

# CORRELATION BETWEEN SPECIFIC GAS PERMEABILITY AND SOUND ABSORPTION COEFFICIENT IN SOLID WOOD

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Received November 2012

**TAGHIYARI HR, ZOLFAGHARI H, SADEGHI ME, ESMAILPOUR A & JAFFARI A. 2014. Correlation between specific gas permeability and sound absorption coefficient in solid wood.** Correlations were found between specific gas permeability values and sound absorption coefficients in five solid wood (poplar, beech, walnut, mulberry and fir) with different specimen lengths and directions (longitudinal and tangential). Permeability was measured in 10- and 50-mm long longitudinal as well as 10-mm long tangential specimens. Absorption coefficients were also measured at four frequencies, namely, 800, 1000, 2000 and 4000 Hz. High correlation was observed in 50-mm long longitudinal specimens between specific gas permeability and absorption coefficients at different frequencies. However, insignificant correlations were observed in 10-mm long specimens, both in longitudinal and tangential directions. Mulberry showed the lowest absorption coefficient. Cluster analysis showed that mulberry had different clustering from the other four species.

**Keywords:** Frequency, fluid flow, non-destructive tests, porous, ultrasonic techniques, vacuum pressure

**TAGHIYARI HR, ZOLFAGHARI H, SADEGHI ME, ESMAILPOUR A & JAFFARI A. 2014. Korelasi antara kebolehtelapan gas spesifik dengan pekali penyerapan bunyi dalam kayu padu.** Korelasi dicarap antara nilai kebolehtelapan gas spesifik dengan pekali penyerapan bunyi dalam lima kayu padu (poplar, bic, walnut, mulberi dan fir) yang mempunyai panjang spesimen serta arah keratan (memanjang dan tangen) yang berbeza. Kebolehtelapan disukat pada spesimen berkeratan memanjang yang panjangnya 10 mm dan 50 mm serta spesimen berkeratan tangen yang panjangnya 10 mm. Pekali penyerapan juga disukat pada empat frekuensi yang berlainan iaitu 800 Hz, 1000 Hz, 2000 Hz dan 4000 Hz. Korelasi tinggi dicarap antara kebolehtelapan gas spesifik dengan pekali penyerapan pada frekuensi berlainan dalam spesimen berkeratan memanjang yang panjangnya 50 mm. Namun, korelasi adalah tidak signifikan bagi spesimen berkeratan memanjang dan berkeratan tangen yang panjangnya 10 mm. Kayu mulberi menunjukkan pekali penyerapan yang terendah. Analisis kelompok menunjukkan yang kayu mulberi berbeza daripada empat spesies yang lain.

## INTRODUCTION

Understanding porous structure in solid wood is important as it has great impact on utilisation (Ghorbani et al. 2012). Gas permeability in solid wood (Taghiyari et al. 2012) and composite materials can be measured up to 0.001 s precision. Therefore, it is noteworthy to study scientific and commercial aspects of solid wood. Gases usually do not interact with cell wall materials and the testing procedure is non-destructive. It also shows high correlation with liquid permeability (Taghiyari 2012). Therefore, results of gas permeability measurement can be analysed and compared with absorption coefficients measured on the same specimens. Many factors affect the quality of wood such as initial spacing (Taghiyari et al. 2011), intercropping (Taghiyari & Efhami

2011), drying procedures (Dashti et al. 2012, Tenorio et al. 2012), moisture content and hygroscopicity of wood (Borrega & Karenlampi 2009, Hering et al. 2012) as well as extractive content. A more comprehensive knowledge of wood properties would result in better utilisation of wood. Ultrasonic techniques were previously used for studying the mechanical characterisation of composite boards (Kazemi et al. 2005). Since permeability and absorption coefficient depend on the porous structure of the material and to date little has been studied on the correlation between them, the present project was conducted to investigate the possible correlation between these two physical properties in solid wood.

