

RESEARCH PAPER

Green Synthesis and Characterization of Guar Gum/Polyacrylamide/Activated Carbon Hydrogel for Efficient Methylene Blue Removal

Uday Abdul-Reda Hussein ¹, Dhurgham Hani Kadhim Alalwan ², Hussein Ali Qabel ³, Fadhil M. Abid ⁴, Hadil Hussain Hamza ⁵, Boyjanov Nodirbek Ilxomovich ⁶, Aseel M. aljeboree ⁷, Ayad F. Alkaim ^{7*}

¹ Department of pharmaceuticals, College of Pharmacy, University of Al-Ameed, Iraq

² College of pharmacy, University of Karbala, Iraq

³ Department of Pharmaceutical Chemistry, College of Pharmacy, University of Kerbala, Karbala, Iraq

⁴ Al-Hadi University College, Baghdad, Iraq

⁵ Department of Medical Laboratories Technology, Al-Nisour University College, Baghdad, Iraq

⁶ Department of Food Technology, Urgench State University; Uzbekistan

⁷ Department of Chemistry, College of Science for Women, University of Babylon, Iraq

ARTICLE INFO

Article History:

Received 05 June 2025

Accepted 27 September 2025

Published 01 October 2025

Keywords:

Acrylamide

Activated carbon

Guar gum

Hydrogel

Methylene blue

ABSTRACT

An innovative approach was developed for removing highly potent dyes, such as methylene blue (MB), from simulated solutions under various application conditions. The sorbent material was green hydrogels based on guar gum/polyacrylamide (GG/PAm) fabricated with activated carbon (GG/PAAm/AC). The crosslinker N, N'-methylene bisacrylamide (MBA) and the initiator potassium persulfate (KPS) were used in minimal amounts to adhere to green chemistry principles. The synthesis was performed under mild conditions, and the polymerisation was carried out at 60 °C, indicating a lower energy requirement. Different combinations were tried, varying the concentrations of GG (0.12–0.2 g), PAm (0.3–3 g), AC (0.01–0.1g), KPS (0.01–0.1 g), and MBA (0.02–0.12 g). Of the ratios investigated, the best configuration of hydrogels was 0.15 g GG, 2.0 g, PAM, 0.08 g AC, 0.05 g KPS, and 0.08 g MBA, which generated a hydrogel with increased water-holding and hardness, and a higher adsorptive rate. The effect of AC on the crystallographic and thermal properties of the hydrogel composites was verified via the XRD and TGA analyses, respectively. The reactivation efficiency of the prepared composite surface initially reached 98% after the first regeneration cycle and decreased to 81% by the fifth cycle. This gradual decline indicates partial loss of active sites over successive uses. However, the presence of active carbon (AC) played a critical and effective role in maintaining regeneration performance by providing a stable, high-surface-area network that supports dye desorption and functional group recovery. The reusability investigation demonstrated that the sorbents were highly effective in removing significant amounts of pollutants after four adsorption–desorption cycles.

How to cite this article

Hussein U., Alalwan D., Qabel H. et al. Green Synthesis and Characterization of Guar Gum/Polyacrylamide/Activated Carbon Hydrogel for Efficient Methylene Blue Removal. J Nanostruct, 2025; 15(4):1808-1819. DOI: 10.22052/JNS.2025.04.029

* Corresponding Author Email: alkaimayad@gmail.com



INTRODUCTION

Freshwater scarcity, a pressing global issue, is addressed through green solutions in green chemistry. Several options for recovering and reusing existing resources have been proposed. Pollution of water by various contaminants appears to be one of the significant threats to the globe, as water serves as a vital source of life for all living organisms on Earth. These contaminants may be inorganic, organic, or biological in nature. Some, such as biological pollutants and certain dyes, can be broken down by bacteria, while others are resistant to this process. Heavy metals are among the most hazardous types of contaminants, as they persist up the food chain, leading to severe health problems and a significant mutagenic impact. Additionally, the decomposition of dye derivatives kills microorganisms and algae in aquatic organisms by blocking sunlight and altering the genetic

information of various cellular systems. Thus, the removal of these pollutants is one of the most promising solutions and has aroused considerable attention [1, 2]. Dye molecules consist of two key components: the chromophores, which are primarily responsible for producing the color, and the auxochromes, which not only supplement the chromophore but also render the molecule soluble in water and enhance its affinity (to attach) toward the fibers [3]. Due to their toxic effects, dyes have generated much concern regarding their use. It has been known to cause mutagenesis, chromosomal fractures, carcinogenesis, and respiratory toxicity. Therefore, focusing on specific methods and technologies to remove dyes from various types of wastewater streams is desirable [4-9]. In fact, multiple materials derived from agricultural waste and natural resources have been utilised in this field. Among the various methodologies applied

