Supporting Information

For ***RSC Adv.***

"Green" Nano-Filters: Fine Nanofibers of Natural Protein for High Efficiency Filtration of Particulate Pollutants and Toxic Gases

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Gelatin solution and nanofiber mat preparation. Gelatin was dissolved in mixed solvent (volume ratio, acetic acid : DI water = 80 : 20) with a concentration of 18 wt% at 65 °C. The mixed solvent was used to achieve a good electrospinning of the gelatin solution. With that ratio between water and acetic acid, it was found that a homogenous yellow solution and stable electrospinning of the solution can be achieved. The electrospinning of gelatin solution is a well-known process and the effect of viscosity on electrospinning of gelatin has been studied before.[1] After the homogenous gelatin solution (18 wt%) is prepared, the nanofibers were spun at room temperature on an aluminum mesh substrate. The areal density of the nanofabrics was controlled by controlling the volume of the solution that was electrospun on the substrate. The gelatin nanofabrics possessed a thickness within the range of 8 – 20 µm. In particular, the sample with the best air filtration properties (areal density = 3.43 g/m^2) possesses a thickness of about 16 µm. The gelatin nanofabrics can be handled manually even though they are not crosslinked, but it is challenging due to very high electrostatic charge of the nanofibers. Therefore, the nanofabrics fixed on the aluminum mesh were used for filtration testing. Presence of the aluminum mesh did not affect the filtration properties of the nanofabrics (removal efficiencies and pressure drop) due to very large pore size of the mesh (1 mm x 1mm).

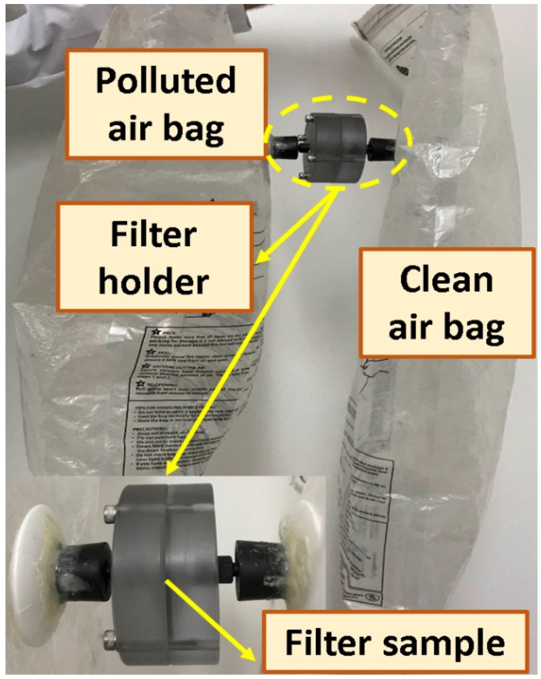

Figure S1. Digital picture of the air filtration experimental setup

The digital image of the experimental setup is shown in Figure S1. For the air filtration testing, medium and large plastic vacuum air bags (commercial magicbag™) and modified to be able to connect to a home-made filter holder. Each sample was exposed to the air filtration testing for 30 minutes at standard face velocity. Due to the volume limitation of the bags, continuous testing was not possible. Therefore, for long-term filtration testing, we performed multiple numbers of testing with 30 minutes filtration time on each sample.

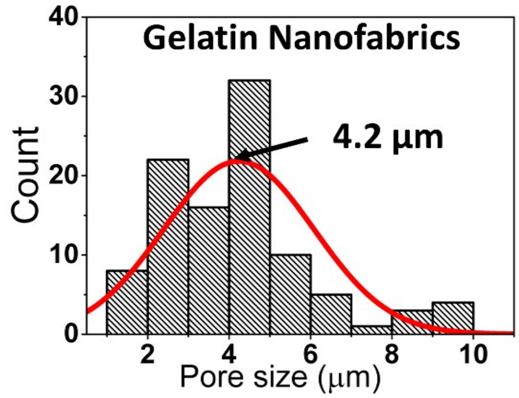

Figure S2. Pore size distribution of gelatin nanofabrics.

