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# Experimental and mathematical survey of sound absorption performance of date palm fibers

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ABSTRACT

The present study examines the acoustic behavior sample composites made of date palm natural fibers and polyvinyl alcohol. It also provides the comparison between the sound absorption coefficients obtained from the experimental tests and the ones predicted by the mathematical models. An impedance tube system was used to measure the normal sound absorption coefficient of the samples. Using the differential equation algorithm, the predicted sound absorption coefficient for the Johnson-Champoux-Allard model was also calculated. The sound absorption properties of samples increased significantly by increasing the frequency, and increasing the thickness of materials with constant density. Comparison of the data from the experimental tests and mathematical model showed that increasing the thickness of samples will make the predicted and tested values of acoustic absorption coefficient significantly comparable. Date palm fibers have a good potential for dissipating the energy of sound waves particularly when an air gap is introduced behind the sample and can be used as a new source for the fabrication of natural fiber reinforced composites.

## 1. Introduction

Despite the prosperity and welfare brought about by the modern technologies, they have in principle jeopardized the basis of life by disturbing the natural balance. Various diseases and incidents, as well as, numerous environmental issues are a few of such problems in the present era. Exposure to the excessive levels of noise is undoubtedly a major problem among both industrial and non-industrial nations. In fact, a great number of people are exposed to the risks that are generated by noise in their workplaces or even at their homes [1, 2]. Noise pollution is currently identified as one of the principal risks that threatens human's quality of life. Yet, this type of pollution has been highlighted to a lower extent in comparison to other closely related issues such as air pollution [3]. Many indoor and outdoor work environments generate extremely harmful and disturbing levels of noise pollution which exert negative impacts on the physical and psychological health of individuals, resulting in workplace violence and anxiety along with noise induced hearing loss, hypertension and increased heartbeat rate, elevated levels of cortisol hormone and communication and sleep disorders. Noise pollution seriously affects the life span of man-made structures such as buildings and declines the productivity of individuals mainly through absenteeism among the employees [4, 5, 6, 7].

Providing quiet environments, free from disturbing noise, has turned into a requirement for many residential areas and workplaces all over the world. This has subsequently led to the significant growth of noise control techniques as well. Various methods have been proposed to control or minimize higher levels of noise in the work environments, namely technical and engineering controls, administrative controls, and provision of hearing conservation programs. One of the methods of attenuating the sound energy in its propagation path is to apply a variety of insulators and absorbers [8]. Sound absorbers used in indoor and outdoor areas are currently classified into several categories, namely granular, cellular, and fibrous materials [9, 10].

In porous absorbers made of fibrous materials, sound waves usually propagate through a network of interconnected cavities. Given the very small size of the cavities and the interaction of the wave with the walls, viscous and thermal dissipation takes place which transforms the energy of the sound wave into heat [11, 12].

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Most synthetic fibrous sound absorbers such as fiberglass are neither renewable nor biodegradable and thus, they remain in the environment over long periods of time. The growing concern about human and wildlife health and safety issues, the increased emissions of greenhouse gases such as $CO_2$, the massive amount of wastes produced globally, as well as, the high cost of production and use of synthetic fibers in recent years have inclined manufacturers and engineers toward using natural and environmentally friendly fibers as possible alternatives. On the other hand, since the natural fibers possess features such as greater biodegradability, lighter weight, lower density, higher electrical resistance, acceptable specific strength, lower cost and no toxic effects, they are deemed as decent alternatives for acoustic absorbers with synthetic origin [13, 14, 15]. With respect to the desirable physical properties, as well as, economic and environmental advantages, natural fibers can also be used to produce high-performance composites [16, 17].

Various types of such composites are available in the form of lignocellulosic natural fibers (including flax, coconut, date and oil palm, hemp, bamboo, cannabis, jute, straw, rice, wheat, barley, corn husk, sugarcane, reed, hemp, ramie, sisal and pineapple leaf fibers) which can be used as biodegradable and sustainable acoustic absorbers [18, 19, 20, 21, 22, 23, 24, 25, 26].

While porous absorbers are mainly applied for absorption of sound waves in high frequency ranges, their thickness has to be increased to enhance the absorption in the low-frequency region. As Othmani et al. [27] reported, resin content reduction in the sugarcane fiber composite raises the air flow resistivity along with the sound absorption coefficient. This is usually achieved by the higher levels of porosity in the composite that is the result of applying lower resin content. Furthermore, according to the findings of the study by Putra et al. (2018) on the acoustic properties of pineapple fibers for sound absorption applications, as the density of the samples increases, the acoustic absorption coefficient also rises in medium and high frequency ranges [22].

Abundance of plant sources containing fibers in different parts of a country is a major incentive to use them as the components of various types of composites. According to Food and Agriculture Organization (FAO) [28], Iran was the second largest producer of date in 2016 just after Egypt. Given the vast date cultivation area in the southern, eastern and even central parts of Iran, natural fibers derived from date palm trees (Phoenix dactylifear L.) is an appropriate alternative to make bio-based sound absorber composites [29]. As the available data indicate, a majority of waste produced by the date palm cultivation in Iran are either burned or buried as a result of poor agricultural waste management in the country, and that is while they can be used for multiple purposes. Iranian experts estimate that approximately 220000 hectares of Iran's agricultural lands are devoted to date cultivation, comprising around % 20 of date palm plantations worldwide. Since the production of high quality date depends on the regular pruning of palm trees, a considerable amount of lignocellulosic fiber waste is produced annually in the date palm plantations of Iran. Each palm tree yields around 34 kilos of waste during pruning and harvesting processes on average which may include fibers from date palm fronds, trunk and petioles (rachis), empty fruit bunch, etc. [30].

