Asian Journal of Water, Environment and Pollution, Vol. 21, No. 3 (2024), pp. 53-60.
DOI 10.3233/AJW240034

Synthetic Water-Gel Crystals (Orbeez Balls) as Environmentally Friendly Adsorbent for Removal of Toxic Brilliant Green Dye From Aqueous Solutions

Haneen H. Ghazi and Aseel M. Aljeboree*

Department of Chemistry, College of Sciences for Girls, University of Babylon, Hilla, Iraq
✉ annenayad@gmail.com

Received March 13, 2024; revised and accepted April 1, 2024

Abstract: Water pollution caused by dyes is a major threat to marine organisms. Hydrogels (decorative balls), called water-gel crystals, are widely used to treat wastewater pollution caused from toxic dyes. This study aims to remove Brilliant Green (BG), a toxic harmful pigment that can cause widespread biota and environmental damage, from the aqueous solution. Water-Gel Crystals efficiently eliminate BG in a short time frame. Furthermore, several variables, such as counting equilibrium time, pH solution, the concentration of BG dye and adsorbent dosage were investigated. The results of this study exhibited that the adsorption equilibrium increased as BG dye concentration increased at pH = 7 after an equilibrium time of 2h, with 0.1 g of water-gel crystals having the top adsorption efficiency at 95.567 mg/g. This water-gel crystals adsorbent is regarded as an effective candidate that can be utilised for water treatment because the re-usability method of produced beads can successfully complete four cycles, and the adsorbent maintained its ability to remove BG dye. The water-gel crystals are therefore excellent candidates to be used as potent BG dye adsorbents from aqueous solutions. The water-gel crystals regeneration and re-usability investigation for the removal of BG dye was completed in at least four cycles successfully. This indicates that the Water-Gel Crystals produced have a high adsorption value. The (ΔG) was negative for the adsorption processes, indicating that the process was spontaneous. In addition, (ΔH) was determined for the adsorption method utilising water-gel crystals at 5.146 KJ/mol. ΔH Positive indicates that the method is endothermic in the range of 15-35 °C, using water-gel crystals.

Key words: Hydrogel, polymer, dye, water-gel crystals adsorption, methylene blue, removal.

Introduction

In the studies, the textile industry emerges as one of the fundamental sectors for any nation, while simultaneously ranking among the leading contributors to water pollution. This fact underlines the imperative of wastewater treatment. Additionally, projections indicate an imminent severe water shortage due to excessive consumption in the coming years. In this context, treated wastewater becomes the second most significant non-potable water source for industrial use. Consequently, the process of dye removal, despite its costs and the generation of secondary pollutants, is essential. These dyes, primarily from industries like textiles, dyeing, and paper production, hinder sunlight penetration and disrupt water deoxygenation, posing severe threats to aquatic life. Industrial dyes are used in many industrial fields such as cosmetics, leather, foodstuffs, printing papers, plastics, packaging materials and other industries. The waste of these industries is discharged directly into water systems and soil, which enters the environmental cycle and thus poses a threat to human

*Corresponding Author

life and aquatic organisms (Magriotis and Carvalho et al., 2014; Mahdi and Gholam et al., 2018; Mahmood and Hassan, 2023; Zhu and Guan et al., 2017).

Dyes are carcinogenic, highly toxic, and poorly biodegradable. Moreover, toxic and carcinogenic dyes such as Brilliant Green (BG) have gained attention due to their extensive use in many industries as biological colouring agents such as rubber, silk dyeing, paper, wool, jute, ceramics, cotton, etc. Pigments are rapidly soluble in water and non-biodegradable, causing, tissue necrosis, respiratory toxicity, neurological injury, and liver tumours in humans (Chen, 2021; Megha et al., 2021). Therefore, the most important methods for simultaneous disposal and removal of toxic substances are reverse osmosis, sedimentation, filtration, co-filtration, solvent extraction, flocculation, ion exchange and oxidation, to remove harmful effects of industrial dyes from wastewater. However, these techniques have inherent disadvantages of being economically infeasible, time-consuming, expensive, ineffective removal, etc., leading to secondary pollution (Aljeboree et al., 2023; Salman et al., 2023; Syahida et al., 2021; Tayebeh et al., 2017). Therefore, the adsorption process is considered the utmost attractive and desirable method for removing industrial dyes from aqueous solutions because it is simple, inexpensive, effective, economical and versatile. Different adsorbents like activated carbons, clays, Metal oxides and hydrogels have been reported to remove BG dye. Hydrogels are characterised by their high ability to swell and absorb pollutants with high efficiency and also have the advantage of increasing the surface area, which makes them excellent absorbents for wastewater (Mandal and Ray, 2016; Malek et al., 2021; Manelle et al., 2022; Yongde et al., 2020).