Pore size is one the most important parameters affecting the filtration performance as the filtration of particulate pollutants are generally governed by four primary and size-based physical mechanisms, sieving, inertial impaction, interception, and diffusion. This result shows that the gelatin filter nanofabric mats possess the average pore size of around 4.2 μm. Additionally, a novel interaction-based filtration mechanism was proposed in this work that only is provided from the multifunctional materials such as proteins that take the fiber-pollutant interactions into account. Therefore, this novel interaction-based mechanism alongside with the four primary physical mechanisms enable the gelatin nanofabrics to possess such extremely high pollutant and chemical filtration efficiencies.

Table S1. Number concentration of particulate pollutants before and after filtration using gelatin nanofiber filter with areal density of 3.43 g/m^2.

	0.3	0.5	1	2.5	5	10
Number [con.] in polluted air	2046623	1753416	962801	218498	15641	12633
Number [con.] after filtration	13763	14621	1982	314	4	2

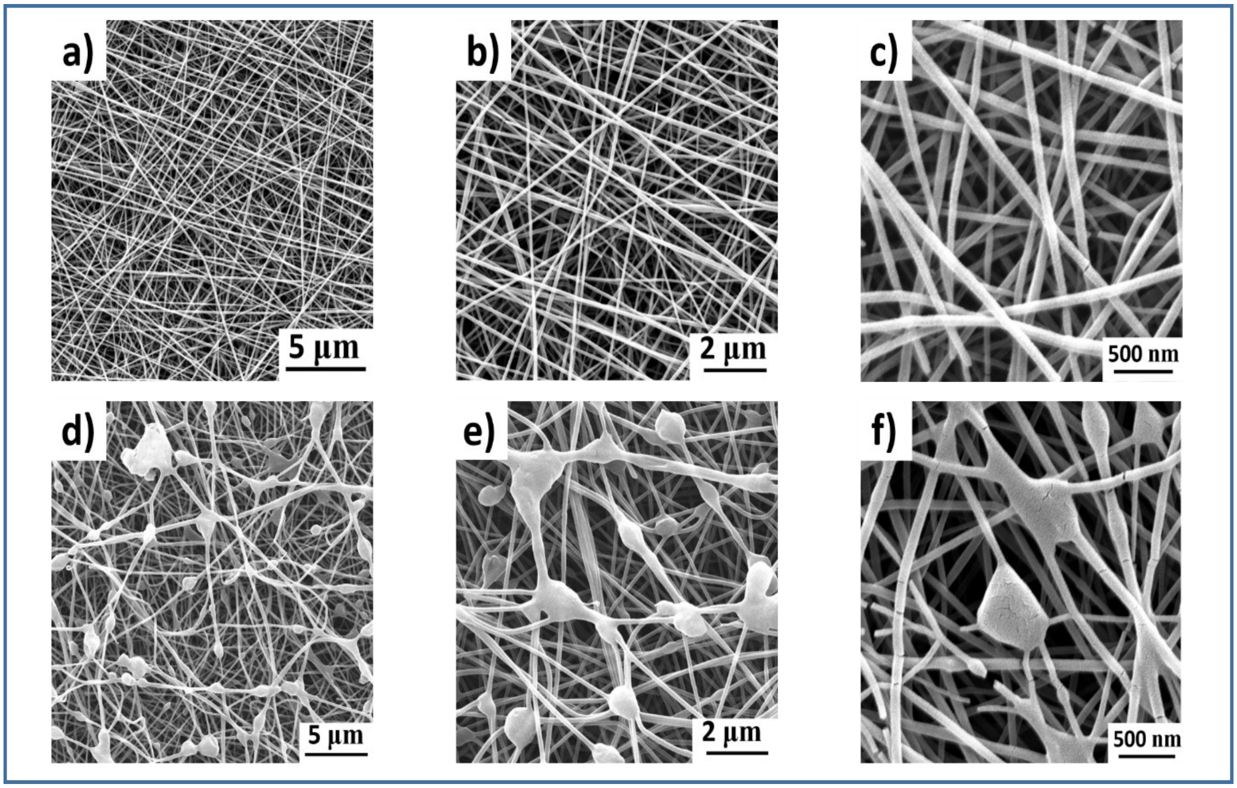

Figure S3. SEM images of gelatin filter nanofabrics with different magnifications (a–c) before filtration test and (d–f) after filtration test showing the pollutants were grabbed around the fibers and deformed.