Given the 20 to 27 million date palm trees in the country, this comprises approximately 200,000 tons of lignocellulosic material which can be used in conversion industries, such as manufacturing of the composites [31].

The large volume of such waste has encouraged the researchers to look for new approaches for its use and application. During the past few years, the number of studies on the acoustic properties and sound absorption coefficient of natural fibers has grown dramatically. Nevertheless, few researchers have attempted to deal with the acoustic properties of date palm fiber or its composites. Since the use of date palm fibers as acoustic absorber is superior to the application of man-made sound absorbers particularly in terms of being more ecofriendly, this study attempts to investigate the possibility of producing such absorbers by employing the natural fibers from the palm trees. On the other hand, since the development of predict mathematical models has paved the way for the measurement and prediction of acoustic properties (including absorption coefficient) of such natural fibers. The main objective of the present study is to investigate as well as measure and predict the normal sound absorption coefficients of the fibrous composite samples fabricated from date palm fiber (DPF) by an impedance tube method and a mathematical model.

## 2. Materials and methods

### 2.1. Sample preparation

During the course of the research, the natural date palm waste fibers (mainly lignocellulosic fibers from the date palm branches and clusters) were procured from Tabas city in southern Khorasan province in Iran (Fig. 1). Having transferred to the laboratory, the raw DPFs were rinsed with distilled water before being placed inside an oven at 70 °C for 24 hours to dry and get a fixed weight. The DPFs were then cut into smaller pieces by a pair of scissors and crushed and pressed through a 2 mm mesh sieve to make their size fairly homogenous. In order to bind the fibers together and form a composite, polyvinyl alcohol-PVA (Sigma-Aldrich) was utilized. PVA is a polymeric chemical binder with high solubility in water and is known to be a biodegradable material reportedly used as natural fiber binder in previous studies [32].

In order to prepare 5% PVA concentration, 5 g of the substance was first weighed by a scale and later dissolved in 100 ml of distilled water. The solution was then stirred with a magnet at 80 °C for 3 hours. Having prepared the solution, the fibers were soaked with it to bind. The fibers were then shaped by an aluminum mold by compression molding. Two groups of circular samples with diameters of 30 and 100 mm were therefore fabricated to be separately fitted inside the two tubes (large and small) of an impedance tube system and obtain the sound absorption coefficients at lower (63–1600 Hz) higher (1000–6300Hz) frequencies respectively. Having performed the molding process, the samples were left at room temperature for 12 hours to dry completely before being transferred to the laboratory for absorption coefficient measurement. The samples created by this process had the thicknesses of 20, 30 and 40 mm and a constant density of 65 $kg/m^3$. Totally, 6 samples (3 with 30mm-diameter and 3 with 100mm diameter) were made to be tested in the impedance tube to determine the acoustic absorption coefficient. Also, the measurement of the sound absorption coefficient was performed at least three times for each sample. Fig. 2 shows the SEM images of the DPFs which were used to form the samples. The outer diameter of the DPFs ranged from 200 to 720 μm with the mean diameter, the density and porosity of 465 μm, 930 $kg/m^3$ and >90% respectively.

**Fig. 1.** Locations of date palm cultivation in Iran.

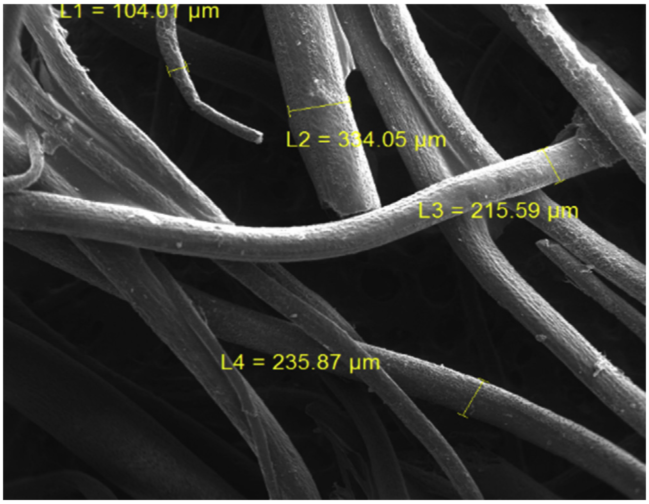

**Fig. 2.** Scanning electron microscope image of date palm composite.

### 2.2. Measuring the air flow resistivity of acoustic material

One of the principal parameters influencing the absorption of sound in porous materials is airflow resistivity (σ), which is equal to the ratio of air pressure difference (ΔP) on both sides of the porous material to the average air velocity (V) per unit of thickness (l) of specimen in the direction of air flow. This parameter is measurable according to the below equation:

$$\sigma = \frac{\Delta P}{V \times l} \tag{1}$$

The measurement and calculation of air flow resistivity of the samples were performed based on the steady-state (direct) method recommended by ISO 9053-1:2018. According to this method, a constant one-way air flow with the definite velocity and volumetric flowrate was laminarly sucked through the surface area of the test sample by a vacuum pump (Rocker 400) in a circular cylinder made of Plexiglas. A sensitive differential pressure gauge (TESTO 512) was also employed to determine the difference in pressure on the front and rear sides of the samples. The thickness of the samples was measured by a digital caliper prior to and during performing the experiments. Fig. 3 shows the schematic diagram of the air flow resistivity measurement system in the present study.

### 2.3. Measuring the sound absorption coefficient in the impedance tube

Generally, there are various methods for measuring the absorption coefficient of sound absorbers. The sound absorption coefficient in this study was measured via the impedance tube according to the transfer function method with respect to ISO 10534-2 [33]. The measurement setup and impedance tube (Type SW 477, BSWA Technology Co., Ltd., China) used in this study are shown in Fig. 4. The sample and the loudspeaker were located at the two ends of the tube.

