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ESTIMATION OF SOUND ABSORPTION COEFFICIENTS OF POROUS MATERIALS

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Abstract

In the paper, the influence of structural parameters on sound absorption properties of porous materials is analysed. The theoretical and empirical relationships between sound absorption coefficients and air flow resistivity of material and the thickness of the layer are discussed.

The characteristics of sound absorption coefficients for several porous materials calculated in accordance with the procedure recommended by EN 12354-6:2003 are compared with measured values obtained in reverberation room and tube method.

The nomograms, which allow to estimate sound absorption coefficients from knowledge of air flow resistivity and the thickness of material layers, are presented.
From these graphs optimal values of air flow resistivity and the thickness of sound absorption materials can be evaluated.

1. INTRODUCTION

For the producers of sound absorption materials and designers of sound protection using sound absorption materials, it is important to have the possibility to estimate sound absorption properties based on knowledge of structural-technical parameters of these materials. This is why work has been going on for a long time on determining the relationships between the structural-technical parameters and the sound absorption coefficient of different porous materials.

Many models have been developed, describing sound absorption phenomenon, i.e. changing acoustic energy into other types of energy inside the material. In general, these models may be divided into macrostructural and microstructural ones. In macrostructural models, the porous material is described by parameters such as porosity, air flow resistivity and skeleton elasticity (e.g. Zwikker & Kosten's model [5]). Microstructural models take into account the specific character of the structure of the porous material and the models and parameters describing their structure are different for fibrous materials (mineral wool), and materials with duct (foam) or grain structure. For example, in the case of fibrous materials their structure in Voronina's model [4] is described by: the thickness and length of the fibres and the density of the material.

In the last few years, the simplified empirical model by Delany & Bazley [1] has gained in popularity. According to it, the structure of the porous material is only described by air flow resistivity. These researchers, on the basis of measurements of acoustic impedance in impedance (Kundt's) tube for a large number of fibrous materials, developed empirical dependencies allowing for the determination of sound absorption coefficents on the basis of knowledge of air flow resistivity *r*, measured for the material according to EN 29053 and the thickness of the layer of material. Dunn & Davern [2] proposed similar dependencies for foams.

The dependencies of both Delany, Bazley (for fibrous materials), and Dunn, Davern (for foams) were recommended in EN 12354-6:2003 for determining the diffusive sound absorption coefficients of these materials.

Further on in this paper, are given the empirical dependencies recommended in EN 12354-6:2003 [9]. Their usefulness for determining sound absorption coefficients of fibrous materials and foam has been evaluated. Next, nomograms are presented which allow to determine the sound absorption coefficient on the basis of knowledge of flow resistivity and the thickness of the porous material. They also allow to set the optimal air flow resistivity values and material thickness for different frequencies.

2. THE METHOD FOR CALCULATING THE SOUND ABSORPTION COEFFICIENT RECOMMENDED ACCORDING TO EN 12354-6:2003

The norm EN 12354-6:2003 [9] introduced in 2003 recommended the calculation of diffuse sound absorption coefficients of porous materials, placed directly on the reflecting surface, based on the dependence given below:

For the diffuse acoustic field, the absorption coefficient α_s may be determined from:

$$\alpha_s = \int_0^{\pi/2} \alpha_\varphi \sin 2\varphi d\varphi \tag{1}$$

$$\alpha_\varphi = 1 - \left| \frac{Z'\cos\varphi - 1}{Z'\cos\varphi + 1} \right|^2 \tag{2}$$

$$Z' = Z'_c \coth \gamma d \tag{3}$$

where:

φ – angle of incidence, in radians;

α_φ – absorption coefficient for a plane sound wave, incident at an angle φ;

Z' – the $\rho_0 c_0$ normalised surface impedance of the layer;

Z'_c – the $\rho_0 c_0$ normalised characteristic impedance of the absorbing material;

γ – propagation constant in the absorbing material, in radians/m;

d – thickness of the layer, m.

