Experimental verification of how relative air humidity influences the results of sound absorption coefficient measurements in model tests

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Summary

Performing sound absorption coefficient measurements in a model reverberation chamber requires scaling all the elements with given similarity criteria. One of them is air absorption, in scaled models most commonly regulated by relative air humidity, which is usually kept below 5%. However, the process of drying the air is time consuming and difficult to perform, which makes the measurement procedure problematic. This raises a question if there is a possibility to change or simplify it. To answer this question the authors performed a series of sound absorption coefficient measurements in a one-to-eight scale reverberation chamber for different values of relative air humidity (3% - 35%). Eleven diverse materials used for the measurements were chosen based on their flow resistivity. Gathered data was then statistically tested, using the one-way analysis of variance and post-hoc tests, which enabled to choose three representative materials for further measurements. In the main study sound absorption coefficient of the chosen materials was measured with better resolution of relative air humidity (5% to 45%, 2-3% step) and a profound statistical analysis was carried out to verify the initial assumption. The results show that the influence of relative air humidity on the final results of the measurements is negligible and therefore the measurements can be performed in a regular air humidity of a chamber. As statistical analysis shown, to improve the accuracy of the measurement additionally, one can repeat the procedure in several different air humidity values and then take an average result. Proposed solution, which is a substitution for commonly used air drying, allows considerable savings of time and efforts while performing the measurements.

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1. Introduction

Drying the air is one of the ways of lowering the air absorption inside a model reverberation chamber during the measurement of sound absorption coefficient of scaled samples[1]. However, it is time-consuming and requires specialized equipment. On the other hand, other methods of dealing with excessive air absorption in model reverberation chambers, such as digital compensation, may not be equally effective and may introduce errors, especially in the highest frequency bands [2–4]. The following paper briefly describes a research which was conducted in order to verify if drying the air inside a reverberation chamber in order to lower the air absorption is necessary to obtain correct results of the sound absorption coefficient measurements. This research has explicitly pointed that the results of the measurement do not depend on the relative air humidity inside the chamber. However, slight differences in the results may be observed, no matter the air humidity. This is because the measurement is influenced by many other factors, such as the air temperature, the way a certain person performs the measurements, the conditioning of the equipment, etc. In order to mitigate the influence of all those factors and increase the accuracy of the measurements, the Stein's method was proposed and will be described in detail.

2. Air humidity vs sound absorption coefficient

The research aimed at the determination of the influence of relative air humidity on the results of sound absorption coefficient in model tests consisted of two steps. It was based on the fact that this measurement procedure is indirect, and therefore the impact of air humidity on the final result of the measurement may be eliminated. In the first step, the preliminary measurements, eleven different materials were chosen to be tested, based on their varying flow resistivity. The absorbing properties of the materials were measured in a 1:8 scale model of a reverberation chamber of the Department of Mechanics and Vibroacoustics AGH. The measurement procedure was based on the ISO 354 requirements. The measurements of the reverberation times were taken in twelve independent source-receiver combinations. The Dirac v5.0 software was applied. The measurements were taken in different relative air humidity values, varying from 3% to 35%. A detailed description of the measurement stand, procedures and the materials properties can be found in [5]. The obtained values were then statistically tested in order to divide the materials into groups and choose a representative of each group. The results were statistically tested using the one way analysis of variance ANOVA and post-hoc tests. If the samples did not come from a normal distribution, instead of using ANOVA, the Kruksall-Wallis test was applied, which is a non-parametric version of ANOVA. When the ANOVA test was used, in the post-hoc analysis the Tuckey's test was applied, and if the Kruksall-Wallis test was used in the first step, the Dunn's test was chosen for the post-hoc analysis. The whole analysis led to the formation of three groups characterized by different variation coefficients and choosing the representatives:

- material 4 (M4) – the group of low variation coefficient,
- material 5 (M5) – the group of average variation coefficient,
- material 10 (M10) – the group of high variation coefficient.