By measuring the reflected signals in two fixed points via the microphones mounted on the tube wall and later calculating the composite acoustic transfer function, the normal incidence absorption coefficient and absorption matrix impedance ratios were determined. As it is typical of research on obtaining the normal incidence absorption coefficient of materials, the impedance tube system in this study was equipped with two tubes, a larger diameter tube (100 mm) to measure the absorption coefficients and transmission loss at lower frequencies (63–1600 Hz), and a smaller diameter tube (30 mm) for measuring the absorption coefficient and transmission loss at higher frequencies (1000–6300Hz). Measurement of the impedance tube was carried out three times for each sample to minimize the possible effects due to the irregularities or misalignment of the samples. Also, the possible effect that the air gaps behind the samples might have on the levels of sound absorption coefficient was investigated using the impedance tube system (Fig. 5).

### 2.4. Mathematical model

In the past decades, the authors such as Delany-Bazley [34], Miki [35] and Garai-Pompoli [36] presented empirical models and fast approximation to get sound absorption coefficient to using the characteristic impedance and the wavenumber are related to the static airflow resistivity of the porous material. With the spread of science, phenomenological models, like Johnson–Champoux–Allard [37] is an arduous task due to the complicated cell structure of these materials. These models require a larger number of non-acoustical elements (tortuosity, viscous characteristic length, thermal characteristic length, porosity), which are not easily accessible at an early stage, so, apart from few exceptions, simpler models are normally preferred. In order to measure the sound absorption coefficient of porous materials, the characteristic impedance, as well as, the propagation constant of the porous material must first be determined. The aim of mathematical models is to provide the two above parameters for porous materials in a wide range of frequencies. Many studies have been conducted to model and measure these two quantities for such materials, among which the Johnson- Champoux –Allard (JCA) can be mentioned.

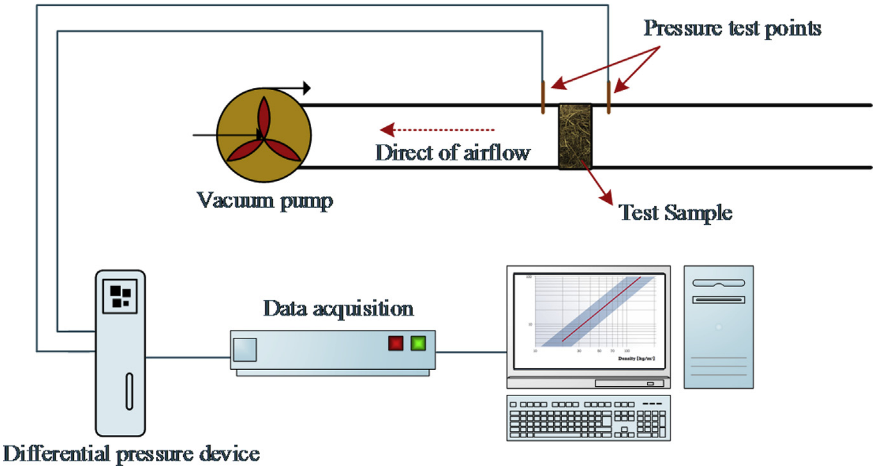

**Fig. 3.** Airflow resistivity measurement setup.

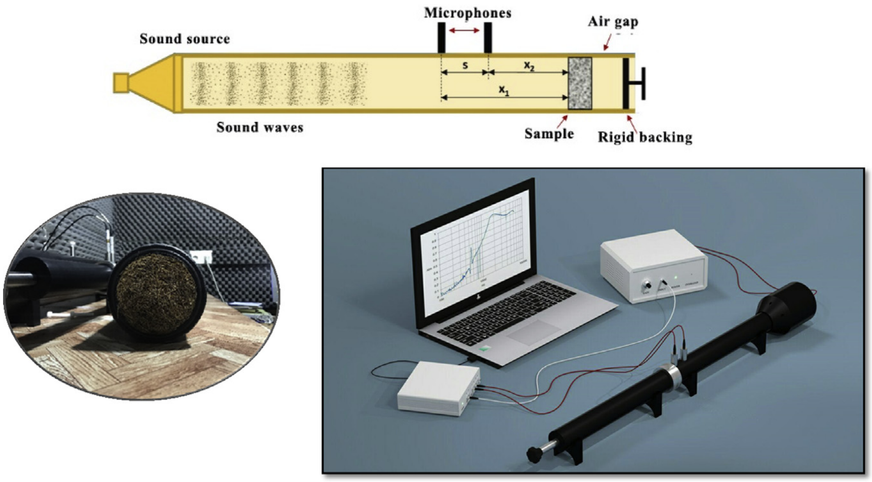

**Fig. 4.** Schematic view of impedance tube utilized in this study.

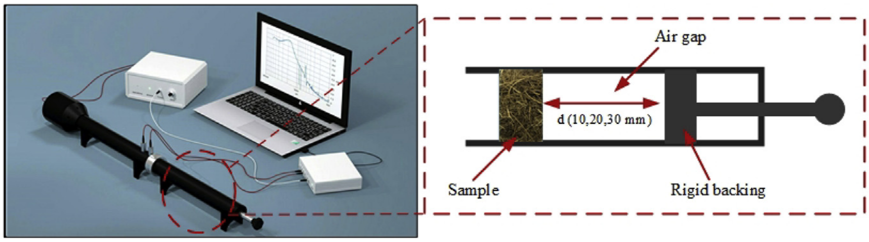

**Fig. 5.** The impedance tube system used in the experiment and introduction of air gap behind the sample.

### 2.4.1. *Johnson–Champoux–Allard model (JCA)*

Allard and Champoux in 1992 [37] proposed a phenomenological model for propagation of sound in porous materials, in order to estimate the acoustic absorption coefficient. Allard and Champoux defined the equivalent bulk and density module as follows:

$$\rho(\omega) = \alpha_\infty \rho_0 \left[ 1 + \frac{\sigma\phi}{j\omega\rho_0\alpha_\infty} \left( 1 + \frac{4i\alpha_\infty^2 \eta\omega\rho_0}{(\sigma\Lambda\phi)^2} \right)^{1/2} \right] \tag{2}$$

$$K(\omega) = kp_0 \left( k - (k-1) \left[ 1 + \frac{8\eta\alpha_\infty\phi}{\Lambda'^2 \phi i\omega\rho_0\alpha_\infty N_{pr}} \left( 1 + \frac{4i\alpha_\infty^2 \eta N_{pr}\omega\rho_0}{(\sigma'\Lambda'\phi)^2} \right)^{1/2} \right]^{-1} \right)^{-1} \tag{3}$$

The physical parameters of the sample include air flow resistivity σ [Ns/m$^4$], porosity φ [-], tortuosity $\alpha_\infty$ [-], viscous characteristic length Λ [μm] and thermal characteristic length $\Lambda'$ [μm].

Meanwhile, the $\rho_0$ indicates air density [kg/m$^3$], $N_{pr}$ is Prandtl number [≈ 0.71], η is the viscosity of the air [$\approx 1.85 \times 10^{-5}$], k is the ratio of the specific heat capacity [≈ 1.4] and ω is the angular velocity [1/s].

To express the characteristic impedance $Z_c(\omega)$ and the characteristic wave number $K_\omega$, the surface acoustic impedance Z can be estimated by the following equations [38]:

$$Z_c(\omega) = \frac{1}{\phi}\sqrt{\rho_{(\omega)} \cdot K_{(\omega)}} \tag{4}$$

$$K_c(\omega) = \omega\sqrt{\frac{\rho_{(\omega)}}{K_{(\omega)}}} \tag{5}$$

$$Z = Z_c(\omega) \cdot \cot(K_c(\omega) \times d) \tag{6}$$

$$R = \frac{Z_s - \rho_0 c_0}{Z_s + \rho_0 c_0} \tag{7}$$

where *R* is sound pressure reflection coefficient; $Z_s$ is the surface impedance; *d* is the thickness of the sample.

The absorption coefficient is calculated by

$$\alpha = 1 - |R|^2 \tag{8}$$

also presents the prediction error rates (PERs) of the data obtained from the JCA model for each sample in the frequency range between 125Hz and 6.3 kHz calculated by

$$PER = \frac{|\alpha_m - \alpha_p|}{\alpha_m} \times 100 \tag{9}$$

where $\alpha_m$ and $\alpha_p$ are the measured and predicted absorption coefficients, respectively.

## 3. Results and discussion

Results from the laboratory data for the three thicknesses of 20, 30 and 40 mm of the sample absorbers of DPF and the impact of the air gaps on their sound absorption coefficients are presented in Table 1. Using the mathematical model, the sound absorption coefficient in the frequency range of 125–6300 Hz was next coded by MATLAB software. As shown in Table 2, the predicted values of the physical parameters of the DPF were measured using differential equation algorithm in the MATLAB software through the available laboratory data such as the thickness, density, airflow resistivity and absorption coefficient. Later, the prediction error rate determined by the JCA model - shown on the right axes of Fig. 6 was compared to the data obtained from the experiments.

Sound absorption coefficients of the natural fiber samples of date palm trees were first analyzed at low (125–1600 Hz) and high

**Table 1**
Acoustic absorption measurements with different air gap in one-third octave bands.

| Material | Thickness (mm) | Air gap (mm) | Frequency (Hz) | | | | | | | | | | | | | | | | | | *ASAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | 6300 | |
| Date palm fiber (DPF) | 20 | 0 | 0.02 | 0.02 | 0.04 | 0.06 | 0.08 | 0.08 | 0.10 | 0.12 | 0.13 | 0.16 | 0.30 | 0.51 | 0.65 | 0.69 | 0.63 | 0.65 | 0.76 | 0.79 | 0.32 |
| | | 10 | 0.02 | 0.03 | 0.03 | 0.06 | 0.07 | 0.08 | 0.11 | 0.13 | 0.18 | 0.27 | 0.45 | 0.65 | 0.77 | 0.70 | 0.66 | 0.70 | 0.78 | 0.84 | 0.36 |
| | | 20 | 0.03 | 0.04 | 0.05 | 0.08 | 0.08 | 0.08 | 0.12 | 0.19 | 0.28 | 0.44 | 0.59 | 0.68 | 0.70 | 0.69 | 0.61 | 0.68 | 0.79 | 0.86 | 0.38 |
| | | 30 | 0.04 | 0.05 | 0.07 | 0.09 | 0.10 | 0.11 | 0.15 | 0.25 | 0.38 | 0.52 | 0.61 | 0.67 | 0.71 | 0.65 | 0.60 | 0.67 | 0.75 | 0.77 | 0.40 |
| | 30 | 0 | 0.03 | 0.05 | 0.07 | 0.08 | 0.10 | 0.13 | 0.15 | 0.17 | 0.24 | 0.38 | 0.57 | 0.68 | 0.79 | 0.76 | 0.70 | 0.74 | 0.81 | 0.86 | 0.40 |
| | | 10 | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 | 0.16 | 0.19 | 0.26 | 0.41 | 0.50 | 0.63 | 0.73 | 0.76 | 0.69 | 0.66 | 0.77 | 0.84 | 0.90 | 0.44 |
| | | 20 | 0.05 | 0.08 | 0.09 | 0.12 | 0.14 | 0.18 | 0.25 | 0.37 | 0.55 | 0.64 | 0.71 | 0.74 | 0.73 | 0.70 | 0.69 | 0.79 | 0.85 | 0.86 | 0.47 |
| | | 30 | 0.07 | 0.08 | 0.10 | 0.13 | 0.17 | 0.23 | 0.33 | 0.46 | 0.61 | 0.71 | 0.74 | 0.75 | 0.71 | 0.66 | 0.68 | 0.76 | 0.82 | 0.84 | 0.49 |
| | 40 | 0 | 0.05 | 0.07 | 0.08 | 0.10 | 0.12 | 0.17 | 0.22 | 0.29 | 0.40 | 0.52 | 0.65 | 0.78 | 0.84 | 0.87 | 0.81 | 0.88 | 0.89 | 0.90 | 0.48 |
| | | 10 | 0.07 | 0.10 | 0.12 | 0.15 | 0.19 | 0.23 | 0.29 | 0.39 | 0.47 | 0.58 | 0.65 | 0.74 | 0.83 | 0.80 | 0.78 | 0.82 | 0.86 | 0.87 | 0.50 |
| | | 20 | 0.07 | 0.12 | 0.13 | 0.18 | 0.22 | 0.26 | 0.33 | 0.47 | 0.56 | 0.66 | 0.73 | 0.79 | 0.88 | 0.84 | 0.79 | 0.80 | 0.79 | 0.84 | 0.52 |
| | | 30 | 0.09 | 0.15 | 0.17 | 0.20 | 0.25 | 0.31 | 0.38 | 0.49 | 0.60 | 0.75 | 0.78 | 0.82 | 0.90 | 0.81 | 0.78 | 0.79 | 0.81 | 0.80 | 0.55 |

