, 0.212 \cdot X^{-1}} & \text{for } x \leq \frac{1}{60} \end{cases} \tag{4}$$

$$Z_c = \rho_0 c_0 \cdot \begin{cases} 1 + 0.489 \cdot X^{-0.754} - j\, 0.0870 \cdot X^{-0.731} & \text{for } X > \frac{1}{60} \\ \dfrac{0.159 \cdot X^{-1} + j\, 1.403}{\sqrt{-1.466 + j\, 0.212 \cdot X^{-1}}} & \text{for } x \leq \frac{1}{60} \end{cases} \quad (5)$$

Reference [5].applies this approach for the acoustic design of nonwoven materials.

ALLARD-JOHNSON MODEL

The **Allard-Johnson Model** (also known as Johnson-Champoux-Allard model) consists of equations for the **complex density** (describing visco-inertial dissipative effects) and the **dynamic bulk modulus** (characterizing thermal dissipative effects). This model is applicable to porous materials with a rigid frame and arbitrary pore shapes.

AcoustoDict computes four parameters involved in the calculation of the **complex density** ($\tilde{\rho}(\omega)$): σ, the static air flow resistivity; ϕ, the open porosity; α_∞, the high frequency limit of the tortuosity; and Λ, the viscous characteristic length.

The complex density is expressed by:

$$\tilde{\rho}(\omega) = \frac{\alpha_\infty \rho_0}{\phi}\left(1 + \frac{\sigma\phi}{j\omega\rho_0\alpha_\infty}\sqrt{1 + j\frac{4 \propto_\infty^2 \eta\, \rho_0 \omega}{\sigma^2\Lambda^2\phi^2}}\right) \quad (6)$$

AcoustoDict also computes the thermal characteristic length (Λ') for the calculation of the **dynamic bulk modulus** as expressed in:

$$\tilde{K}(\omega) = \frac{\frac{\gamma P_0}{\phi}}{\gamma - (\gamma - 1)\left(1 - j\frac{8\kappa}{\Lambda'^2 C_p \rho_0 \omega}\sqrt{1 + j\frac{\Lambda'^2 C_p \rho_0 \omega}{16\kappa}}\right)^{-1}} \quad (7)$$

To calculate the media-dependent acoustic parameters, AcoustoDict executes two computations. First, the air flow field is calculated, and then, if necessary when the Allard-Johnson model is selected due to the geometry of the porous material, the diffusion through the material as well.

	Delany-Bazley Model	Allard-Johnson Model
Geometrical analysis	Porosity	Thermal characteristic length
Air flow computation	Flow resistivity	Tortuosity
Diffusion equation solving		Viscous characteristic length

AcoustoDict Computations

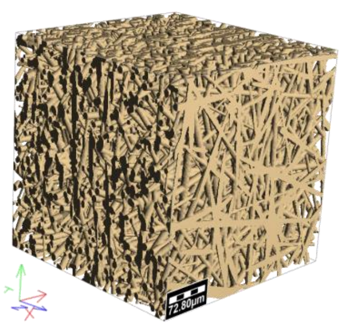
After choosing the model adequate to the geometry of the material, the acoustic parameters of porous media for the chosen model can be predicted by AcoustoDict on generated or imported structures. The options for the solver (EJ-Stokes) and the physics parameters for the flow need to be entered.

If considered necessary, the fluid flow can be visualized by loading the volume field (*.vap file) stored in the result files folder. For the Allard-Johnson model, diffusion can be visualized by loading the homogenized heat file (*.hht file), containing the pressure and velocity distribution. See the GeoDict Visualization handbook for information on visualization of the volume field (Arrow field and Stream lines).

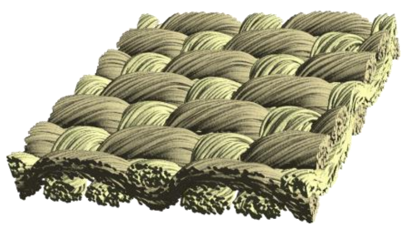
Material structures for computations with AcoustoDict

AcoustoDict computes porosity, thermal and viscous characteristic length, and tortuosity of porous media, as well as flow resistivity across the porous media. Flow resistivity is an intrinsic property of the structure that strongly depends on its geometry.

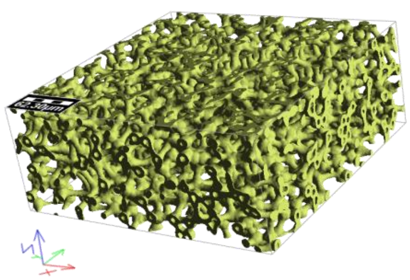
To some extent, the choice of model depends on the particular structure. When the structure is highly porous, the **Delany-Bazley Model** is appropriate. When the porous material has a rigid frame and arbitrary pore shapes, the **Allard-Johnson Model** is preferable.



Large-pores fibrous structure created in FiberGeo



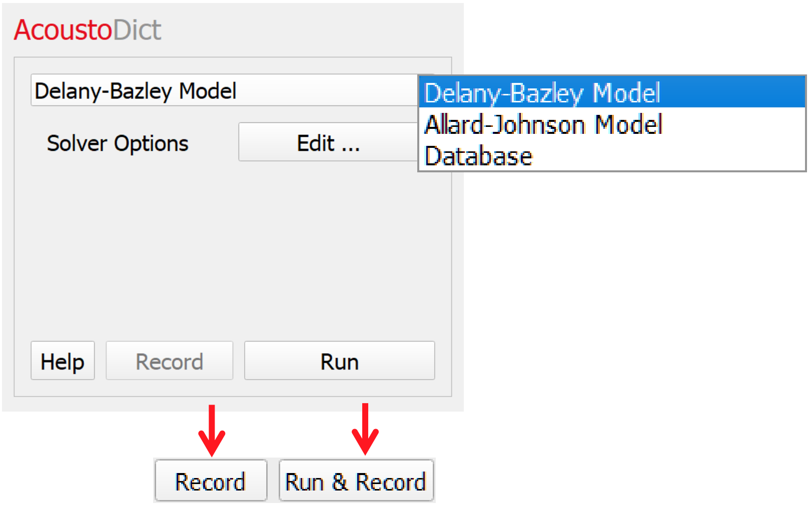
Twill multifil woven structure created in WeaveGeo



Foam membrane structure created in FoamGeo

AcoustoDict Section

Switch to AcoustoDict by selecting **Predict → AcoustoDict** in the Menu bar. In the AcoustoDict section, the pull-down menu lists the two models for which AcoustoDict can compute the media-dependent acoustic parameters, as well as provides access to the AcoustoDict Database.



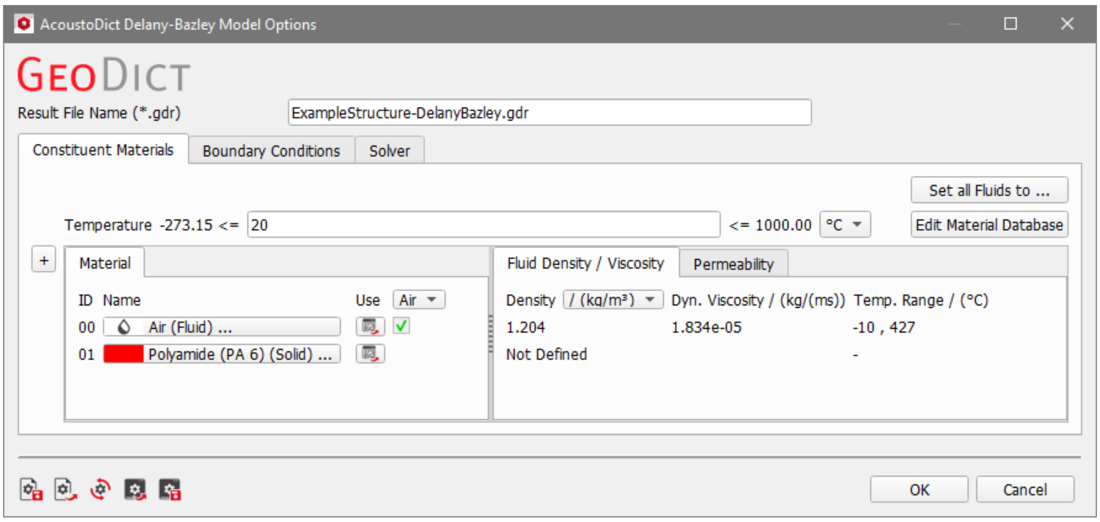
The settings for **Solver Options** necessary for the computations of the solver for the two models can be modified through the **Edit...** buttons. After entering the **Solver Options**, click **Run** in the **AcoustoDict** section to start the computations. A progress dialog box opens to follow the computations.

