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MXenes, An Emerging 2D Class of Materials for Water Treatment Purposes

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ABSTRACT

Advanced water treatment technologies are needed to address global freshwater scarcity. MXenes, a new class of 2D transition metal carbides and nitrides, show great promise for water purification. They excel in adsorption, membrane filtration, sensing, photocatalysis, and thermal desalination due to their high surface area, tunable functional groups, and conductivity. MXene-based membranes improve water permeability, selectivity, and fouling resistance, making them promising ultrafiltration, nanofiltration, and reverse osmosis candidates. MXenes' superior conductivity and surface reactivity make them popular for electrochemical sensing of environmental contaminants. Their photocatalytic degradation and thermal desalination demonstrate their environmental remediation versatility. Research is optimizing MXene-based materials for large-scale water treatment, despite synthesis complexity and stability issues. MXenes have made significant progress in water purification, as this editorial shows.

Introduction

The worldwide problem of freshwater scarcity is getting worse due to the rapid development of cities and people's population. To address this challenge, there is an increasing necessity to investigate alternative water treatment technologies. Recently, the utilization of advanced 2D nanomaterials, including MXenes, for water purification has garnered considerable interest. Today, this class of materials is involved in many water processes due to their merit properties, such as their charged surface that contains functional groups, relatively high surface area, and unique structure that can be tuned and engineered. MXenes follow the general formula $M_{n+1}X_nT_x$, where M refers to a transition metal, including elements like zirconium (Zr), titanium (Ti), niobium (Nb), tantalum (Ta), vanadium (V), molybdenum (Mo), chromium (Cr), and scandium (Sc). X represents carbon or nitrogen, while n can take values of 1, 2, or 3. These materials exhibit structural resemblances to graphene and other two-dimensional materials [1].

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It is good to mention that MXene can be incorporated with other materials to fabricate novel composites with exceptional properties.

MXenes are used in water treatment processes, including adsorption, membranes, sensing, photocatalytic, and thermal desalination. As an example of dyes adsorption, $Ti_3 C_2 T_x$ was employed as an adsorbent to remove Malachite Green dye in both its chromatic and leuco forms. The findings showed that increasing the adsorbent dose enhanced removal efficiency, reaching a peak efficiency of 94.1% at an adsorbent dose of 0.09 g in 50 ml of solution [2]. The process of dye adsorption on porous materials typically involves three distinct steps, with various operating conditions influencing one or more of these stages. In the beginning, dye molecules transfer from the bulk solution to the external surface of the adsorbent. Subsequently, the molecules undergo diffusion within the internal macropores and mesopores of the material. Ultimately, the dye attaches to the accessible adsorption sites. Here, dye removal via adsorption in MXenes primarily occurs through a physical process that involves two essential mechanisms. An electrostatic reaction occurs between the dye of positive charge and the π-electrons on the MXene surface, which can be characterized as a π-π interaction where the MXene acts as an electron donor and the dye serves as an electron acceptor. The second aspect pertains to π-π stacking interactions that occur between the aromatic structure of the dye and the active groups present in the MXene [3]. Similar to dyes, MXenes were used to adsorb heavy metals. For instance, a chitosan-modified MXene was used to adsorb cadmium (Cd(II)) and zinc (Zn(II)) ions from simulated waste solutions. The results presented that the synthesized adsorbent had adsorption capacities of 106.84 mg/g and 93.07 mg/g for Cd(II) and Zn(II), respectively, while the competitive adsorption capacities were 93.47 mg/g of Zn(II) and 79.66 mg/g of Cd(II) [4]. These results show the activity of MXenes in complex systems.

The investigation of MXene in membrane-based processes is dominated by the polymeric membranes, encompassing applications such as ultrafiltration (UF), nanofiltration (NF), forward osmosis (FO), reverse osmosis (RO), and membrane distillation (MD), reveals significant potential. The membranes exhibit several important characteristics, including outstanding conductivity, high surface area, and capability to manipulate surface chemistry. MXene-based membranes have an active role in enhancing water permeability, which offers a viable approach to treating water. Studies indicate that altering MXene surfaces can result in enhanced resistivity against fouling, membranes of more excellent selectivity, and improved total performance. The extensive surface area and hydrophilicity of MXene nanosheets play essential roles in enhancing water permeability, where they can impact the separation processes' efficiency [5].