* Average sound absorption coefficient.

(1000–6300 Hz) frequency range with the thicknesses of 20, 30 and 40 mm and the constant density of 65 kg/m$^3$. As the results on Table 1 show, sound absorption properties of DPF increases significantly as frequency rises. In other words, at low frequencies, lower absorption coefficients and at high frequencies, higher absorption coefficients are obtained. Moreover, the average sound absorption coefficient in the above mentioned thicknesses and frequency range of 125–6300 Hz are 0.32, 0.40 and 0.48 respectively. The effect of sample thickness particularly at lower frequencies plays a significant role in attenuating the sound waves energy. According to Table 1, thickness and acoustic absorption coefficient at the frequency of 2000 Hz directly affect one another, in a way that at the thickness of 40 mm (as compared to 20 mm), the absorption coefficient reached 0.84 (0.23% increase). As a result, the effectiveness and efficiency of attenuation of sound absorbing materials at lower frequencies is directly related to their thickness. According to a study by Gliscinska, sound absorption coefficient in any porous structure is proportional to the thickness of the material [39]. Xie et al, too, found that as the thickness and porosity of the samples increase, the absorption coefficient of materials rises as well [40]. Sound absorption enhancement might be due to a longer dissipative process in the thermal and viscous conduction between air and absorbing materials. As the composite thickness increases, sound absorption rate will also become larger subsequently [41].

Tests performed on materials such as grain straw, textile waste, glass wool, chopped rubber, felt fibers and polyester indicate that increasing the thickness of absorbing materials will improve the sound absorption, particularly at lower frequencies [42, 43, 44]. Furthermore, the acoustic tests performed on date and oil palm fibers have shown that increase in the thickness of the prepared samples lead to the growth of absorption coefficients and the peaks of such absorption moves towards lower frequencies [45].

In their study, Noor et al. [46] found that the fiber layer (mass) thickness plays a significant role in the acoustic absorption of coconut fibers. They applied the JCA hard frame model to estimate the acoustic absorption of samples made of coconut fibers with various thicknesses and found that increased thickness improves the acoustic absorption and that maximum absorption moves toward lower frequency ranges.

Porosity is one of the effective factors in acoustic absorption coefficient rate of the materials. Accordingly, the results from Table 2 indicate that higher levels of porosity (caused by increased thickness) enhances sound absorption coefficient rate of the material. In a similar study on natural fibers derived from coconut, corn, and sugar cane, Fouladi et al. reported that raising the porosity of the samples increases the sound absorption coefficient [47].

Air flow resistivity of the material is also a major parameter in sound absorption rate of the porous material. In terms of the physical aspect, porous materials resistance is in fact caused by the viscous interaction of the material and frequency [48]. According to Del Ray et al., air flow resistivity is directly related to the capacity of materials in absorbing the sound energy. In other words, as the air flow resistivity increases, so is the energy and in a certain thickness and at low frequencies, the absorption coefficient and dissipation of the sound is enhanced [49].

Developing and applying predictive models is increasingly advancing and there is an urgent need to create practical, accurate, and easy-to-use experimental models. The field of acoustic and sound absorption is no exception and the models proposed must be able to predict the sound absorption coefficients in various absorbers including fibrous ones. Therefore, the present research has investigated the prediction of absorption coefficients using one of the major mathematical models, JCA, and has subsequently compared the results with the laboratory data obtained from the impedance tube tests. In fact, in the JCA model, almost all of the physical properties of the materials such as thickness, mass density, airflow resistivity, tortuosity and viscous and thermal characteristic length are taken into account. This will also provide a comprehensive understanding of the existing acoustic properties of the material.

