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Development of Zeolite-Based Nanofibers for the Removal of Uremic Toxins in Kidney Removal Patients

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Abstract:

Kidney failure patients in disaster areas and developing countries face the danger of having conventional hemodialysis treatments become inaccessible due to limited resources. For this reason, our goal is to develop a wearable device consisting of polymer fibers with a smart material that will selectively adsorb uremic toxins from the bloodstream, eliminating the need for more expensive treatments. The nanofibers would contain the blood compatible poly(ethylene-co-vinyl alcohol) (EVOH) as the main polymer, embedded with zeolites, a porous aluminosilicate that has the capacity to absorb toxins such as creatinine. The polymer and the zeolites were characterized separately to determine the ideal combination for the polymer meshes. This ideal combination was found to be 9 w/v% D2908 EVOH polymer fibers with a 10 wt% ratio of 940HOA zeolites. This fiber was found to absorb an impressive 57.43 mg of creatinine per gram of zeolite in the fiber. It was unusual and unexpected for the nanofiber to have a higher per gram adsorption than the free zeolites, and so further studies will be performed. These results suggest that these nanofibers could substitute for specialized equipment in removal of waste product from the bloodstream.

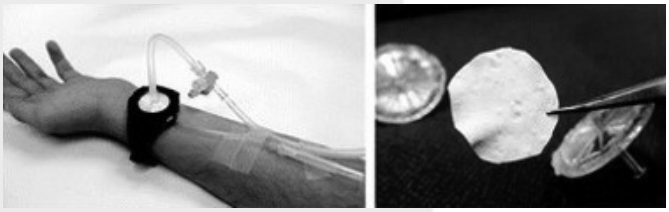

Figure 1: Possible application in wearable device. (Ebara, et al., Fabrication of zeolite-polymer composite nanofibers for removal of uremic toxins from kidney failure patients).

Introduction:

The final objective of this study is to develop zeolite-based polymer fibers that may be used in a wearable device to treat kidney failure patients (Figure 1). These nanofibers have two components, a polymer and a smart material, and they are intended to adsorb uremic toxins such as creatinine.

EVOH is ideal as a polymer because it is blood compatible, as well as insoluble in water, both of which are vital because the final application would involve blood being passed through EVOH-based meshes. Zeolites are porous, crystalline aluminosilicates. The microscopic pores are often called "molecular sieves," because they can trap small molecules on their surface. There are different types and frameworks with properties varying according to pore and molecule size, as well as the orientation.

Methodology:

Fibers were first fabricated without embedded zeolites by electrospinning, which is a process in which a potential difference (voltage) is applied between a syringe with a solution and a collector, in our case a piece of aluminum paper. The voltage made the solution turn into random, solid strands that were deposited on top of the collector in the form of small fibers. To create the fibers, we first spun a PVA-water layer on top of the collector as a sacrificial layer. Then, after the EVOH

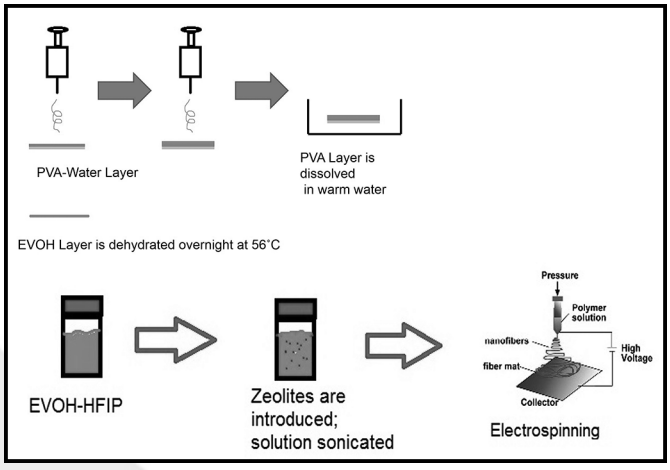

Figure 2: Fabrication techniques.