The normalised characteristic impedance Z'_c and propagation constant γ can be deduced from the air flow resistivity r of the material by empirical relationships as follow:

A. Delaney & Bazley's relationships (for fibrous material)	**B**. Dunn & Davern's relationships (for open-cell foams)	
$Z'_c=(1+0.0571\,C^{0.754}) - i\,(0.087\,C^{0.732})$	$Z'_c=(1+0.0571\,C^{0.754}) - i\,(0.087\,C^{0.732})$	(4)
$\gamma = k_0(0.189\,C^{0.595}) - i\,k_0(1+0.978\,C^{0.7})$	$\gamma = k_0(0.168\,C^{0.715}) - i\,k_0(1+0.136\,C^{0.494})$	(5)

where:

$$C=r/\rho_0 f, \qquad k_0=2\pi f/c_0$$

r – air flow resistivity, Pa sec/m^2

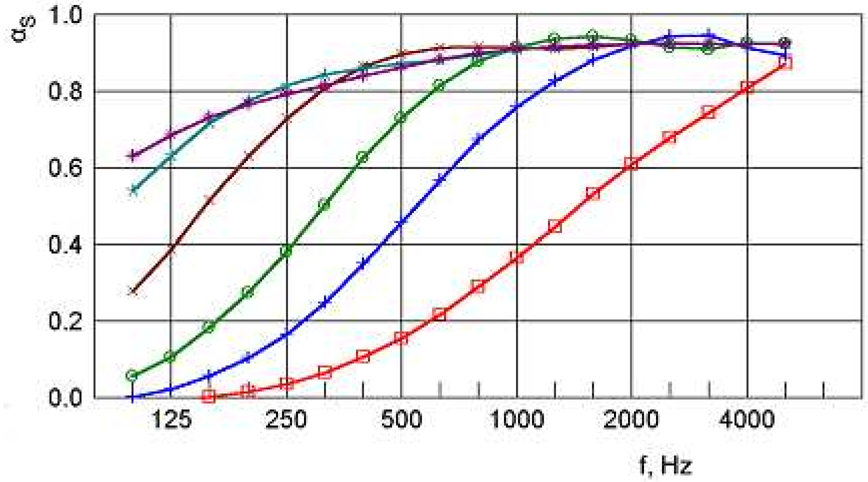
f - frequency, Hz

ρ_0-density of air, kg/ m^3 (=1,2 kg/m^3)

3. VERIFICATION AND EVALUATION OF THE USEFULNESS OF THE METHOD FOR CALCULATING THE SOUND ABSORPTION COEFFICIENT OF POROUS MATERIALS RECOMMENDED BY EN 12354-6:2003

On the basis of the dependencies given in point 2 above, according to EN 12354-6:2003, a computing programme was developed to enable the setting of diffusive and practical sound absorption coefficients for porous materials with known air flow resistivity, determined for these materials according to EN 29053 [8].

Examples of characteristics of the sound absorption coefficient determined according to this programme for mineral wool boards with flow resistivity r=16 900 Pa s/m^2 (nominal density of 60 kg/m^3 and different thicknesses are illustrated in fig 1.



Symbol	d, cm
□	2
+	4
⊙	6
×	10
⋆	15
✳	20

Fig 1. Sound absorption coefficients of mineral wool boards of different thickness (2 cm- 20 cm), calculated according to EN 12354-6:2003, based on measured air flow resistivity

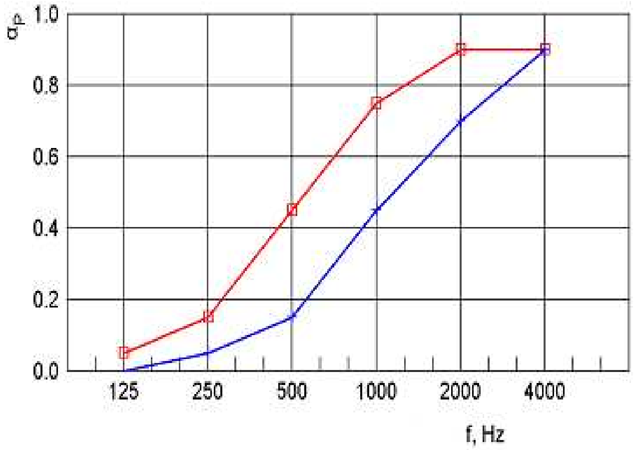
In order to verify the method for calculating the sound absorption coefficient recommended in EN 12354-6:2003, measurements of the sound absorption coefficient in reverberation room acc. EN ISO 354 [6] and air flow resistivity for several sound absorption products were performed, and the measured and calculated absorption coefficients were compared.

A comparison of the characteristics of the practical sound absorption coefficient - measured (rating acc. EN ISO 11654 {7]) and calculated for two types of mineral wool boards are illustrated in fig. 2. A comparison of the characteristics of the practical sound absorption coefficient (α_p) - measured and calculated for polyurethane foams are illustrated in fig. 3.

The comparative analysis of measured and calculated results shows that in general, the calculated coefficients - of both the diffuse absorption coefficient and the practical one are underestimated. The differences are particularly apparent in the range of medium frequencies and amount to 0.2-0.3.