Table S2. Concentration of toxic gaseous chemicals before and after filtration using gelatin nanofiber filter with areal density of 3.43 g/m^2.

	Formaldehyde	Carbon monoxide
Concentration in polluted air (ppm)	1.75	34
Concentration after filtration (ppm)	0.3	8

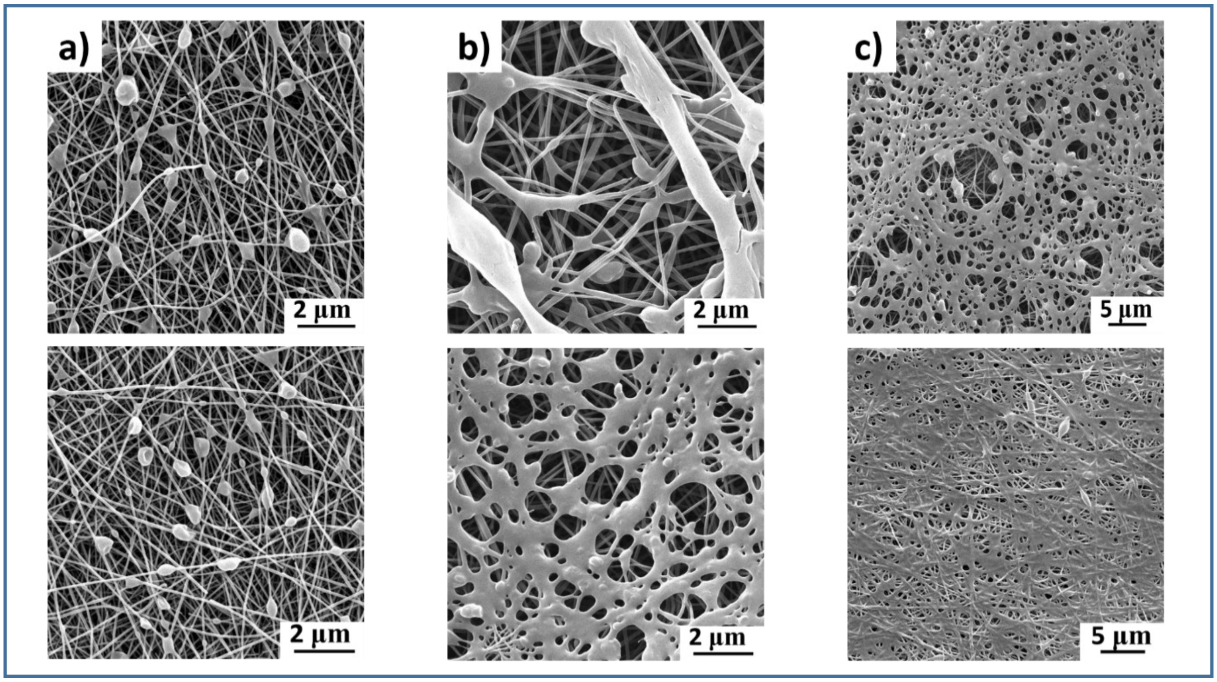

Figure S4. SEM images of gelatin air filter nanofabrics after being tested with cigarette smoke showing the deformation and migration of soft PM during filtration procedure, a) first stage, b) semi-saturated stage,and c) saturated stage.