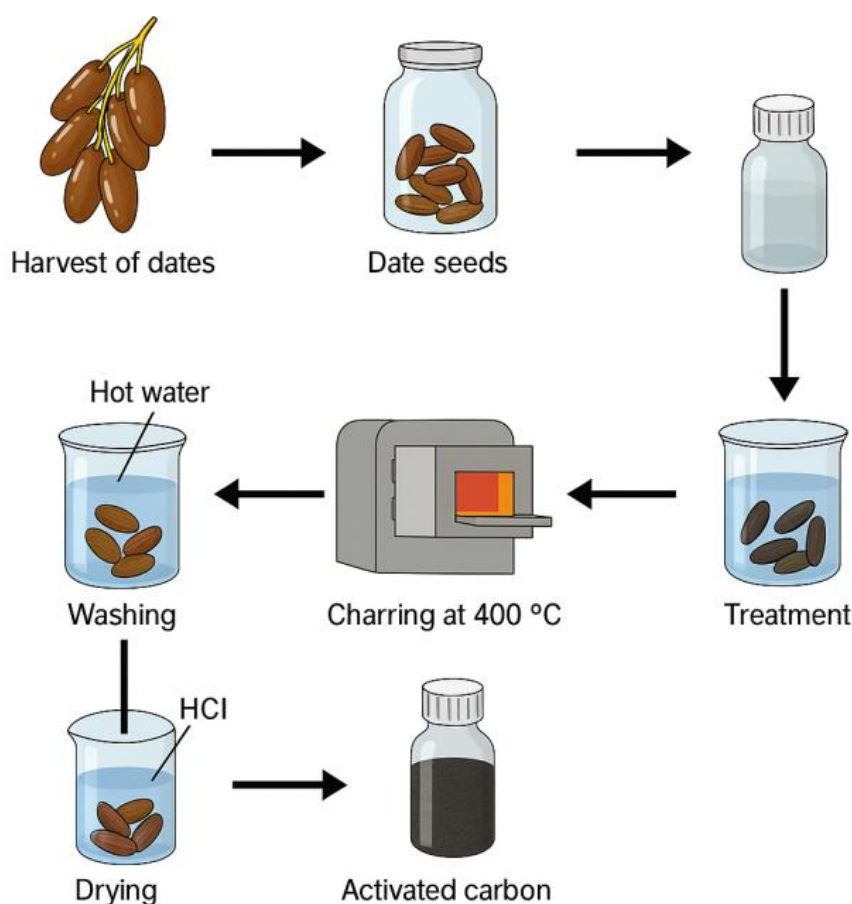


Fig. 1. Preparation of Date Pits as activated carbon.

to water purification, adsorption has proven to be highly effective due to its high efficiency, low waste generation, versatility, and reusability. Over the past two decades, hydrogels have emerged as promising candidates for water treatment. The most important of these are those prepared from or based on natural materials, such as guar gum, chitosan, pectin, cellulose, and starch [10, 11].

Hydrogels have several advantages, including high hydrophilicity, biocompatibility, and a three-dimensional porous structure that closely resembles the extracellular matrix, making them one of the most competitive materials for wound dressings. Compared to traditional wound dressings (such as gauze, bandages, and cotton), hydrogel dressings can be easily modified to meet the diverse demands during various stages of wound repair. Gellan gum, an exopolysaccharide derived from non-pathogenic bacteria of the *Sphingomonas* group, can be easily converted into hydrogels through gentle heating and cooling. Recently, gellan gum has received extensive

attention in the biomedical field, particularly in soft tissue engineering, due to its structural similarity to the extracellular matrix of soft tissues. These excellent properties make gellan gum an ideal scaffold for loading PDA particles, and its porous structure can maintain good dispersion and controlled release of heat energy [12-14].

Hydrogels have numerous applications due to their structural adaptability, high water content, and biocompatibility. These have been widely applied in biomedical applications such as drug delivery systems, wound dressings, tissue engineering scaffolds, and contact lenses. Regarding environmental engineering, hydrogels have been proved as efficient adsorbents for the removal of heavy metals, dyes and other pollutants from wastewater. Additionally, they are employed in agriculture as soil conditioners to maintain water content and can be combined for their stimulus-responsive properties in actuators and sensors. Advances in hydrogel technology, such as nanocomposite hydrogels and stimuli-

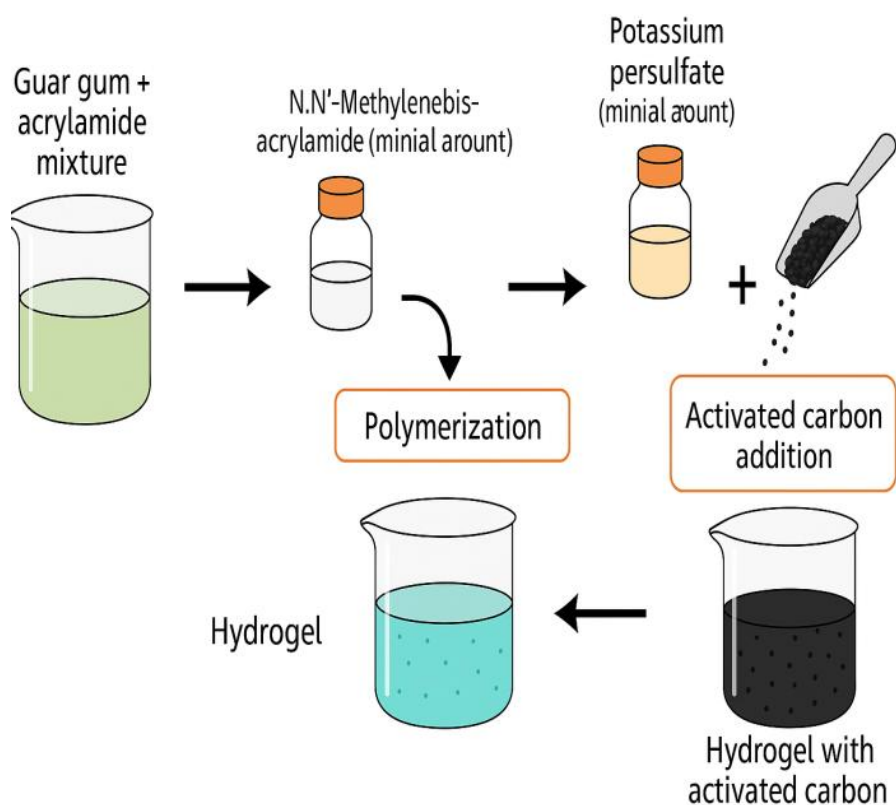


Fig. 2. Preparation of GG/PAm/AC Hydrogel Composite.

responsive (“smart”) hydrogels, have enhanced their applicability and created new opportunities in modern applications [15-18].

MATERIALS AND METHODS

Activation of Date Pits

Activated carbon was produced from date pits collected from Iraqi farms. The pits were initially hand-separated from the date palm fruits and thoroughly washed with hot distilled water to eliminate any residual sugars and adhering impurities, followed by drying in the open air at room temperature for 24 h. The dried pits were carbonized by thermal. They were carbonised in a furnace at 400°C for two hours under a reduced oxygen environment to produce biochar. The carbonised product was ground and sieved to a uniform particle size after cooling. The biochar obtained was subsequently chemically activated. It was immersed in a 0.1 M hydrochloric acid (HCl) solution and mixed at room temperature for 2 h to remove inorganic impurities and increase the porosity. The mixture was filtered and washed a few times with hot distilled water until a neutral solution was obtained. The acid-treated carbon was eventually oven-dried at 105°C for 12 h, cooled in a desiccator and packed in clean, air-tight glass containers for subsequent use in adsorption studies. As shown in Fig. 1.