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## MATERIALS AND METHODS

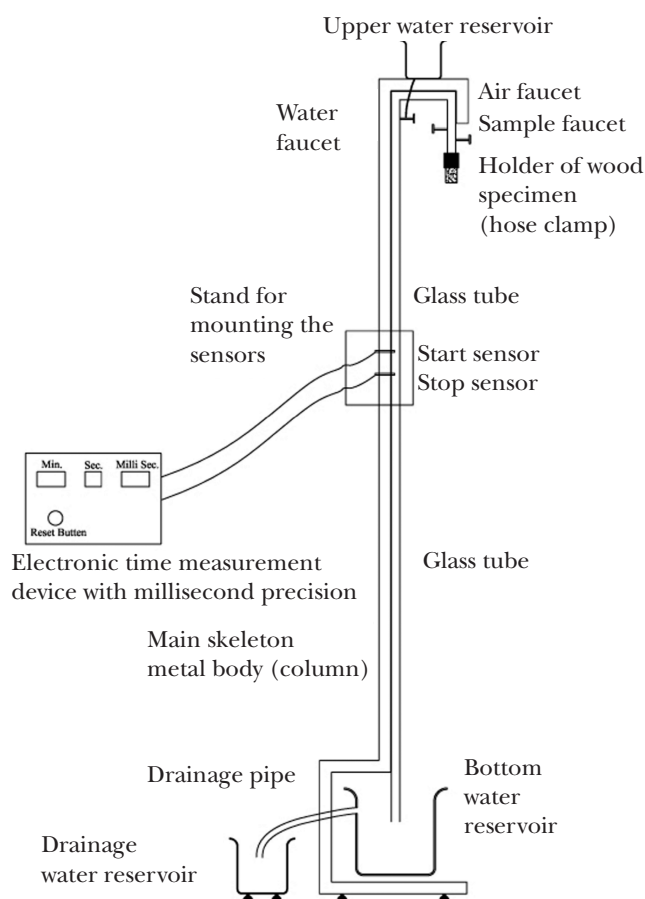
### Specimen procurement

Four hardwood and one softwood were chosen, namely, beech (*Fagus orientalis*), poplar (*Populus nigra*), walnut (*Juglans regia*), white mulberry (*Morus alba*) and fir (*Abies alba*). Mulberry and walnut were chosen as they are traditionally used for musical instrument in Iran. The other two hardwood species (beech and poplar) were chosen because they are important commercial wood in Iran. In order to compare the behaviour of hardwood with softwood, fir wood was selected as over the last three decades, there have been huge commercial applications of this species in Iran.

From each species, 10 longitudinal specimens each of 50 mm length and 10 mm length as well as 10 tangential specimens of 10 mm length were cut. Diameter of all specimens was 29 mm. In total, 150 specimens were prepared. Specimens were free from knots, fissures and checks. The absorption coefficient of each specimen was measured. Each specimen was covered with adhesive all around before gas permeability was measured by letting air flow only through the desired direction. All specimens were kept in a conditioning room ( $25 \pm 2$  °C and  $40 \pm 3\%$  relative humidity) for 4 weeks. The moisture content of specimens was  $9 \pm 0.2\%$  during testing.

### Gas permeability measurement

Longitudinal gas permeability was measured using an apparatus (Figure 1) equipped with 7-phase electronic-time-measurement device with millisecond precision (Taghiyari & Farajpour 2013). Falling-water volume-displacement method was used to calculate specific longitudinal gas permeability values based on the microstructure porosity of wood (Shi 2007). For each specimen, gas permeability was measured at seven different water-column heights, i.e. at seven different vacuum pressures in a single run (Taghiyari & Farajpour 2013). Internal diameter of the glass tube was 13 mm. Water level was 15 cm above the starting sensor of the first time-measurement device (gas 1). Connection between the specimen and holder was made fully airtight. A pressure gauge with millibar precision was connected to



**Figure 1** Schematic diagram of the gas permeability apparatus equipped with single-storey millisecond precision electronic time measurement device

the whole structure to monitor pressure gradient ( $\Delta P$ ) and vacuum pressure at any particular time as well as height of water column so that a viscose flow could be monitored.

Three measurements were taken for each specimen. Superficial permeability coefficient was calculated using equations 1 and 2 (Taghiyari et al. 2010). The superficial permeability coefficients were then multiplied by the viscosity of air ( $\mu = 1.81 \times 10^{-5}$  Pa s) for the calculation of specific permeability ( $K = k_g \mu$ ).

$$k_g = \frac{V_d CL (P_{\text{atm}} - 0.074 \bar{z})}{t A (0.074 \bar{z}) (P_{\text{atm}} - 0.037 \bar{z})} \times \frac{0.760 \text{ mHg}}{1.013 \times 10^6 \text{ Pa}} \quad (1)$$

$$C = 1 + \frac{V_r (0.074 \Delta z)}{V_d (P_{\text{atm}} - 0.074 \bar{z})} \quad (2)$$

where

$k_g$  = longitudinal specific permeability ( $\text{m}^3 \text{m}^{-1}$ )