When recording a macro, the **Record** button becomes active and the **Run** button changes to **Run & Record**.

Clicking **Help** gives direct access to this AcoustoDict handbook through our web page.

Delany-Bazley model

The **AcoustoDict Delany-Bazley Model Options** dialog box opens when clicking the **Solver Options**' **Edit...** button in the **AcoustoDict** section. The parameters necessary to run the solver can be entered under the **Constituent Materials**, **Boundary Conditions**, and **Solver** tabs.



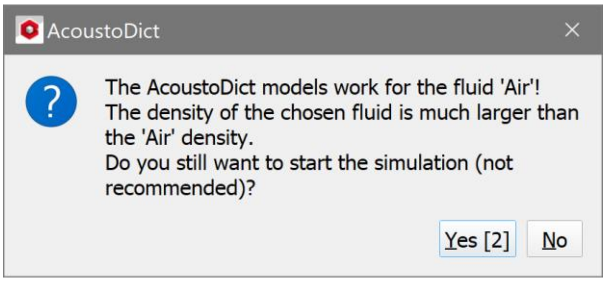
Clicking **OK** confirms the entered solver options, while clicking **Cancel** closes the dialog without modifications.

The **Result File Name (*.gdr)** of the AcoustoDict simulation must be entered in the edit box. Choose a name according to your current project. The results files are saved in the chosen project folder (**File → Choose Project Folder**, in the menu bar).

Constituent Materials

Under the **Constituent Materials** tab, the constituent materials of the fluid phase and the solid phase in the structure model currently in memory are shown.

The Delany-Bazley model is only valid when the fluid is air and the simulations assume that this is the case. If the constituent material for the fluid occupying the pore space is changed to some other constituent material (which is possible to do), a warning pops up when trying to run the simulation.

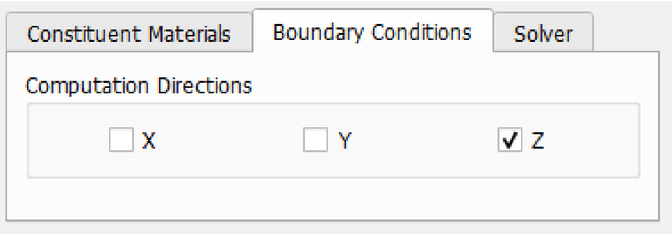


Click **No** and go back to the Constituent Materials tab. Click on the button for Material ID 00 to change it to Air through the **Material Selector**.

Under the assumptions made in the Delany-Bazley model, only the air flow resistivity and the porosity of the material are important for the acoustic absorption. Thus, the constituent material(s) chosen for the solid phase does not influence the results.

Boundary Conditions

For the **Boundary Conditions**, in the **Computation Directions** panel, choose the direction of the calculated flow. In most situations, it is only necessary to compute the direction orthogonal to the direction of wave propagation. To obtain results for all three directions, it is necessary to check all three.



Solver

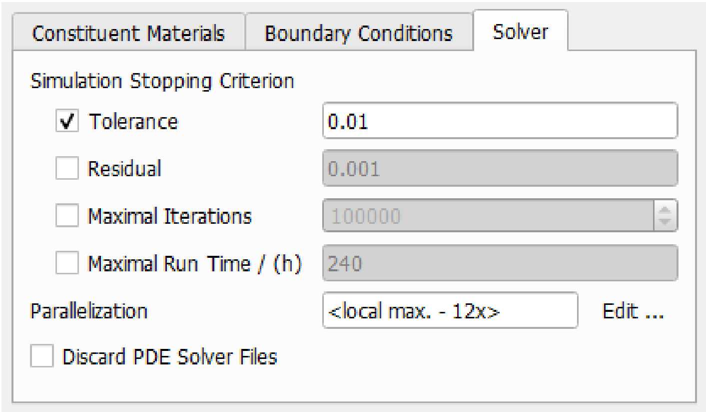
Internally, AcoustoDict solves iteratively the Stokes' equation to compute the air flow resistivity. The basic idea of an iterative method is to:

1. Start with some initial guess for the unknown values.

2. Improve the current values in each iterative step. The improvement can be fast or slow depending on problem parameters,
3. Repeat the iterative process until one of the stopping criteria (**Tolerance**, **Residual**, **Maximal Iterations** or **Maximal Run Time**) occurs.

Under the **Solver** tab, different **Simulation Stopping Criterions** are available. One or multiple of the stopping criteria can be checked.

- The default criterion, **Tolerance**, detects if the iterative process becomes stationary. This occurs when from iteration to iteration the change in the permeability value becomes extremely small. As a default, the solvers check for changes in the permeability after each 100 iterations. If the relative change is smaller than the value entered for **Tolerance**, the iteration is stopped.
- By setting the stopping criterion to **Residual**, the computations terminate as soon as the relative norm of the residual drops below the selected value. During the computations, the relative norm of the Schur Complement residual is calculated and displayed in the console window.
- When **Maximal Iterations** is chosen, the solver stops after the given number of iterations.
- When **Maximal Run Time** is active, the solver stops after the given time has passed.



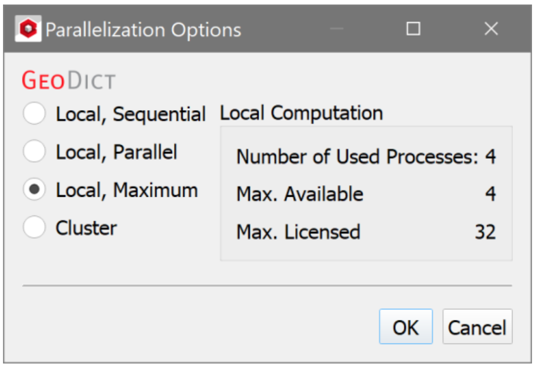
When the solver stops because the **Maximal Iterations** value or **Maximal Run Time** has been reached, no guarantee on the quality of solution can be given. Following possibilities might help:

- Check the corresponding .log file to see how large the residual values and permeability changes are. If these values are already very close to the desired result, you may decide to use the current result.
- Double check the structure and parameter values. Unphysical parameters or too rough resolution of the structure (leading, e.g., to artificial unconnected components) can cause an iterative solver to fail.

Parallelization

AcoustoDict solver computations can be parallelized if the user's license and hardware allow it.

The **Parallelization Options** dialog box opens when clicking the **Edit…** button, to choose between **Local, Sequential**, **Local**, **Parallel** or **Local, Maximum**. When **Local, Parallel** is selected, the **Number of Threads** can be entered. If **Local, Maximum** is selected, the maximum number of parallel processes is used. The maximum number depends on the available hardware and on the maximum number of processes licensed.



How to use the **Cluster** option is described in the High Performance Computing handbook of this User Guide.

Discard PDE Solver Files

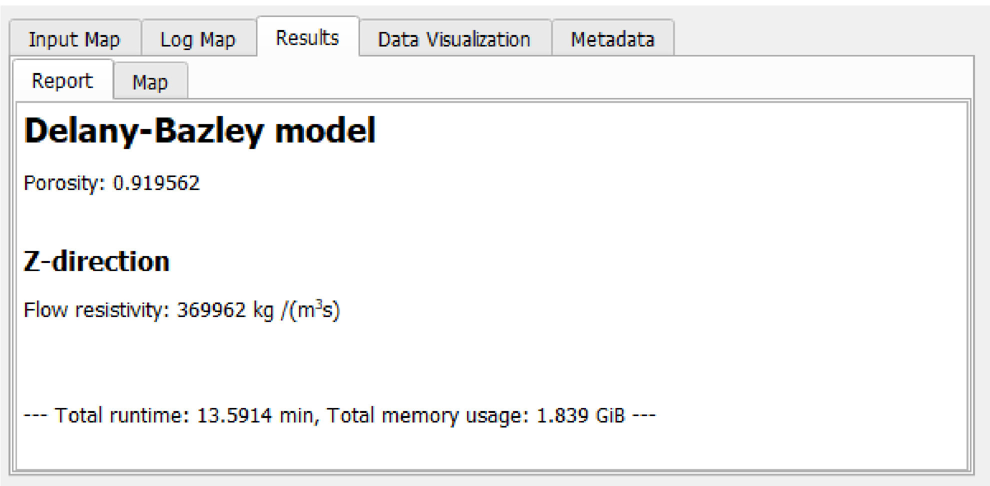
Checking **Discard PDE Solver Files** causes the deletion of the additional folder containing the intermediate computation files at the end of the computations.

While having the benefit of saving storage place, discarding those files has also the effect of disabling the 3D visualization of the flow results, because the *.vap file containing the flow field is also removed. Of course, the contents of the *.gdr result file are not discarded even in this case.

