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Differences in absorption coefficient determination using the Sabine and Millintong-Sette equations for different samples of natural virgin cork

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Abstract
Absorbent materials are frequently used in acoustic solutions to improve people's feeling of comfort and well-being. The ISO 354:2003 standard provide a standardised procedure for the characterisation of their absorbing properties in a reverberation chamber. The formula used in ISO 354:2003 for the calculation of reverberation time is known as the Sabine formula, but it provides values of the absorption coefficient that in some cases are higher than 1. Other alternative formula such as that of Millintong-Sette is proposed in the scientific literature. Considering different samples of natural virgin cork with reduced industrial exploitation, a study was conducted to analyse the differences in the sound absorption coefficients determined with Sabine and Millington-Sette equations, finding variations of up to 28%.

Keywords: reverberation time, sound absorption, reverberation chamber, ISO 354:2003, building material

1 Introduction

Acoustic comfort in dwellings is an issue studied in the scientific literature because of its relationship with the residents' feeling of well-being [1,2]. But it is also an aspect to be taken into account in the satisfaction of users in libraries, music halls, conference rooms, as well as customers in restaurants, coffee shops, stores and other types of venues for public use [3,4,5]. Therefore, a design phase of acoustic solutions for sound insulation and acoustic conditioning in the original construction project of building would be beneficial in this regard [6,7].

The search for materials applicable in solutions that contribute to the improvement of the acoustic insulation of buildings with respect to the environmental noise [8,9,10] and noise transmitted between indoor enclosures [11,12], as well as acoustic conditioning [13,14,15], is a line of work addressed in the scientific literature. Martellota et al. [16] studied the behaviour of sound absorbers obtained from olive pruning wastes and chitosan binder under normal incidence conditions in an impedance tube. Khan et al. [17] tested some samples of sound absorbers made from recycled granulates using the small impedance tube according to ISO 10534-2 [18]. Berardi and Iannace [19] carried out experimental tests in a tube for the acoustic characterization of natural fibers for sound absorption applications. In this context, the ISO 354:2003 [20] and ISO 11654:1997 [21] standards are often considered for the determination of sound absorption coefficient (α_s) as well as the practical (α_p) and weighted (α_w) sound absorption coefficients in a reverberation chamber [22,23].

The ISO 354:2003 standard [20] proposes the use of the Sabine equation to calculate the equivalent sound absorption area (A_T), a parameter from which the absorption coefficient can be calculated. The comparison of materials using the Sabine equation according to ISO 354:2003 standard [20] is perfectly possible and accepted in the scientific literature [22,23]. However, values of this coefficient higher than 1 may result in some special cases with the Sabine equation [24,25,26,27]. If the absorption coefficient of a material is understood as the ratio between the absorbed and incident energy, this fact raises an interesting question from a physical point of view and discussed by researchers concerning the specific case of concert hall audience and chair absorption [27,28,29]. Based on the results of experimental tests, Eyring, C [30] indicated that the failure of Sabine's formula occurs when the average absorption coefficient of a room is quite high (above 0.5). More recently, Beranek, L. [27] pointed out that Sabine absorption coefficients must be able to take all values from zero to infinity and that the concept that a Sabine coefficient of 1.0 is equivalent to complete sound absorption by a surface is false. This study also showed some differences between the values for the absorption coefficient calculated from the Sabine and Eyring equations in different halls. The values derived from the Sabine equation were higher and the difference between them was greater as the value of the absorption coefficient increased.

Taking into consideration this scientific discussion of the Sabine equation and given that it is used in the ISO 354:2003 standard [20], its application in engineering consultancy may become a problem in some cases. In this context, it seems interesting to compare the results of alternative formulas for the calculation of the absorption coefficient. This manuscript presents a comparison between the results obtained using the Sabine equation and that proposed by Millington-Sette [29,31,32] in the calculation of the sound absorption coefficient (α_s), the practical (α_p) and weighted (α_w) sound absorption coefficients with random sound incidence in a standardised reverberation chamber for some samples of natural virgin cork.

2 Methodology

In this paper, experimental investigations with different samples of virgin natural cork were performed in a normalised reverberation chamber to determine their sound absorption coefficient (α_s) as well as the practical (α_p) and weighted (α_w) sound absorption coefficients with random sound incidence according to the guidelines of ISO 354:2003 [20] and ISO 11654:1997 [21]. Figure 1 shows two small pieces of natural virgin cork with the outer bark facing upwards (Fig. 1a) and downwards (Fig. 1b) from which the samples studied were made.