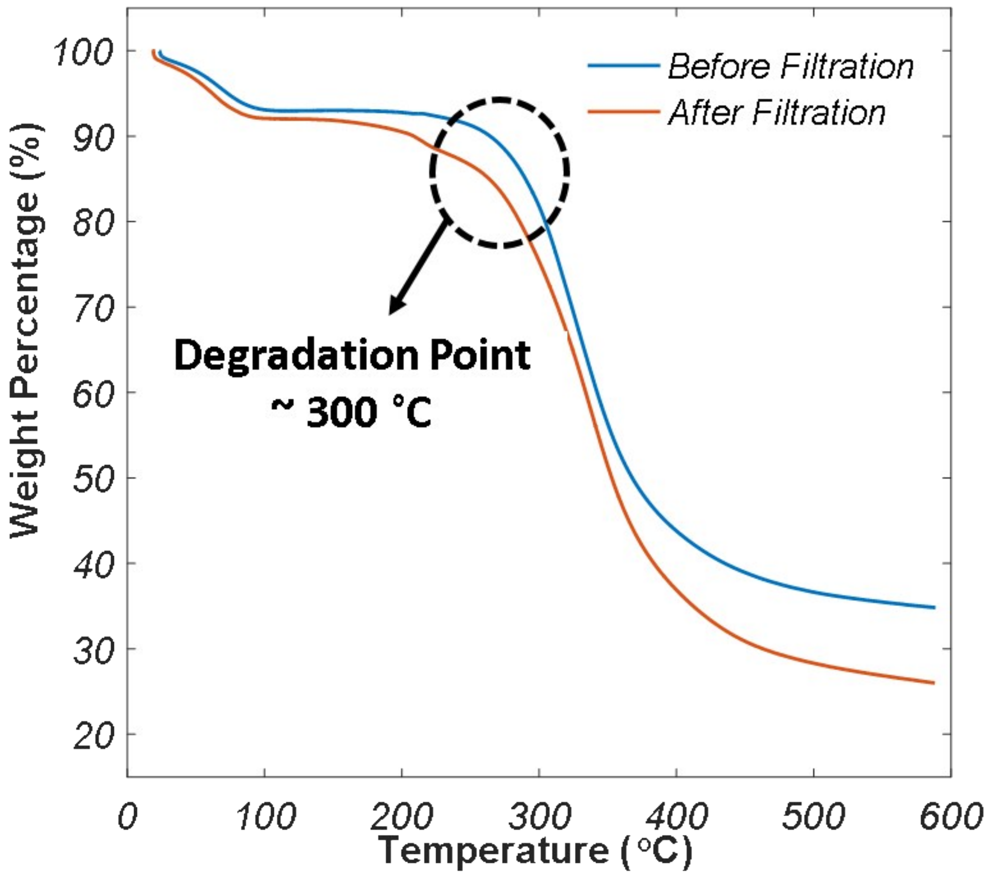

Figure S5. Thermogravimetry analysis (TGA) results for gelatin nanofabrics before and after filtration.

Thermogravimetric analysis (TGA) is utilized to study the thermal stability and degradation of the gelatin nanofibers before and after filtration testing. The test was performed at 20°C/min heating rate. The TGA results show that the gelatin nanofiber mats were very stable in a broad range of temperatures (20–250 °C) both before and after filtration. The filter mats were degraded at around 300 °C.

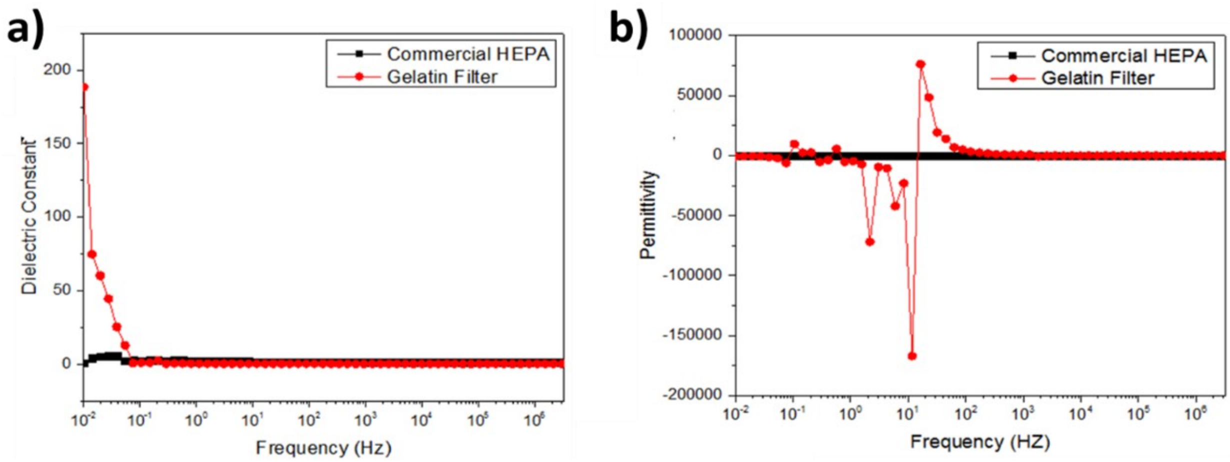

Figure S6. Testing the functional group movements in the gelatin nanofabrics structure, a) dielectric measurement, b) permittivity measurement.