Preparation of GG/PAAm/AC Hydrogel Composite

The GG/PAAm/AC hydrogel was prepared using a free radical polymerization process at ambient

condition. In the beginning, 0.1 g of guar gum (GG) was dissolved in deionized water of 20 mL with continuous magnetic agitation at 60°C until a homogeneous viscous solution (Solution A) was achieved. PAm monomer (1.2.0 g) was dissolved in 10 mL of de-ionized water in another beaker. 0.05 g of a radical initiator, potassium persulfate (KPS), was then added, and 0.08 g N, N'-methylene bisacrylamide (MBA) was used as a crosslinking agent (Solution B). The solution was then mixed at room temperature for 30 minutes to obtain a homogeneous dispersion. Then a certain quantity of activated carbon (AC) was added to Solution B and homogenised with mechanical agitation and ultrasonication (where necessary) for a good distribution. Solution A was followed by Solution B with continuous stirring, and the mixture was then cast into clean Petri dishes or moulds for polymerisation. The polymerisation was conducted in a hot-air oven for 1.5 h at 60°C. Hydrogel product was collected, rinsed with abundant deionized water to wash away unreacted monomers and soluble impurities and then placed in hydrated or dehydrated condition before the intended analysis. As shown in Fig. 2

RESULTS AND DISCUSSION

Scanning electron microscopy SEM

The SEM micrograph (Fig. 3a) displays the surface morphology of the activated carbon-loaded hydrogel before the adsorption of MB dye. At a magnification of 50,000×, the surface appears rough and highly porous, characterized by

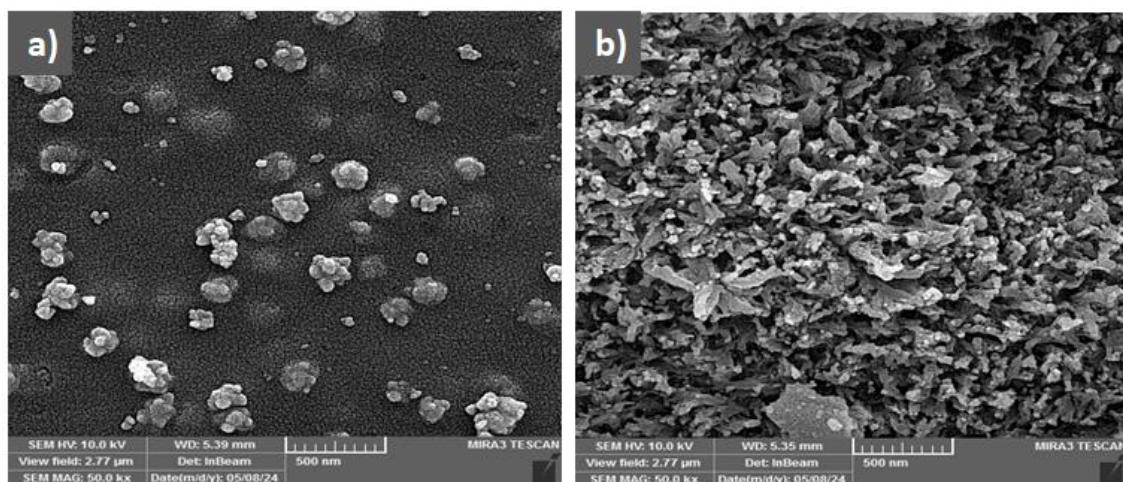


Fig. 3. FESEM image a) Hydrogel, b) hydrogel after adsorption of MB dye.

an interconnected network of irregularly shaped cavities and ridges. These features are indicative of a well-developed three-dimensional hydrogel structure. The dispersion of activated carbon particles is evident throughout the polymer matrix, contributing to the heterogeneous texture and enhancing the overall surface area available for adsorption. The porous architecture and the presence of micro- and mesopores are critical for facilitating rapid dye diffusion and interaction with active adsorption sites. The morphology suggests that the hydrogel composite has a high potential for efficient adsorption due to its increased surface roughness, pore density, and the synergistic effect of the incorporated activated carbon [19–21].

The SEM photomicrograph (Fig. 3b) presents a surface morphological view of the activated carbon laden hydrogel after the adsorption of methylene blue (MB) dye. The surface is significantly altered, as an abundance of spherical compounds and aggregates have formed within the hydrogel matrix compared to the pre-adsorption image. These surface deposits may be attributed to the adsorbed MB dye molecules in clusters, representing the available active site with which the successful interaction is maintained. The coarse and rough structure of the hydrogel surface, observed before treatment, is now compacted and partly blocked (resulting from the occupation of inner pores and surface functional

groups by the dye). The reduction in apparent porosity was recorded and the enhancement of apparent particles deposited firmly on the surface was observed, which also reflect efficient adsorption. These morphological transformations also demonstrate the strong interaction of the hydrogel with the cationic dye molecules and thus may have potential applications in wastewater treatment technologies.

This TEM image in Fig. 4 of the hydrogel reveals its internal nanostructure, showcasing a well-defined, nearly spherical or slightly cuboidal nanoparticle embedded within the matrix. The particle size is approximately 100, and 200 nm, indicating nanoscale features consistent with a nanocomposite system. The relatively uniform contrast suggests a homogeneous distribution and incorporation of nanoparticles or dense regions within the hydrogel network. This morphology supports the presence of a compact internal structure, potentially contributing to enhanced mechanical stability and efficient interaction with target molecules during adsorption processes [22].

