Ibn Al-Haitham Journal for Pure and Applied Sciences
Journal homepage: jih.uobaghdad.edu.iq
PISSN: 1609-4042, EISSN: 2521-3407
IHJPAS. 2024, 37(3)

Polyacrylonitrile Nanofiber Composites as Efficient Removal of Pollutants for Wastewater: A Review Article

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Received: 9 March 2023 Accepted: 14 May 2023 Published: 20 July 2024
doi.org/10.30526/37.3.3320

Abstract

Polyacrylonitrile nanofiber (PANFS), a well-known polymers, has been extensively employed in the manufacturing of carbon nanofibers (CNFS), which have recently gained substantial attention due to their excellent features, such as spinnability, environmental friendliness, and commercial feasibility. Because of their high carbon yield and versatility in tailoring the final CNFS structure, In addition to the simple formation of ladder structures through nitrile polymerization to yield stable products, CNFS and PAN have been the focus of extensive research as potential production precursors. For instance, the development of biomedical and high-performance composites has now become achievable. PAN homopolymer or PAN-based precursor copolymer can be employed to make CNFS. Water gets polluted because it throws industrial waste bodies of water, especially those containing dyes, heavy metals, and inorganic and organic wastes. Adsorbents, which are cheap and readily available, can be used to address the issue of water deterioration. According to this review, numerous PAN variations are being employed in scientific and technological settings. Nanocomposite fibers need extensive research efforts to advance technology and bring them to commercialization.

Keywords: Polyacrylonitrile, electrospinning, stabilization, nanofibers.

1. Introduction

Polyacrylonitrile (PAN) and its copolymers have been widely explored for both commercial and technical reasons. Theoretically, other proteins could bind to PAN. Cross-linking PAN can increase its physical properties, such as its insolubility and resistance to swelling. It has recently been studied for its processing and fiber-forming abilities. PAN is the most commonly employed polymer in the manufacture of CNFs due to its high carbon yield and ease of nitrile polymerization [1–5]. With the help of precursor PAN, researchers have created porous composites with excellent strength and stiffness for use in electronics and energy storage. Numerous PAN variations are included in the following sections for research and commercial purposes [6-10]. Acrylonitrile is the primary monomer in most copolymers employed to make PAN resins. These include ultrafiltration membranes, hollow reverse osmosis fibers (HRF), textile fibers, and oxidized polyamide nanotube fibers. High-quality carbon fiber is made from PAN fibers, which are derived chemically from PAN fibers. To produce the carbon fibers, oxidized PAN fibers are heated to 230 degrees Celsius in the open air before being carbonized for more than a thousand degrees Celsius in an inert atmosphere. Fiber-reinforced concrete and hot gas filtration systems have both employed polyacrylonitrile homopolymers. It is popular to employ polyacrylonitrile-based copolymers in the production of knitted items, such as socks and sweaters, and outdoor gear, such as tents. Acetate is the acrylonitrile, styrene, and acrylonitrile/acrylate polymer concomitant, while acrylonitrile is the styrene co-monomer [11]. A vast number of metal ions can be absorbed by PAN, making the use of absorption materials more convenient as a result. In order to handle this, the polymers that contain amidoxime groups can form complexes with metal ions.

2. Materials and Methods

2.1 The PAN and PAN fibers.

The PAN's small weight and high strength make it useful. Its unique properties have made it an essential polymer in high-tech, as shown in **Figure 1**.

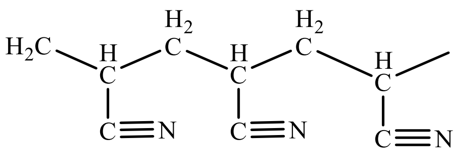

Figure 1. Structure of polyacrylonitrile

A variety of nanofiber mats manufactured from polyacrylonitrile can be created, stabilized, and carbonized, according to Lilia S. and her colleagues [12]. The photocatalytic characteristics of tin oxide (TiO_2) make it a viable material for dye removal. Polyacrylonitrile/TiO_2 is electrospun, stabilized and carbonized polyacrylonitrile/ TiO_2 mats were examined in detail. Because the fibrous structure of rougher carbon/ TiO_2 nanofibers with increasing content is better preserved during stabilization, rougher nanofibers with increasing content have an even bigger interior surface area than smoother carbon/ TiO_2 nanofibers [13].