- $V_d = \pi r^2 \Delta z$  [ $r$  = radius of measuring tube (m)] ( $m^3$ )  
 $C$  = correction factor for gas expansion as a result of change in static head and viscosity of water  
 $L$  = length of wood specimen (m)  
 $P_{atm}$  = atmospheric pressure (m Hg)  
 $\bar{z}$  = average height of water over surface of reservoir during period of measurement (m)  
 $t$  = time (s)  
 $A$  = cross-sectional area of wood specimen ( $m^2$ )  
 $\Delta z$  = change in height of water during time  $t$  (m)  
 $V_r$  = total volume of apparatus above point 1 (including volume of hoses) ( $m^3$ )

### Sound absorption coefficient measurement

Absorption coefficient was measured in accordance with ASTM C384-98 (ASTM 1998) at four different frequencies of 800, 1000, 2000 and 4000 Hz for each single specimen using standing wave apparatus type 4002, sine random generator type 1024 and beat frequency oscillator type 1022 (Figure 2). The standing wave apparatus is designed for measurement of absorption coefficients of circular cut specimens of sound absorbing materials. A loudspeaker sets up a sound field in a tube terminated by the specimen to be investigated. Due to reflection from the specimen, standing waves are produced in the tube. By measuring the ratio between the maximum and minimum sound pressure, the absorption coefficient of the specimen from zero degree incident sound can be calculated using equation 3.

$$\alpha = \frac{4.10^{\Delta L/20}}{(10^{\Delta L/20} + 1)^2} \quad (3)$$

where

$\alpha$  = absorption coefficient

$\Delta L$  = the difference between the maximum and minimum sound pressure

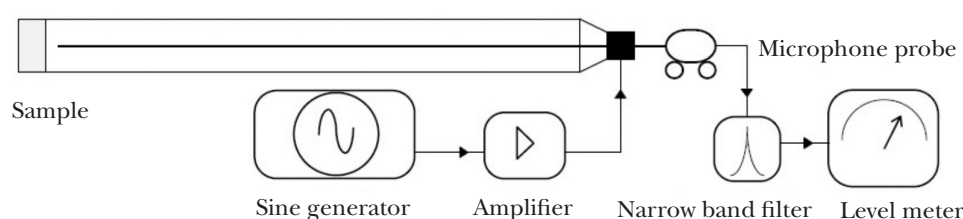
Since the only absorbing material is the specimen, the numerical figures obtained are very closely related to its sound absorbing properties. To set up the arrangement, a circular disc was cut out of the absorbing material and placed in one of the three specimen holders supplied with each tube. Using a clamping device, the specimen holder was fastened to one end of the measuring tube, the other end of which was screwed onto the box containing the loudspeaker. The probe microphone was supported at one end (inside the measuring tube) by a small gliding carriage and at the other, a microphone car (carriage) containing the microphone. The microphone car was guided by brass rails and its position was indicated on a rule.