The TGA curve of the GG/PAAm/AC hydrogel exhibits a three-step weight loss trend. The first slight weight loss under 150°C is assigned to the evaporation of adsorbed moisture. A second, more stable plateau, valid up to approximately 300°C, is evidence of the stability of the polymer backbone. A significant weight loss in the range of 300–500°C

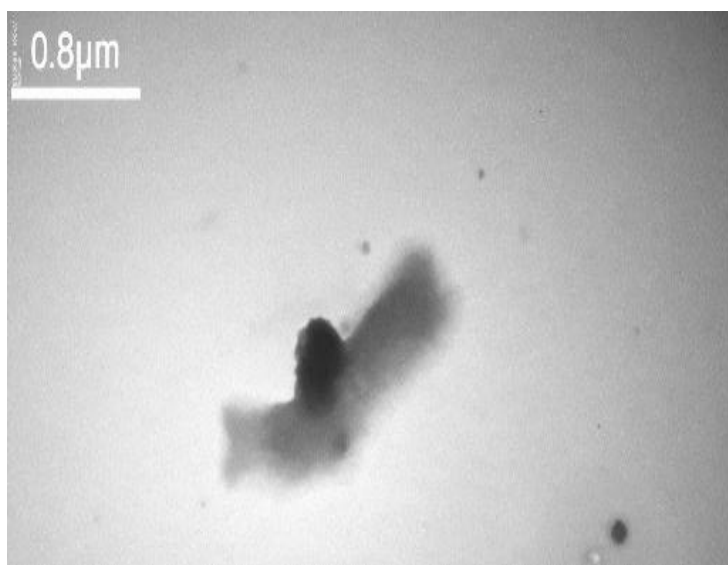


Fig. 4. TEM image of hydrogel composite.

is due to the thermal degradation of polymer chains, GG and polyacrylamide. Above 500°C, little residue is left, indicating that the organic material is sufficiently decomposed. These results suggest that the hydrogel exhibits good thermal stability, which is suitable for moderate-temperature work, including wastewater treatment. As shown in Fig.

5 a [5, 6, 23].

The XRD pattern of the hydrogel (Fig. 5 b) displays a broad and low-intensity diffraction peak located between 20° and 25°, which is assigned to an amorphous or semi-crystalline structure. Such a broad hump indicates the existence of randomly oriented polymer chains with short-

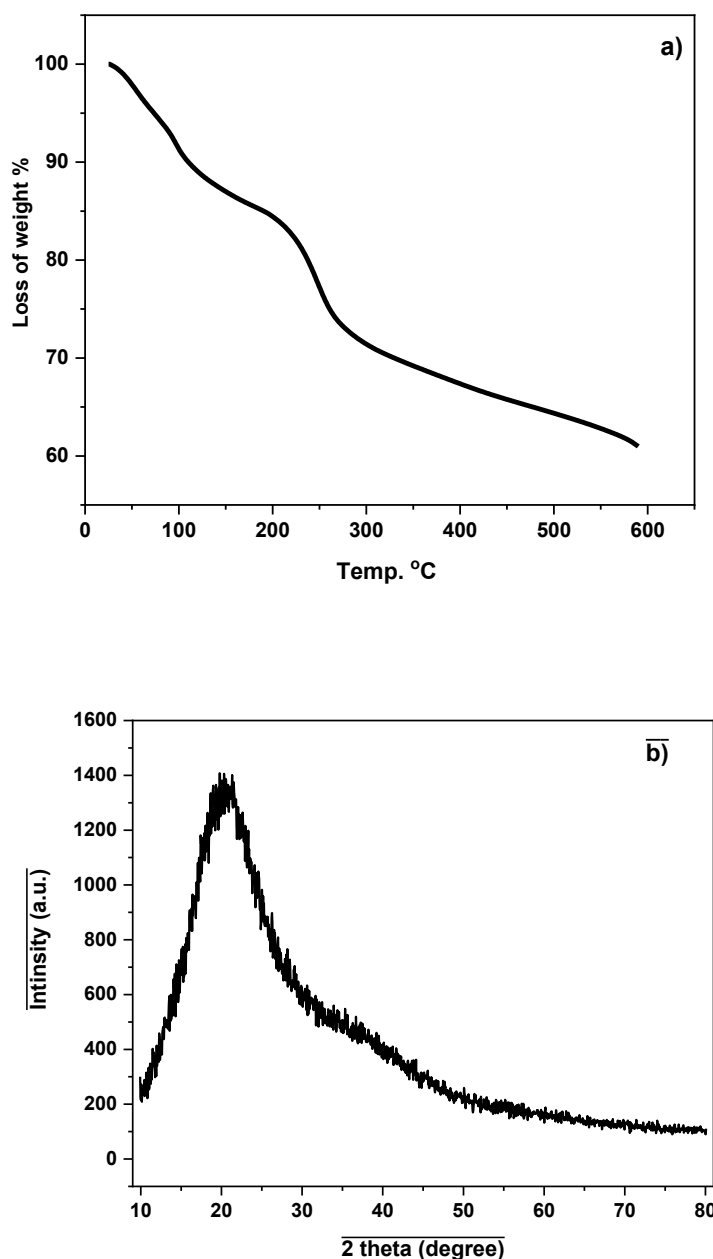


Fig. 5. a) Thermogravimetric Analysis TGA curve of the GG/PAm/AC hydrogel, b) XRD of GG/PAm/AC hydrogel nanocomposite.

range order, which is typical in natural polymer-derived or synthetic hydrogels. No sharp and well-defined diffraction peaks were observed, indicating that the hydrogel lacks a crystalline phase and is predominantly amorphous. Such structural disorder is common in the case of free-radical polymerisation-derived gels, particularly when involving natural biopolymers (e.g., guar gum). Minor and sharp peaks can be observed for composite hydrogels with AC. But if there are no peaks seen here, it must be that there is low filler present or that it is distributed well within the hydrogel. The amorphous characteristic is favorable for the swelling ability as well as dye adsorption due to its flexibility, pore accessibility, and functional group exposure.

Optimization of the swelling behavior for the synthesis of hydrogel

Effect of Acrylamide Monomer Content on Swelling Ratio

The monomer plays a dual role: it interacts with the cross-linker and initiator to form the hydrogel's 3D network and introduces hydrophilic groups that enhance water absorption. Varying the acrylamide (AM) content from 0.3 g to 2.0 g revealed its significant impact on swelling behavior. As the AM concentration increased, the swelling ratio peaked

at 1500% with 1.2 g, indicating enhanced chain propagation and water uptake (Fig. 6). However, further increases led to a decline, with a swelling ratio of 1100% at 1.5 g.

