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NOISE REDUCTION USING FLAX AND KENAF FOR HOUSEHOLD VACUUM CLEANER

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Abstract

Noise produced by a vacuum cleaner is highly unpleasant and may cause hearing damage if exposed to it for a long period. Thus, this study aims to identify the noise source of household vacuum cleaner and provide a solution to reduce its noise level. The commercial household vacuum cleaner is used in this study to reflect the actual noise level of the household appliance. Two noise source identification methods are used. First, the overall Sound Pressure Level (SPL) of the vacuum cleaner is measured using six units of microphone that installed in a hemisphere setup. Microflown scan and paint are further used to identify the noise source within the vacuum cleaner. Few materials are selected, and their acoustic properties are measured. The selected materials are 300 gsm flax, 1000 gsm flax, and 1300 gsm kenaf. The materials are used as sound-absorbing materials and as filters in the vacuum cleaner. The measurement is then repeated to compare the effectiveness of the proposed materials in reducing noise on the vacuum cleaner. Results indicate that 1000 gsm flax shows better performance in noise reduction compared to the other two materials. Vacuum cleaner with 1000 gsm flax as a sound-absorbing material reduced the overall SPL by 6.08%.

Keywords: Flax, Kenaf, Noise control, Sound pressure level, Vacuum cleaner.

1. Introduction

A vacuum cleaner is an electrical device that collects small particles, such as dust, from surfaces for cleaning purposes. Vacuum cleaners are acoustically unpleasant electronic household appliances because they produce a high noise level during operation. Most electrical home appliances, including vacuum cleaners, produce noise at approximately 85 dB to 95 dB. Exposure to noises at or above 85 dB can lead to noise-induced hearing loss. A Recommended Exposure Limit (REL) from the National Institute for Occupational Safety and Health (NIOSH) that follows the standard by the Occupational Safety and Health Administration (OSHA) for an exposure level of 85 dB(A) is 8 hours [1]. REL changed according to the measured noise level. Therefore, if the noise generated by the vacuum cleaner is higher than the recommended level, exposure to vacuum cleaner noise will be considered hazardous to users. Thus, noise identification on vacuum cleaners for improving noise control is important to provide a healthy living environment. Designing vacuum cleaners with a low noise level will benefit the community and thus becomes the concern of manufacturers in complying with regulations. Most of the sources of vacuum cleaner noise are generated from the motor, suction, centrifugal fan, and the vibrating surface [2-4]. Altmsoy and Erol [2] indicated that the connection between the motor and vibrating surface of the vacuum cleaner will transmit force and motion, which is then converted to sound. Cudina and Prezelj [4] stated that the total noise generated from the suction is produced partially by the blower and electric motor; the noise consists of aerodynamic, mechanical, and electromagnetic noise.

For a measurement made by using limited bands of the frequency with A-weighting applied, a frequency range between 20 Hz and 20 kHz can be used based on UNI EN ISO 3744 standard measurements [5, 6]. Altmsoy and Erol [2] used a frequency range between 200 Hz and 8000 Hz for their sound pressure measurement. In the present study, the relevant frequency range is between 50 Hz and 6400 Hz, which is the operating frequency of a vacuum cleaner. Many methods have been used by previous researchers to identify the noise source produced by vacuum cleaners, among which, is the multidimensional spectral analysis (MDSA). MDSA can remove the overlapping noise sources and extract only the pure noise sources [7]. It is suitable for small and complicated systems, such as handheld vacuum cleaners. In the present study, sound mapping method and the total average power spectrum of pressure method are used for noise source identification.

Several methods have been developed to reduce the noise generated from vacuum cleaners. One of the methods is applying active noise control (ANC) in a vacuum cleaner. Paurobally [8] reduced the sound pressure level (SPL) by 2 dB(A) by installing ANC in a vacuum cleaner without decreasing the airflow rate. However, this method only eliminated airborne noise. In passive control methods, sound-absorbing materials must be included to eliminate structure-borne and flow noises. Lauchle and Brungart [3] reduced noise level from blade rate by 8 dB by modifying the vacuum fan. The modification was performed on the fan shroud or the stone shield by filling-in and re-sharpening the corners and by using a vacuum fan with unequally divided blade spacing rather than an equally divided one to reduce the fan-blade rate tone of the vacuum. However, this modification introduced a few sideband tones that increased the overall sound power level.

