Stochastic Modelling and Computational Sciences

SOUND WAVE ABSORPTION BY FABRICS MATERIALS

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ABSTRACT

The ordinary incident absorption coefficient of fabrics with various densities has been measured using the tube technique in order to analyse the mechanism of the sound wave absorption by fabrics. This has demonstrated that fabrics absorb sound waves via two different processes. Firstly, there is the viscosity resistance type, where absorption happens because sound waves induce energy loss during their passage through fabrics, which helps them exceed the resistance created by friction with the air in the fibres. The other sort of absorption is called resonance, and it happens when the sound wave vibrates the system made up of the fabric and the elastic air space behind it. The energy consumption of a sound wave by a fabric in a sound field, The vibration energy of air (sound wave energy) is initially consumed in thermodynamic energy form in consequence of viscous resistance between the surfaces of threads and air when a sound wave passes through the fabric. It is consumed also by the vibrations of fibers. If the absorbing mechanism of the fabric is like this when the fabric is placed in a place where the particle velocity is large, the energy loss ought to be larger. we have found that their absorption characteristics vary with their densities and that fabrics have one or the other of two types of absorbing mechanisms. One is the viscosity resistance type in which absorption occurs because a sound wave passing through the fabric produces energy-loss to overcome the frictional resistance between the fiber and air in it. The other is the resonance type in which absorption occurs because the sound wave vibrates the system composed of the fabric and the elastic air space behind the fabric.

Keywords: Absorption coefficient, frequency, Absorption characteristics, sound wave.

1. INTRODUCTION

The behavior of fibre assemblies and fibre products under a sound wave has seldom been the subject of comprehensive reports. Printed Research on the topic is patchy and mostly restricted to measuring the absorption coefficients of building materials like glass fibres. We have conducted a number of studies on fibre assemblies and fibre products to look into the relationships between their physical characteristics and absorption mechanism as well as the sound wave condition in fibre assemblies the absorption of sound wave by textiles is discussed in this article. Another article will cover how fibre assemblies absorb sound waves. Practical information about the absorption coefficients of textiles has been published [1, 2], but as far as we are aware, very few published papers address the topic from the perspective of fabric manufacturing. We assessed the absorption qualities in our studies using textiles that we woven from yarns with varying densities. The findings of our studies were taken into consideration while studying the absorption process.

2. METHOD TO MEASURE ABSORPTION COEFFICIENT:

The absorption coefficient of a substance may be determined in two ways [3], the tube technique and the reverberation room approach. Method 1 is practical since it allows sound waves to enter the sample from various directions. Since Method 2 only allows sound waves vertically, it deviates from the actual absorption state. In contrast, Method 2 uses small sample sizes and produces highly precise findings that are simple to understand. In our experiments, we applied the tube approach. Consequently, the absorption coefficient provided in this article represents the absorption coefficient for a normal occurrence.

2-1. Theory of Measuring Absorption Coefficient

A portion of the energy of an incoming sound wave is absorbed and the remainder is reflected when it reaches the sample to be examined. Therefore, the absorption coefficient may be defined as follows:. The energy of a sound wave being proportional to the square of the absolute value of sound pressure, eq.(1) is substituted as follows:

$$\alpha_0 = (W_i - W_r)/W_i \qquad \text{.................1}$$

$$\alpha_0 = 1 - |p_r|^2/|p_i|^2 \qquad \text{....................2}$$

A sample is put into one end of a rigid-body tube with a smooth interior surface, which is then sealed with a rigid body armour. When a pure tone enters the tube from the opposite end, the interference of the incident and reflected waves creates a standing wave inside the tube. Given the standing wave, the maximum and lowest sound pressures are given by

$$P_{max} = D(|p_i| + |p_r|)$$
$$P_{min} = D(|p_i| - |p_r|) \qquad \text{..................3}$$

$$\alpha_0 = 4/(N + N^{-1} + 2) \qquad \text{....................4}$$

The absorption coefficient of the sample is therefore, calculable by the measurement of N.