(a) **(b)**

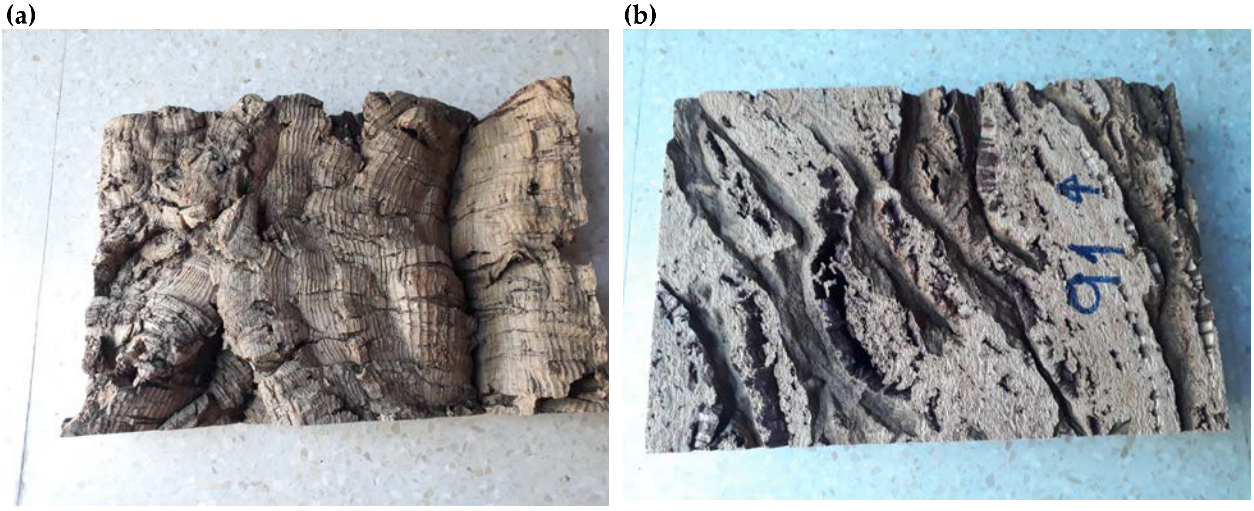


Figure 1 – Small pieces of virgin cork where outer bark faces: (a) upwards; (b) downwards

Since the analysis presented in this paper is based on the results obtained from a previous publication [23], in which all the details of the methodology such as the cork sample collection and treatment, the testing methodology, the samples analysed and the calculation method are described, a brief description of the methodology is included.

For the reverberation time (RT) measurements, the interrupted noise signal method with pink noise was employed and 12 source-microphone combinations were considered. The reverberation time was obtained in the third octave bands between 100 Hz and 5 kHz.

Three samples of natural virgin cork were designed for the tests and placed on the floor of the reverberation chamber according to the indications of the type A mounting of annex B of the ISO 354:2003 standard [20]. Table 1 describes the main characteristics of samples S1, S2 and S3. In the case of samples S1 and S2, they had an area of 10.2 m^2 and an average thickness of 6 cm. In sample S1, the outer bark of the cork was facing upwards, while in S2 it faced downwards. Sample S3 was a decorative absorbent panel proposed as a final product. While the edges of S1 and S2 were covered with an acoustically reflective frame following the indications of the ISO 354 standard, in S3 they were not covered because the standard indicates that this should be the case for those samples that are commonly exposed in a real application.

Table 1. Characteristics of the virgin cork samples S1, S2 and S3

Sample	**Description**	**Area (m^2)**	**Average thickness (cm)**
S1	Outer bark facing upwards	10.2	6
S2	Outer bark facing downwards	10.2	6
S3	Decorative absorbent panel made of S1 and S2	10.1	4

Concerning the calculation method for the absorption coefficients, the sound absorption coefficient (α_s) was first determined for each of the three samples of natural virgin cork by means of Equation 1, where A_T is the equivalent sound absorption area and S is the area of the test sample. The specifications of ISO 354:2003 [20] standard were followed to this end. The practical (α_p) and weighted (α_w) sound absorption coefficients of each sample was then calculated in accordance with the procedure of ISO 11654 [21].

$$\alpha_s = A_T / S \quad (1)$$

The formula used in ISO 354:2003 [20] for the calculation of reverberation time is known as the Sabine formula (Equation 2). Although the use of this equation is widely accepted for comparing materials, given the discrepancies about the values obtained for the absorption coefficient in some cases [24,25,26,27], a wide discussion was raised in the scientific literature [27,28,29,30] and other alternative formula for the calculation of reverberation time such as that of Millintong-Sette (Equation 3) was proposed [29,31,32].