Using porous material as a noise control method is a simple and effective alternative to reduce the noise produced by vacuum cleaners. Instead of using synthetic fibres, such as polyester or polypropylene as sound-absorbing materials, natural fibres, such as coconut and oil palm fibres, are used. Rice husks and tea leaves have also been proposed as absorptive materials [9-12]. These green sound-absorbing materials are eco-friendly and biodegradable. They are also easily available and inexpensive. Mohanty and Fatima [13] used a natural plant fibre, jute, and its derivatives as materials to reduce noise produced by domestic clothes dryer, which resulted in 6 dB noise reduction. The results showed that using jute without treatment with natural rubber as a binder improved performance in terms of noise reduction compared with jute fibre with natural rubber treatment. Sambu et al. [14] investigated similar properties on kenaf by using natural rubber as a binder. The results showed that kenaf with natural rubber as binder exhibits better sound absorption at low frequency and kenaf without natural rubber as binder perform better at a high frequency of 4000 Hz and above. The sound absorption coefficient of kenaf fibre, ijuk fibre, coconut coir and palm oil frond have been studied after reinforced with fix ratio of 60:40 to natural rubber [15]. However, specimens' single density and thickness are used in the study. Wong et al. [16] at same year studied the sound absorption properties for the mixing of kenaf and bamboo particle. The mixture is done for two different densities (400 kg/m^3 and 600 kg/m^3) and four different ratios. The study showed that overall performance for the mixture with 400 kg/m3 exhibits better sound absorption characteristics. Lim et al. [17] recently reported the acoustic properties of natural kenaf fibres. The effects of thickness and bulk density of the specimens that involved full fibre and air-fibre are discussed. The results showed that the sound absorption could reach above 0.5 above 500 Hz. The tested bulk density is 140-150 kg/m^3 and the thickness of 25-30 mm. Therefore, natural flax fibre without special treatment is proposed in this study as absorptive material for noise reduction in a vacuum cleaner.

In this study, few materials are identified as absorptive materials for noise reduction in a household vacuum cleaner. First, noise level identification is conducted on overall running frequency ranges and specific frequencies. Sound mapping is conducted on the entire vacuum cleaner unit. Then, the acoustic properties of the original filter in the vacuum cleaner and the proposed absorptive materials are measured. The absorptive materials with improved sound absorption ability are selected and used as a new filter in the vacuum cleaner. Measurements are conducted to compare the performance of the original filter in the vacuum cleaner and the proposed absorptive materials.

2. Methodology

A lightweight vacuum cleaner with 1800 W motor is used in this study. The overall SPL of the vacuum cleaner with the original filter is measured. Sound mapping is conducted by scanning the noise source on the entire vacuum cleaner unit. The noisiest area of the vacuum cleaner is identified. Afterwards, three absorptive materials are identified, namely, 300 gsm flax, 1000 gsm flax, and 1300 gsm kenaf. The acoustic properties of these three materials are measured. The absorptive materials with superior sound absorption ability are used as new vacuum cleaner filters. The filters are installed in the noisiest point of the vacuum cleaner. The overall SPL and sound mapping are repeated to compare the effectiveness of the new filters compared with the original filter.

2.1. Overall sound level measurement

The overall sound level identification is measured to understand the original sound level that is generated by the selected vacuum cleaner. The direct method is used in this measurement based on BE ISO 3742. LMS TestXpress and LMS Scadas Mobile are used as data acquisition (DAQ) units. Six microphones are attached to the dome; their positions are at equal distances on the dome surface, as shown in Fig. 1. The microphones are located 1 m away from the vacuum cleaner, as indicated in the standard KSC 9101 [7, 18]. Each of the microphones is connected to the LMS Scadas Mobile. The vacuum cleaner is placed directly on the floor and aligned with the centre of the microphone dome. If the vacuum cleaner is placed 25 cm over the floor, this position may acoustically influence the noise sources, thereby causing the vacuum cleaner to emit different powers [19]. All microphones are calibrated before each measurement. The background and surface noises are recorded by the system separately.