Results

Click **OK** to input the entered parameters, and then click **Run** in the AcoustoDict section to start the command.

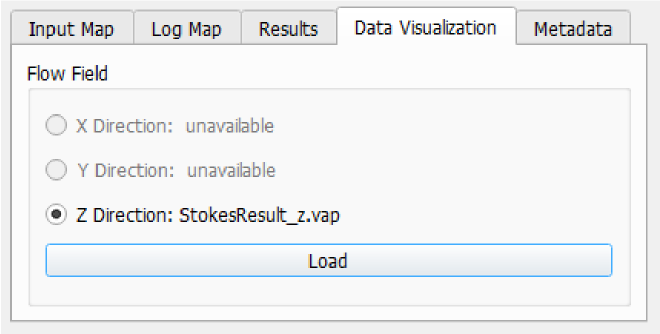
The results are immediately shown in the opening Result Viewer after the process is finished, the screenshot below shows the calculated acoustic parameter values for the Delany-Bazley model. The tab shows porosity and flow resistivity calculated in the direction of interest. The porosity value must be close to 1 (or over 90%), indicating a highly porous structure and the Delany-Bazley model is (indeed) applicable.



The **Results - Map** subtab gives access to the media-dependent acoustic parameters values computed for the selected acoustic model

Data Visualization

The fourth tab contains the setup for the **Data Visualization**. Flow fields that have been calculated to determine the flow resistivity values can be visualized by clicking **Load**.

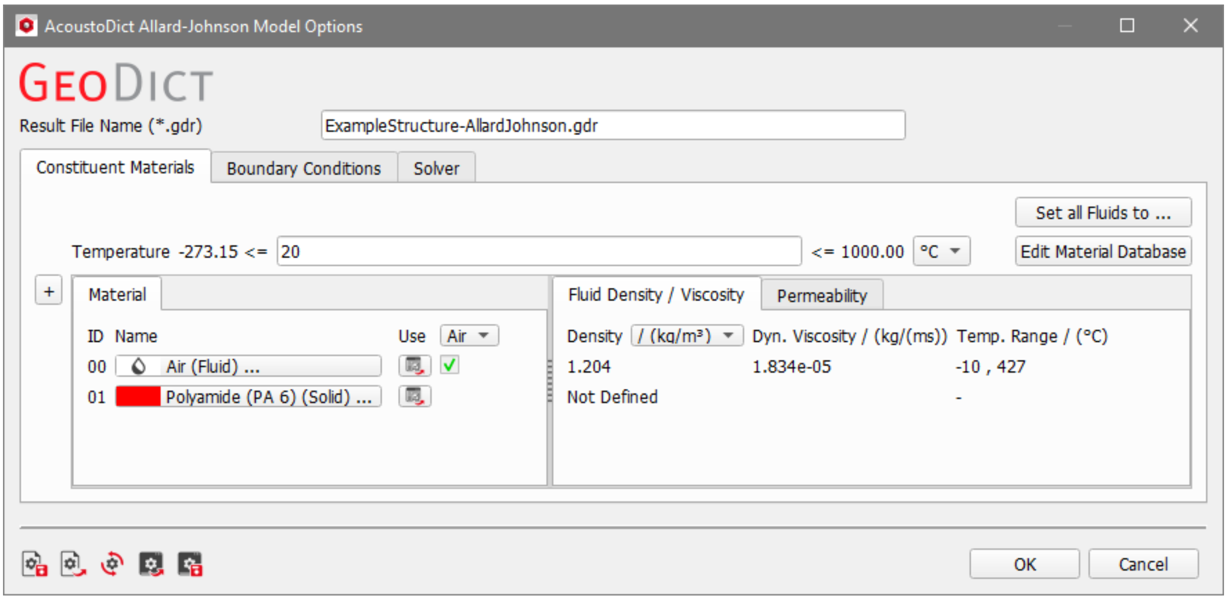


The options for the visualization of results are explained in detail in the GeoDict Visualization handbook.

ALLARD-JOHNSON MODEL

The **AcoustoDict Allard-Johnson Model Options** dialog opens when clicking the **Solver Options**' **Edit…** button in the **AcoustoDict** section.

As above for the Delany-Bazley model (page 6), the options necessary to run the solver can be entered under the **Constituent Materials**, **Boundary Conditions**, and **Solver** tabs.



CONSTITUENT MATERIALS

Under the **Constituent Materials** tab, all parameters are as described for the Delany-Bazley model. The Allard-Johnson model also assumes that the fluid in the pore space is air and it should be set that way.

BOUNDARY CONDITIONS

For the **Boundary Conditions**, in the **Computation Directions** panel, choose the direction of the calculated flow. In most situations, it is only necessary to compute the direction orthogonal to the direction of wave propagation. To obtain results for all three directions, it is necessary to check all three.

SOLVER

The AcoustoDict module internally has to solve two partial differential equations:

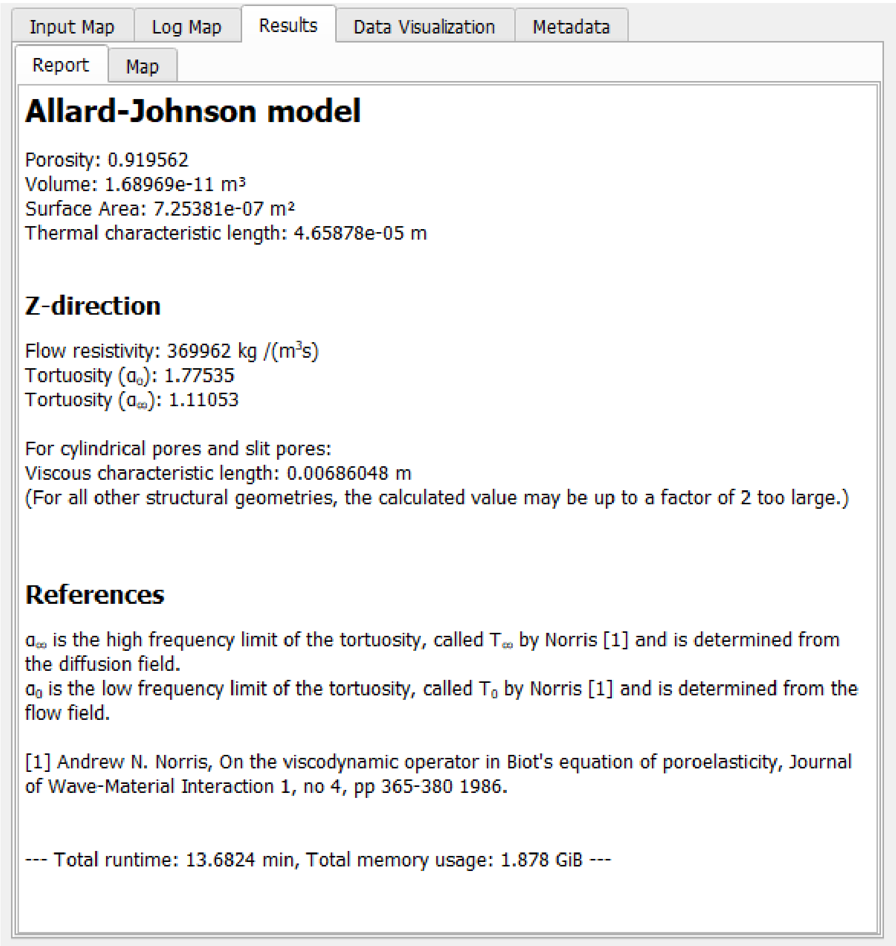
- Stokes' equation to compute the air flow resistivity
- Laplace equation to determine the tortuosity

The parameters entered under the **Solver** tab are used by both solvers and have the same meaning as described in pages 6ff. for the Delany-Bazley model.

Results

Click **OK** to input the entered parameters, and then click **Run** in the AcoustoDict section to start the command.

The results are immediately shown in the opening Result Viewer after the process is finished, the screenshot below shows the calculated acoustic parameter values for the Allard-Johnson model. The tab shows porosity, volume, surface area, and thermal characteristic length, as well as flow resistivity and tortuosity values in the direction of interest, are shown under the **Results - Report** subtab.

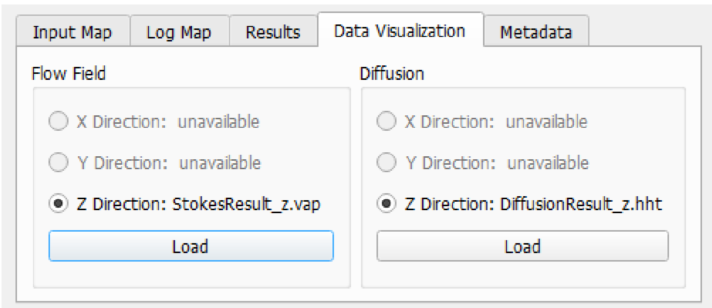


The **Results - Map** subtab gives access to the media-dependent acoustic parameters values computed for the selected acoustic model.