This reduction is attributed to diminished electrostatic repulsion and increased solution viscosity, which restrict free radical mobility. Additionally, homopolymer formation and self-crosslinking at higher AM concentrations limit network flexibility. Hydrogen bonding among hydroxyl groups may also contribute to network contraction, further reducing swelling capacity [24, 25]

Effect of Guar Gum on Swelling Ratio

Fig. 7 illustrates the effect of varying guar gum (GG) concentrations (0.2–1.5 g) on the swelling ratio of the hydrogel. The maximum swelling ratio (1500%) occurred at 1.0 g GG, likely due to electrostatic repulsion among negatively charged (COO^-) groups and lone electron pairs on oxygen atoms. Beyond this concentration, increased GG leads to more free radicals and active sites, promoting crosslinking and polymer chain entanglement, which limits water absorption and reduces the swelling ratio. Excessive GG also increases solution viscosity, hindering macromolecular mobility and reducing

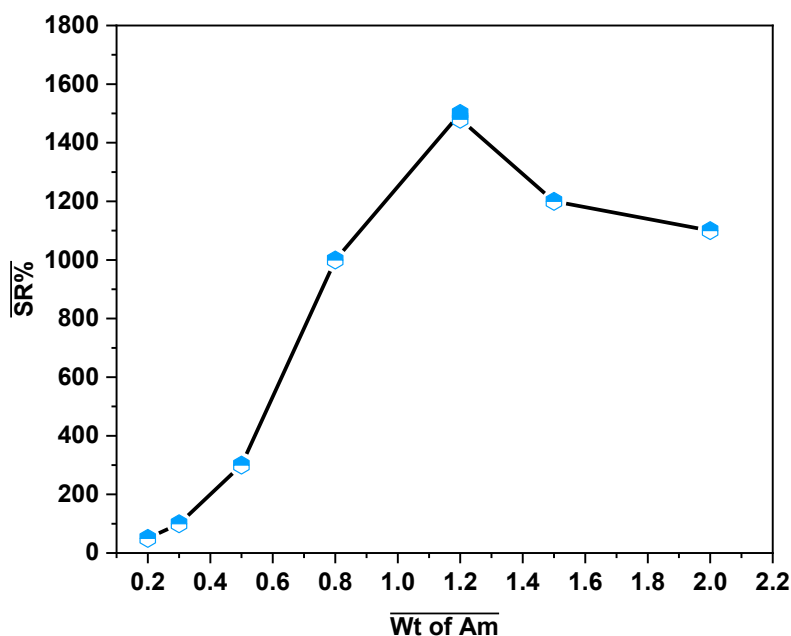


Fig. 6. Effect of acrylamide on the Swelling Ratio.

recombination efficiency. This results in a more heterogeneous structure and diminished swelling and adsorbate loading capacity [26, 27].

Effect of Activated Carbon Content on Swelling Ratio

The incorporation of activated carbon (AC) into the hydrogel significantly influences its swelling properties. At low AC content, the swelling

ratio was relatively low, likely due to insufficient porosity and limited interaction between the hydrogel matrix and water molecules. As the AC content increased, the swelling ratio improved, reaching a maximum at 0.08 g as shown in Fig. 8. This enhancement can be attributed to the porous nature of AC, which increases water uptake and creates additional pathways for fluid diffusion within the hydrogel network [28, 29].

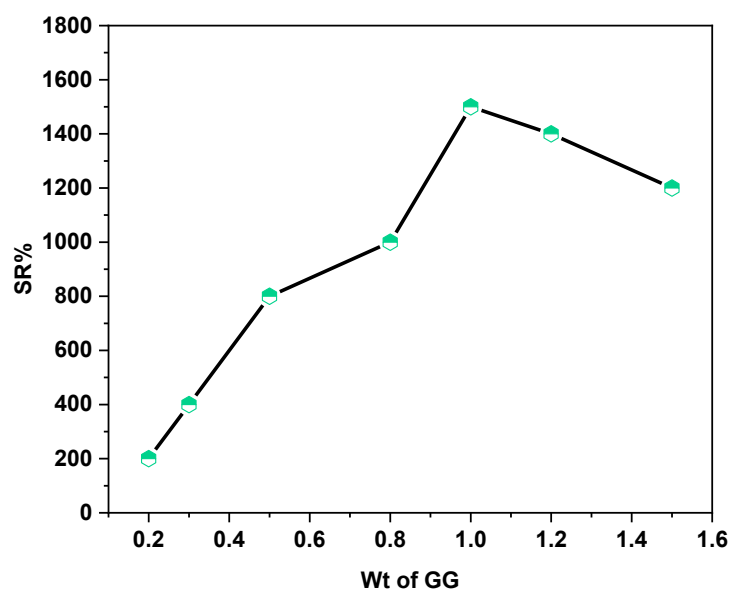


Fig. 7. Effect of the GG on the Swelling Ratio.

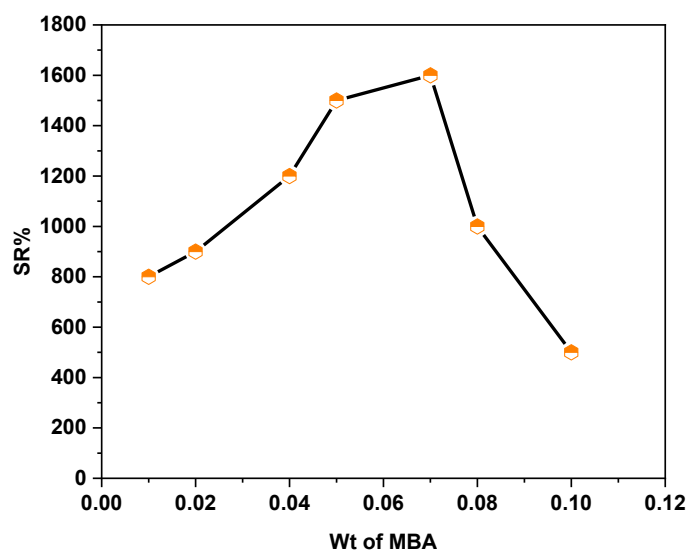


Fig. 8. Effect of Activated Carbon Content on Swelling ratio.