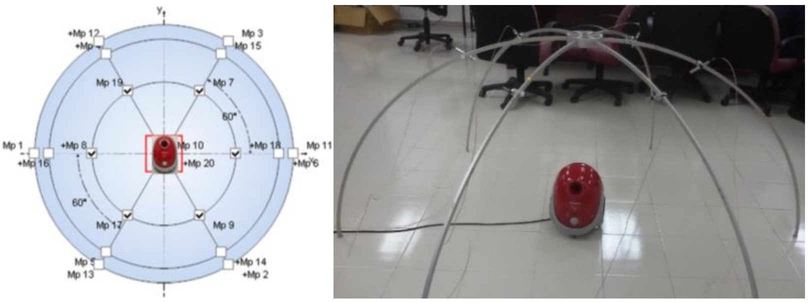

Fig. 1. Configuration of microphone position in the experimental setup.

2.2. Sound mapping and noise source identification

Sound mapping is conducted on the vacuum cleaner via Microflown Technologies. It identifies the noise source by screening all surfaces of the vacuum cleaner. The mapping also determines the SPL and noise intensity level produced by the vacuum cleaner. The results are shown in sound mapping and the total average power spectrum of pressure. The measurement is conducted in an open space by using the point-and-scan method. Measurement devices include Microflown Technologies software, camera, PU Probe, two-channel signal conditioner and DAQ units, and the vacuum cleaner, as shown in Fig. 2. A PU Probe is used to scan the entire vacuum cleaner at each surface. The probe detects the sound pressure and its velocity from the vacuum cleaner. The camera is mounted on a tripod and records the image of the vacuum cleaner. The vacuum cleaner operates at maximum power during the measurement. The PU Probe is moved as close as possible to the surface of the vacuum cleaner for ensuring the record of actual noise emitted from the vacuum cleaner. The distance must be consistent as SPL is influenced by the measurement distance from the source. Each surface, namely, the front, left, and bottom parts of the vacuum cleaner are measured. The measurement process identifies the noise source of the vacuum cleaner.

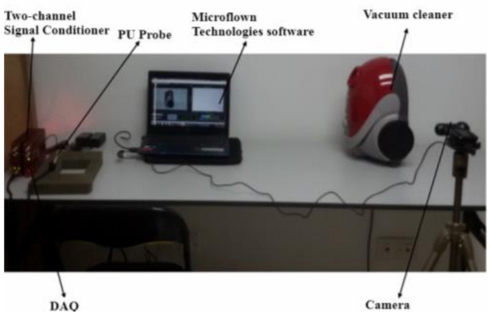

Fig. 2. Measurement set up for noise source identification via Microflown Technologies.

2.3. Sample preparation for sound absorption test

The passive noise control method is used in this study. To reduce the noise level generated from the vacuum cleaner, three materials are proposed to replace the original filter in the vacuum cleaner. The materials are 300 gsm flax, 1000 gsm flax, and 1300 gsm kenaf. Kenaf (Hibiscus cannabinus) and flax (Linum usitatissimum) are natural plants that are extremely fibrous. The materials are prepared by a needle-punching process with 100% content of raw materials without mixing with a binder. The output from the needle-punching process is in fibre bed form. The sample filters are prepared by using the three proposed materials. The thickness of the sample is based on the thickness of the original filter that is 0.5cm. This allows the new sample to easily fit into the current slot in the vacuum cleaner. The materials are cut into the desired shape to be later used in the vacuum cleaner. The sound absorption coefficient is measured by using an impedance tube for the three proposed materials and the original filter. Samples made from different materials that will be used in this study are shown in Fig. 3.

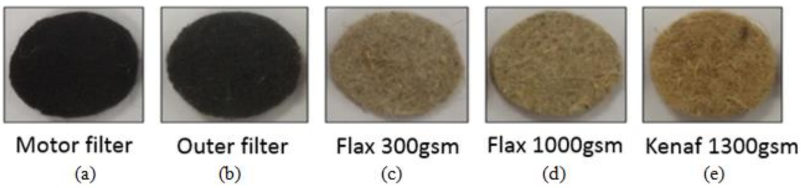

Fig. 3. Sample used in impedance tube measurement: (a) Motor filter, (b) Outer filter, (c) 300 gsm flax, (d) 1000 gsm flax, (e) 1300 gsm kenaf.

Figure 4 shows the measurement setup of the impedance tube in measuring the sound absorption of different filters. The measurement is conducted based on ISO 10534-2 and ASTM E 1050-98, which are the standards for the two-microphone transfer function method and for horizontally mounted orientation-sensitive materials, respectively. An impedance tube is a standing wave tube used in sound absorption tests. The tube determines the normal incidence of impedance surface and absorption coefficient under controlled conditions. The prepared materials are inserted into the sample holder and locked with the tube termination. All microphones are calibrated before each measurement. Three repeated tests are used as an average for each material. The sound absorption coefficient is obtained and compared by this measurement.