Data Visualization

The fourth tab contains the setup for the **Data Visualization**. Flow fields and concentration fields that have been calculated can be visualized by clicking **Load.**

The options for the visualization of results are explained in detail in the GeoDict Visualization handbook.



DATABASE

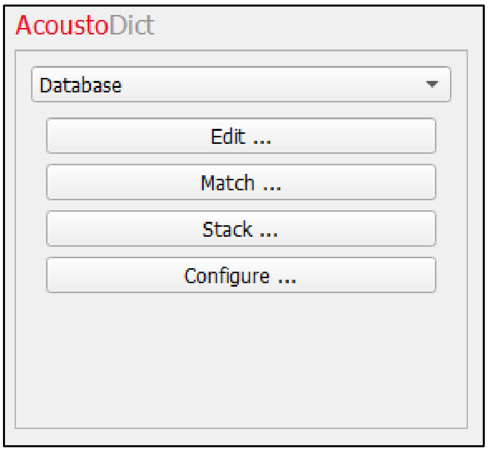
The flow resistivity values calculated for the Delany-Bazley model can be entered into the user's AcoustoDict **Database** to predict the frequency-dependent acoustic absorption of his/her structure.

A default database is included in the installation and, if the default installation settings have been kept, it is located at:

C:\Users*username*\GeoDict2022\AcoustoDictDataBase

This editable AcoustoDict **Database** can be used to store own results and later predict the acoustic properties of virtual materials at different degrees of compression.

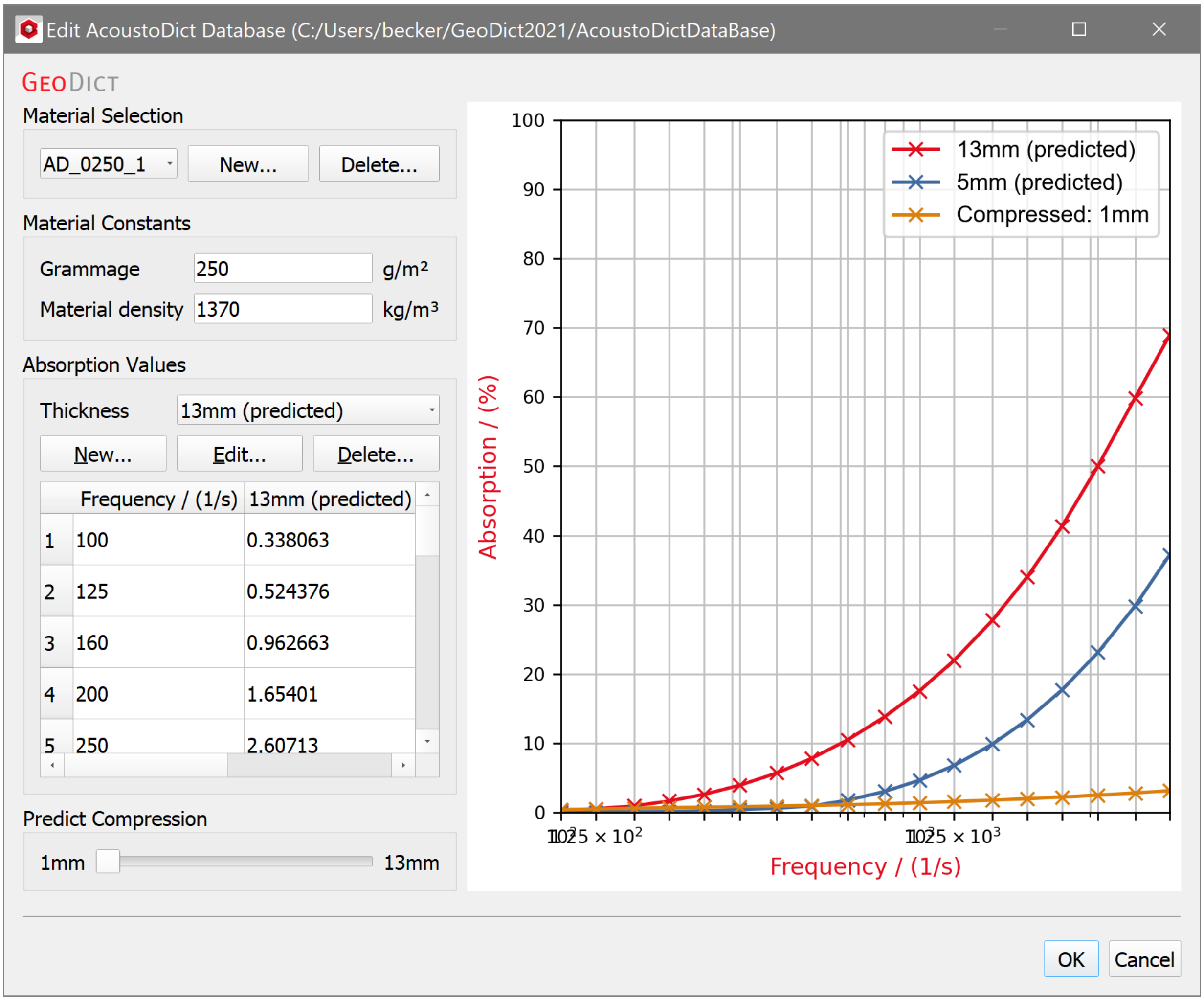
To access the AcoustoDict **Database**, select Database from the pull-down menu in the AcoustoDict section. Four options are available: **Edit**, **Match**, **Stack** and **Configure**.



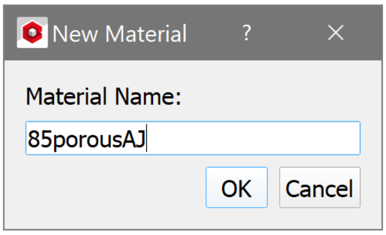
The database works different from the a usual GeoDict command, and the Record and Run buttons disappear from the AcoustoDict section when **Database** is selected. When opening a dialog by clicking on one of the four push buttons, the whole functionality of modifying and accessing the database happens inside the dialog widgets. No macro can be stored for those actions and no results files are created during those actions.

EDIT

To edit the AcoustoDict **Database**, click **Edit...**. in the **AcoustoDict** section. The **Edit AcoustoDict Database** dialog box opens, showing the path to the database in the caption.



In the **Material Selection** panel, the pull-down menu displays the names of the database materials. New materials can be added to the database by clicking **New...** and entering the **Material Name**.