In the work, synthetic water-gel crystals (Orbeez balls) are utilised as an effective adsorbent for the adsorption of basic dyes alike BG dye. The properties of structural water-gel crystals have been estimated via utilising several analytical instrumentation techniques like TEM, FE-SEM, and XRD. The effect of equilibrium time, pH, adsorbent dose, and concentration of BG dye has been studied and Thermodynamics parameters have been analysed. The adsorption efficiency has been estimated via the adsorption isotherm like isotherm Freundlich, isotherm Langmuir models.

Experimental Part

Preparation of Stock Solution for BG Dye

A stock solution was created by dissolving 0.5 g in 500 mL distilled water. BG dye have molecular formula $C_{16}H_{18}ClN_3S$ and molecular weight 319.85 g·mol^{-1}. BG dye is a odourless blue powder. The calibration curve was prepared for different concentrations of dye (2-10 mg /L). The maximum wavelength was λ_{max}630 = nm as shown in Figure 1**.**

Synthetic Water-Gel Crystals (Orbeez Balls)

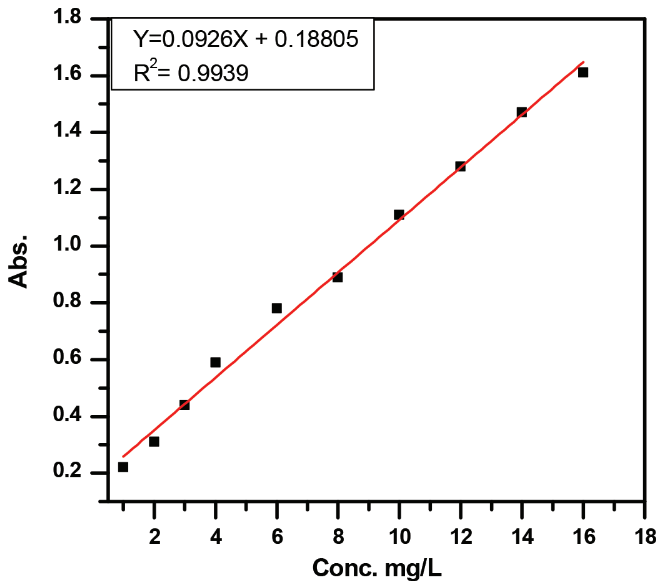

Figure 1: Calibration curve of Brilliant Green (BG) dye.

Either water-gel crystals (decorative beads) or so-called (orbeez balls) were obtained from local markets in Hilla-Iraq, of Chinese origin. Each box contains 100 small balls.

Adsorption Isotherm

All experiments were carried out under experimental conditions in a shaker water bath in 100 ml elementary flasks. The effect of different adsorption parameters, pH (3-10), initial concentration BG dye (10-100) and temperature solution (15-45 °C) were studied under best adsorption experiment condition at 25 °C and rate agitation of 120 rpm. The residual concentration of BG dye in each aliquot was calculated via a UV-Vis. The adsorption efficiency (Qe) and removal percentage (E%) adsorption were calculated, as shown in Eqs. (1 and 2).

$$Qe\left(\frac{mg}{g}\right)=\frac{(Co-Ce)Vml}{mg} \quad (1)$$

$$E\%=\frac{Co-Ce}{Co}\times 100 \quad (2)$$

where E% is removal percentage, Qe adsorption efficiency mg/g, Ce equilibrium concentration mg/L , Co initial dye concentration mg/L.