### Statistical analysis

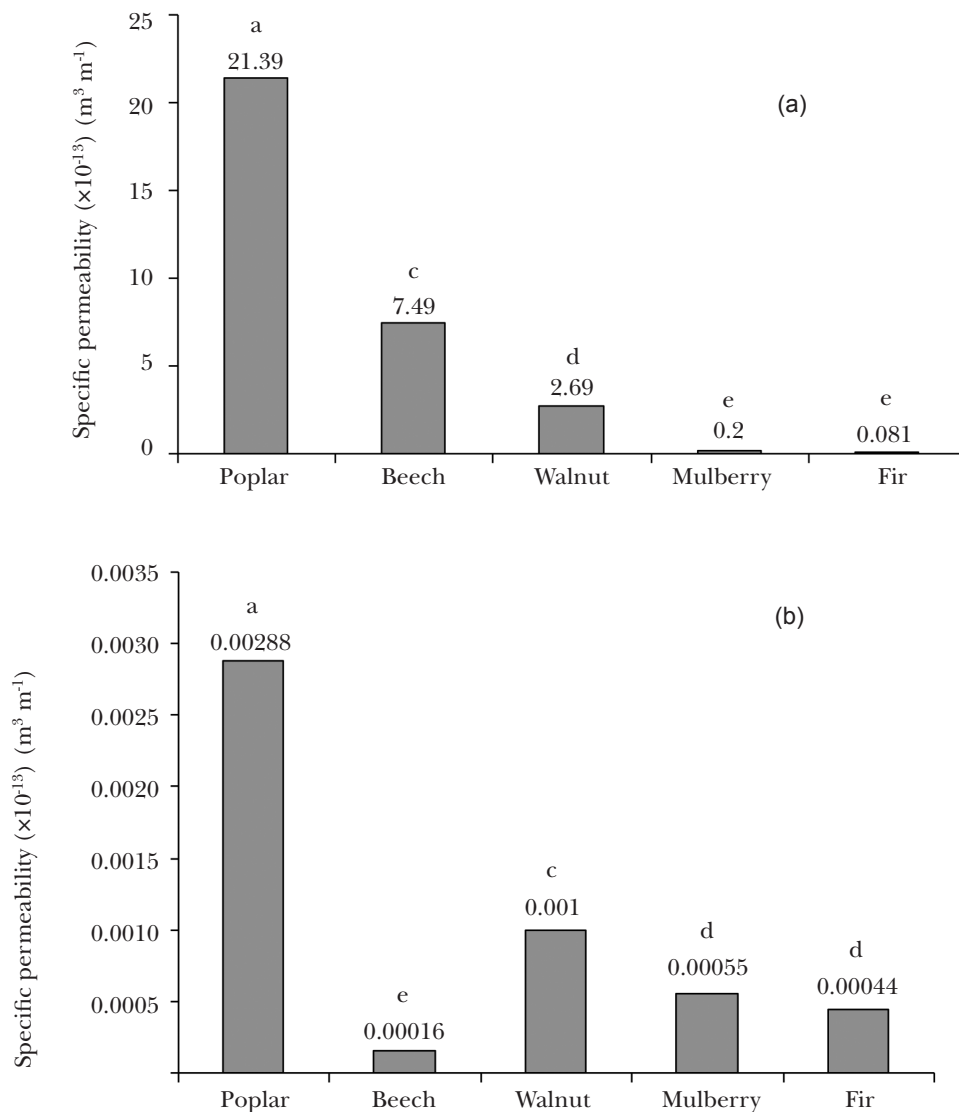
One-way analysis of variance was conducted to discern significant difference at 95% level of confidence using SAS software program. Grouping was made between treatments using the Duncan's test. Regression and hierarchical cluster analyses, including dendrogram using Ward methods with squared Euclidean distance intervals were carried out by SPSS/16.

## RESULTS AND DISCUSSION

The highest longitudinal and tangential specific permeability values were found in poplar specimens—21.39 and  $0.00288 \times 10^{-13} m^3 m^{-1}$  in longitudinal and tangential directions respectively (Figure 3). The lowest longitudinal permeability was found in fir specimens ( $0.081 \times 10^{-13} m^3 m^{-1}$ ) and the lowest tangential permeability was found



**Figure 2** Schematic diagram of the standing wave apparatus type 4002 and the way it is connected to the sine generator, amplifier, microphone probe and filter



**Figure 3** Specific gas permeability values in (a) 50-mm long longitudinal and (b) 10-mm long tangential directions in poplar, beech, walnut, mulberry and fir; letters on each column represent Duncan's test grouping