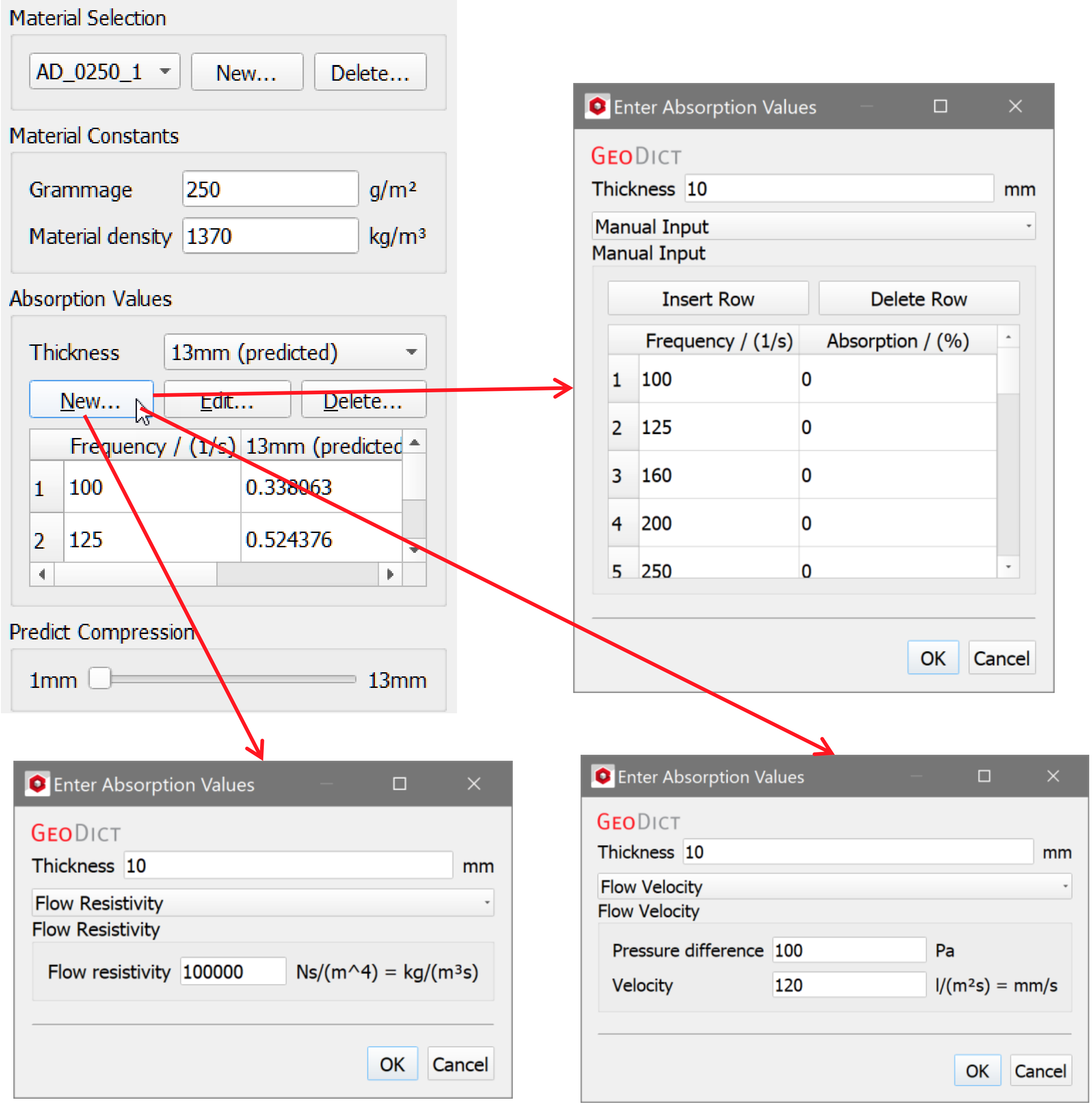


Materials can be removed from the database by clicking **Delete...**. and confirming the deletion.

When a material that is already in the database is selected, its **Grammage** and its **Material Density** are shown (and can be edited too) in the **Material Constants** panel.

In the **Absorption Values** panel, clicking **New** opens the **Enter Absorption Values** dialog box.

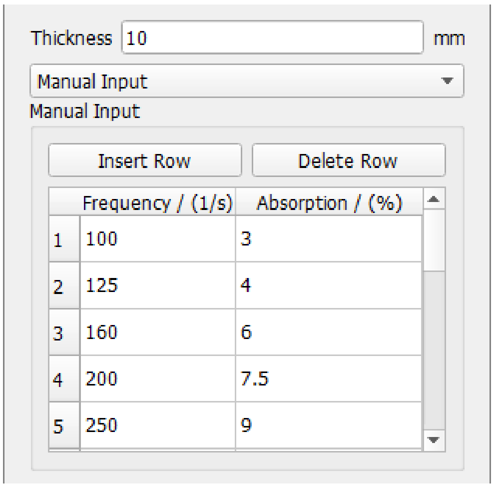
The default material **Thickness** of 10 mm can be changed and the way of entering the acoustic data (as **Manual Input**, **Flow Velocity**, or **Flow Resistivity**) can be selected by the user from the pull-down menu below.

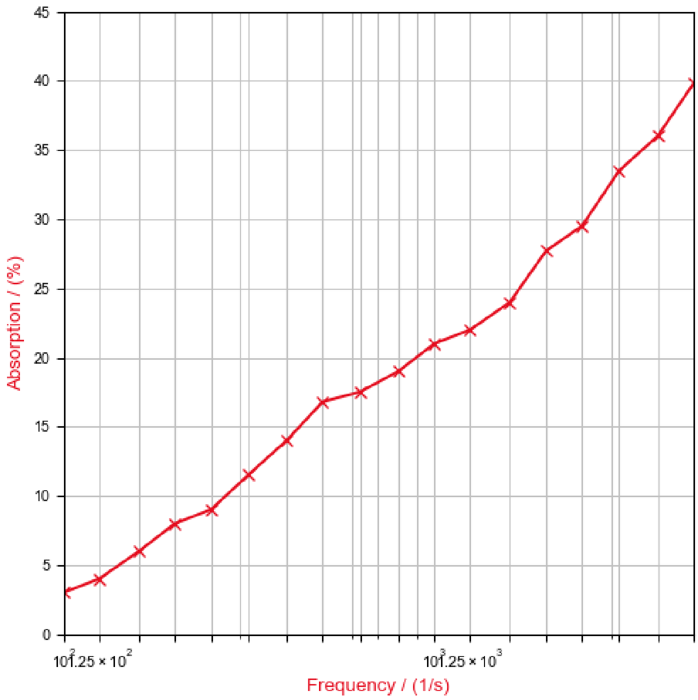


The acoustic absorption of real materials, experimentally measured in an impedance tube, can be entered by the user after selecting **Manual Input**. The measured absorption coefficients are entered manually in the table.

Typical fluid flow measurements can also be used to predict acoustic absorption by selecting **Flow Velocity** from the pull-down menu and entering the applied pressure drop and the measured flow velocity for a material.

After clicking **OK**, the absorption values at varying frequency values predicted for a material at the given thickness fill now the previously empty table in the **Absorption Values** panel and the predicted **Acoustic Absorption Curve** appears on the right.





When data for the same material at different degrees of compression exists, they can be entered and saved to obtain curves at each material thickness. In this case, the slider in the **Predict Compression** panel at the bottom left corner is activated and the user can obtain the predicted acoustic absorption curves for arbitrary thicknesses.

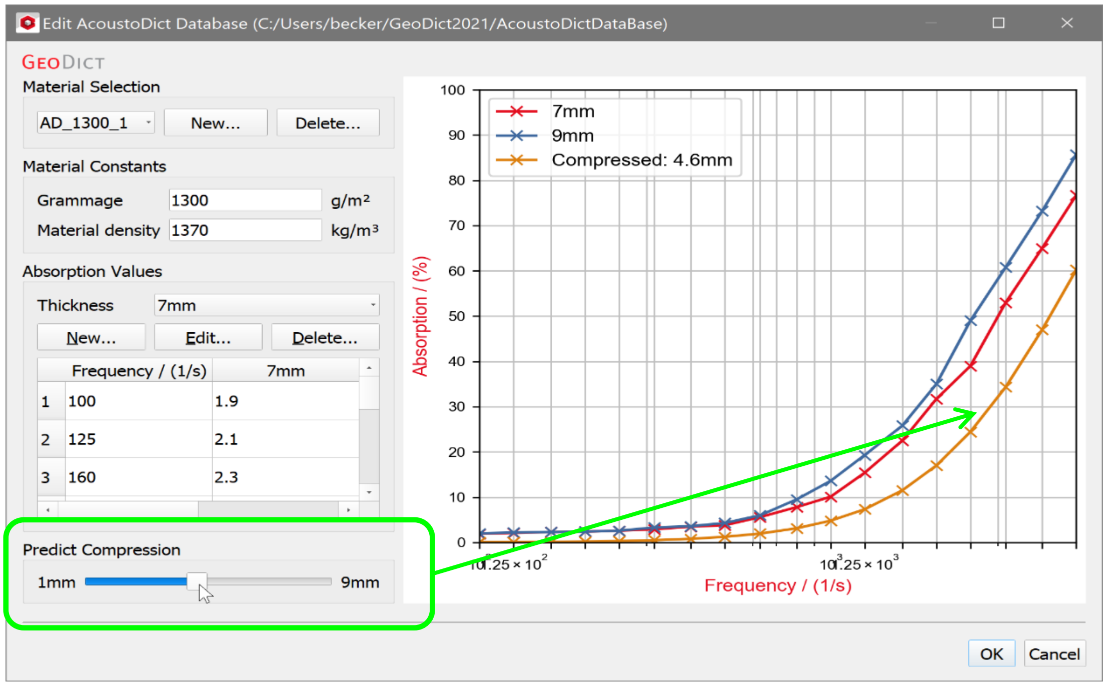
The prediction relies on the fact that the Delany-Bazley model allows to compute the sound absorption from the viscous flow resistivity of the porous material. This is combined with an approximation for the dependency of the viscous flow resistivity σ of the porous material on the thickness d of the material. We use the Ansatz function:

$$\sigma(d) = \alpha\rho(d)^{\beta} \tag{8}$$

where $\rho(d)$ is the thickness-dependent density of the porous material. Under the assumption of mass conservation, the density $\rho(d)$ can be computed from the **Material density** of the constituent fiber materials, the porosity of the uncompressed layer and the rate of compression. Note that the **Grammage** and the **Material density** of the constituent fiber material need to be entered in the **Material Constants** panel, for this computation to be accurate.