However, when the AC content exceeded 0.08 g, the swelling ratio began to decline. This reduction is likely due to excessive AC loading, which may lead to aggregation, reduced flexibility of the polymer chains, and obstruction of the hydrogel network. Such effects limit the hydrogel's ability to expand and retain water, resulting in decreased swelling performance at higher AC concentrations [28, 30].

Effect of Crosslinker Content on Swelling Ratio

The crosslinker is essential for forming a stable, insoluble hydrogel network by reinforcing structural integrity and controlling crosslink density, which directly influences fluid absorption. In this study, N, N'-methylenebisacrylamide (MBA) was used in varying amounts (0.02–0.09) g, dissolved in 5 mL distilled water, to evaluate its effect on the hydrogel's swelling behavior

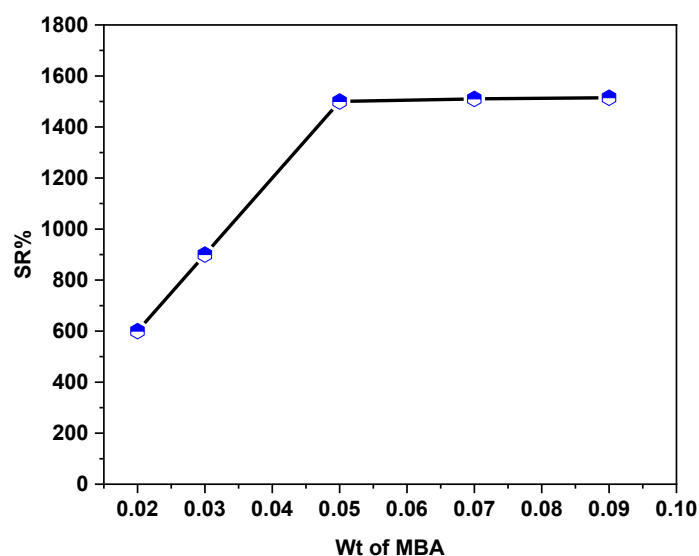


Fig. 9. Effect of cross-linker on the swelling behavior.

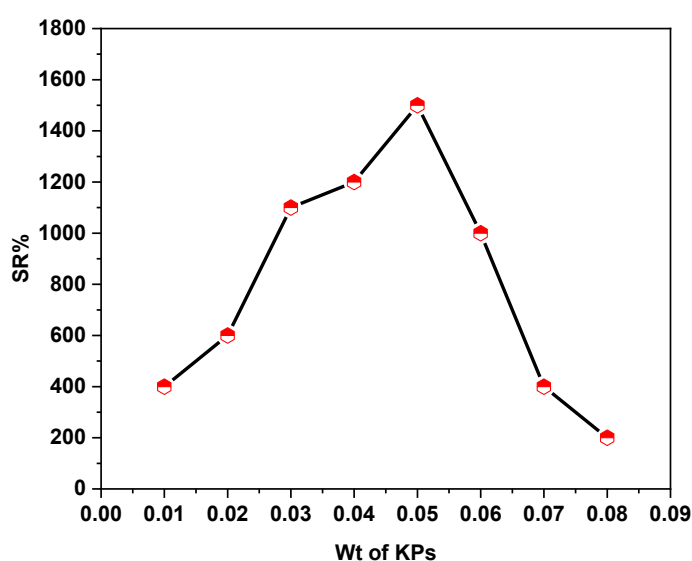


Fig. 10. Effect of the initiator on the swelling ratio.

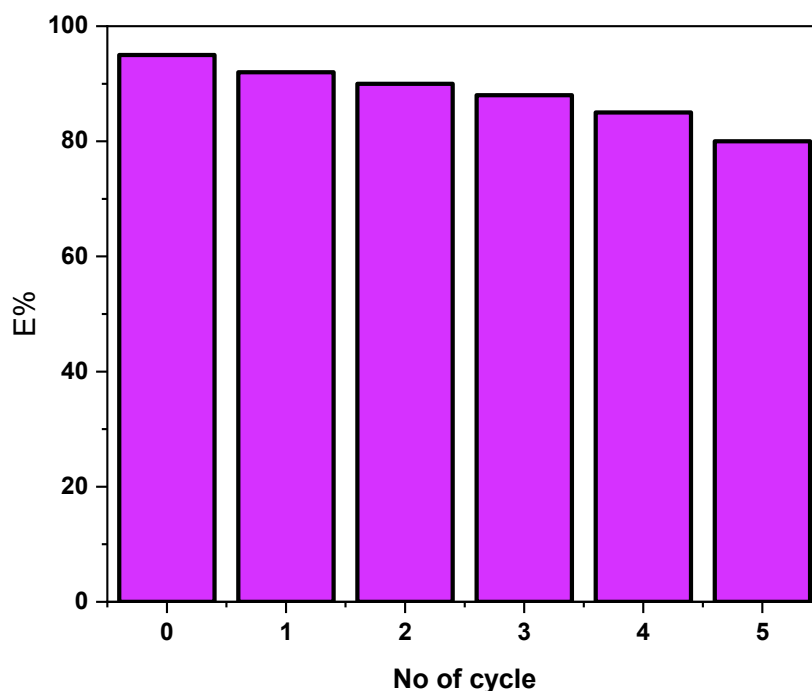


Fig. 11. Reusability Performance of the GG/PAAm/AC Hydrogel. experimental conditions (0.05 gm of the surface with 100 mg/L of the dye under condition 25 °C, pH 7 and equilibrium time 60 mins.).

(Fig. 9). The highest swelling ratio (1500%) was observed at a dosage of 0.05 g MBA. At lower concentrations, insufficient crosslinking limited the network's ability to trap dye molecules, while higher concentrations led to excessive crosslinking, reducing pore size and water uptake capacity, Fig. 9 [31, 32].