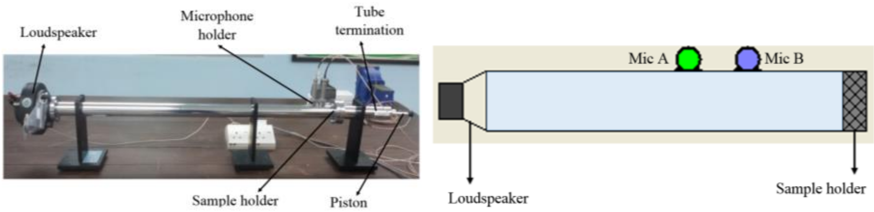

Fig. 4. Measurement setup and microphone positions for measuring sound absorption coefficient.

3. Results and Discussion

3.1. Sound absorption coefficient of different materials

The sound absorption coefficient for the original filter of the vacuum cleaner and the proposed new filters are measured by using the impedance tube, as shown in Fig. 5. The vacuum cleaner is allowed to run on its maximum speed and the maximum noise level occurred at 2000 Hz at this operation speed. Thus, the sound absorption coefficient is measured from 0 Hz to 5500 Hz to cover the interested frequency range. The results show that the original filter has a relatively low sound absorption coefficient for the entire range of frequencies. At 2000 Hz, the original filter has a value of 0.7 for the motor filter and 0.6 for the outer filter. The proposed materials used as new filters have improved sound absorption coefficient through the frequency ranges. The 1000 gsm flax shows the highest sound absorption coefficient among the tested materials with a value of 0.98, followed by 1300 gsm kenaf with 0.96 and 300 gsm flax with 0.85. In general, natural fibre composite with lower density exhibits better sound absorption in the low-frequency region and natural fibre composite with higher density exhibits better sound absorption at a frequency more than 1500 Hz [15]. However, these properties may change if different materials are used as a binder. Thus, 1000 gsm flax and 1300 gsm kenaf are used as new filters. The filters are prepared exactly with the same thickness and size as the original filter but using the proposed materials. The selected materials are used as filters in the vacuum cleaner to replace the original filter. Measurement is conducted to compare the performance of each filter.

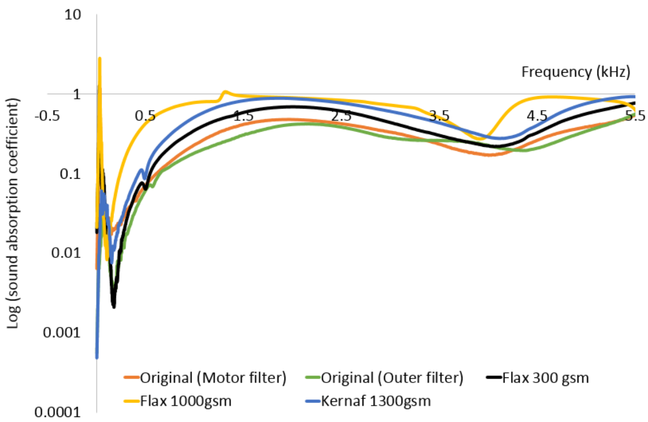

Fig. 5. Comparison of sound absorption coefficient for different filters.

3.2. Sound mapping and identification of the vacuum cleaner

Noise mapping and measurement are completed via Microflown Technologies. The noise generated from the vacuum cleaner is scanned at each surface, including the front, side, and bottom. The sound mapping shows the area in which, the highest sound level occurs. Figure 6 shows the comparison of the sound mapping on each side of the vacuum cleaner when different filters are installed. The critical areas that have the highest SPL are labelled with red, and the areas that are labelled with blue have lower SPL. The SPLs that are generated from the vacuum cleaner with the original filter is shown in Figs. 6(a), (d) and (g). The figures clearly indicate that the bottom part of the vacuum cleaner has the highest SPL from three sides. Thus, the source of noise produced by the vacuum cleaner is the motor and the exhaust part. The maximum airflow of the vacuum cleaner exhaust produces high noise levels.