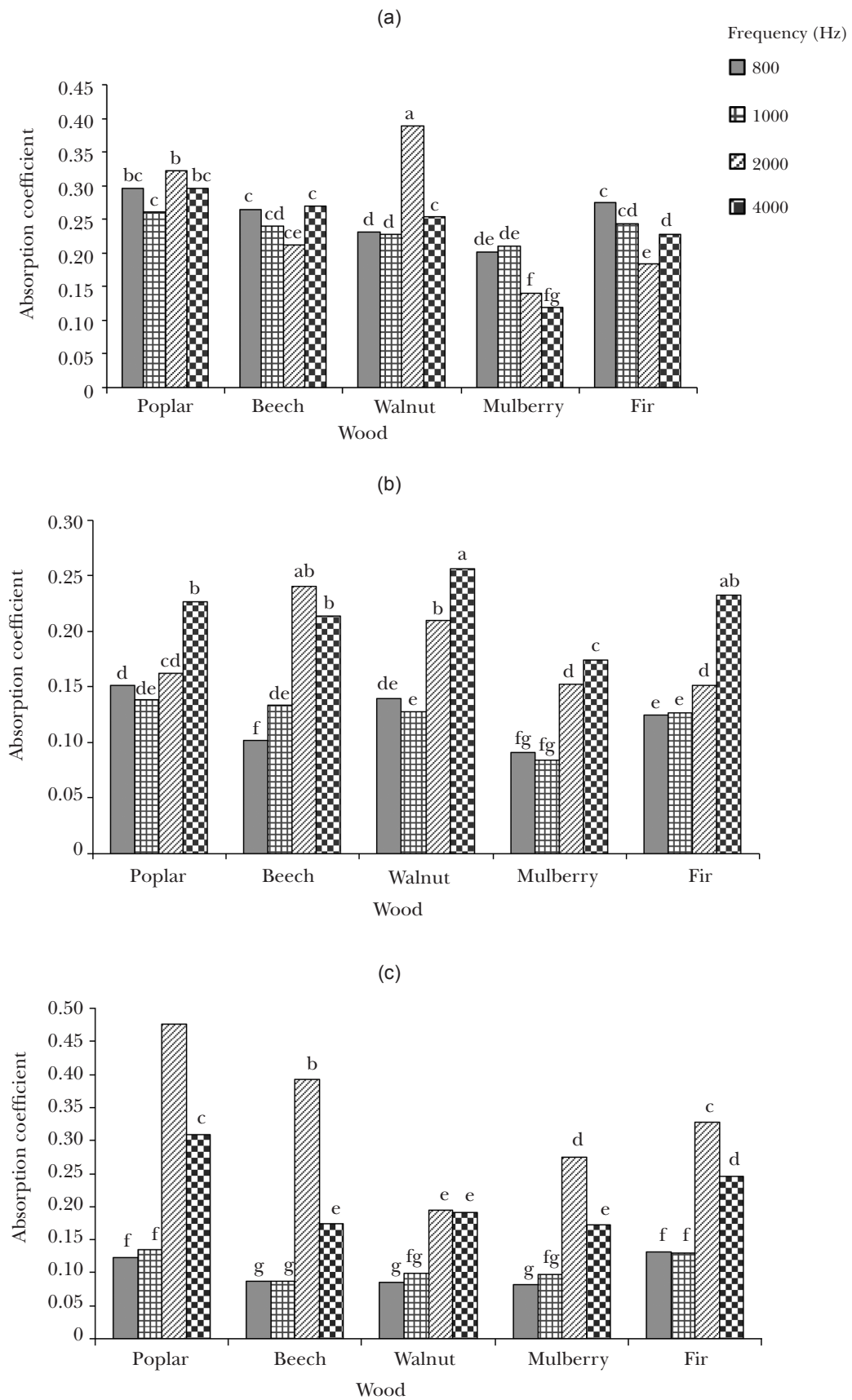
in beech specimens ( $0.00016 \times 10^{-13} \text{ m}^3 \text{m}^{-1}$ ). Longitudinal permeability in poplar was 99.99% higher than that of the tangential direction. In fir, longitudinal permeability was 99.45% higher than that of the tangential direction. 10-mm long longitudinal specimens did not provide authentic values for gas permeability and thus were not reported.

The highest absorption coefficient was found in 10-mm long longitudinal poplar specimens (0.47613 at 2000 Hz) and the lowest was observed in 10-mm long longitudinal mulberry specimens (0.08211 at 800 Hz) (Figure 4). The percentage of difference between the highest and lowest sound absorption coefficient values in

50-mm long longitudinal specimens was 69.6%. The percentage of difference in tangential direction was 67.3%.

Among the five species studied, only fir was softwood, lacking vessel elements to facilitate fluid flow. Therefore, it was expected that the lowest longitudinal permeability was found in fir specimens. Furthermore, poplar perforation plates were simple. The passages readily provided easy fluid flow.

