Plasma Surface Engineering: Revolutionizing Wet Lay Mats for Heavy Metal Remediation from Aerosols

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Introduction

- Heavy metals (HMs) are one of the major perceived poisons for general prosperity, plants, and animals.
- Airborne heavy metal (Pb, Ni, Cd, As, Cu, Cr, Hg, **Mn**, Zn, etc.) pollution results from human activities like industrial processes, mining, and vehicular emissions.
- Exposure to airborne heavy metals has been linked to a wide range of diseases, including cardiovascular and respiratory diseases and lung cancer.
- Heavy metals can persist in the atmosphere for extended periods and travel long distances before settling into soil and water bodies.
- Filters are essential for airborne heavy metal remediation because they can effectively capture and remove toxic heavy metal particles from the air.
- We aim to utilize an activated carbon fiber mat (ACF 1800) and low-temperature plasma process to achieve improved heavy metal adsorptive removal efficiency from aerosol.

Materials and Methodology

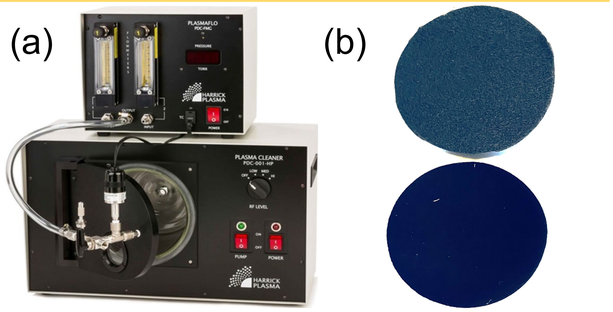

Figure 1: Images of (a) Plasma Chamber used to modify the ACF with Cold Plasma (b) Pristine and air plasma-treated ACF 1800 mats.

- The commercially available ACF 1800 grade mats were cut into disc shapes to fit in the custom-built filtration chamber.
- The mats were surface modified with plasma surface treatment using Air, VP, MCE, Thiophene, Pyrrole, and THF as precursors.
- The ACF mats were extensively characterized at different stages of modifications to examine the effect of various plasma treatments using SEM, XPS, and 3D imaging.
- The aerosol was prepared from $MnCl_2$ solution using a particle generator.
- The effect of various plasmas on the filtration efficiency of the mats was examined using a custom-built filtration system (*Figure 2*).

Materials and Methodology Cont.

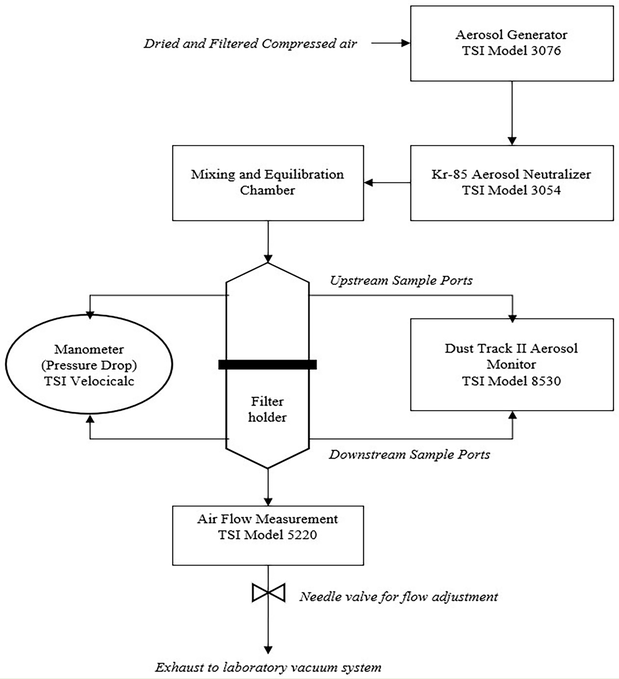

Figure 2. Schematic representation of the filtration efficiency experimental system.

Results and Discussion

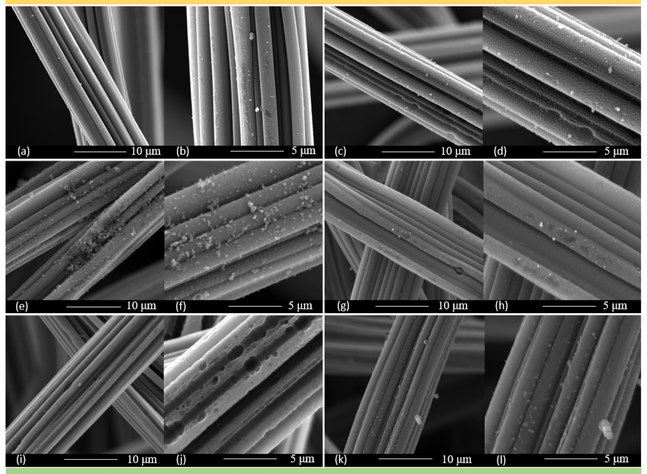

Figure 3. SEM images of ACF 1800 mats after various plasma surface modifications.

- Low-temperature plasma can perform surface activation, surface etching, surface functionalization, and surface coating.
- Various changes in morphology can be examined from SEM imaging (*Figure 3*).
- The outcome is that these modifications intensify and increase the amount of heavy metal adsorption on these mat's surface by furnishing the surface with various active sites.

Results and Discussion Cont.