Based on this observation, the filter of the vacuum cleaner is replaced with better absorptive materials. The location of the filter is at the bottom of the vacuum cleaner to absorb the highest SPL. Figures 6(b), (e), and (h) show the sound mapping from three sides of the vacuum cleaner after using 1000 gsm flax as the filter. Furthermore, Figs. 6(c), (f), and (i) show the SPLs measured from three sides of the vacuum cleaner after using 1300 gsm kenaf as the filter. The comparison indicates that the vacuum cleaner that used 1300 gsm kenaf as the new filter reduced the maximum SPL in the front part from 124 dB to 114 dB.

The minimum SPL is also reduced from 106 dB to 102 dB. The same observation is found at the bottom part of the vacuum cleaner; a reduction from 126 dB to 120 dB is observed. The reduction in SPL in the vacuum cleaner in which, 1000 gsm flax is used as the filter is from 124 dB to 122 dB at the front part and 126 dB to 122 dB at the bottom part. Although the reduction in SPL caused by 1000 gsm flax is lower compared to 1300 gsm kenaf, the area for maximum SPL is smaller. Figure 6(h) indicates that the maximum of 122 dB only occurs in a small area compared with Fig. 6(i), which depicts a relatively large area.

Table 1 shows the comparison of the overall sound levels for different filters that are measured based on BE ISO 3742. The measurement is conducted after the new filters are installed on the vacuum cleaner. Table 1 indicates that the new filters can achieve lower SPL compared with the original filter. The vacuum cleaner with 1000 gsm flax as the new filter has an SPL that is 5.9 dB lower than the original filter. The reduction in SPL is also higher compared with 1300 gsm kenaf, which has 4.4 dB reductions. Table 1 explains the phenomenon in Fig. 6, in which, the maximum SPL value is higher for 1000 gsm flax but with a smaller area. This condition resulted in a lower value of the overall SPL in the vacuum cleaner that used 1000 gsm flax as the filter.

Table 1. Comparison of the sound pressure level for different filters.

Materials	SPL, dB(A)	% reduction in SPL compared with the original filter
Original filter	80.6	-
1000 gsm flax	75.7	6.08
1300 gsm kenaf	76.2	5.46