The dielectric measurements demonstrated that the commercial HEPA filter, which has no active functional groups in its structure, showed a constant dielectric constant which means, as expected, it is an isolating material. In contrary, gelatin nanofabrics showed higher dielectric values at lower frequencies which means that the gelatin fibers do not have an isolating behavior. In addition, fluctuations in the permittivity values of a material at low frequencies are mostly representative of the rotation and the respond of active functional groups with the electric field to some extent.[2–5] These results showed a huge amount of fluctuations at lower frequencies for gelatin nanofibers while there was not any changes for commercial HEPA filter that is made of an isolating material. Dielectric test results, as well as FTIR results that have been mentioned in the main paper, proved the existence of many active functional sites to interact with particles and chemicals present in polluted air that resulted in high removal efficiency for both $PM_{2.5}$ and toxic chemicals (HCHO and CO) with very low areal density compared with commercial HEPA filter. The quantitative analysis of air flow resistance was carried out by investigating the pressure drop of the gelatin filter.

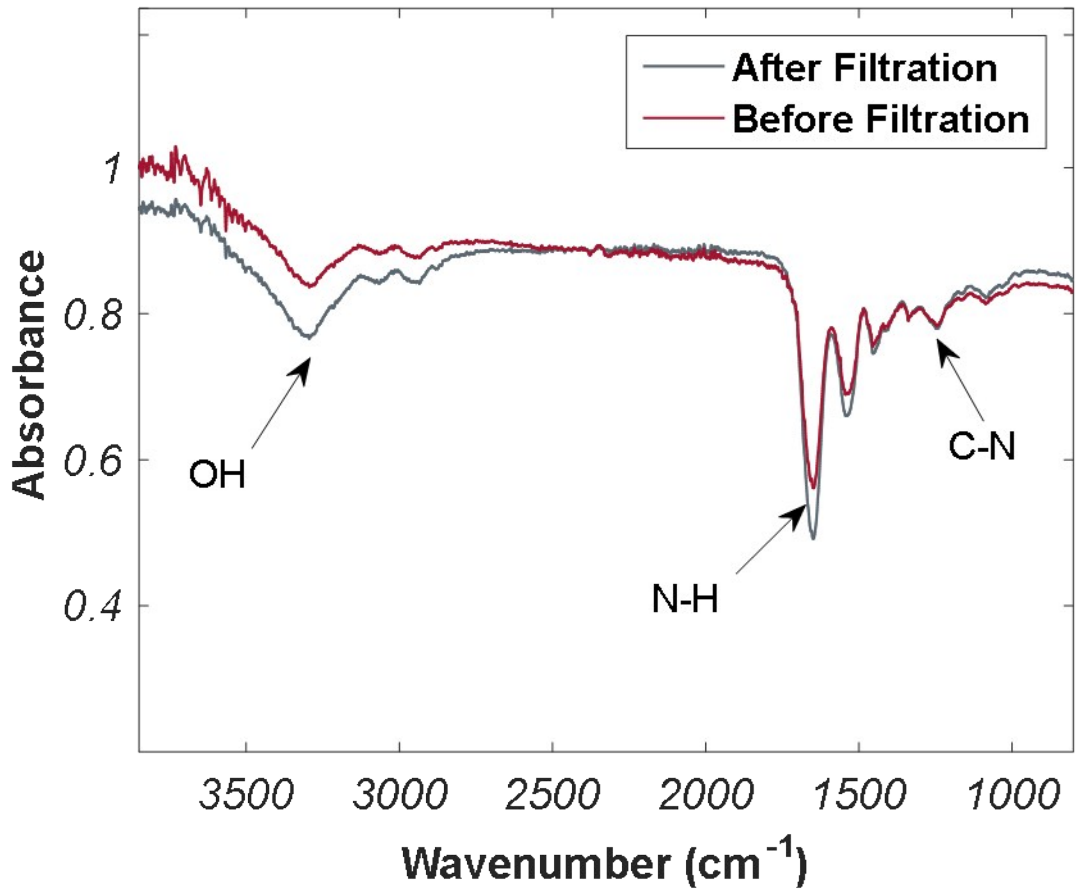

Figure S7. FTIR characterization of gelatin filter before and after filtration of regular “clean“ air, showing the active functional groups.

The FTIR spectra of gelatin nanofiber before and after the “regular clean air” passes through the filter were collected. It is known that the regular air contains some moisture and particulate pollutants which can be captured by the gelatin nanofabrics. Therefore, it is observed that the intensity of the peak for –OH group was increased slightly which is the result of moisture absorption from the air. However, the intensity of the peaks for other functional groups does not change significantly and no new peak was found for the sample after filtration of regular air.

One-way analysis of variance (ANOVA) tables. Data were analysed using one-way analysis of variance (ANOVA) multiple comparison method. The confidence interval was set to 95%. The differences among the data with a p-value < 0.05 were reflected to be statistically significant.

Particulate filtration

Table S3. ANOVA results for dependence of the $PM_{2.5}$ removal efficiency on filter type

$PM_{2.5}$ removal Efficiency	DF	SS	MS	F-statistic	P-value