In the main study three previously chosen materials were tested. The range of air humidity was expanded to 5-45%, with the step of about 2%. The measurement procedure remained the same. The results for the material 5 (M5), which show the general trends, are presented in Figure 1.

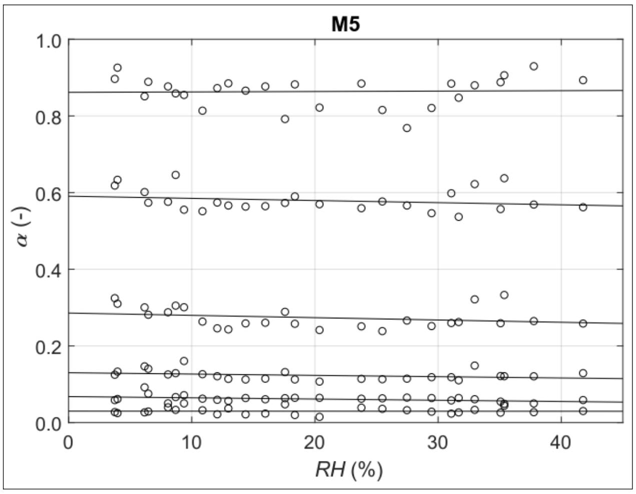

Figure 1. Sound absorption coefficient of material 5 (M5) measured in different relative air humidities. The lines are regression lines for the frequencies: 1 kHz, 2 kHz, 4 kHz, 8 kHz, 16 kHz and 32 kHz from the botton to the top of the graph.

In order to statistically determine how the values of relative air humidity influence the results of sound absorption coefficient measurements, the regression lines for the results obtained in different relative humidities were determined, for each material. The regression line takes the form:

$$\alpha = \beta_1 \cdot RH + \beta_0, \quad (1)$$

where $\beta_1 = r\frac{s_\alpha}{s_{RH}}$ and $\beta_0 = \bar{\alpha} - \beta_1 \cdot \overline{RH}$, RH is the relative air humidity value (%), r is a correlation coefficient for α and RH, s_α and s_{RH} are the standard deviations of sound absorption coefficient and relative air humidity values and $\bar{\alpha}$ and $\overline{RH}$ are the mean values of α and RH. It can be noted that when the value of β_1 is not statistically significant, it can be assumed to be equal to 0 and α can be modeled as the mean value of the measurement results. As a matter of fact, the Fisher test indicated that it is true for all the materials and all the frequency bands except three. Taking into account, that even these values are negligible in a practical sense (fourth digit after the decimal point), the thesis that the relative air humidity does not influence the results of sound absorption coefficient measurement has been proven.

3. Improving the accuracy of the measurement

3.1. Stein's Method

As it was previously mentioned, relative air humidity is not the only variable affecting the results of the sound absorption coefficient measurements. The results can also be influenced by the conditioning of the equipment, the way a certain person performs the measurement or air temperature fluctuations. To reduce the impact of the external factors on the final results, the conclusion that the arithmetic mean value is the best estimation of the actual sound absorption coefficient was reached. Instead of drying the air to get an accurate result, one can perform a number of measurement procedures at different random *RH* values and take an average. The final result is then within the confidence interval of a length *2l*, at the level of confidence $1-\delta = 0.95$. The length *2l* depends on the number of elements in the sample. The more numerous it is, the shorter the confidence interval *2l* is.

The procedure which allows the estimation of the minimal number of elements required in the sample to get a result within a confidence interval $2l$ is that which was proposed by Stein [6]. Firstly, n_0-element sample is drawn from the population of a normal distribution. The minimal number of elements in the sample is then given by the formula:

$$n = \left[\left(t\left(1-\frac{\delta}{2}, n_0 - 1\right)\frac{s_\alpha}{l} \right)^2 \right] + 1, \quad (2)$$

where $[\cdot]$ is a floor function and $t\left(1-\frac{\delta}{2}, n_0-1\right)$ is the $1-\delta/2$ quantile of t-student distribution of $n_0 - 1$ degrees of freedom. In the case where $n > n_0$, more samples must be drawn and the procedure should be repeated. If $n < n_0$, one can assume that $k = \left[\left(t\left(1-\frac{\delta}{2}, n_0 - 1\right)\frac{s_\alpha}{l} \right)^2 \right] + 1$ is the minimal number of elements in the sample.