When the user has entered values for at least two different thicknesses (i.e. at least two pairs σ_i, d_i are known), the Ansatz function can be solved for α and β. After α and β are determined, the viscous flow resistivity σ can be estimated for any material thickness, and thus a prediction of the sound absorption becomes possible.

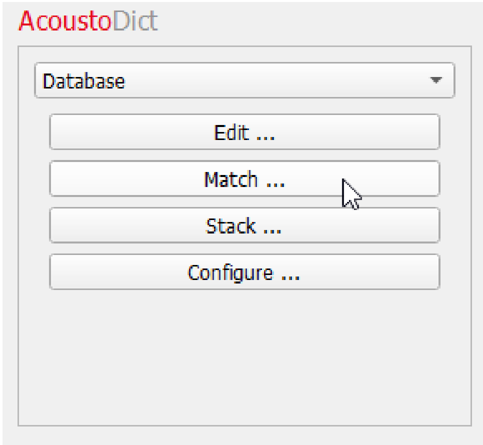
The entered values can be edited at any time when clicking the **Edit...** button. This reopens the **Edit Absorption Values** dialog box. Finally, click **OK** in the **Edit AcoustoDict Database** dialog box to save the newly entered or the edited materials in the AcoustoDict Database.


Edit AcoustoDict Database (C:/Users/becker/GeoDict2021/AcoustoDictDataBase)
GeoDict
Material Selection
AD_1300_1
New...
Delete...
Material Constants
Grammage 1300 g/m²
Material density 1370 kg/m³
Absorption Values
Thickness 7mm
New...
Edit...
Delete...
Frequency / (1/s)
7mm
1 100 1.9
2 125 2.1
3 160 2.3
Predict Compression
1mm
9mm
7mm
9mm
Compressed: 4.6mm
Absorption / (%)
Frequency / (1/s)
OK
Cancel

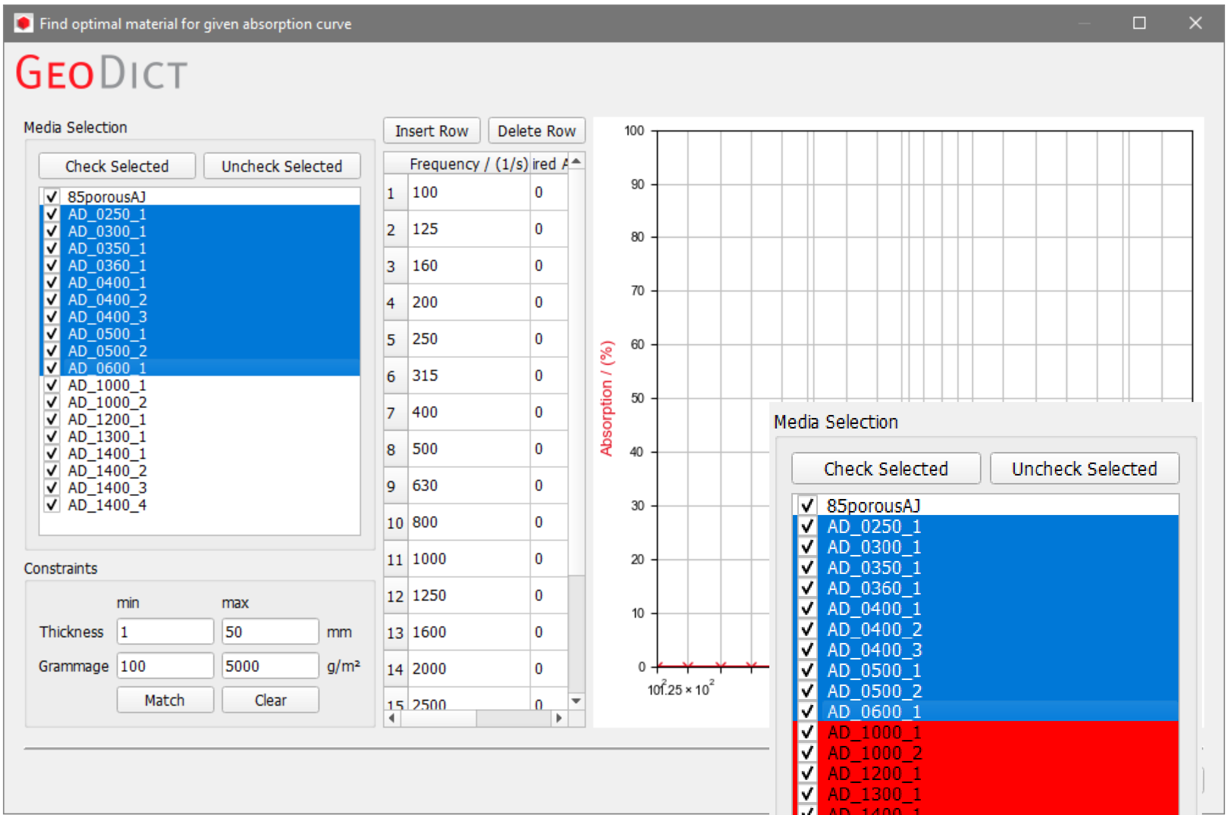
MATCH

Once the AcoustoDict database has been populated, clicking **Match...** allows finding a combination of material and thickness that best matches a desired absorption curve.

In the opening dialog box, in the **Media Selection** panel, select the database materials to be considered for the optimization. As default, all materials are selected.



To un-select one material, click on the name to highlight it and then click **Uncheck Selected** or just uncheck the box. To unselect multiple materials, it is faster to press Shift+Left mouse button while moving the mouse over a range of materials and then, click **Uncheck Selected**. The selection of unselected materials is done in the same way and then, clicking **Check Selected**.



In the **Constraints** panel, enter minimum and maximum **Thickness** as well as the **Grammage**.

All materials that fall outside the specified grammage interval or that are uncompressible to the indicated thickness range are marked in red in the database and are ignored in the matching.

The user enters the values for the desired absorption curve in the table, consisting of **Frequency** and corresponding **Desired Absorption** coefficient pairs. Select one of the rows and use **Insert Row** or **Delete Row** to add or eliminate pairs of values.

The curve of these frequency/absorption values is displayed on the right already while the user enters the values.

Insert Row | Delete Row

	Frequency / (1/s)	Desired Absorption / (%)
6	315	13
7	400	18
8	500	22
9	630	34
10	800	39
11	1000	45
12	1250	78
13	1600	89
14	2000	94
15	2500	96
16	3150	97
17	4000	99

When clicking **Match** in the **Constraints** panel, AcoustoDict considers the materials fulfilling the given thickness and grammage constraints and computes the absorption curve at different thicknesses within the given interval.

A graph with the five materials that best match the desired absorption characteristics is displayed on the right, with the name of the materials in the legend. The table now includes new columns with the absorption values at the given frequencies for these five materials.

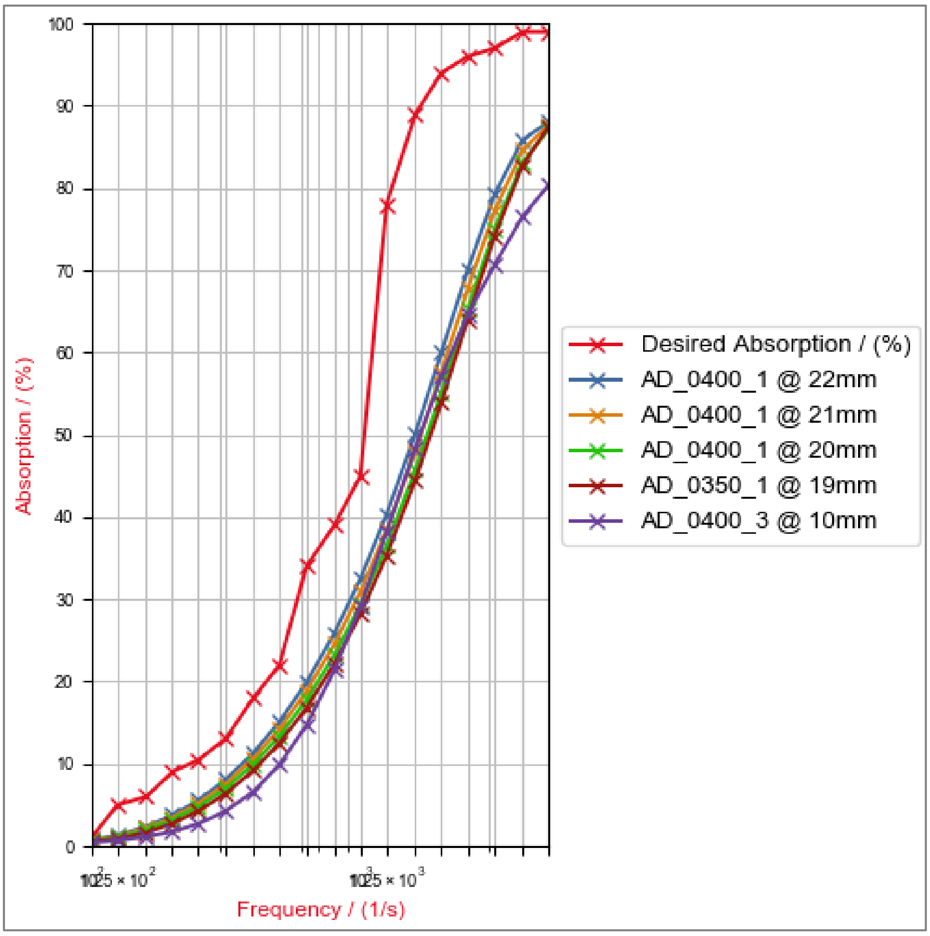
Notice that the thickness of the database materials is also taken into account and, thus, the name of the materials indicates at which thickness of that material the best match occurs.