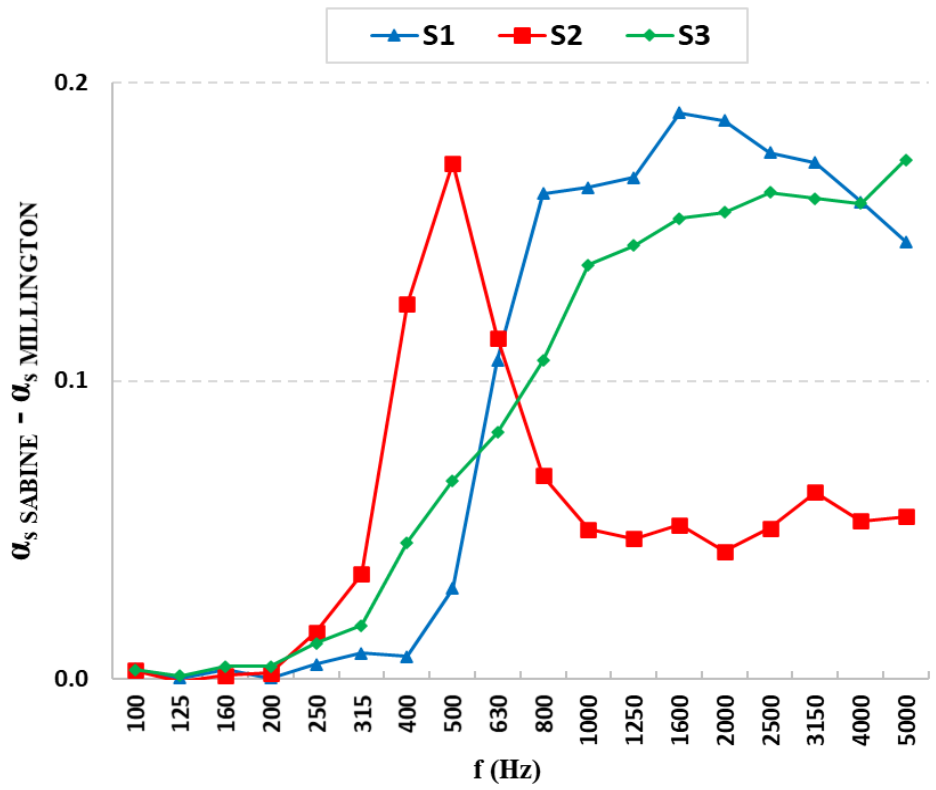
$$RT_{\text{Sabine}} = \frac{0.162 \cdot V}{S \cdot \alpha_m} \text{ or } RT_{\text{Sabine}} = \frac{0.162 \cdot V}{\sum S_i \cdot \alpha_i} \quad (2)$$

$$RT_{\text{Millington-Sette}} = \frac{0.162 \cdot V}{\sum S_i \cdot [-\ln(1-\alpha_i)]} \quad (3)$$

3 Results and discussion

In this section, a comparison is made between the results obtained using the Sabine equation (Equation 2) indicated in ISO 354:2003 and that proposed by Millington-Sette (Equation 3) in the calculation of the sound absorption coefficient (α_s), together with the practical (α_p) and weighted (α_w) sound absorption coefficients with random sound incidence in a standardised reverberation chamber for samples S1, S2 and S3 of natural virgin cork. Figure 2 shows the values of the difference between the coefficients α_s (Figure 2a) and α_p (Figure 2b) calculated using the Sabine (Equation 2) and Millintong-Sette (Equation 3) equations. If the values of the absorption coefficients of the three samples are observed in [23] (they were not greater than 1 in any case), a relationship between the magnitude of $\Delta\alpha_s$ and $\Delta\alpha_p$ and the value of the corresponding absorption coefficient can be found. That is, the difference between the absorption coefficients calculated with the Sabine (Equation 2) and Millington-Sette (Equation 3) equations increases as the value of the absorption coefficient increases. The maximum $\Delta\alpha_s$ value obtained for samples S1, S2 and S3 is 0.19 for an $\alpha_{s\ \mathrm{SABINE}}$ value of 0.68, which represents a variation of up to 28% with respect to the calculated $\alpha_{s\ \mathrm{SABINE}}$ value. Similar results were found for α_p. These values of $\Delta\alpha_s$ and $\Delta\alpha_p$ implied a slight variation of 0.05 in the α_w coefficient of the tested samples, which did not translate into a variation in the sound absorption classification in accordance with the ISO 11654:1997 standard (Table 2).