3. MEASURING APPARATUS AND METHODS:

The Kobayashi Institute of Physical Research's laboratory of architectural acoustics lent us the equipment, which is seen in Figure 1's block diagram. An iron tube with a completed inside surface, 290 cm in length, and an inside diameter of 10 cm was employed as the measurement tube. The dimensions of the tube employed determine the frequencies at which absorption coefficients may be measured. Normally, the tube we used could measure between 250 and 2,000 c/s. Absorption coefficients were measured in our studies at intervals of 1/3 octave, i.e., 250, 320, 400, 500, 640, 800, 1,000, 1,280, and 1,600 c/s, ranging from 250 c/s to 1,600 c/s. We also measured using intermediate frequencies where needed.

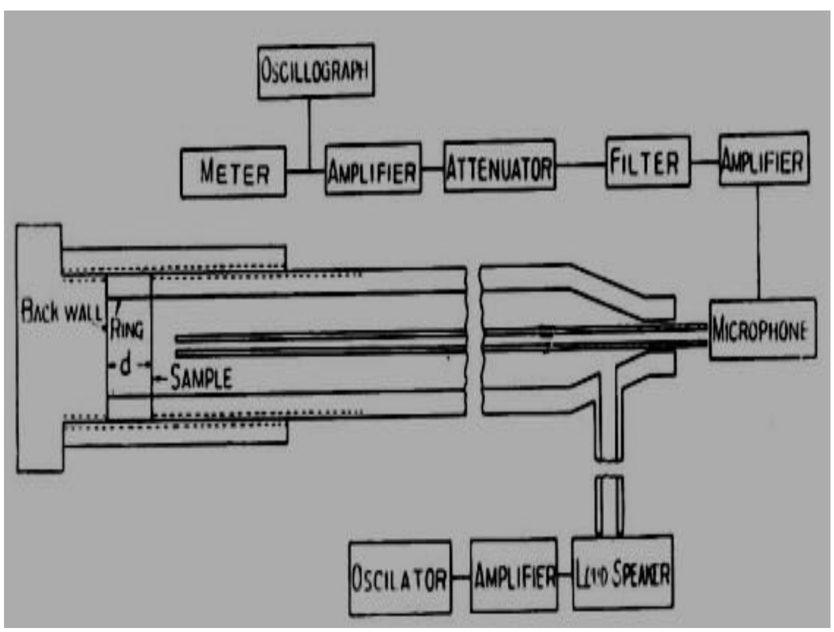

Fig.1: The tube method of measuring the normal incident absorption coefficient.

By producing a pure tone of a measurement frequency from a signal oscilator via a speaker, the value of N may be obtained using equation (3).creating a vertical wave within the tube. Next, by moving a probe tube, we may determine the maximum voltage, which is the maximum sound pressure of the sample's surface at the beginning. An attenuator allows us to obtain the voltage provided by the initial minimum sound pressure as well as the ratio of those voltages displayed in decibels:

$$N = P_{max}/P_{min} = E_{max}/E_{min}$$

Therefore, by substituting this value into eq. (4), the absorption coefficient at the frequency is determinable.

4. Samples and their Settings

We selected seven different cotton fabric types (T1–T7) with different weft densities and a herringbone pattern as examples. They used a single 20s yarn for their weft and a two-ply 40s yarn for their warp. They consistently had 98 endpoints per inch of warp. Table 1 provides the fabric measurements. Their thickness was measured at 5g/cm2 with a compression tester. We may regard the seven fabrics (T1～T7) as of an equal thickness.

Table 1: Dimension of fabrics

FABRIC	PICKSS PER INCH	WEIGHT (g/cm2)	THICKNESS (5g/cm)	P*
T_1	42	147	0.77	29.5
T_2	54	166	0.72	26.7
T_3	66	177	0.69	23.6
T_4	70	181	0,71	22.6
T_5	76	194	0.67	21.2
T_6	84	207	0.70	19.3
T_7	92	219	0.70	17.3

P is the ratio of the total area of open spaces in a fabric to the area of the samples.

One sample was sliced along the ring after being loosely fastened to a ring with a diameter of 10 cm. Next; insert the ring into the device as seen in Figure 1.

In order to determine the depth of the air space beneath the fabric, the sample's distance from the rigid body cover was typically altered at intervals of two centimetres, ranging from zero to twelve centimeters. In this way, the absorption properties for every air space were discovered.