Such large differences are unjustified. The calculation dependencies were determined empirically, based on results of measurements. An explanation for these differences may be the fact that empirical dependencies were selected for sound absorption coefficients measured in the impedance tube, i.e. at normal incidence, and in EN 12354-6:2003, unverified in practice formulas for calculating the diffuse sound absorption coefficient by integration of the sound absorption coefficient α_φ in the range from 0 to $\pi/2$ (see formula (1)) were proposed.

a)



b)

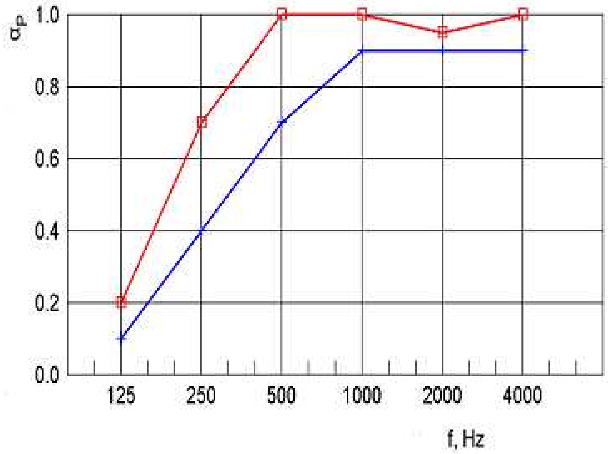


Fig. 2. A comparison of measured (red line) and calculated (blue line) practical sound absorption coefficients for mineral wool boards:

a) mineral wool boards 80 kg/m^3, 20 mm thick, r = 28303 Pa s/m^2
b) mineral wool board 60 kg/m^3, 100 mm thick, r = 14813 Pa s/m^2

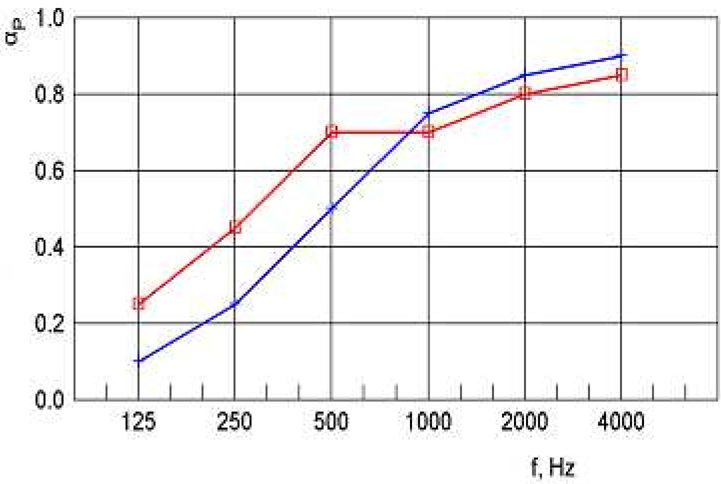


Fig. 3 A comparison of measured (red line) and calculated (blue line) practical sound absorption coefficients for polyurethane foam 50 mm thick, flow resistivity r=49 640 Pa s/m^2.

In earlier comparative studies [3] , carried out for relationships between flow resistivity and the sound absorption coefficient measured in impedance tube for fibrous materials, a greater consistency of the results of measurements and calculations according to the dependence by Delany & Bazley was obtained.

This is seen in fig. 4, where a comparison was made of sound absorption coefficients determined in the impedance tube (α_0)and calculated according to the dependencies given in point 2 for the angle φ=0 i.e.

