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SOUND ABSORPTION OF POLYMERIC NANOFIBROUS MEMBRANES

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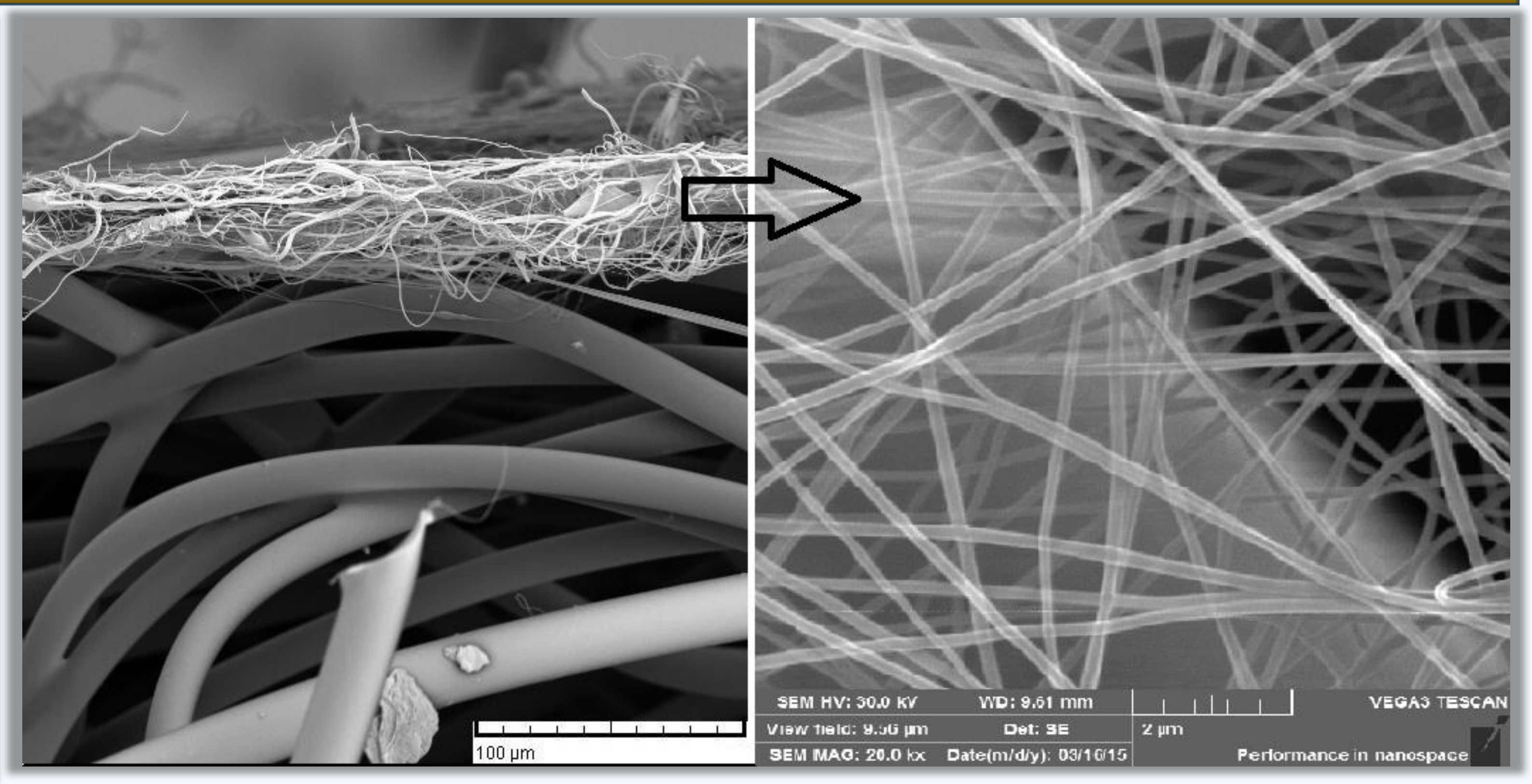
The standardized characterization of nanofibrous membranes used to coat three porous bulk acoustical materials (melamine foam, a polyester fleece, and an MDF perforated panel) is done in order to offer sustainable alternatives to predominantly used glass, mineral, and ceramic fibrous materials. The membranes are manufactured from recyclable Polyamide 6 (PA6) and water-soluble Polyvinyl Alcohol (PVA) using the needleless electrospinning technique. This results in very thin membranes of high porosity and very high airflow resistivity. Both an impedance tube and reverberation room measurements show significant improvements in the sound absorption performance of the bulk materials after incorporating the nanofibrous layer on them.