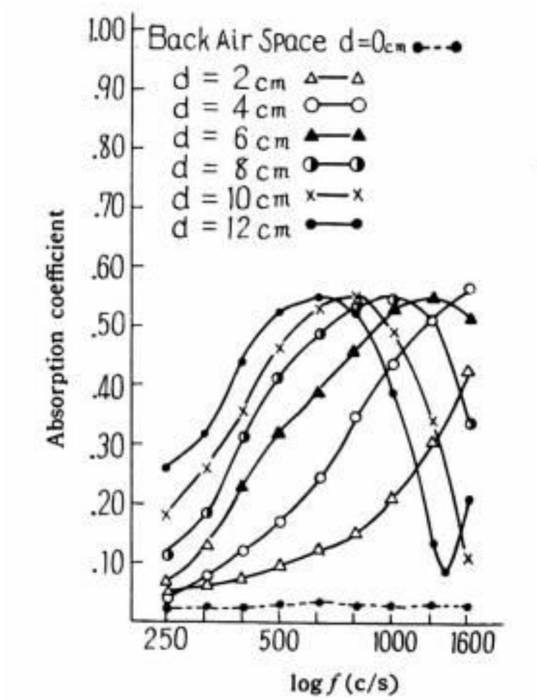

Fig. 2 Absorption characteristics of fabric T

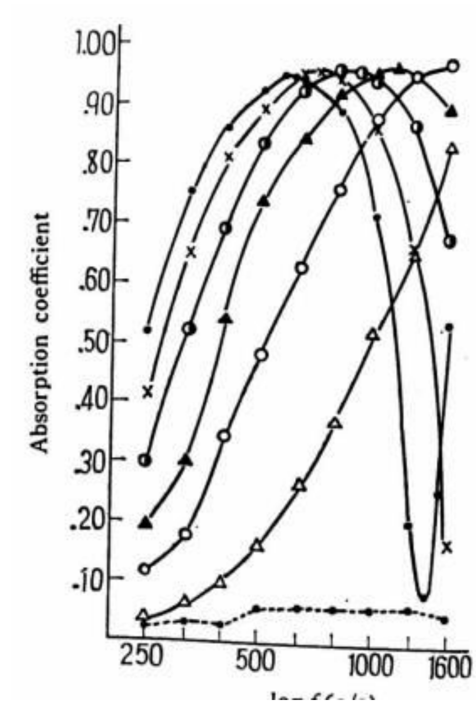

Fig.3 Absorption characteristics of fabric T2

When d=2cm, the absorption coefficient increases abruptly with frequency. If the air space is thicker than a certain dimension, the maximum value of the absorption coefficient shows. Within the range of measuring frequency. That value shows at lower frequency as the air space gets thicker.

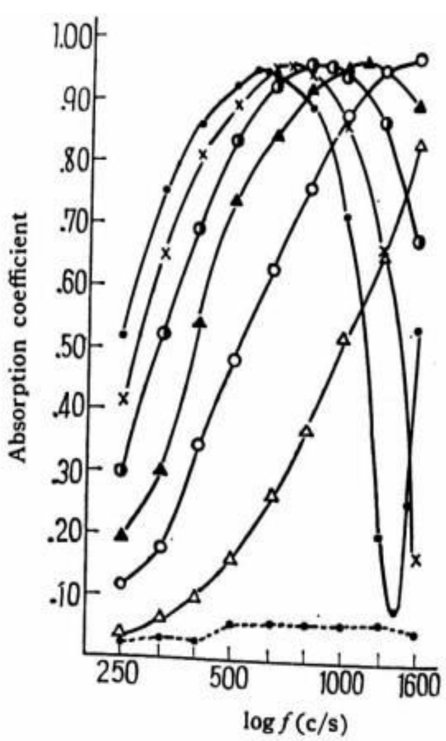

Fig. 4 Absorption characteristics of fabric T3.