Polyethylene diamine tetraacetic acid (EDTA) is employed as a cross-liker to change (PAN) nanofiber surfaces prior to electrospinning. It was used to remove Cd (II) and Cr (III) from wastewater (VI). While Langmuir, Freundlich, and Temkin adsorption equilibrium models were employed to study the metal removal from a polymer surface, The removal mechanism of target metals is best described by the Freundlich model. A 2 M HCl solution was also employed to remove the nanofibers. For the removal of Cd(II) and Cr(VI), EDTA-EDA-PAN nanofibers were found to be effective [14].

2.1.1 Electrospining of PAN

Electrospinning removes the polyacrylonitrile-polyamidoamine (PAMAM) complex. Fourier Transform Infrared Spectroscopy (FTIR) was utilized to improve comprehension of the functional groups, shape, surface area, and distribution of pore sizes of the nanofibers. We looked at how much adsorbent, how much dye, and the pH of the solution affected dye removal. The kinetics, besides the isotherm of dye adsorption, have been shown to agree using pseudo-second-order kinetics and the Langmuir model.

Huang Chang and his colleagues electrospun PAN and polymethylhydrosiloxane solutions in N, N-dimethylformamide to make porous carbon nanofiber composites (NFCS) (DMF). After heat treatment at 800°C with homogenous silica dispersion, fibers with the maximum specific surface area (4.91 cm^{-1}) and conductivity (4.91 cm^{-1}) were discovered to be made with this concentration. One of the highest particular capacitances and energy densities was observed in a 6.0 M KOH solution at 5 percent PMHS [15].

Electrospinning was employed to create polyacrylonitrile (PA) nanofibers containing diethylenetriamine (DETA) and polyacrylonitrile (PA). SEM and FTIR were used to characterize the PDN/DET composite nanofibers. For the purpose of determining if DETA might be released from the nanofibers, researchers examined the total carbon content of the samples. Toplam organic carbon nanofibers' shapes can be altered by incorporating DETA into them. The initial pH, DETA amount, and contact time, as well as the dye solution's concentration, all affect dye adsorption in PAN/DETA nanofiber mats. The best adsorption capacity of the dye PAN/DETA nanofiber mats was determined using the Langmuir model [16].

2.2 The Ag/Go Nanocomposite

Silver nanoparticle-modified graphene oxide (Ag/Go) was reliably produced using NaBH4 and citric acid as a capping agent. Accurate dispersion of the Ag/Go composite was demonstrated in a hydrophilic polyacrylonitrile solution (PAN). No notable defects were found while electrospinning this precursor solution to generate nanofibers. An ultra-thin, water-resistant membrane was created by heating nanofibers to their melting point. Gram-negative bacteria have antimicrobial activity. Both E. coli and Gram-positive bacteria can cause diarrhea. The Ag/Go-PAN nanofiber membrane contained Staphylococcus Aureus (Gram-positive). Ag/Go composite filler is easily modified to be reliably integrated into polymer nanofiber membranes for wastewater treatment [17].

Electrospun diethylenetriamine, diethylenetriamine, and triethylenetriamine produce a variety of amine-containing compounds. SEM, AFM, and ATR spectroscopy were all utilized to investigate the morphology and surface properties of nanofibers. This study found that functionalized PAN nanofibers exhibited a rougher surface than untreated ones. Adsorption of dye on functionalized PAN nanofibers was affected by factors such as contact time and dye solution concentration (FPAN). In accordance with the Langmuir isotherm, both colors were observed to be adsorbing [18]

2.3 The PAN / metal ions

Raw polyacrylonitrile has low metal ion binding capacity, even though (Chuangchen et al). utilized industrial waste, polyacrylonitrile (PAN) (CN, CN). Following electrospinning, APAN nanofibers were grafted with polyethyleneimine branches. Sixty-one percent of the initial adsorption capacity is maintained after five cycles. These factors are under thorough investigation to understand their impact on Cu^{2+} adsorption in the solution. APAN nanofibers exhibit higher adsorption capacity compared to most low-density sorbents. Langmuir and second-order dynamics models confirm agreement between adsorption kinetics and isotherms. [19].