There is a justified need in the acoustic market to incorporate sustainable materials as alternatives to glass, mineral, and ceramic fibrous materials, which have high carbon footprints [1]. Thus, a thin layer of nanofibrous material can be added to a standard bulk sound-absorbing material in the form of an attached membrane. Such layers are commonly used for the protection and structural integrity of the material. However, since this layer must be permeable in order not to degrade the acoustic performance, the membrane can also add acoustic resistance to the overall system, providing an increase in the total sound absorption. Therefore, a nanofibrous layer with its unique properties has the potential to work well as a thin, lightweight absorbing solution. It can be successfully applied in numerous areas, including room acoustics and construction, automotive, transportation, aerospace, and, interestingly today, as a solution to reduce noise coming out of drones [1–2].



SEM images of a PA6 membrane cross-section (on the left) and morphology of the PA6 nanofibers (on the right).

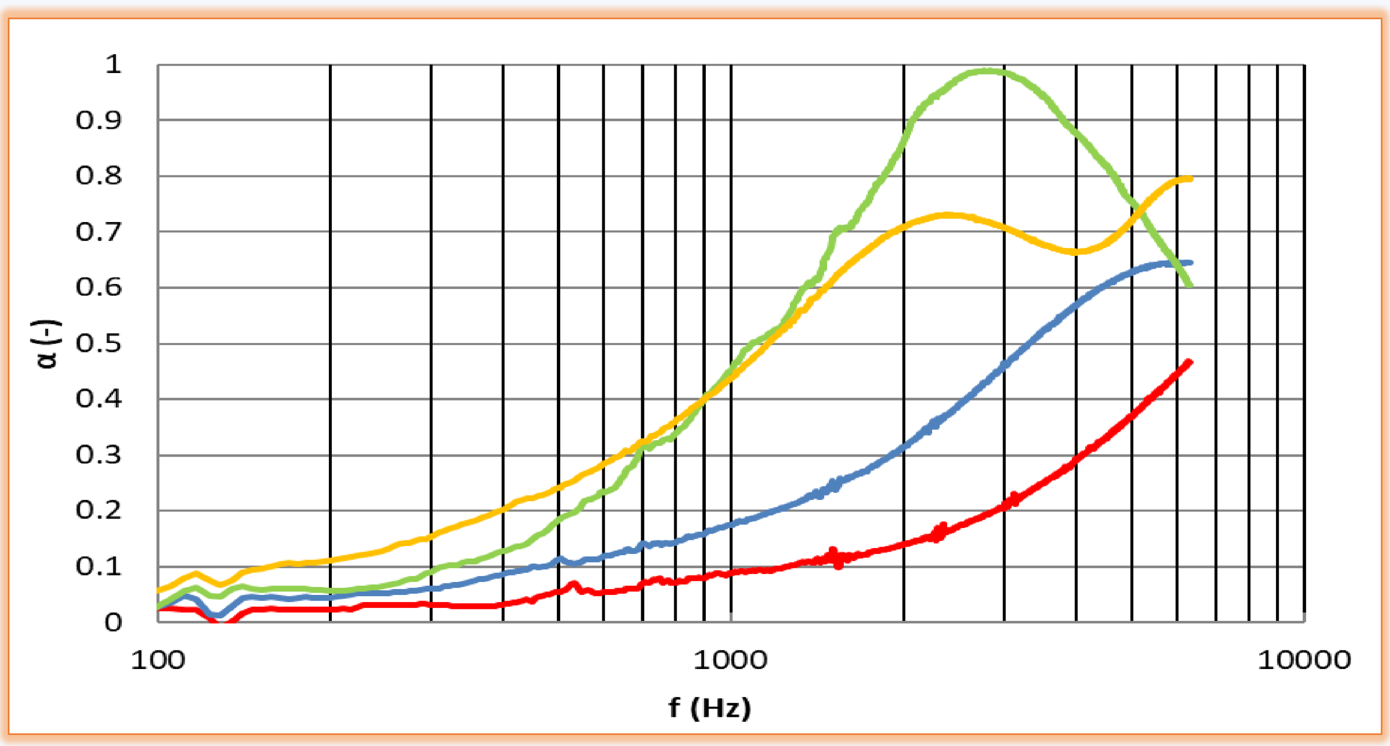
Both the fiber morphology and the fiber diameter of the electrospun nanofibers were determined using scanning electron microscopy (SEM). Characterization of non-acoustical properties also involved: airflow resistivity, air-permeability, pore size, porosity, and surface area determination.