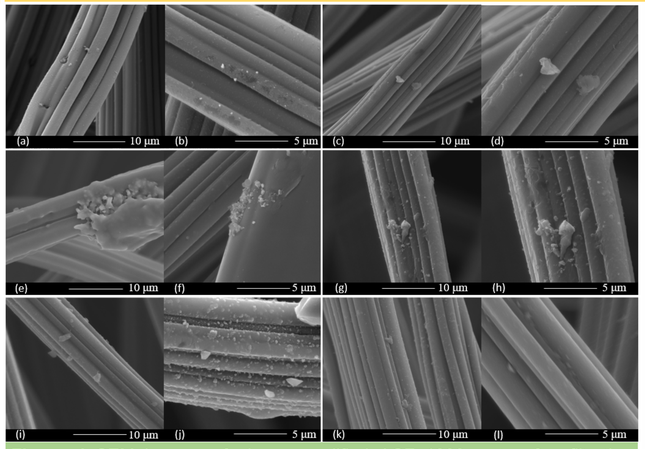

Figure 4 SEM images of plasma-modified ACF 1800 mats after filtration efficiency experiments using Mn aerosols.

- The surface-modified ACF 1800 mats were used for filtration efficiency experiments from Mn aerosol.
- *Figure 4* shows the adsorbed particles and changes in the morphology of the ACF nano-microfibers after the adsorptive removal of Mn.

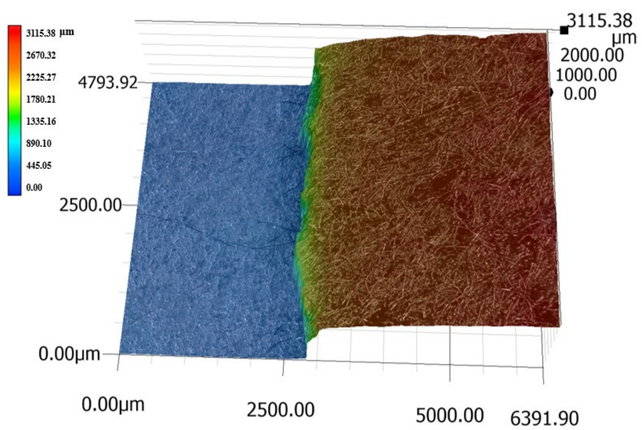

Figure 5. Ultra-high resolution 3D image of the ACF 1800 mats.

- The thickness of the ACF 1800 mat was measured as 2667.65 µm.

Elements (%)	Pristine	VP	THF	Thiophene	Pyrrole	Air
Carbon (C)	92.0	74.9	93.5	78.8	52.9	71.1
Oxygen (O)	7.6	20.4	6	15.4	32.8	25.3
Sulfur (S)	-	-	-	5.4	-	-
Nitrogen (N)	0.3	3.5	-	-	13.7	2.6
Manganese (Mn)	0.1	1.2	0.5	0.4	0.6	1.0

Figure 6. XPS results of various plasma-modified ACF mats after filtration experiments from Mn aerosol.

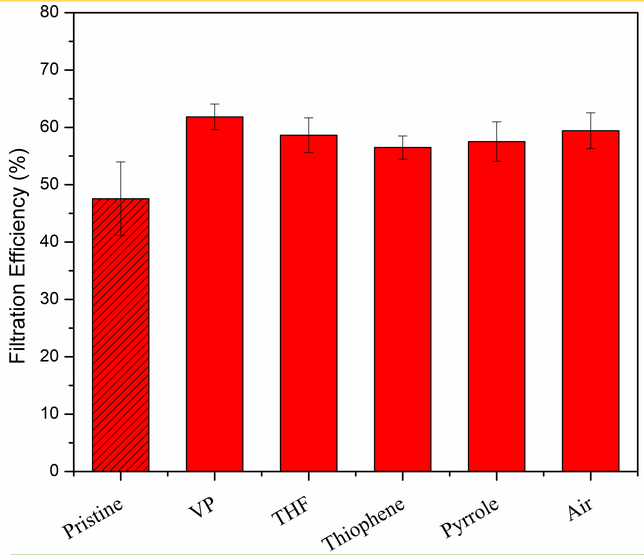

Figure 7. The plot of the filtration efficiency of various plasma-modified ACF-1800 mats from Mn aerosol.

- The data shows the effect of various plasma treatments on the heavy metal removal efficiency of the ACF mats.

Summary

Various plasma modifications have significant effects on the adsorption efficiency of the ACF mats. Plasma processing requires much less chemicals and retains the bulk properties of materials. Before and after filtration, the plasma-modified ACF mats were examined physico-chemically with SEM, XPS, and Keyence. The thickness of the mat was measured as 2667.65 µm. The filtration efficiency of the mats was examined using a custom-built experimental setup. VP plasma-modified ACF 1800 mats noted the highest filtration efficiency, followed by Air, THF, Pyrrole, and Thiophene. Since the LTP treatment is green and easy, the processing is highly recommended for the ACF mats to be used as a household or industrial filter.

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References

(1) Zhu, L. et.al. RSC Adv 2022, 12 (31), 20062-20073. DOI: 10.1039/d2ra01521h From NLM.
(2) Ji, Y. et.al. Environmental Science and Pollution Research 2023, 30 (9), 23372-23385.
(3) Bhatnagar, A. et.al. Chemical Engineering Journal 2013, 219, 499-511.