Photochromic materials aroused enormous interest due to their potential applications. To prepare photochromic nanofibers by electrospinning, we suggest that we dissolve spiropyran, photochromic material, polyacrylonitrile, and polymer matrix in dimethyl fumarate. FTIR, UV-vis spectra, scanning electron microscope, and contact angle were used to diagnose nanofibers. The results demonstrated that nanofiber membranes have extraordinary color-converting properties, including a clear color change from white to purple. [20].

2.4 The PAN/ TiO_2 nanofibers

Nanofibers made of polyacrylonitrile (PAN) and titanium dioxide (TiO_2) were utilized to remove the lead and cadmium from aqueous solutions. An investigation of the adsorption capability and mechanical response of PAN/TiO_2 nanofibrous materials is conducted at various TiO2 weight percentages. This study discovered that electrospun PAN nanofibers are not as effective in adsorbing cadmium (Cd) and lead (Pb). Using a pseudo-second-order kinetic model, this process can be explained without considering the nanofibers' role in the adsorption of lead Pb (II) and cadmium Cd (II). The Langmuir model can reflect the adsorption isotherm study. Because the outer shell of PAN/TiO_2 composite nanofibers is more vulnerable to agglomeration and hollow space development, TiO_2 nanofibers have lower tensile strength [21].
Polyacrylonitrile (PAN) nanofibers were treated with polyamidoamines to remove dyes from their surfaces (PAMAM). We utilized data to functionalize the PAN polymer and used glutaraldehyde to adhere the PAMAM dendrimer to the surface of the functionalized nanofiber as an adhesive. The formation of amine groups in nanofibers by PAMAM molecules was shown to be connected to DETA, as was discussed in detail. To understand the adsorption process, it is essential to understand the Langmuir isotherms and pseudo-second-order models used. The RSM results show that the pH is more critical in dye adsorption than previously thought. The amount of dye adsorption onto the targeted nanofibers was demonstrated to be affected by the initial pH and concentration of the dye solution [22].

3. Results and Discussion

3.1 Produce nanofibers and electrospinning

Electrospin technology has created polyacrylonitrile (PAN)/$FeCl_2$ composite nanofibers. It was found that PAN/$FeCl_2$ porous nanofibers have a diameter between 100-300 nanometers and a specific surface area of 10 $m^2.g^{-1}$, which were excellent at removing the trace metals Cr and 207= from solutions. Nanomaterials like FeCl2 can remove more than 110 mg Cr/$FeCl_2$, according to recent findings on Cr(VI)-removing adsorbents. There is a lack of coordination links between PAN-Fe(II) in nanofibers, which prevents them from removing Cr [23]. The PAN/$FeCl_2$ composite nanofibers may be effective in the removal of Cr from wastewater and in the complete cleansing of polluted water to explore the removal of negative Sb(V) ions by FMBO of positively charged Cd. (II). Maximum cadmium concentrations (Cd(II)) in Sb(V) were 0.25 and 0.50 mmol/L, which had a more significant impact on adsorption than either calcium (Ca^{2+}) or manganese (Mn^{2+}). Adsorption of Sb(v) on FMBO is not affected chemically by Cd(II) and has a noticeable synergistic effect [24]. They studied the adsorption of lead (II) from aqueous solutions using TiO_2/PAN nanofibers. TGA, scanning electron microscopy (SEM), and FTIR were also used, as were X-ray diffraction and TGA. One nm in diameter is what the data shows for nanoparticles and fibers, respectively. The TiO_2 content and pH of the adsorbent were manipulated to examine adsorption performance. An adsorption isotherm was employed to predict adsorption. Adsorption, then, is endothermic and spontaneous [25]. A pseudo-first-order kinetic sample can be used to describe the adsorption of lead ions onto

TiO_2/PAN nanofibers.