Average and standard deviation results for the nanofibers studied:

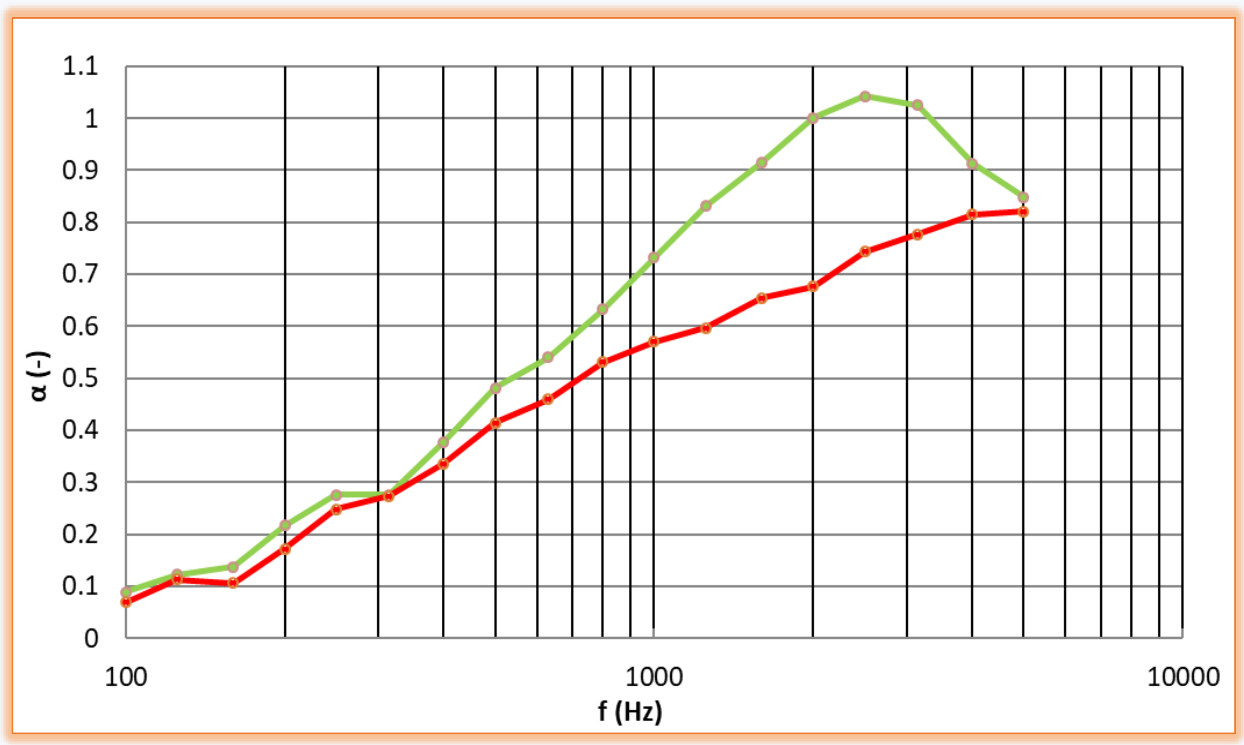
Nanofibers	0.2 gsm PA6	1.0 gsm PA6	0.6 gsm PVA	1.0 gsm PVA
Thickness (mm)	3.2 ± 0.84	12.2 ± 1.48	10.6 ± 1.52	18.8 ± 1.64
Airflow resistivity (10^7 Pa s/m^2)	3.6 ± 0.384	9.1 ± 0.085	7.2 ± 0.083	8.8 ± 0.098
Air permeability (mm/s)	111.5 ± 5.831	42.38 ± 0.102	81.6 ± 4.9	68.75 ± 3.2
Mean pore diameter (nm)	648 ± 88	491 ± 36	936 ± 41	897 ± 35
Calculated porosity (%)	98.8 ± 0.25	94.1 ± 0.3	97.3 ± 0.45	95.5 ± 0.17
Measured Porosity (%)	97.1 ± 0.98	96.4 ± 2.15	92.1 ± 2.41	91.7 ± 3.17
Calculated specific surface area (m^2/g)	24.3 ± 6.7	25.5 ± 4.9	14.5 ± 1.8	16.8 ± 4.1
Measured specific surface area (m^2/g)	21.0 ± 4.0	25.0 ± 3.0	13.0 ± 3.0	17.0 ± 4.0
Mean fiber diameter (nm)	153.5 ± 37.5	142.9 ± 27.3	263 ± 29.4	238.1 ± 83.2
Min fiber diameter (nm)	90.4	90.6	115.4	149.4
Max fiber diameter (nm)	331	196.8	345.2	512.6
Porosity [1] (%)	98.4 ± 0.44	97.7 ± 0.49	96.3 ± 0.45	96.3 ± 1.41

[1] Estimated from the Kozeny-Carman equation.