Effect of Initiator Concentration on Swelling Ratio

To investigate the impact of initiator concentration, varying amounts of potassium persulfate (KPS) were tested, ranging from 0.01 to 0.08 g (Fig. 10). The swelling ratio peaked at 1500% with 0.05 g of KPS, attributed to optimal generation of free radicals that initiate effective grafting onto the κ -carrageenan backbone and enhance network expansion via interaction with sulfate radicals. However, at concentrations above 0.08 g, the swelling ratio declined. This reduction is likely due to excessive radical generation, leading to increased bimolecular termination, shorter polymer chains, and structural irregularities, as explained by Flory's theory. Higher initiator levels may also favour homopolymerization over grafting and decrease polymer molecular weight, resulting

in reduced water absorbency [33, 34].

Regeneration Efficiency of the Hydrogel

Fig. 11 presents the regeneration efficiency (E%) of the GG/PAAm/AC hydrogel over five adsorption-desorption cycles for methylene blue (MB) dye, experimental conditions (0.05 gm of the surface with 100 mg/L of the dye under condition 25 °C, pH 7 and equilibrium time 60 mins.). The initial adsorption efficiency exceeded 85%, indicating a strong affinity toward MB. However, a gradual decline was observed with each cycle, reaching approximately 50% by the fifth cycle. This decrease is likely due to partial saturation of active sites, structural degradation, or irreversible dye adsorption during repeated use. Nevertheless, the hydrogel maintained a substantial portion of its adsorption capacity, demonstrating good reusability and structural stability, which supports its potential for practical wastewater treatment applications [35, 36].

CONCLUSION

In this study, a novel and environmentally friendly hydrogel based on gaum Gum (GG) grafted

with polyacrylamide (PAM) was successfully synthesized via free radical polymerization. The synthesis process utilized biodegradable and low-toxicity components, demonstrating a green chemistry approach. By optimizing the monomer and cross-linker ratios, a hydrogel with excellent mechanical integrity, high porosity, and adequate swelling capacity was obtained. Hydrogels blended with activated carbon were employed in the removal of MB dye pollutant from simulated solutions under various application conditions. The reusability investigation proved that the active carbon supported hydrogels can be repeatedly applied four times with comparable quantities of pollutant removed. The obtained findings depict that the prepared materials can be used as effective candidates in wastewater remediation with repeated applicability. Its eco-friendly nature, ease of preparation, and effective dye removal performance support its potential application in sustainable wastewater treatment technologies.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFERENCES

1. Cho E, Tahir MN, Kim H, Yu J-H, Jung S. Removal of methyl violet dye by adsorption onto N-benzyltriazole derivatized dextran. *RSC Advances*. 2015;5(43):34327-34334.
2. Aladağ E, Fil BA, Boncukcuoğlu R, Sözüdoğru O, Yılmaz AE. Adsorption of Methyl Violet Dye, A Textile Industry Effluent onto Montmorillonite—Batch Study. *J Dispersion Sci Technol*. 2014;35(12):1737-1744.
3. Adegoke KA, Bello OS. Dye sequestration using agricultural wastes as adsorbents. *Water Resources and Industry*. 2015;12:8-24.
4. Tkaczyk A, Mitrowska K, Posyniak A. Synthetic organic dyes as contaminants of the aquatic environment and their implications for ecosystems: A review. *Sci Total Environ*. 2020;717:137222.
5. Yang X, Zhang X, Feng X, Xu B, Du C, Zhang E, et al. Novel porous hydrogel beads based on amidoxime modified polymer of intrinsic microporosity for efficient cationic dye removal. *Microporous Mesoporous Mater*. 2024;377:113218.
6. Ullah N, Ali Z, Khan AS, Adalat B, Nasrullah A, Khan SB. Preparation and dye adsorption properties of activated carbon/clay/sodium alginate composite hydrogel membranes. *RSC Advances*. 2024;14(1):211-221.
7. Karam FF, Hussein FH, Baqir SJ, Halbus AF, Dillert R, Bahnemann D. Photocatalytic Degradation of Anthracene in Closed System Reactor. *International Journal of Photoenergy*. 2014;2014:1-6.
8. Indhumathi P, Sathiyaraj S, Shoba US, Syed Shabudeen PS, Jayabalakrishnan C. Thermodynamic and Kinetic Models for Removal of Thorium from Aqueous Solution. *Journal of Advanced Physics*. 2017;6(1):148-156.
9. Mzinyane NN, Chiririwa H, Ofomaja AE, Naidoo EB. Effect of Ammonium Ceric Nitrate As Initiator in Grafting of Acrylic Acid onto Pine Cone Powder. *Cellul Chem Technol*. 2019;53(9-10):971-979.
10. Bouasla C, Samar ME-H, Ismail F. Degradation of methyl violet 6B dye by the Fenton process. *Desalination*. 2010;254(1-3):35-41.
11. Maryudi M, Amelia S, Salamah S. Removal of Methylene Blue of Textile Industry Waste with Activated Carbon using Adsorption Method. *Reaktor*. 2019;19(4):168-171.
12. Thakur S, Chaudhary J, Thakur A, Gunduz O, Alsanie WF, Makatsoris C, et al. Highly efficient poly(acrylic acid-co-aniline) grafted itaconic acid hydrogel: Application in water retention and adsorption of rhodamine B dye for a sustainable environment. *Chemosphere*. 2022;303:134917.
13. Taktak FF, Özyaranlar E. Semi-interpenetrating network based on xanthan gum-cl-2-(N-morpholinoethyl methacrylate)/titanium oxide for the single and binary removal of cationic dyes from water. *Int J Biol Macromol*. 2022;221:238-255.
14. Aljeboree A M. Adsorption and removal of pharmaceutical riboflavin (RF) by rice husks activated carbon. *International Journal of Pharmaceutical Research*. 2019;11 (2):255-261.
15. Khan S, Rahman NU, Alam S, Zahoor M, Shah LA, Umar MN, et al. Synthesis of Poly(GG-co-AAm-co-MAA), a Terpolymer Hydrogel for the Removal of Methyl Violet and Fuchsin Basic Dyes from Aqueous Solution. *ACS Omega*. 2024.
16. Chopra L, Sharma A, Chohan JS, Upadhyay VV, Singh R, Sharma S, et al. Synthesis and characterizations of super adsorbent hydrogel based on biopolymer, Guar Gum-grafted-Poly (hydroxyethyl methacrylate) (Gg-g-Poly (HEMA)) for the removal of Bismarck brown Y dye from aqueous solution. *Int J Biol Macromol*. 2024;256:128518.
17. Cai Z, Zhou W, Chen W, Huang R, Zhang R, Sheng L, et al. Preparation and properties of cationic starch-carrageenan-sodium alginate hydrogels with pH and temperature sensitivity. *Food Chem*. 2024;459:140272.
18. Aljeboree AM, Hasan IT, Al-Warthan A, Alkaim AF. Preparation of sodium alginate-based SA-g-poly(ITA-co-VBS)/RC hydrogel nanocomposites: And their application towards dye adsorption. *Arabian Journal of Chemistry*. 2024;17(3):105589.
19. Aljeboree AM, Alkaim AF. Studying removal of anionic dye by prepared highly adsorbent surface hydrogel nanocomposite as an applicable for aqueous solution. *Scientific Reports*. 2024;14(1).
20. Tyagi R, Dangi D, Sharma P. Optimization of Hazardous Malachite Green Dye Removal Process Using Double Derivatized Guar Gum Polymer: A Fractional Factorial L9 Approach. *Sustainable Chemistry for Climate Action*. 2024:100043.
21. Swaminathan P, Venugopal R, Mallayan P, Lakshmanan U. Chromium-induced in vivo DNA changes in marine algae *Oscillatoria willei* BDU 130511 (Cyanophyta). *International Journal on Algae*. 2009;11(4):394-402.
22. Aljeboree AM, Alkaim AF, Al-Dujaili AH. Adsorption isotherm, kinetic modeling and thermodynamics of crystal violet dye on coconut husk-based activated carbon. *Desalination and Water Treatment*. 2015;53(13):3656-3667.
23. Yazdanbakhsh MR, Yousefi H, Mamaghani M, Moradi EO, Rassa M, Pouramir H, et al. Synthesis, spectral characterization and antimicrobial activity of some new azo dyes derived from 4,6-dihydroxypyrimidine. *J Mol Liq*. 2012;169:21-26.
24. Abo El Dahab H, El-reefy S, Hassan R, Shehata F, Abd Elwahab