(a)



(b)

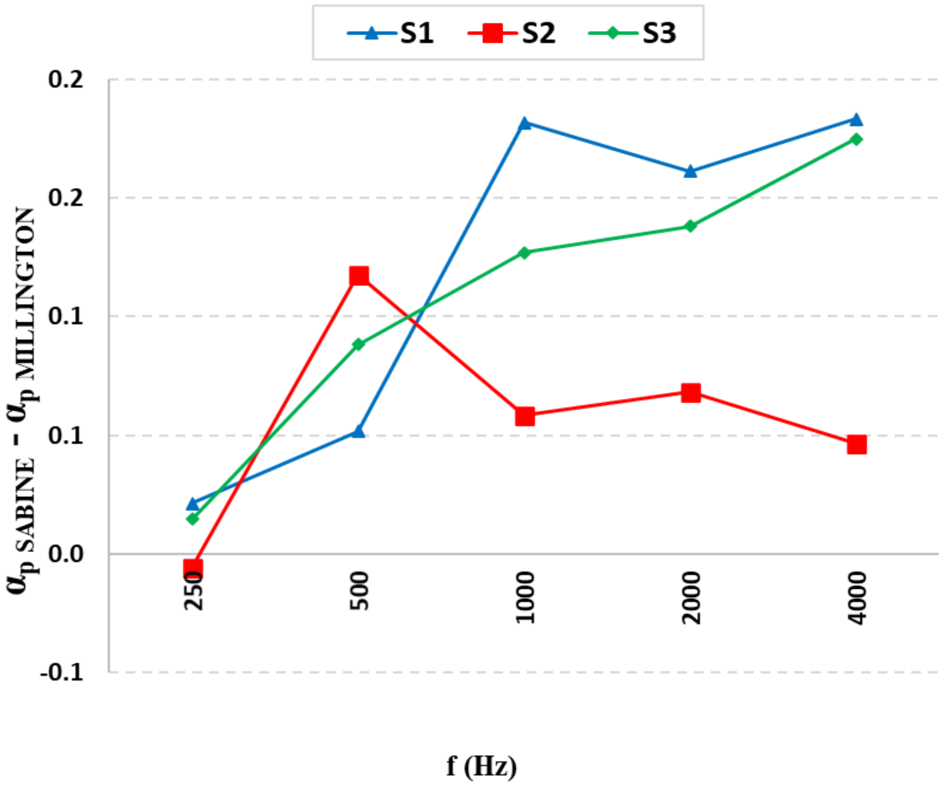


Figure 2 – Differences between Sabine and Millington-Sette sound absorption coefficients for samples S1, S2 and S3: (a) α_s; (b) α_p

Table 2. Sabine and Millington-Sette weighted sound absorption coefficients and sound absorption classification for samples S1, S2 and S3.

Sample	$\alpha_{w\ SABINE}$	$\alpha_{w\ MILL.}$	Sound absorption classification (SABINE - MILL.)
S1	0.35	0.30	D - D
S2	0.35	0.30	D - D
S3	0.40	0.35	D - D

Since a proportional relationship was found for $\Delta\alpha_s$ and $\Delta\alpha_p$ with respect to the value of $\alpha_{s\ SABINE}$ for the samples of virgin cork studied in the reverberation chamber, higher values of $\Delta\alpha_s$ and $\Delta\alpha_p$ could be found in materials with higher $\alpha_{s\ SABINE}$, as is the case of sheep wool and PET [13,22]. Some researchers compared Sabine's absorption coefficient with others such as Eyring's proposal [30]. Beranek, L. [27] found a ratio of Eyring to Sabine coefficients of about 0.85 in concert halls and lower than 0.5 in rooms with short reverberation times. This indicates that the characteristics of the room may influence the results. It would therefore seem interesting to extend research in this direction to find out whether this is transferable to experimental tests in different standardised reverberation chambers. But Beranek, L. also found that the values for the absorption coefficient from the Sabine equation were greater than those from Eyring equation and the difference between them increased as the value of the absorption coefficient rose. Therefore, taking into account the difference in the results of the sound absorption coefficient with the Sabine and alternative equations, it might be interesting to consider the possibility of using these other equations in engineering consultancy applications.

4 Conclusions

This paper presents a comparison between the results obtained using the Sabine and Millington-Sette equation in the calculation of the sound absorption coefficient (α_s), the practical (α_p) and weighted (α_w) sound absorption coefficients with random sound incidence in a standardised reverberation chamber for some samples of natural virgin cork.

A variation of up to 28% in the coefficient αs was found in the calculation with the Sabine and Millington-Sette equations, with similar values for α_p. These variations ($\Delta\alpha_s$ and $\Delta\alpha_p$) showed a relationship with the value of the corresponding absorption coefficient. That means that the difference between the absorption coefficients calculated with the Sabine and Millington-Sette equations increases as the value of the absorption coefficient increases. Only a slight variation of 0.05 in the α_w coefficient of the samples was found, which did not translate into a variation in the sound absorption classification indicated in the ISO 11654 standard.

Considering the difference in the results derived from the Sabine and alternative equations, an interesting discussion could be raised on the question of using these other equations in engineering consultancy applications.

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