Functional Nanoparticles for Energy and Environmental Applications

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Introduction: There is a current climate crisis that is worsened by the world's reliance on fossil fuels and persistent water pollution due to anthropogenic activities. Pollutants from pharmaceuticals (ex. antibiotics, hormones, pain killers) and textile industry (ex. synthetic dyes) are resistant to traditional water treatment methods. Nanotechnology combining modified poly vinyl chloride (PVC) membranes and Metal Organic Frameworks (MOFs) can offer a more viable solution for this problem as these materials are capable of adsorbing pollutants with high efficiency due to their high surface area, tunable chemical characteristics, and the possibilities of reusing them [1]. MOFs are comprised of metal ions that are linked by organic ligands to form highly porous and tunable materials with highly catalytic and adsorptive capabilities. In addition to MOFs, soft and rigid PVC membranes with different organic fillers, such as: graphene, graphene oxide, nano-hydroxyapatite, and nano-bentonite, all have capabilities of effectively adsorbing pollutants by increased surface area of the membrane and adding different chemical properties based on the type of the applied filler to target certain contaminants. Overall, this research focuses on synthesizing and testing these functional nanomaterials that provide renewable and cost effective solutions for adsorbing pollutants and catalyzing their photodegradation via clean energy reactions.

Materials and Methods: The synthesis of zinc MOF materials was performed on nickel foam as a substrate. To achieve the synthesis, cetyltrimethylammonium bromide (CTAB) was introduced to a solution of zinc acetate ($Zn(OAc)_2 \times 2H_2O$), and was dissolved in deionized water. This mixture was then combined with a solution of 2-methylimidazole (2-MiM) containing nickel foam, and allowed to react for the designated time period. Figure 1 shows the illustration for the similar synthesis of cobalt MOF. Subsequently, the obtained MOFs undergo sulfurization using ammonium thiomolybdate. Modified nickel foam was used as a working electrode in the three electrode system to investigate the electrocatalytic performance toward oxygen evolution reaction (OER) in 1 M KOH electrolyte, with Pt wire and Ag|AgCl|KCl serving as a counter and reference electrodes, respectively.

Soft (PVC-P) and rigid (PVC-R) polyvinyl chloride membranes to be used as effective adsorbents in water pollution treatment were synthesized via electrospinning from polymer solutions containing various concentrations of different fillers, graphene oxide (GO), graphene (GN), nano bentonite (nB), and nano-hydroxyapatite (HAp). Prior to testing, the isoelectric point of all of the PVC membranes was determined to be approximately 6. Then, adsorption studies were performed in a function of pH. Adsorption studies were made using model water pollutants like crystal violet, and methyl violet with the concentration of dye ranging from 10-25 ppm depending on the dye. UV-vis spectrophotometry was used over the course of 24 hours to quantify the adsorption and removal efficiency of the PVC membranes towards pollutants.

Results: Adsorption studies using UV-vis spectrometry shows that among the different PVC nano-fillers tested across multiple dyes, the most effective pollutant removal was observed with the GO, which achieved even 97% adsorption efficiency for crystal violet within 24 h Interestingly, other fillers work with lower effectiveness. Kinetics studies show that the adsorption undergoes pseudo-first kinetics.

When characterizing the MOFs by means of linear sweep voltammetry, it was found that the sulfurized MOFs had a lower potential than those that were without sulfurization. When the MOFs are used for water splitting and renewable energy applications, the sulfurized MOFs were recognized as a better catalyst than those that are un-sulfurized because of their larger electrochemical surface area as seen in scanning electron microscopy imaging. This is further supported by the Tafel slope plot, where a smaller slope suggests the lower potential that is needed for a catalyst. The lower the potential needed, the better a catalyst can perform.

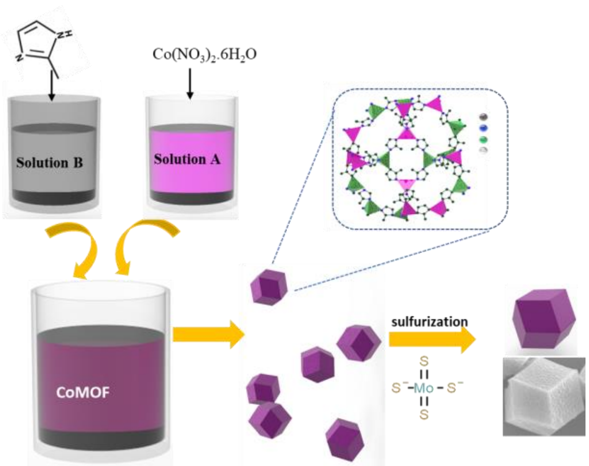

Figure [1]: Synthesis of cobalt MOFs using an organic solution.

Conclusion: This research highlights the development and application of two nanomaterials, MOFs and PVC membranes, for addressing challenges in energy and environmental sustainability. Sulfurized zinc and cobalt based MOF's had demonstrated an enhanced electrochemical performance as catalysts due to their increased conductivity and active surface area. Additionally, PVC-P membranes containing the nanofillers such as: GO, GN, and nB were found to effectively adsorb organic dyes best from crystal violet and methyl violet solutions at pH 8 above the isoelectric point. These PVC-P membranes exhibited top pollutant removal due to their high surface area and chemical interactions. Together, these materials demonstrate the potential for nanotechnological innovation in clean energy applications and water purification, offering a low-cost and renewable solution to current pressing global issues.

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