To check whether the procedure described above can be applied for the data gathered, the normality tests of the samples distributions were performed. The Shapiro-Wilk (S-W) and the Lilliefors tests were chosen. Both tests were performed on each sample, as they use different statistics to assess the normality. The evaluation of the normality of each sample is based on the analysis of p-values obtained in the tests. If the p-value is greater than the chosen level of significance of the test, δ= 0.05, the null hypothesis (that the distribution is normal) is accepted, if p value is less than 0.01 the hypothesis is rejected. Any p-values between 0.01 and 0.05 indicate an inconclusive result. In general, the normality of the samples was confirmed and if it was not, the deviations from normality were minor, which is still acceptable by the Stein's procedure.

3.2. Results

Figure 2. shows how many measurement procedures of the sound absorption coefficient need to be performed in each frequency band to obtain the results within the 95% confidence interval (for unknown, estimated value of α) no longer than $2l$. The value of $2l$, in this case equal to 0.1 was considered to be sufficient on the basis of previous experience in this kind of measurements.

The problem can be also presented in an inverse way – what length of the confidence interval will be achieved if the measurement procedure is repeated an arbitrary number of times? Table 1 shows the lengths of the confidence interval of sound absorption coefficient measurement results which need to be given in the Stein's procedure to

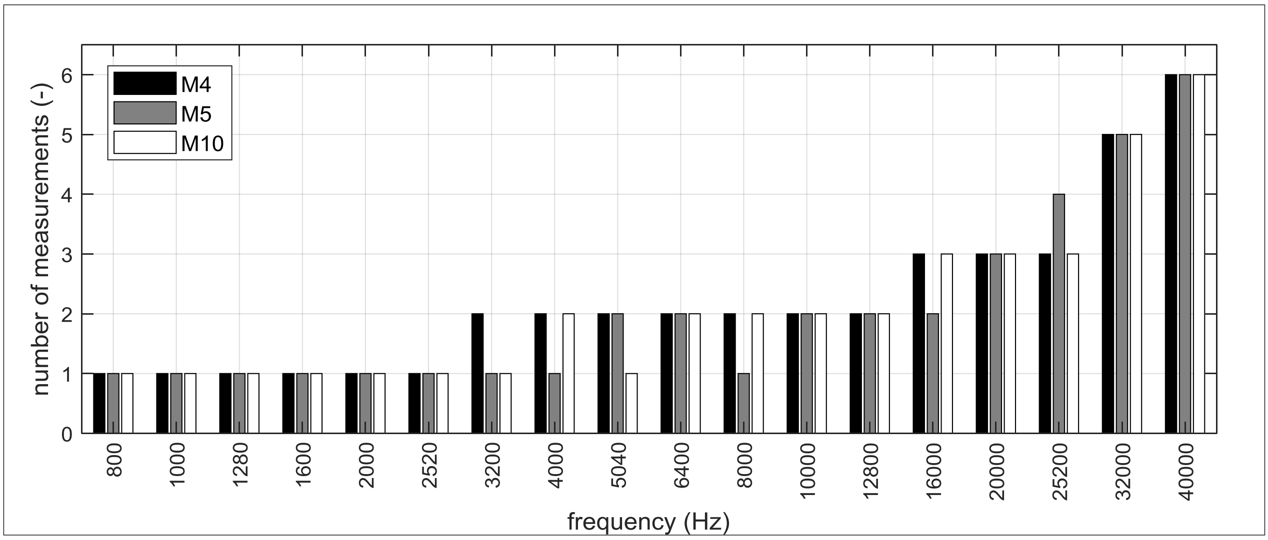

Figure 2. Number of measurement results which need to be averaged to obtain the final value of sound absorption coefficient within the confidence interval of $2l = 0.1$ – data for materials M4, M5 and M10

obtain the minimal number of elements to be averaged equal to 1, 2 or 3. It can be noted that *2l* increases with the frequency; however, high frequencies are rarely an issue in modeled spaces, so this uncertainty may be accepted for some applications. One should also remember that the final results do not only depend on the relative air humidity but also on many random factors. Nevertheless, the obtained lengths of the confidence interval for the performed scale measurements do not vary from the ones in full-scale ISO measurements [7]. One should remember that the values presented in this paper are characteristic for the chosen materials, the laboratory stand in use and the applied procedure. They can be used as an example to follow with caution, however, the Stein's procedure should be applied individually in order to obtain reliable results.