$$\alpha_0 = 1 - \left| \frac{Z' - 1}{Z' + 1} \right|^2 \tag{6}$$

where Z' – normalized surface impedance of the porous material layer

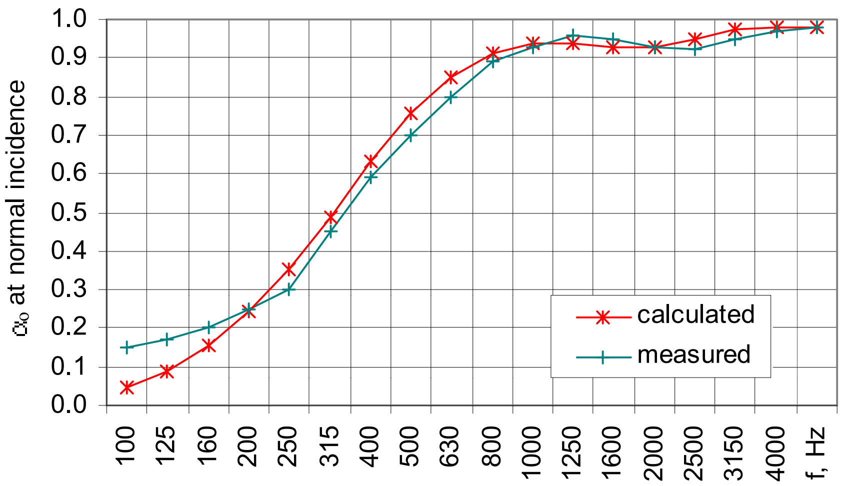


Fig. 4. A comparison of sound absorption coefficients measured in the impedance tube and calculated: For mineral wool board 80 kg/m^3 (r=22 500 Pa s/m^2, d=6 cm)- calculation according to Delany & Bazley's dependencies.

4. OPTIMISATION OF STRUCTURAL PARAMETERS OF POROUS MATERIALS WITH RESPECT TO THEIR SOUND ABSORPTION PROPERTIES

As the results of calculations given in the previous point show, it is possible to estimate the characteristics of the sound absorption coefficient of the layer of material based on knowledge of the air flow resistivity for the given thickness.

The problem was therefore formulated whether it is possible to determine the flow resistivity or thickness of material for obtaining the given sound absorption coefficient?

Taking into consideration the dependencies recommended in EN 12354-6:2003 (Delany, Bazley and Dunn, Davern), after meticulous calculations, the nomograms were developed, that made it possible to estimate the sound absorption coefficient for any frequency on the basis of knowledge of flow resistivity and the thickness of the material. They also make it possible to determinine optimal values of flow resistivity and thickness of material, after which the sound absorption coefficient no longer rises.

The developed nomogram of the sound absorption coefficient of fibrous materials placed on reflected surface at normal incidence for frequency 500 Hz is presented on fig 5. The nomogram for foams - for the same frequency bands is given in fig.6.

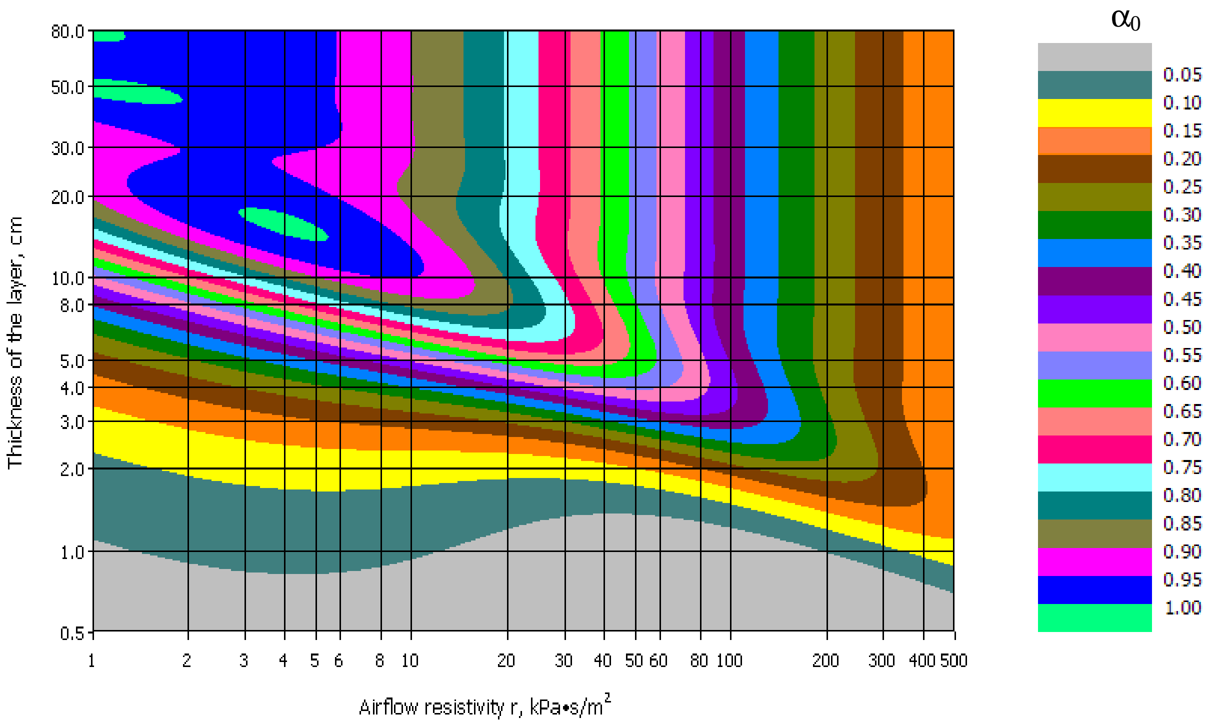


Fig.5. Nomogram of sound absorption coefficient dependence on air flow resistivity and layer thickness of fibrous materials for 500 Hz