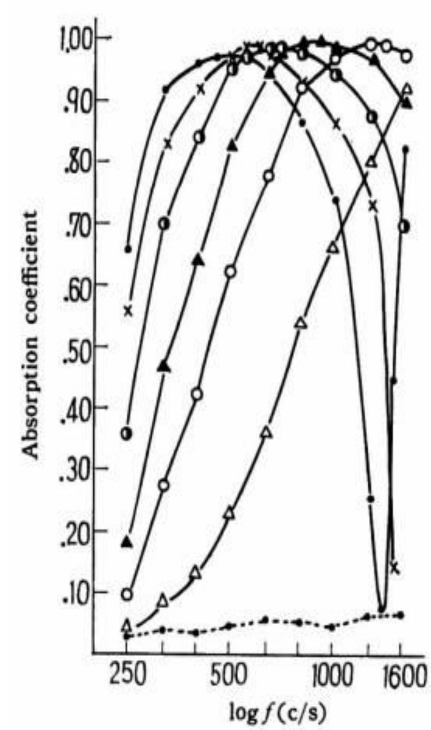

Fig.5 Absorption characteristics of fabric T4

In general, T1⁝T4 have similar absorption properties, and regardless of the air space behind the samples, their maximum absorption coefficients remain constant. The maximum absorption coefficients of T5⁝T7 exhibit variability based on the air space depth, reaching their greatest value at the following depths: Every cloth has the lowest absorption coefficient at 1,400 c/s when d is 12 cm. We used the air space's depth as a variable when tabulating the measurement's findings. The connection between the absorption coefficients at 1,600 c/s and the air space depth, for instance, is seen in Fig. 9. At other frequencies, the same absorption properties were also observed. The commonality across the absorption characteristics of T1⁝T7 is that the absorption coefficient has a minimum at d=0 and λ/2.

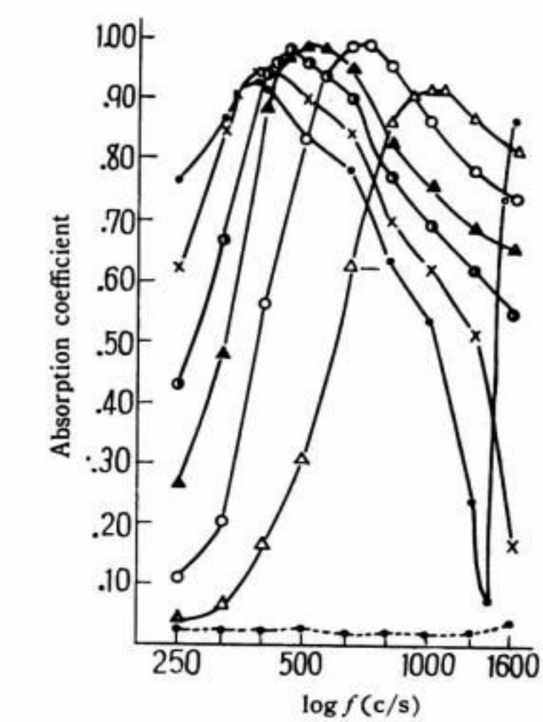

Fig. 6. Absorption characteristics of fabric T6

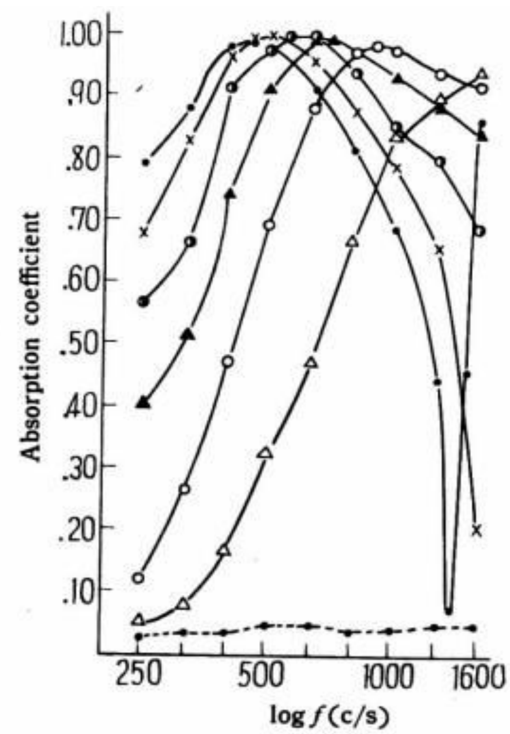

Fig.7. Absorption characteristics of fabric T5

The point where the air space is marginally thinner than λ/4 is where the greatest value of T appears. The air area that yields the highest value thins down in an inverse proportion to the symbols T2 through T7's ascending sequence. The T1–T4 characteristic curves are smooth, convex curves, but the T5–T7 characteristic curves are asymmetrical.

Fig. 10 illustrates the relationship between d and freguency fo, which provides the greatest absorption coefficient, when a fabric has air space behind it.