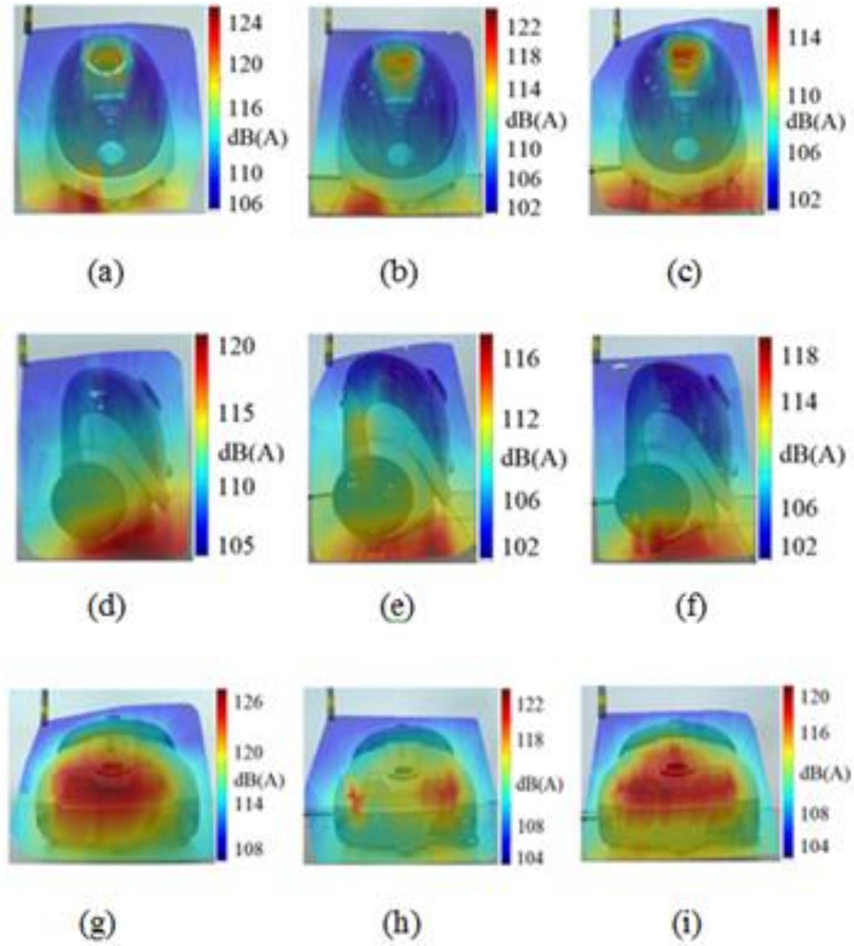

Fig. 6. SPL sound mapping of vacuum cleaner: (a) Front with original filter, (b) Front with 1000 gsm flax, (c) Front with 1300 gsm flax, (d) Side with original filter, (e) Side with 1000 gsm flax, (f) Side with 1300 gsm kenaf, (g) Bottom with original filter, (h) Bottom with 1000 gsm flax, (i) Bottom with 1300 gsm kenaf.

3.3. Comparison of the overall SPL for new filters and original filter

The measurement of the overall SPL that used six microphones and a dome are repeated on each vacuum cleaner filter to validate the reduction of SPL. Figure 7 shows a comparison of the overall SPL measured from 0 Hz to 6000 Hz for the vacuum cleaner with different filters. The measurement results shown in Fig. 7 validate the reduction of SPL using 1000 gsm flax and 1300 gsm kenaf as the filters. The reduction is evident in the entire range of frequencies. Furthermore, SPL is reduced when running frequency is higher. Maximum SPL always consistently occurs from 50-2000 Hz.

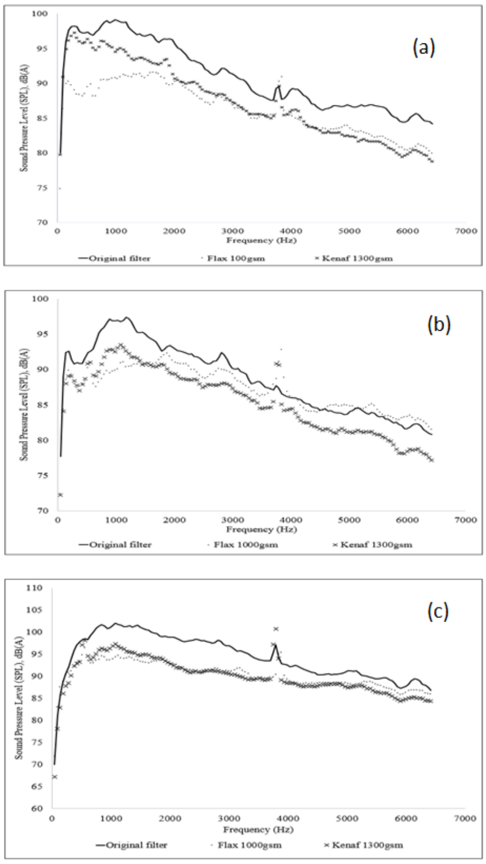

Fig. 7. Total average SPL ("A-weighted"): (a) Front part of vacuum cleaner, (b) Side part, (c) Bottom part with different types of material.

4. Conclusion

The measurements of overall SPL and noise identification are conducted on the vacuum cleaner. Three materials are proposed and their acoustic properties are measured by using the impedance tube. Based on the results, 1000 gsm flax and 1300 gsm kenaf are selected and proposed as the new filters for the vacuum cleaner. The size of the new filters is the same as that of the original filter. The measurement of the overall SPL and noise identification are repeated to compare the noise from the vacuum cleaner with the original filter and that with the new filters (1000 gsm flax and 1300 gsm kenaf). The results show that 1000 gsm flax reduces the noise level from the vacuum cleaner by 4.9 dB compared to the vacuum cleaner with the original filter. The vacuum cleaner that used 1300 gsm kenaf as the new filter produced a noise level that is 4.4 dB lower compared to the vacuum cleaner with the original filter. This finding indicates the effectiveness of 1000 gsm flax and 1300 gsm kenaf for the noise control in vacuum cleaners. Both materials can be proposed as filter materials in vacuum cleaners. The proposed new filters can also reduce the noise generated throughout the range of frequencies instead of at a single frequency.

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Abbreviations	
ANC	Active Noise Control
ASTM	American Society for Testing and Materials
DAQ	Data Acquisition
ISO	International Standards Organization
MDSA	Multidimensional Spectral Analysis
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
REL	Recommended Exposure Limit
SPL	Sound Pressure Level

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