Three comparisons between the data from the experiment on the

**Table 2**
Basic Properties and physical parameters for the acoustic model.

| | Thickness (mm) | Bulk density (kg/m$^3$) | Measured Flow resistivity $\sigma (Nm^{-4}s)$ | Porosity $\varnothing$(%) | Tortuosity $\alpha_\infty$ | Characteristic lengths ($\mu m$) | |
|---|---|---|---|---|---|---|---|
| | | | | | | $\Lambda$ | $\Lambda'$ |
| DPF | 20 | 65 | 1068 | 92.76 | 2.95 | 251 | 422 |
| | 30 | 65 | 956 | 92.78 | 2.90 | 247 | 430 |
| | 40 | 65 | 879 | 92.80 | 2.90 | 245 | 418 |
| Average Diameter of fiber ($\mu m$): 420 | | | | | | | |
| Average Density of fiber (kg/m$^3$): 930 | | | | | | | |

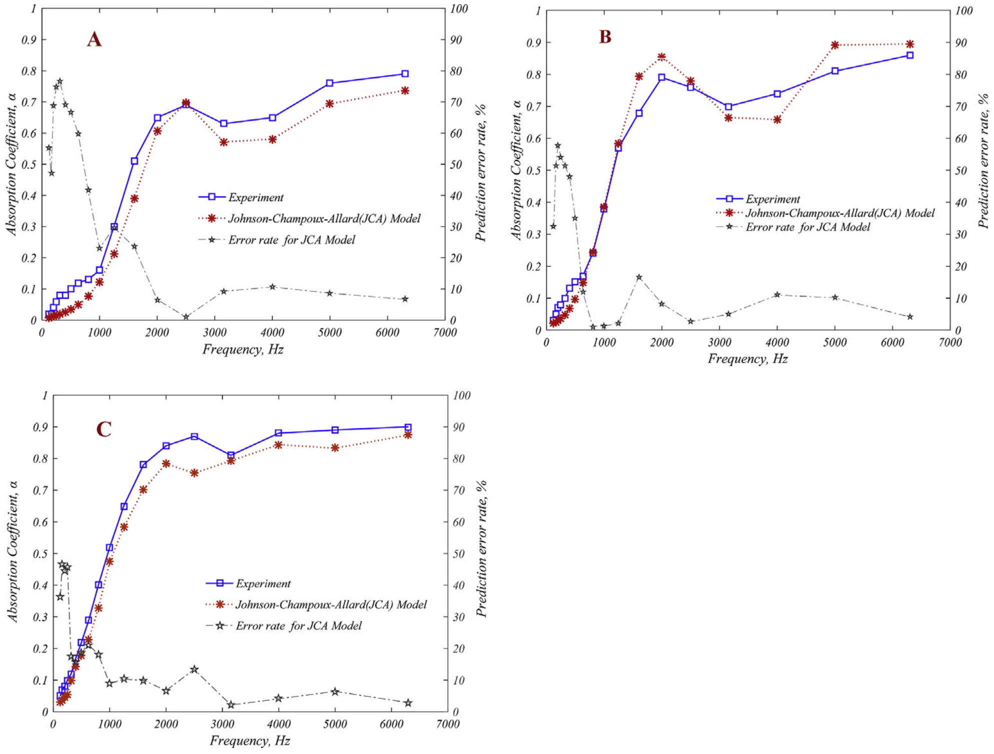

**Fig. 6.** Comparison of the experimental vs. mathematical models for sound absorption coefficient of DPF fiber (A = 20mm, B = 30mm, C = 40mm thickness).

impedance tube and the outputs from mathematical models are presented in Fig. 6. It is evident that, as the thickness of the samples of DPF increases, the absorption coefficients values of the materials predicted by the model get closer to the values obtained from the experiments performed in the impedance tube. As can be seen, the JCA model has an acceptable accuracy in predicting the sound absorption coefficient in different thicknesses. Therefore, the accuracy of prediction by the model for the thicknesses of 20, 30, and 40 mm at low frequencies (125–1600 Hz) are 52%, 30% and 24% respectively while at high frequencies (1000–6300 Hz) such values are 7.08%, 6.83% and 5.71%, respectively.

Introduction of air gap behind the DPF samples in the impedance tube transfers the maximum values of sound absorption coefficient from the upper to the lower frequency range. The results in Table 1 indicate that, as the sample distance from the rigid surface of the backing (up to 30 mm) increases, the sound absorption coefficient at frequencies lower than 1000 Hz will rise as well. Fatima et al., in their study, found that a further increase in the distance from the back of the sample, enhances the noise reduction rate (NRC) in the jute fibers of TD5 degree [50]. Likewise, based on the study by Fouladi et al., the tests and analyses on coconut fibers indicate that increasing the sample distance from the rigid back behind it, exerts a positive impact on sound absorption coefficient at low frequency ranges. They found that by moving the maximum absorption rates to lower frequencies, the sound absorption coefficients at medium and high frequencies decrease [18].

This is probably due to the increased levels of impedance in absorbing materials. In this case, the acoustic resonance moves towards lower frequencies and thus improves the absorption rate in that range. As a result, introduction of air cavity behind the samples in this study seem to significantly contribute to lower production cost by improving the acoustic absorption of thinner layers of absorbing materials.

Previously published studies have confirmed the inherent potential of natural fibers as an alternative for the synthetic fibers commonly used in the production of acoustic absorbers.

In general, it appears that the existing mathematical models fail to predict the absorption coefficient of a large number of natural-fiber absorbers. For Instance, the mathematical model studied in the previous studies suggested relatively good results for only a certain thickness range. A majority of natural fibers are excluded from the studies conducted with these models, since the fibers have higher levels of irregularity and larger diameter in comparison with the synthetic fibers. These properties reduce the accuracy of predicted values by the models [24]; a factor which must be taken into account in developing future experimental models of natural fibers. Nevertheless, one can always apply more precise models such as JCA to predict sound absorption coefficient of materials.