A composite of cellulose and polyacrylonitrile nanofibers was synthesized by electrospinning by Xiao *et al*., and Cu^{+2} nanofibers were made by adding Cu(II) ions to cellulose, polyacrylonitrile, and the composites. The shape, mechanical properties, and hydrophilicity of nanofibers were examined. According to the data, a Cu(II) ion concentration of 0.01 mol/L resulted in outstanding mechanical characteristics and antibacterial activity for cellulose, PAN, and Cu nanofibers [26].

Electrospinning was utilized to produce ZnO/PAN nanofibers. There was a test for adsorbent, adsorbent quantity, pH, time in contact, and temperature. Langmuir's adsorption isotherm model accurately depicts the process of adsorption. Adsorption is exothermic, according to thermodynamic data. The adsorption of lead (II) on PAN/ZnO nanofibers was effectively described by a pseudo-second-order kinetic model [27].

Liu Qing et al. utilized an oval adsorbent, Fe3O4 combined polyacrylonitrile nanofiber mat (Fe-NFM), created through a combination of electrospinning and solvothermal techniques. Their study focused on the cation exchange resin. By applying the Freundlich isotherm model, a more precise representation of the adsorption isotherm could potentially be achieved [28].

In the context of Cd and As removal, Induni W. et al. employed an electrospinning technique to fabricate nanomagnetites and nanotitania-incorporated (PAN) materials. The presence of these components within the composite fiber matrix was identified using EDX, XRD, and FT-IR analysis. When nanomagnetite and nanotitanium (MPAN besides TPAN fibers) were inserted into the fibers, it was discovered that the fibers could remove As(V) and Cd(II) from the air. Isotherm experiments based on the Freundlich model showed that TPAN had the best capacity to adsorb Cd(II). MPAN had the best ability to absorb As (V) as (V), and Cd(II) may be removed from water using the novel PAN-based nanofiber material as a polymeric filter [29].

Using a two-step electrospinning/solvothermal technique and new Fe_3O_4/PAN composite nanofibers (NFS). Liu et al. evaluated a nanoparticle coating on the PAN nanofiber spine using field emission scanning and transmission electron microscopy. The Fe3O4 nanoparticles of well-crystallized cubic phase formed the coating, according to X-ray diffraction analysis. NFS's surface area doubled as a result of the coating. Fe_3O_4/PAN composite NFS was tested as an antibiotic adsorbent using tetracycline (TC) as an adsorption reagent. There were no metal losses in the pH range throughout the tetracycline extraction process using Fe_3O_4/PAN composite NFS. Assuming a pH of 6, the maximum possible TC adsorption was calculated using the pseudo-2^{nd} order Langmuir isotherm model. After numerous adsorption and desorption cycles, the NFS composite regenerates successfully. An essential element in the adsorption of NFS was revealed to be surface complexation between NFS and TC [30].

4. Conclusion

A new class of materials appears to be emerging from the PAN-based CNFS, which appears in various fields of filtering and insulation as well as in medical equipment and clothing, along with energy storage devices. In addition to engineering and medicine, their unique qualities make them suitable modern materials. Anionic dye adsorption from colored wastewater was a favourable application for functionalized PAN nanofibers owing to their huge dye adsorption capacity. Moreover, the nanofibers produced demonstrated that airborne particles are efficiently blocked by nanofiber membranes consisting of layers of randomly oriented nanofibers. PAN-based nanofibers are expected to be employed in numerous scientific fields in the future.

Acknowledgment

The authors express their gratitude to all who contributed to completing this review.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Funding

There is no financial support.

Ethical Clearance

The Scientific Committee at the University of Baghdad/College of Education for Pure Science (Ibn Al-Haitham) has granted approval for this work.

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