The potential of MXene-based membranes is significant; however, some challenges persist, especially regarding intricate manufacturing processes and stability concerns. Nonetheless, ongoing investigations are tackling these bottlenecks. The synergizing of ascorbic acid with $Ti_3C_2T_x$ MXene has demonstrated enhancements in membrane stability, a decrease in adsorption impact, and enhanced performance in various applications. MXene membranes exhibit remarkable potential in water purification and ion exchange, where they leverage the adjustable characteristics of their surface chemistry to enable selective ion permeability customized for various functional groups. The mechanisms for separation in these membranes are relying on the Donnan exclusion and size exclusion. The strong negative charge and conductive properties of MXene play a vital role in selective permeability, enabling ion exchange and efficient mass transfer. To achieve commercial success for MXene-based membranes, it is important to tackle the outstanding challenges in their development [6].

In sensing, MXenes exhibit great promise for sensor development due to their outstanding characteristics of superior metallic conductivity, ease of surface modification, strong hydrophilicity, and excellent ability to intercalate with other substances. These features enhance their effectiveness in sensor applications [7]. MXenes have been effectively employed for the electrochemical detection of numerous environmental contaminants, including nitrite ions, arsenic, mercury, lead, cadmium, Bisphenol-A, 4-Nitrophenol, hydrazine, thiabendazole, hydroquinone, and catechol. Various electroanalytical techniques, such as amperometry, differential pulse voltammetry, linear sweep voltammetry, and square wave anodic stripping voltammetry, are highly proficient in identifying these contaminants in aqueous settings. A comparison of analytical parameters, including sensitivity, linear dynamic range, limit of quantification, and detection limit, with existing studies underscores the crucial role of MXenes in pollutant detection [8].

Thus far, the sensory characteristics of MXenes, especially those derived from titanium, molybdenum carbide, and vanadium, have been recorded, with improved sensor efficacy ascribed to alterations in surface terminals, precursor conditions, morphology, and interlayer configurations. These results highlight the potential of MXenes. The utilization of MXene-based adsorbents in analytical extraction has attracted considerable interest, with numerous studies evidencing their efficacy in pollutant elimination and environmental remediation, prompting additional investigation in sample preparation for analytical applications. Nonetheless, the exact mechanisms through which MXenes operate as sensors, especially regarding the interactions between MXene substrates and pollutants that influence sensor selectivity, remain ambiguous. Recent studies indicate that the interaction between the MXene surface and contaminants is crucial for sensor efficacy [9]. Nevertheless, a comprehensive investigation of MXenes remains necessary to identify novel avenues for the electrochemical detection of hazardous pollutants in aquatic environments.

In comparison to alternative photocatalysts for contaminant degradation, MXene-based photocatalysts exhibit exceptional photodegradation efficiency and enduring stability. MXene is frequently employed to degrade organic compounds and to convert CO_2 into valuable products for environmental remediation. MXene-based composites exhibit superior photodegradation performance compared to plain MXene, attributed to the latter's deficiency in active sites and porous architecture. The NiFe/MXene nanocomposite can degrade organic pollutants at rates 4 and 6.72 times greater than virgin MXene and NiFe, respectively. MXene and its derivatives serve as highly efficient photocatalysts due to their abundance, affordability, non-toxicity, and superior photocatalytic properties. The existence of active functional groups on the MXene surface substantially enhances its photodegradation efficacy [10].

MXenes were also utilized in thermal desalination. A recent study reported the synthesis of $Ti_3C_2T_x$ from low-cost waste and incorporated it with graphite (MXene@GF). The composite was applied to obtain high water flux in a thermal desalination system. The nanocomposite exhibited solar evaporation rates reaching 3.0 kg m^{-2} h^{-1}, attaining a solar steam conversion efficiency of 96.03% under 1 sun solar irradiation. The system can generate 15–18 L/m^2 of purified water daily in a solar water purification configuration. The MXene@GF composite is promising for moisture absorption, environmental cooling, and pollution remediation applications [11].

In conclusion, MXenes still have plenty of room for research in all water treatment applications due to the possibility of preparing new types of them. Furthermore, they showed exceptional performance when combined with other materials, enhancing their physicochemical properties. We believe that the use of MXenes in water treatment will show further progress and continue growing.

References:

[1]. Albayati N, Naser ZA, Baqi Ahmed HA, Kadhom M, Olusakin Oladoye P. A comprehensive review on the use of Ti3C2Tx MXene in membrane-based water treatment. Sep Purif Technol 2024;345:127448 . https://doi.org/10.1016/j.seppur.2024.127448.