Tangential specimens generally showed lower sound absorption in all four frequencies. This was due to the orientation of cells in the specimens and the way cell cavities were oriented in the wood structure. Sound absorption



**Figure 4** Absorption coefficients at four frequencies of 800, 1000, 2000 and 4000 Hz in poplar, beech, walnut, mulberry and fir in (a) 50-mm long longitudinal specimens, (b) 10-mm long tangential specimens and (c) 10-mm long longitudinal specimens; letters on each column represent the Duncan's test grouping



significantly increased with increase in frequency in all five species. High coefficients were also reported in the tangential direction in solid wood with increase in frequency (Bucur & Bohnke 1994). However, lower frequencies of 800 and 1000 Hz resulted in very low absorption in 10-mm long longitudinal specimens. The open-end vessel elements made lower internal friction causing lower damping of the sound radiation in shorter longitudinal specimens. However, in fir specimens, slight increase in absorption coefficients at 800 and 1000 Hz was observed. This may be related to the special structure of softwood, i.e. softwood does not have vessel elements. It can be hypothesised that sound waves cannot pass through cells as easily as in vessels of hardwood. Consequently, more absorption was observed in fir specimens. Mulberry specimens showed the lowest absorption coefficients in 50-mm long longitudinal and 10-mm long tangential specimens. The lower values justify the luthier craftsmen's traditional preference for mulberry timber to make wooden musical instruments. Furthermore, authentic specific gas permeability was reported to be obtained through specimens not shorter than 50-mm long. In this connection, 10-mm long longitudinal mulberry specimens showed slightly more sound absorption coefficients than other specimens.

Cluster analysis of the species based on specific gas permeability as well as absorption coefficients showed that mulberry specimens were clustered quite differently in 50-mm long longitudinal specimens (Figure 5). Considering the overall lowest absorption coefficients in mulberry specimens (Figures 5, 4a and b), this different clustering would be quite logical.

Regression analysis showed high significant relationship between gas permeability and

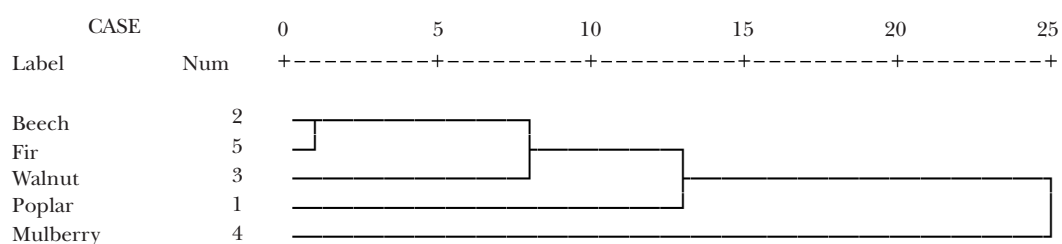
absorption coefficients in many of the species in 50-mm long longitudinal specimens (Table 1). Furthermore, high significant correlations were found between the absorption coefficients when measured at different frequencies. However, low insignificant relationships were observed when the length of specimens was 10 mm, either in longitudinal or tangential direction. Therefore, their correlation values were not reported. It could be concluded that 50-mm long longitudinal specimens were not only authentic for specific gas permeability measurement but they provided good criterion for absorption coefficient. Fitted-line plot between the specific gas permeability versus sound absorption coefficient showed increasing trend in sound absorption as permeability increased (Figure 6).

## CONCLUSIONS

There was high significant correlation between specific gas permeability and sound absorption coefficient at different frequencies. Both specific gas permeability and sound absorption were significantly dependent on the length of specimens as well as their direction. Higher correlations were found between specific gas permeability and sound absorption in 50-mm long longitudinal specimens.

## ACKNOWLEDGEMENTS

The present study was financed by Shahid Rajaee Teacher Training University. EA Azim-Bagirad provided technical consultation on the design and building of the electronic time measurement device with millisecond precision for the 7-phase gas permeability measurement apparatus.