The user can drag the corners and expand the dialog box to better observe the graph and the table columns.

Right-click inside the graph to change the graph settings or right-click inside the table to save it as a .txt file.

Insert Row | Delete Row

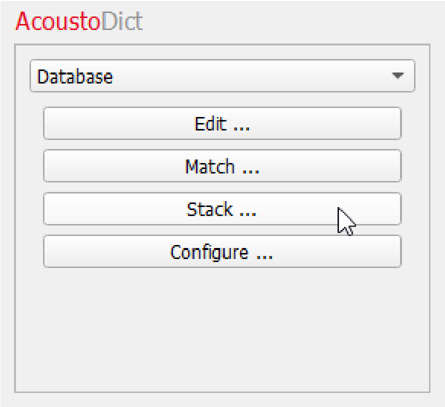
	d Absorption	AD_0400_1 @ 22mm	AD_0400_1 @ 21mm	AD_0400_
1	2	0.774296	0.712115	0.651632
2	5	1.30257	1.16656	1.03209
3	6	2.37497	2.16801	1.96282
4	8	3.74152	3.45126	3.16293
5	10	5.57097	5.17723	4.78562
6	13	8.04246	7.51863	6.99734
7	18	11.3094	10.6247	9.94352
8	22	15.1032	14.2417	13.3854
9	34	19.8854	18.8104	17.7431
10	39	25.8597	24.5275	23.2062
11	45	32.5065	30.9005	29.3071
12	78	40.2781	38.3767	36.4851
13	89	50.1763	47.9657	45.7482
14	94	60.0227	57.6283	55.1919
15	96	70.0175	67.6454	65.1741



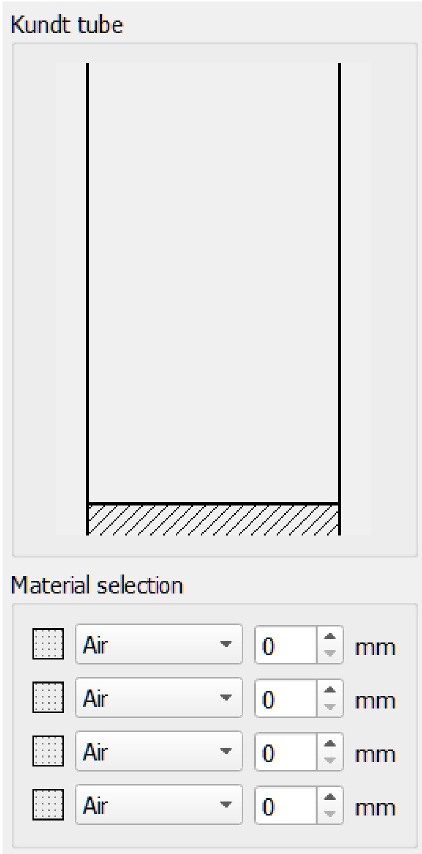
Clicking **Clear** in the **Constraints** panel, makes the values of the matched materials in the table and their curves in the graph disappear. The user can begin again trying to match other materials in the database.

STACK

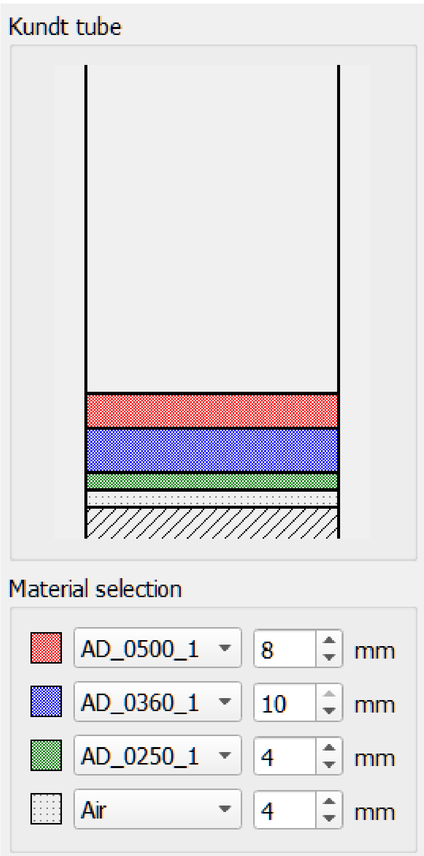
Stack... is designed to simulate the acoustic absorption of a stack of material layers chosen by the user.



Click **Stack...** to open the dialog box. On the left, the **Kundt tube** panel shows a cross-section schematic drawing of a virtual impedance tube for the measurement of the absorption coefficient of materials. The heavy backing plate is shown at the bottom, as a block of slanted stripes.



Under the **Material selection** panel, select materials from the AcoustoDict Database using the pull-down menus to construct stacks of them. Stacks of up to four different materials can be constructed. All materials in the database are available, as well as **Air** to allow for air gaps in the stacked multilayer construction.