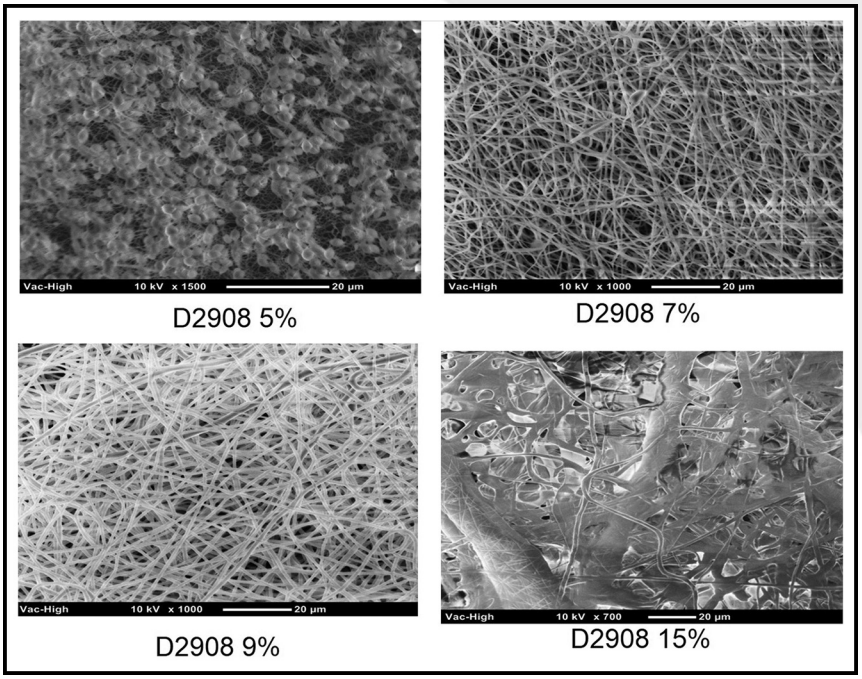

Figure 3: SEM imaging of fibers.

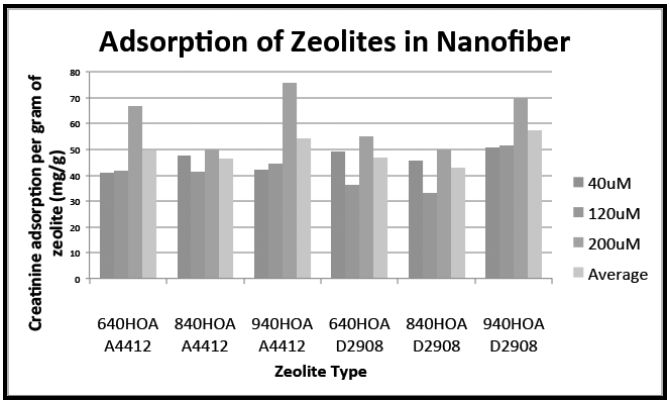

Figure 4: Adsorption capacity of zeolites in meshes.

was spun on top of it, the collector was dipped in warm water to dissolve the EVOH layer, simplifying the removal of the polymer fiber. It was then dehydrated at 56°C. This process is detailed in Figure 2. After a separate characterization of polymer fibers and zeolites, zeolites were sonicated into the EVOH solution and then electrospun to create the nanofibers.

To determine creatinine adsorption in zeolites and nanofibers, ultraviolet light (UV) absorption was used. Parting from the principle that higher concentrations of solute absorb more UV light, a calibration curve for different concentrations of creatinine-water was created. Free zeolites were introduced to a known concentration of creatinine-water and left stirring at 37°C for 24 hours, then centrifuged out of the solution. The remaining concentration was determined using UV absorption and the calibration curve. The mass of creatinine adsorbed could be obtained from the drop in concentration of the solution.

Results and Conclusions:

Different types of polymer fibers without zeolites were first characterized with a scanning electron microscope (SEM), to determine which would be better suited for the meshes. Two different EVOH polymers were selected: A4412 and D2908 (44% and 29% ethylene content, respectively). We tested 5, 7, 9, 10 and 15 w/v% and found that the lower concentrations produced "beading effects" that may affect the adherence of zeolites to the fibers. Similarly, the highest concentration (15%) produced fibers that were deformed and inconsistent in their diameter. Therefore, we chose 9 w/v% as the ideal concentration for larger, visually consistent nanofibers. The difference in ethylene content did not appear to have an effect on fiber morphology. These fibers may be observed in Figure 3.

Nine different types of zeolites were tested for their creatinine adsorption capacity UV absorption. These zeolites were 980HOA, 690HOA, 720KOA, 940HOA, 840HOA, 640HOA, 320HOA, and 500KOA. Three different experiments using varying mass of zeolites (10, 25 and 50 mg) in 200 μM concentrations gave us an idea of which zeolites adsorbed the most milligrams of creatinine per gram of zeolite. The most adsorbant zeolites were chosen for the meshes and were determined to be 940HOA, 840HOA and 640 HOA, with average adsorbance capacities of 5.56, 5.67, and 5.68 mg/g, respectively.

Six zeolite-polymer nanofibers were made, combining each of the selected zeolites and 9 w/v% solutions of both types of EVOH in a 10 w/w ratio. These fibers were also tested using UV absorption by dipping them in of 40, 120, and 200 μM creatinine-water solutions. The amount of creatinine adsorbed was adjusted to per gram of fiber and per gram of zeolite basis. These results are shown in Figure 4.

The most adsorbant zeolite polymer combinations were the ones containing the 940HOA zeolites, specifically the 940HOA-D2908 combination that had an adsorption capacity of 5.20 mg/g of fiber and 57.43 mg/g of zeolite. The ethylene content of the polymer did not seem to make any significant difference. These results are encouraging for the possible use of these fibers in a wearable device.

Acknowledgements:

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