The grade for the solid lines is -1; the dotted lines,

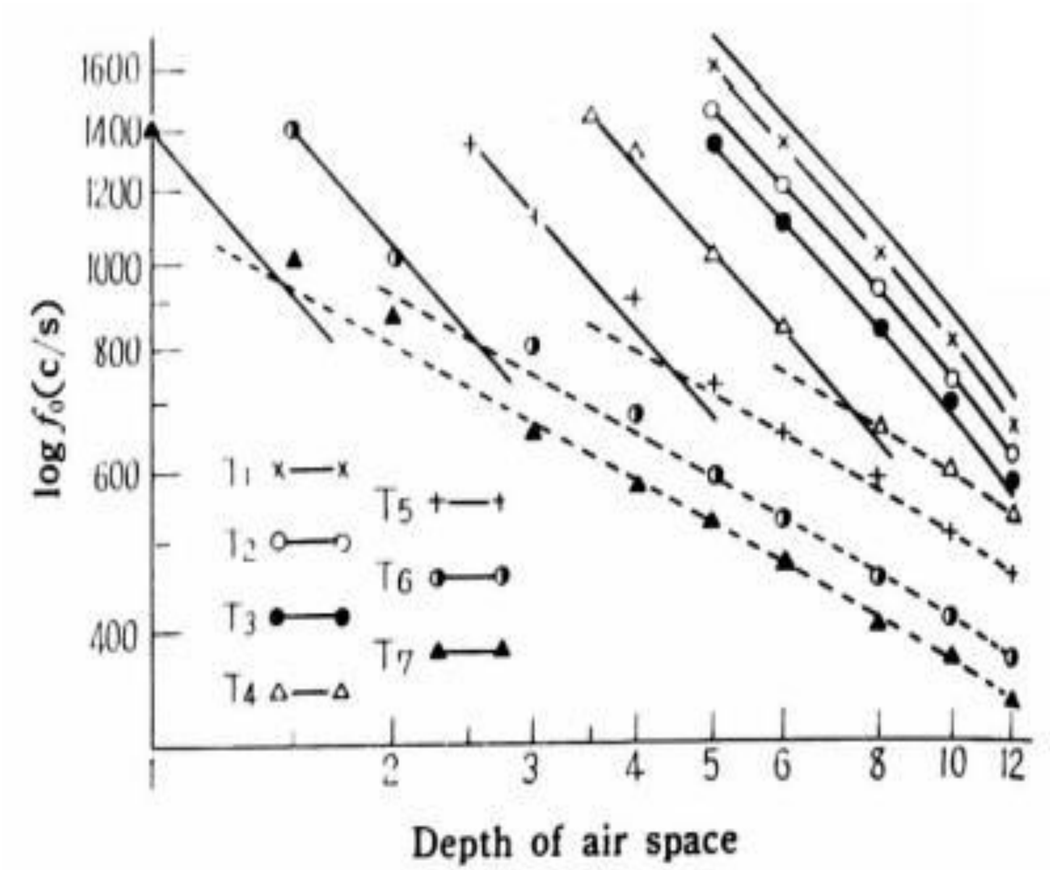

Fig.9. Relation between depth of air space and frequency (fo) at which a sample shows maximum absorption coefficient.

The relations for fabrics T1-T3 are shown by the lines of grade -1. The relations for T4-T7 make lines of grade -1 when the air Fig. 10 Relation between depth of air space and frequency (fo) at which a sample shows maximum absorption coefficient space is thick, and line of grade -1/2 when the air space is thin. Therefore, the relation between f0 and d in fabric Ti is shown as follows, depending on whether the grade is -1 or -1/2:

$$f_0 = K_t d^{-1}$$ ……………..5

$$f_0 = k_t d^{-1/2}$$ …………………….6

K0 and ki are proportional constants and become smaller with the advance of the suffix numbers of the fabric from T1 to T7

DISCUSSION:

In a sound field, think about the energy that a cloth uses to generate a sound wave. Viscosity between the thread and air surfaces causes the air vibration energy (sound wave energy) to be first absorbed in thermodynamic energy form when a sound wave travels through the fabric. The vibrations of the fibres also consume it. If the fabric's absorption process is like this, there should be a greater energy loss when the cloth is in an area with high particle velocities. Let's now examine the particle velocity within the tube. There are the following symbols in use:

Where x: the distance from the surface of the rigid wall, Φ: the velocity potential of a standing wave, Φi: the velocity potential of an incident wave,

The velocity of the standing wave in the tube being shown by Re(-∂ Φ/∂x), the velocity is:

V=k{(Ar+Ai)sin kx cos ωt-(Ar-Ai)cos kx sin ωt}…………7

The demonstrates that the particle's velocity, or velocity amplitude, is lowest on a rigid wall's surface, largest at a position λ/4 from the wall, and again lowest at λ/2.