## 4. Conclusions

In this research, the sound absorption coefficients of several samples made from DPF were studied and reported. These fibers are natural, renewable and are the waste products generated during the process of harvesting and pruning of the date palm trees which do not pose any harm to human health particularly when compared to the synthetic fibers. The results from the experimental tests showed that increase in the thickness of the samples can further enhance their sound absorption coefficients. The findings also revealed that introducing an air gap behind the samples in the impedance tube can effectively improve the frequency bandwidth of absorption especially for thin samples such as those with thicknesses of 20 mm, 30mm and 40 mm.

Although several models have already failed to accurately predict the sound absorption properties of the samples made from natural fibers; mainly due to the higher levels of irregularity and larger fiber diameters, phenomenological models seem to have more chance to better predict the acoustic absorption levels of such samples.

Based on the predicted data, the JCA model had the advantage that not only showed overall consistency with the experimental tests results, but also predicted acoustic resonances very well.

## Declarations

### *Author contribution statement*

Khavanin, A.: Conceived and designed the experiments; Performed the experiments.

Taban, E.: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Faridand, M.: Analyzed and interpreted the data; Wrote the paper.

Jonidi Jafari, A. Kazemi Tabrizi, A.: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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### *Competing interest statement*

The authors declare no conflict of interest.

### *Additional information*

No additional information is available for this paper.

## References

[1] G. Belojevic, Noise and performance: research in central, eastern and south-eastern Europe and newly independent States, Noise Health 15 (62) (2013) 2.
[2] S. Geravandi, A. Takdastan, E. Zallaghi, M. Vousoghi Niri, M.J. Mohammadi, H. Saki, et al., Noise pollution and health effects, Jundishapur J. Health Sci. 7 (1) (2015).
[3] L.A. AL-Rahman, R.I. Raja, R.A. Rahman, Z. Ibrahim, Acoustic properties of innovative material from date palm fibre, Am. J. Appl. Sci. 9 (9) (2012) 1390.
[4] M. Faridan, A. Khavanin, R. Mirzaei, M. Salehnia, The effects of normobaric hyperoxia pre-and post-treatment on the development of noise-induced hearing loss in rats, Health Scope 6 (4) (2017).
[5] T. Münzel, T. Gori, W. Babisch, M. Basner, Cardiovascular effects of environmental noise exposure, Eur. Heart J. 35 (13) (2014) 829–836.
[6] E. Taban, S.B. Mortazavi, S. Vosoughi, A. Khavanin, H. Asilian, Noise exposure effects on blood glucose, cortisol and weight changes in the male mice, Health Scope 6 (2) (2017).
[7] S.J. Linton, G. Kecklund, K.A. Franklin, L.C. Leissner, B. Sivertsen, E. Lindberg, et al., The effect of the work environment on future sleep disturbances: a systematic review, Sleep Med. Rev. 23 (2015) 10–19.
[8] Advanced Materials ResearchE. Jayamani, S. Hamdan (Eds.), Sound absorption coefficients natural fibre reinforced composites, Trans Tech Publ, 2013.
[9] J.P. Arenas, M.J. Crocker, Recent trends in porous sound-absorbing materials, Sound Vib. 44 (7) (2010) 12–18.
[10] L. Cao, Q. Fu, Y. Si, B. Ding, J. Yu, Porous materials for sound absorption, Compos. Commun. 10 (2018) 25–35.
[11] X. Tang, X. Yan, Acoustic energy absorption properties of fibrous materials: a review, Compos. Appl. Sci. Manuf. 101 (2017) 360–380.
[12] S. Rwawiire, B. Tomkova, J. Militky, L. Hes, B.M. Kale, Acoustic and thermal properties of a cellulose nonwoven natural fabric (barkcloth), Appl. Acoust. 116 (2017) 177–183.
[13] L. Mohammed, M.N. Ansari, G. Pua, M. Jawaid, M.S. Islam, A review on natural fiber reinforced polymer composite and its applications, Int. J. Polym. Sci. 2015 (2015).
[14] M. Jawaid, H.A. Khalil, Cellulosic/synthetic fibre reinforced polymer hybrid composites: a review, Carbohydr. Polym. 86 (1) (2011) 1–18.
[15] F. Asdrubali, F. D'Alessandro, S. Schiavoni, A review of unconventional sustainable building insulation materials, Sustain. Mater. Technol. 4 (2015) 1–17.
[16] F. Ahmad, H.S. Choi, M.K. Park, A review: natural fiber composites selection in view of mechanical, light weight, and economic properties, Macromol. Mater. Eng. 300 (1) (2015) 10–24.
[17] A. Ali, K. Shaker, Y. Nawab, M. Jabbar, T. Hussain, J. Militky, et al., Hydrophobic treatment of natural fibers and their composites—a review, J. Ind. Text. 47 (8) (2018) 2153–2183.
[18] M.H. Fouladi, M. Ayub, M.J.M. Nor, Analysis of coir fiber acoustical characteristics, Appl. Acoust. 72 (1) (2011) 35–42.
[19] K.H. Or, A. Putra, M.Z. Selamat, Oil palm empty fruit bunch fibres as sustainable acoustic absorber, Appl. Acoust. 119 (2017) 9–16.
[20] C. Othmani, M. Taktak, A. Zain, T. Hantati, N. Dauchez, T. Elnady, et al., Acoustic characterization of a porous absorber based on recycled sugarcane wastes, Appl. Acoust. 120 (2017) 90–97.
[21] B. Botterman, G.D. de la Grée, M. Hornikx, Q. Yu, H. Brouwers, Modelling and optimization of the sound absorption of wood-wool cement boards, Appl. Acoust. 129 (2018) 144–154.
[22] A. Putra, K.H. Or, M.Z. Selamat, M.J.M. Nor, M.H. Hassan, I. Prasetiyo, Sound absorption of extracted pineapple-leaf fibres, Appl. Acoust. 136 (2018) 9–15.
[23] Z. Lim, A. Putra, M. Nor, M. Yaakob, Sound absorption performance of natural kenaf fibres, Appl. Acoust. 130 (2018) 107–114.
[24] U. Berardi, G. Iannace, Predicting the sound absorption of natural materials: best-fit inverse laws for the acoustic impedance and the propagation constant, Appl. Acoust. 115 (2017) 131–138.
[25] E. Taban, A. Tajpoor, M. Faridan, S.E. Samaei, M.H. Beheshti, Acoustic Absorption Characterization and Prediction of Natural Coir Fibers, Acoustics Australia, 2019.
[26] E. Taban, A. Khavanin, M. Faridan, S.E. Samaei, K. Samimi, R. Rashidi, Comparison of acoustic absorption characteristics of coir and date palm fibers: experimental and analytical study of green composites, Int. J. Environ. Sci. Technol. (2019).
[27] C. Othmani, M. Taktak, A. Zein, T. Hentati, T. Elnady, T. Fakhfakh, et al., Experimental and theoretical investigation of the acoustic performance of sugarcane wastes based material, Appl. Acoust. 109 (2016) 90–96.
[28] Production-, Date-2016, T. http://www.fao.org/faostat/en/#data/QC. in 17 November 2016.
[29] M. Haseli, M. Layeghi, H. Zarea Hosseinabadi, Characterization of blockboard and battenboard sandwich panels from date palm waste trunks, Measurement 124 (2018) 329–337.
[30] M. Gholami, M. Ahmadi, M. Tavanaie, M. Khajeh Mehrizi, Mechanical properties of date palm fiber reinforced polymer composites: a review, Basparesh 7 (1) (2017) 82–93.
[31] H. Hosseinkhani, MDF Production from Date palm Pruning Residues in Pilot Plant Scale, 2015.
[32] C. Chen, Y. Zhang, G. Sun, J. Wang, G. Wang, Windmill palm fiber/polyvinyl alcohol coated nonwoven mats with sound absorption characteristics, BioResources 11 (2) (2016) 4212–4225.
[33] ISO10534-2: I. Acoustics-Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes – Part 2:Transfer-Function Method [Online]. [cited 2001]; Available from. URl: http://wwwisoorg/iso/catalogue_detailhtm?csnumber=22851. ,.
[34] M.E. Delany, E.N. Bazley, Acoustical properties of fibrous absorbent materials, Appl. Acoust. 3 (2) (1970) 105–116.
[35] Y. Miki, Acoustical properties of porous materials-Modifications of Delany-Bazley models, J. Acoust. Soc. Jpn. 11 (1) (1990) 19–24.
[36] M. Garai, F. Pompoli, A simple empirical model of polyester fibre materials for acoustical applications, Appl. Acoust. 66 (12) (2005) 1383–1398.
[37] J.F. Allard, Y. Champoux, New empirical equations for sound propagation in rigid frame fibrous materials, J. Acoust. Soc. Am. 91 (6) (1992) 3346–3353.
[38] J.F. Allard, G. Daigle, Propagation of Sound in Porous media: Modeling Sound Absorbing Materials, ASA, 1994.
[39] E. Gliscinska, M. Michalak, I. Krucinska, J. Kazimierczak, A. Bloda, D. Ciechanska, Sound absorbing composites from nonwoven and cellulose submicrofibres, J. Chem. Chem. Eng. 7 (10) (2013) 942.
[40] Z.K. Xie, T. Ikeda, Y. Okuda, H. Nakajima, Characteristics of sound absorption in lotus-type porous magnesium, Jpn. J. Appl. Phys. 43 (10R) (2004) 7315.
[41] H. Mamtaz, M.H. Fouladi, M. Al-Atabi, S. Narayana Namasivayam, Acoustic absorption of natural fiber composites, J. Eng. 2016 (2016).
[42] A.E. Tiuc, O. Vasile, H. Vermesan, Acoustic performance of composite materials made from textile waste, Rom. J. Acoust. Vib. 12 (2) (2015) 111.
[43] F. Asdrubali, F. D'Alessandro, S. Schiavoni, Sound absorbing properties of materials made of rubber crumbs, J. Acoust. Soc. Am. 123 (5) (2008) 3037.
[44] A. Nick, U. Becker, W. Thoma, Improved acoustic behavior of interior parts of renewable resources in the automotive industry, J. Polym. Environ. 10 (3) (2002) 115–118.