Table 1. The length of the confidence interval *2l* which needs to be given in the Stein's procedure to obtain the minimal number of elements in a sample equal to 1, 2 or 3 – calculated for materials M4, M5 and M10

Material	**M4**			**M5**			**M10**		
f (Hz) / **Number of Meas.**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
800	0.034	0.024	0.020	0.038	0.028	0.022	0.068	0.040	0.030
1000	0.036	0.026	0.022	0.036	0.026	0.022	0.062	0.036	0.028
1280	0.058	0.042	0.034	0.026	0.018	0.016	0.072	0.042	0.032
1600	0.058	0.042	0.034	0.032	0.022	0.018	0.082	0.048	0.036
2000	0.060	0.042	0.034	0.036	0.026	0.020	0.082	0.048	0.038
2520	0.060	0.042	0.036	0.042	0.030	0.024	0.098	0.058	0.044
3200	0.078	0.056	0.046	0.044	0.032	0.026	0.094	0.056	0.042
4000	0.074	0.052	0.042	0.054	0.038	0.032	0.112	0.066	0.050
5040	0.086	0.062	0.050	0.074	0.052	0.044	0.090	0.052	0.042
6400	0.086	0.062	0.050	0.084	0.060	0.048	0.128	0.074	0.058
8000	0.066	0.046	0.038	0.114	0.080	0.066	0.128	0.074	0.058
10000	0.118	0.084	0.068	0.126	0.090	0.074	0.168	0.098	0.076
12800	0.094	0.066	0.054	0.140	0.100	0.082	0.164	0.094	0.074
16000	0.114	0.082	0.066	0.120	0.086	0.070	0.188	0.110	0.084

20000	0.126	0.090	0.074	0.146	0.104	0.084	0.206	0.120	0.092
25200	0.176	0.126	0.102	0.142	0.100	0.082	0.212	0.122	0.096
32000	0.190	0.134	0.110	0.160	0.114	0.092	0.276	0.160	0.124
40000	0.216	0.152	0.124	0.152	0.108	0.088	0.306	0.176	0.138

4. Conclusions

The authors formed a hypothesis that the relative air humidity inside a reverberation chamber does not influence the final results of sound absorption coefficient measurements in model studies. In order to verify this hypothesis, eleven different materials were chosen to be tested in a 1:8 scale reverberation chamber. A profound statistical analysis was carried out and it resulted in confirming the hypothesis given by the authors – the influence of relative air humidity on the sound absorption coefficient measurement in model tests is negligible. However, some discrepancies between the results of single measurements could be observed, caused by other external factors. To improve the accuracy of the measurement and eliminate the influence of this factors, the Stein's method was suggested. This method allows to define a number of measurements to be averaged in order to obtain the final result with a given confidence interval. Exemplary calculations have been presented, showing how many the measurement procedure must be taken to obtain the final results within a confidence interval of 0.1. Then, the same method was used to calculate the confidence interval if the procedure is repeated a fixed number of times, i.e. 1, 2, or 3. In conclusions, the authors indicated that the influence of relative air humidity on the results of the sound absorption coefficient measurements in model tests is negligible and proposed a method to increase the accuracy of this measurement. Instead of drying the air in the chamber, the measurement procedure should be repeated a number of times in different relative air humidity values (which naturally changes over the time) and the average result should be taken. This method not only allows better accuracy of the measurement but also allows a simplification of the laboratory stand, by eliminating the drying apparatus.

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