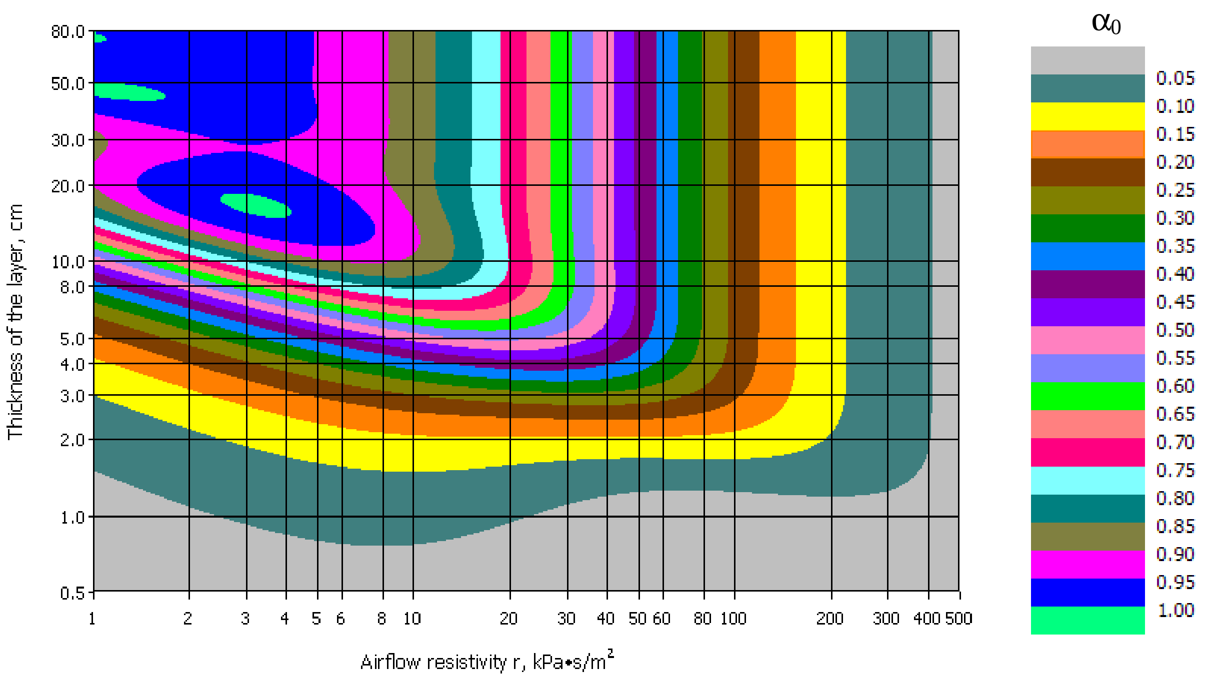


Fig.6. Nomogram of sound absorption coefficient dependence on air flow resistivity and layer thickness of open –cell foams for 500 Hz

5. CONCLUSIONS

The following conclusions may be drawn from the conducted studies of empirical dependencies between the sound absorption coefficient and structural-technical parameters of porous materials:

1. It is possible to determine sound absorption coefficients for porous materials (fibrous and foams) knowing their flow resistivity and thickness of the material layer, according to the dependencies given in EN 12354-6:2003.
2. The values of diffusive and practical absorption coefficients obtained from calculations according to the method given in EN 12354-6:2003 are underestimated in relation to measurement data, but may be adopted when declaring the sound absorption properties and formulating requirements - as minimal values (the “not less than” requirement).
3. Definitely greater agreement of values measured and calculated according to the dependencies Delany, Bazley’s and Dunn, Davern’s is obtained for sound absorption coefficients in the case of normal incidence, and for those absorption coefficients nomograms were developed for an initial estimation of their values.
4. The developed nomograms allow to determine the sound absorption coefficient for chosen frequency on the basis of knowledge of flow resistivity and the thickness of the material. They also make it possible to determine optimal values of flow resistivity and thickness of material, after which the sound absorption coefficient no longer rises.
5. The air flow resistivity determined according to EN 29053 [8] may be treated as a control parameter in evaluating the stability of the sound absorption properties of the given material.

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