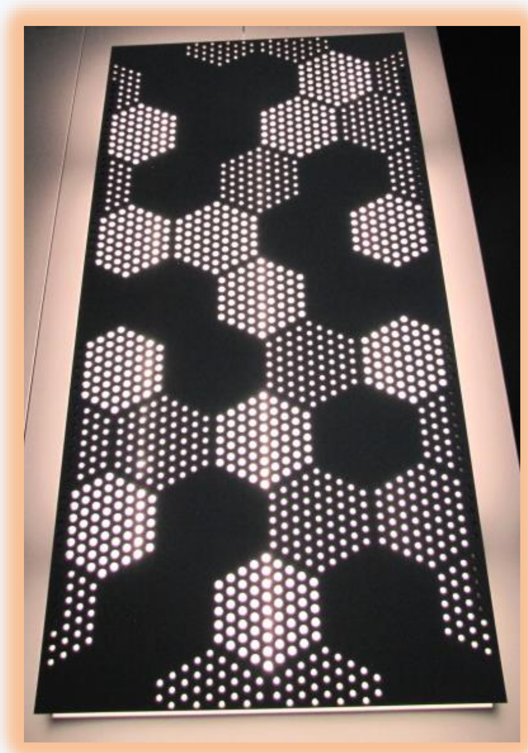
Contrary to conventionally used microscale sound absorbers, sound absorbing membranes based on submicron fibers may show higher sound absorption abilities. As the membrane is forced to vibrate by incident sound waves, there are several physical mechanisms contributing to sound absorption. The kinetic energy of the membrane is transformed into thermal energy due to the friction between individual fibers, as well as the friction of the membrane with air and possibly with other layers of material arranged in its proximity. A certain part of the energy can also be transmitted to the frame (if it is present). In addition, part of the energy can be absorbed by scattering from the fibers and by the vibration caused in individual fibers or fiber segments (considering structural overlaps) [3]. These unique properties come from the nature of nanofibrous layers, i.e., their small fibrous diameter, correspondingly high specific surface area, and high values of porosity close to unity. This causes high viscous losses inside the material and, consequently, more dissipation of acoustic energy. Furthermore, due to resonance at its natural frequency, the membrane is able to absorb low-frequency sound energy. Nanofibrous elements and optimal rigidity of the membrane can lead an acoustic system to vibrate more efficiently [4].



Normal-incidence sound absorption coefficient as a function of frequency for the 8 mm PES non-woven fibrous bulk absorber alone (red line), the same bulk absorber but 18 mm thick (blue line), 46 mm thickness (yellow line), and the 8 mm one treated with the 0.2 gsm PA6 nanofibrous membrane on the substrate (green line).



Diffuse-field sound absorption coefficient of a sample of 18 mm PES non-woven textile bulk absorber with the micro-fibrous substrate layer (red line) and treated with the 0.2 gsm PA6 nanofibrous layer on the substrate (green line).



An example of acoustic wall panel employing nanofibrous membrane.

The sound absorption coefficient results received both from an impedance tube and a reverberation room show that a significant improvement in the sound absorption performance of the bulk materials or traditional air-backed perforated panel can be achieved by incorporating the nanofibrous layer on them. This effect can be explained by the increase in the real part of the surface impedance of the bulk material when the nanofibrous membrane is attached onto it. This added resistance is approximately given by the airflow resistivity of the membrane times its thickness. These high values were obtained after treating low thickness materials. This is of great importance in satisfying the transportation industry aims of high sound absorption values with reduced weight to reduce fuel consumption! Hence, further application of these membranes to recycled bulk materials has the potential of more ecological acoustic materials.

[1] Arenas, J.P.; Crocker, M.J. Recent trend in porous sound-absorbing materials. *Sound Vib.* 2010, *44*, 12–17. **[2]** Beckermann, G.; Hosie, I.; Clarke, A.; Rowe, M.; Rowe, S.; Pentecost, S.; Edlin, S. Sound attenuating performance of nanofiber materials used in unmanned aerial vehicles. *Adv. Mat.: TechConnect Briefs* 2018, 212-215. **[3]** Dahl, M.D.; Rice, E.J., Groesbeck, D.E. Effects of fiber motion on the acoustical behavior of an anisotropic, flexible fibrous material, *J. Acoust. Soc. Am.* 1990, *87*, 54-66. **[4]** Kalinova, K. Nanofibrous resonant membrane for acoustic applications. *J. Nanomaterials* 2011, *2011*, ID 265720.

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