Filter type	1	1035.5	1035.5	39.67	3.6×10^{-9}

Table S3 shows that the $PM_{2.5}$ pollutants removal effieicny highly depends on the filter type, in this case, gelatin nanofiber filters with different areal density.

Table S4. ANOVA results for dependence of the $PM_{10-2.5}$ removal efficiency on filter type

$PM_{10-2.5}$ removal Efficiency	DF	SS	MS	F-statistic	P-value
Filter type	1	0.00001	0.00001	0.0009	0.98

Table S4 shows that the $PM_{10-2.5}$ pollutants removal effieicny does not depend on the filter type, in this case, gelatin nanofiber filters with different areal density.

Toxic chemical filtration.

Table S5. ANOVA results for dependence of formaldehyde removal efficiency on filter type

Formaldehyde removal Efficiency	DF	SS	MS	F-statistic	P-value
Filter type	1	13.62	13.62	191.73	2.2×10^{-16}

Table S5 shows that the folmaldehyde removal effieicny highly depends on the filter type, in this case, gelatin nanofiber filters with different areal density and commercial HEPA filter.

Table S6. ANOVA results for dependence of carbon monoxide removal efficiency on filter type

Corbon monoxide removal Efficiency	DF	SS	MS	F-statistic	P-value
Filter type	1	9.8	9.8	63.55	3.3×10^{-10}

Table S6 shows that the carbon monoxide removal effieicny highly depends on the filter type, in this case, gelatin nanofiber filters with different areal density and commercial HEPA filter.

Pressure Drop and quality factor.

Table S7. ANOVA results for dependence of the pressure drop on filter type

Pressure drop	DF	SS	MS	F-statistic	P-value
Filter type	1	590.74	590.74	1323.3	2.2×10^{-16}

Table S7 shows that the pressure drop values highly depend on the filter type, in this case, gelatin nanofiber filters with different areal density.

Table S8. T-student test results for dependence of the quality factor on filter type

Quality factor	DF	t-value	P-value
Filter type (HEPA vs Gelatin)	10	6.3	8.9×10^{-5}

Table S9. T-student test results for dependence of the quality factor on filter type

Quality factor	DF	t-value	P-value
Filter type (Commercial-1 vs Gelatin)	10	29.6	4.5×10^{-11}

Table S10. T-student test results for dependence of the quality factor on filter type

Quality factor	DF	t-value	P-value
Filter type (Commercial-1 vs HEPA)	10	29.9	4×10^{-11}

The data regarding the PAN filter was extracted from litrature;[6] therefore, we could not perform any statistical analysis based on its absolute value.

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