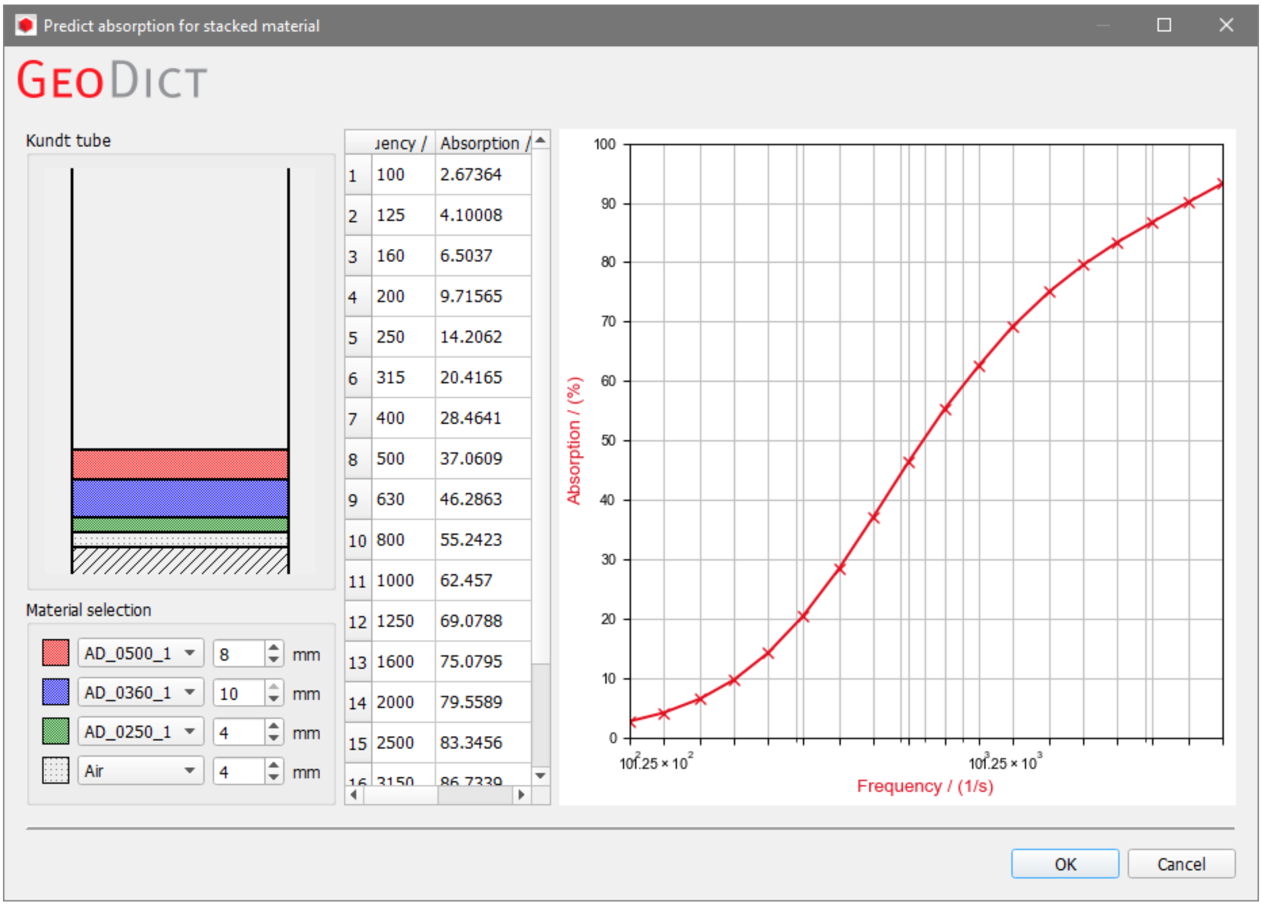


A color is assigned to every material (or air) layer and the thickness of the layer can be directly entered or selected through the up-down arrows.

If the multilayer construction should not have four layers, the unused layers can be set to **Air** and **0 mm**.

While the layers are being stacked, the predicted acoustic absorption values of the multi-layer stack at various frequencies are already listed in the table and the frequency/absorption curve for the complete multi-layer construction is displayed on the right.

Countless variations of the multi-layer construction can be built in real time.



The adsorption coefficient is computed following the approach described in the book of Allard and Atalla [1] in section 2.3. In the Kundt tube two waves propagate in opposite directions parallel to the direction of the tube. In this situation, the **Impedance Transmission Theorem** (formula 2.16 in Allard and Atalla [1]) :

$$Z(M_2) = Z_c \frac{-jZ(M_1)\cot kd + Z_c}{Z(M_1) - jZ_c \cot kd} \tag{9}$$

relates the impedance $Z(M_2)$ at one side of a porous layer with the impedance $Z(M_1)$ at the opposite side of the porous layer. In this formula, the characteristic impedance Z_c and the wave number k describe the acoustic properties of the porous layer, and can be computed with the Mechel-corrected Delany-Bazley formulas (4) and (5).

In the Kundt tube, for the first layer, touching the wall, the impedance $Z(M_0)$ is infinite and thus the transmission theorem states that the impedance $Z(M_1)$ at the first layer interface is:

$$Z(M_1) = -jZ_{c,1} \cot k_1 d_1 \tag{10}$$

where $Z_{c,1}$, k_1 and d_1 are the characteristic impedance, the wave number and the density of the first porous layer, respectively. Continuity of pressure and velocity at the layer interface leads to continuity across the interface also for the impedance.

Therefore, the impedance $Z(M_2)$ at the next interface can be determined using the transmission theorem (9), and all further impedances $Z(M_i)$ can be obtained successively in the same way.

At the outermost interface of N porous layers, the impedance is then given by $Z(M_N)$. Following section 2.4. of Allard and Atalla [1] , the reflection coefficient is

$$R(M_N) = \frac{Z(M_N) - c_0\rho_0}{Z(M_N) + c_0\rho_0} \tag{11}$$

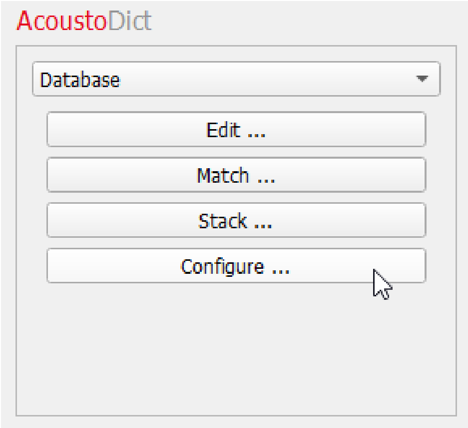
where c_0 is the speed of sound in and ρ_0 the density of the surrounding fluid (air), and thus $c_0\rho_0$ is the characteristic impedance of the surrounding fluid (air).

The absorption coefficient is then given through

$$\alpha(M_N) = 1 - |R(M_N)|^2 \tag{12}$$

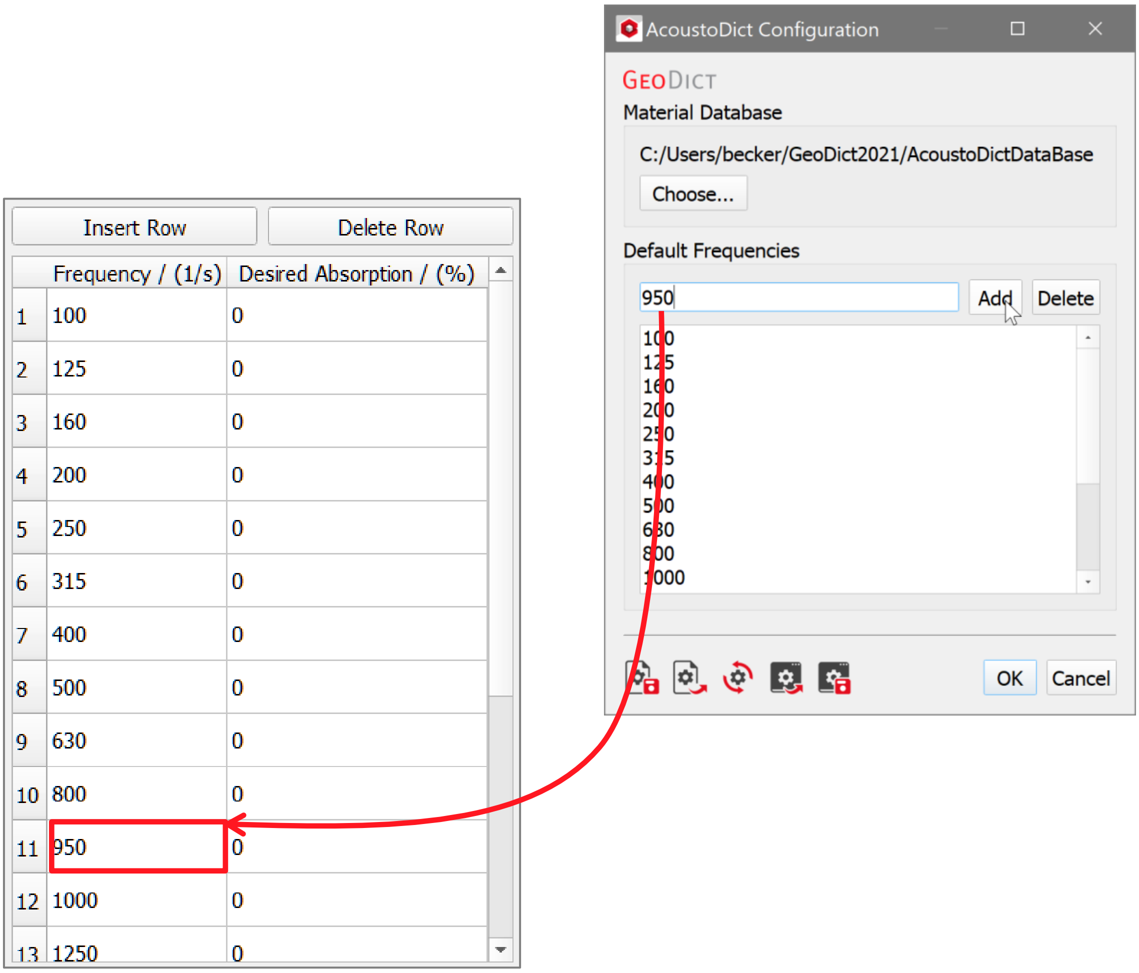
Configure

Clicking **Configure...** opens the **AcoustoDict Configuration** dialog box, where the path to the AcoustoDict Material-Database can be changed at will.



Each material in the AcoustoDict Database is stored in a single file within this folder and can be individually copied, exchanged, or shared with other users of GeoDict.

Additionally, the user can define a set of **Default Frequencies**, which is useful when measuring real samples in an impedance tube.



By pre-defining the frequencies to match those routinely registered by the user's instrument during measurement, only the **Desired Absorption [%]** values have to be manually entered in the table when real measurements are transferred to AcoustoDict.

References

[1] J. F. Allard and N. Atalla, Propagation of sound in porous media: Modeling sound absorbing materials, 2nd Edition, Wiley, 2009.

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