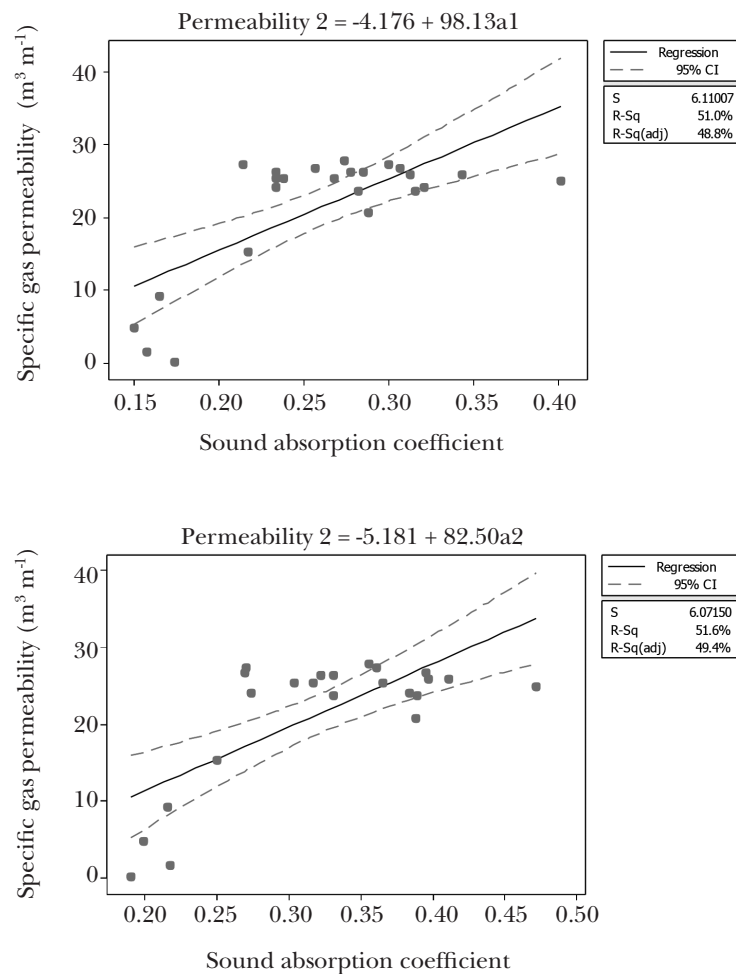


**Figure 5** Cluster analysis of 50-mm long longitudinal specimens based on gas permeability and absorption coefficients at four frequencies of 800, 1000, 2000 and 4000 Hz in poplar, beech, walnut, mulberry and fir

**Table 1** Regression analysis between the longitudinal specific gas permeability and absorption coefficients (ACs) at four different frequencies of 800, 1000, 2000 and 4000 Hz in 50-mm long longitudinal poplar, beech, walnut, mulberry and fir specimens

Wood	Physical property	AC-800	AC-1000	AC-2000	AC-4000
Poplar	Gas 2	0.563	0.714	0.718	0.577
		** (+)	** (+)	** (+)	** (+)
	AC-800	1	0.919	0.784	0.560
			** (+)	** (+)	** (+)
	AC-1000		1	0.864	0.605
Beech				** (+)	** (+)
	AC-2000			1	0.568
					** (+)
	AC-4000				1
Walnut	Gas 2	0.515	0.344	0.076	0.241
		* (+)	NS (+)	NS (+)	NS (+)
	AC-800	1	0.925	0.588	0.537
			** (+)	** (+)	** (+)
	AC-1000		1	0.671	0.556
Mulberry				** (+)	** (+)
	AC-2000			1	0.402
					NS (+)
	AC-4000				1
Fir	Gas 2	0.731	0.581	0.317	0.592
		** (+)	** (+)	NS (+)	** (+)
	AC-800	1	0.890	0.536	0.582
			** (+)	** (+)	** (+)
	AC-1000		1	0.543	0.591
Poplar				** (+)	** (+)
	AC-2000			1	0.413
					* (+)
	AC-4000				1
Beech	Gas 2	0.433	0.495	0.063	0.181
		* (+)	* (+)	NS (+)	NS (-)
	AC-800	1	0.826	0.157	0.098
			** (+)	NS (-)	NS (-)
	AC-1000		1	0.172	0.196
Walnut				NS (-)	NS (-)
	AC-2000			1	0.490
					* (+)
	AC-4000				1
Mulberry	Gas 2	0.333	0.260	0.053	0.094
		NS (-)	NS (-)	NS (+)	NS (+)
	AC-800	1	0.817	0.402	0.135
			** (+)	NS (+)	NS (+)
	AC-1000		1	0.604	0.339
Fir				** (+)	NS (+)
	AC-2000			1	0.426
					* (+)
	AC-4000				1

\*\*Correlation is significant at the 1% level (2-tailed), \*correlation is significant at the 5% level (2-tailed), NS = not significant; gas 2 = gas permeability measured at the 2<sup>nd</sup> water column height; positive (+) or negative (-) correlation



**Figure 6** Fitted-line plots between specific gas permeability versus sound absorption coefficient in poplar specimens at frequencies of (a) 800 and (b) 4000 Hz;  $a_1$  and  $a_2$  = absorption frequencies

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