[45] L.A. ALRahman, R.I. Raja, R.A. Rahman, Z. Ibrahim, Comparison of acoustic characteristics of date palm fibre and oil palm fibre, Res. J. Appl. Sci. Eng. Technol. 7 (8) (2014) 1656–1661.

[46] M.J.M. Nor, M. Ayub, R. Zulkifli, N. Amin, M.H. Fouladi, Effect of different factors on the acoustic absorption of coir fiber, J. Appl. Sci. 10 (22) (2010) 2887–2892.

[47] M.H. Fouladi, M.H. Nassir, M. Ghassem, M. Shamel, S.Y. Peng, S.Y. Wen, et al., Utilizing Malaysian natural fibers as sound absorber, Modeling and Measurement Methods for Acoustic Waves and for Acoustic Microdevices, InTech, 2013.

[48] J. Allard, N. Atalla, Propagation of sound in porous media: modelling sound absorbing materials 2e, John Wiley & Sons, 2009.

[49] J.P. Arenas, R. Rey, J. Alba, J. Ramis, Evaluation of Two Alternative Procedures for Measuring Airflow Resistance of Sound Absorbing Materials, ICSV20, Bangkok, Thailand, 2013.

[50] S. Fatima, A. Mohanty, Acoustical and fire-retardant properties of jute composite materials, Appl. Acoust. 72 (2-3) (2011) 108–114.