- s. Grafting Copolymerization of (Sodium Alginate/ Acrylic Acid/ Methacrylic Acid) by Gamma Radiation: Preparation and Characterization. Arab Journal of Nuclear Sciences and Applications. 2021;0(0):1-8.
25. Ibrahim AG, Elkony AM, El-Bahy SM. Methylene blue uptake by gum arabic/acrylic amide/3-allyloxy-2-hydroxy-1-propanesulfonic acid sodium salt semi-IPN hydrogel. Int J Biol Macromol. 2021;186:268-277.
26. Mhammed Alzayd AA, Radia ND. A Novel Eco-friendly Bionanocomposite: Synthesis, Optimizing Grafting Factors, Characterization, Adsorption of Ofloxacin Hydrochloride, Reinforcement Elimination System to Pharmaceutical Contaminants. J Polym Environ. 2023;32(4):1821-1836.
27. Aljeboree AM, Alkaim AF, Hussein SA, Alsultany FH, Jawad MA. Ecofriendly k-Carrageenan-Based Hydrogel with Strong Adsorption and Higher Abilities to Remove Crystal Violet from Aqueous Solution: Thermodynamic, Isotherm and Kinetic Investigation. Journal of Inorganic and Organometallic Polymers and Materials. 2024;35(4):2921-2942.
28. Sharma AK, Priya, Kaith BS, Sharma N, Bhatia JK, Tanwar V, et al. Selective removal of cationic dyes using response surface methodology optimized gum acacia-sodium alginate blended superadsorbent. Int J Biol Macromol. 2019;124:331-345.
29. Pathania D, Sharma S, Singh P. Removal of methylene blue by adsorption onto activated carbon developed from Ficus carica bast. Arabian Journal of Chemistry. 2017;10:S1445-S1451.
30. Mulla B, Ioannou K, Kotanidis G, Ioannidis I, Constantinides G, Baker M, et al. Removal of Crystal Violet Dye from Aqueous Solutions through Adsorption onto Activated Carbon Fabrics. C. 2024;10(1):19.
31. Kenawy E-R, Azaam MM, El-nshar EM. Sodium alginate-g-poly(acrylic acid-co-2-hydroxyethyl methacrylate)/montmorillonite superabsorbent composite: Preparation, swelling investigation and its application as a slow-release fertilizer. Arabian Journal of Chemistry. 2019;12(6):847-856.
32. Karam FF, Alzayd AAM. Swelling Behavior of Poly (Aam_Ma) Hydrogel Matrix and Study Effects pH and Ionic Strength, Enforcement in Controlled Release System. International Journal of Applied Pharmaceutics. 2018;10(6):318.
33. Galal Ibrahim A. Synthesis of Poly(Acrylamide-Graft-Chitosan) Hydrogel: Optimization of The Grafting Parameters and Swelling Studies. American Journal of Polymer Science and Technology. 2019;5(2):55.
34. Wang Z, Ning A, Xie P, Gao G, Xie L, Li X, et al. Synthesis and swelling behaviors of carboxymethyl cellulose-based superabsorbent resin hybridized with graphene oxide. Carbohydr Polym. 2017;157:48-56.
35. Zaheer Z, Al-Asfar A, Aazam ES. Adsorption of methyl red on biogenic Ag@Fe nanocomposite adsorbent: Isotherms, kinetics and mechanisms. J Mol Liq. 2019;283:287-298.
36. Zhokh A, Strizhak P. Crossover between Fickian and non-Fickian diffusion in a system with hierarchy. Microporous Mesoporous Mater. 2019;282:22-28.