Figure 11: Particle velocity distribution of a standing wave in a tube

As seen in Figure 9, sound energy is used more when textiles T1□T3 are placed at the maximum point of the particle velocity, which is about d=λ/4. This is because there is maximal frictional resistance between the fabric's threads and the air at this location. If the fabric has the maximum point of particle velocity in eq. (8), the relation between the frequency fo and the depth of the air space d is shown as follows in the light of the foregoing experimental results:

$F = C d^{-1/4}$ …………………8

It is shown in Fig. 10 as the complete line without any markers.If the measurement findings allow eq. (5) to demonstrate the relationship between f0 and d, then that relationship is of the same kind as eq. (9) and might be interpreted as an absorption mechanism of the viscosity resistance type. In T4～T6, the relationship between f0 and d in vast air spaces is represented by equation (6), suggesting the existence of an additional mechanism for sound wave absorption. Nonetheless, a characteristic shared by T1～T7 is that, in the case of 0 or λ/2 air space depth, their absorption coefficients are minimal. Stated differently, if any cloth is positioned at the particle velocity minimum, As for fabrics of the non-viscosity resistance type, it is thought that energy consumption occurs because the sound wave vibrates the system composed of the fabric and the air space behind it. Let us, then, analyze the resonance mechanism of this system. Because the vibrations in the fabric are so minute, all of the subsequent studies assume that the displacement caused by the vibrations is uniform across the cloth. (a) Assume that a fabric does not allow air to pass through it and that the sample's whole surface is made of the fabric. The balancing formula of the force in the single-resonance system, which views the fabric as a mass and the air space behind the fabric as stiffness, is as follows when a sound wave operates on the whole surface of the sample as a force to create vibrations:

$$M\frac{d^2u}{dt^2} + r\frac{du}{dt} + \frac{KS}{d}u = SP_0e^{i\omega t}$$ ……………….9

$$f_{res} = (SK/Md)^{1/2}/2\pi$$ ………………10

$$f_{res} = \frac{C}{2\pi}(\rho/m)^{1/2}d^{-1/2}$$ ………………..11

$$(M + Fl_0\rho)\frac{d^2u}{dt^2} + r'\frac{du}{dt} + \frac{KS}{d}u = SP_0e^{i\omega t}$$ ………………12

The resonance frequency, then, is:

$$f_{res} = \frac{c}{2\pi} \left\{ \rho/(m + Pl_0\rho) \right\}^{1/2} d^{-1/2}$$ ……………………………13

Notice only the open space of the fabric and assume that the fabric is unaffected by sound wave. In other words, think of air in the open space of the fabric as a mass and air space behind the fabric as a stiffiness.

$$(F\rho l_0)\frac{d^2u}{dt^2} + r''\frac{du}{dt} + \frac{KF^2}{sd}u = FP_0e^{i\omega t}$$ ………………………..14

The following three problems are reserved for discussion on a future occasion: (1) How does the open space of the fabric act in the mechanism of resonance absorption? (2) Why does not the depth of the air space which gives the maximum absorption coefficient, completely equal the position of the maximum particle velocity if the fabric is of the viscosity resistance type?, (3) Why does the same fabric vary from the viscosity resistance type to the resonance type if the depth of air space behind it increases?

CONCLUSIONS

The normal incident absorption coefficients of seven cotton textiles with varying densities were determined using the tube technique. We have discovered that textiles contain one or both of two types of absorbing processes, and that their absorption properties change with their densities. One is the viscous resistance type, where absorption happens as a result of energy loss caused by sound waves travelling through the fabric and overriding the frictional resistance between the air in the fibre. The other is the resonance kind, where absorption happens as a result of the sound wave vibrating the system made up of the elastic air space behind the fabric and the fabric itself. The following is the expression for these two types: (1) fo=Kid-1 (the viscosity resistance type) (2) fo=kcd-1/2 (the resonance type) where d is the depth of the air space behind the fabric and fo is the frequency which shows the maximum absorption coefficient at the same d.

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