[2]. Kadhom M, Kalash K, Al-Furaiji M. Performance of 2D MXene as an adsorbent for malachite green removal. Chemosphere 2022;290:133256. https://doi.org/10.1016/j.chemosphere.2021.133256

[3]. Zhang X, Yu H, Yang H, Wan Y, Hu H, Zhai Z, et al. Graphene oxide caged in cellulose microbeads for removal of malachite green dye from aqueous solution. J Colloid Interface Sci 2015;437:277–82. https://doi.org/10.1016/j.jcis.2014.09.048.

[4]. Azeez NR, Salih SS, Kadhom M, Mohammed HN, Ghosh TK. Enhanced termination of zinc and cadmium ions from wastewater employing plain and chitosan-modified mxenes: synthesis, characterization, and adsorption performance. Green Chemical Engineering 2024;5:339–47. https://doi.org/10.1016/j.gce.2023.08.003.

[5]. Kadhom M. MXenes in Membrane-Based Water Treatment Applications, 2023, p. 121–39. https://doi.org/10.1021/bk-2023-1445.ch006.

[6]. Ajith S, Almomani F, Qiblawey H. Emerging 2D MXene-based polymeric membranes for water treatment and desalination. J Environ Chem Eng 2024;12:112078. https://doi.org/10.1016/j.jece.2024.112078.

[7]. Hajian S, Maddipatla D, Narakathu BB, Atashbar MZ. MXene-based flexible sensors: A review. Frontiers in Sensors 2022;3. https://doi.org/10.3389/fsens.2022.1006749 .

[8]. Sheikh TA, Ismail M, Rabbee MF, Khan H, Rafique A, Rasheed Z, et al. 2D MXene-Based Nanoscale Materials for Electrochemical Sensing Toward the Detection of Hazardous Pollutants: A Perspective. Crit Rev Anal Chem 2024:1–46. https://doi.org/10.1080/10408347.2024.2379851.

[9]. Rhouati A, Berkani M, Vasseghian Y, Golzadeh N. MXene-based electrochemical sensors for detection of environmental pollutants: A comprehensive review. Chemosphere 2022;291:132921. https://doi.org/10.1016/j.chemosphere.2021.132921

[10]. Solangi NH, Karri RR, Mazari SA, Mubarak NM, Jatoi AS, Malafaia G, et al. MXene as emerging

material for photocatalytic degradation of environmental pollutants. Coord Chem Rev 2023;477:214965. https://doi.org/10.1016/j.ccr.2022.214965.
[11].Zaed M, Saidur R, Pandey AK, Kadhom M, Tan KH, Cherusseri J, et al. Utilization of recycled materials for low-cost MXene synthesis and fabrication of graphite/MXene composite for enhanced water desalination performance. Sep Purif Technol 2025;354:129055. https://doi.org/10.1016/j.seppur.2024.129055.

المكسين، فئة من المواد الناشئة ثنائية الأبعاد واستخدامها لأغراض معالجة المياه

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الملخص

تُعدّ التقنيات المتقدمة لمعالجة المياه ضرورية لمواجهة ندرة المياه العذبة على مستوى العالم. وتُظهر المواد من نوعMXenes ، وهي فئة جديدة من كربيدات ونتريدات الفلزات الانتقالية ثنائية الأبعاد، وعدًا كبيرًا في تنقية المياه. فهي تمتاز بكفاءتها في عمليات الامتزاز، والترشيح الغشائي، والاستشعار، والتحفيز الضوئي، والتحلية الحرارية، وذلك بفضل مساحتها السطحية العالية، والمجموعات الوظيفية القابلة للتعديل، والتوصيلية الممتازة. تُحسّن الأغشية المصنّعة من MXenes نفاذية المياه وانتقائيتها ومقاومتها للتلوث، مما يجعلها مرشحة واعدة لتطبيقات الترشيح الفائق، والترشيح النانوي، والتناضح العكسي. كما أن التوصيلية الفائقة والتفاعلية السطحية لـــ MXenes تجعلها شائعة الاستخدام في أجهزة الاستشعار الكهروكيميائية للكشف عن الملوثات البيئية.

وتُظهر قدراتها في التحفيز الضوئي والتحلية الحرارية مدى تنوعها في مجالات المعالجة البيئية. ويجري حاليًا العمل على تحسين المواد المعتمدة على MXenesلاستخدامها على نطاق واسع في معالجة المياه، رغم التحديات المتعلقة بتعقيد طرق التحضير ومشكلات الاستقرار. وقد حققت MXenes تقدمًا ملحوظًا في مجال تنقية المياه، كما يُبيّن هذا المقال الافتتاحي.4