Results and Discussion

Characterisation of Water-Gel Crystals (Orbeez Balls)

Field Emission Scan Electron Microscopy (FESEM)
This technique was studied in order to know the nature of the surface, whether it is porous or non-porous. The morphological surface characteristics of the water-gel crystals were studied before and after the adsorption process to determine the amount of homogeneity between the surface components, the size and shape of the particles, and the nature of their distribution on the surface. Image shown in Figure 2a at different magnification powers indicates that the surface before adsorption of BG dye is rough, scale-like with a wavy nature, which enables it to play an important role in enhancing a certain surface area and providing additional adsorption sites for BG dye (Al-Mashhadani et al., 2021; Radia et al., 2022). Thus, it was found that the adsorption of the BG dye on the surface of the water-gel crystals (Figure 2b) had a clear morphological effect as shown by FESEM by producing a greater increase in the smoothness of the prepared surface as a result of complete filling the pores on the surface in the form of a layer with particles. that confirms that the adsorption process has occurred (Shweta et al., 2022)

TEM images of water-gel crystals showed formations of clusters with a uniform distribution and are arranged regularly, with the presence of some agglomerations, which are compatible with the polymeric matrices due to the availability of hydrophilic functional groups, which enhance strong H-bonding interactions as shown in Figure 3 (Shirsath et al., 2015).

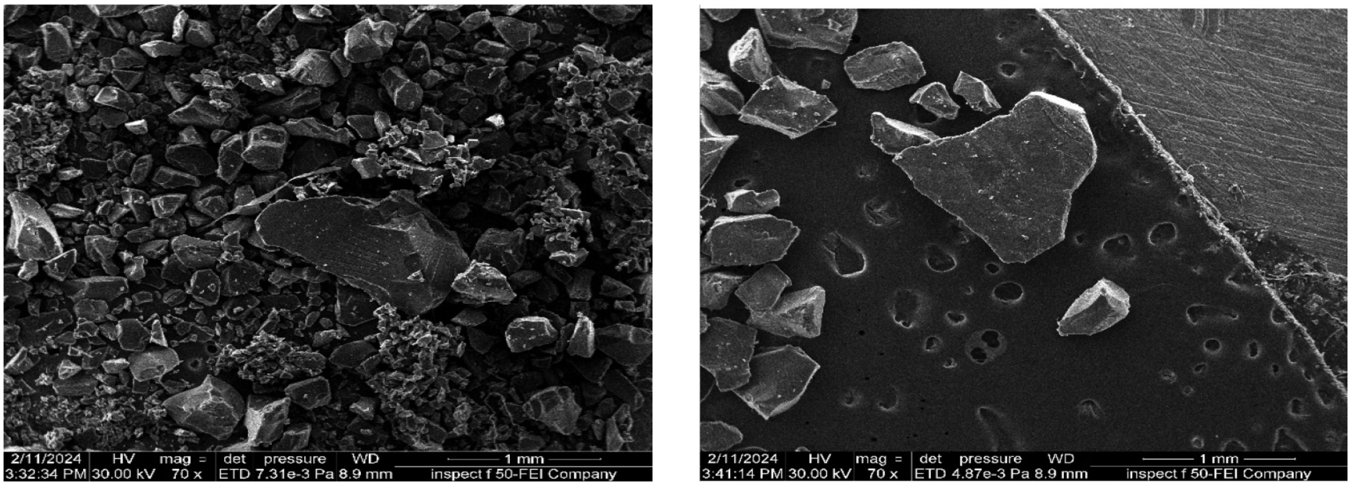

Figure 2: FESEM. (a) Water-Gel Crystals before adsorption and (b) after adsorption.

X-ray diffraction (XRD) spectra were used to study the structural properties, represented by composition, crystalline size, and spacing between crystalline planes, of the water-gel crystals. The broad peak in Figure 4, at 21.66° and 35.109°,indicates that the water-gel crystals are not crystalline, with a significant proportion of amorphous material, which is due to the presence of oxygen-containing functional groups present in the composition of the overlay water-gel crystals, which indicates the non-crystalline nature of water-gel crystals (Sharma et al. 2021; Shen et al., 2023).

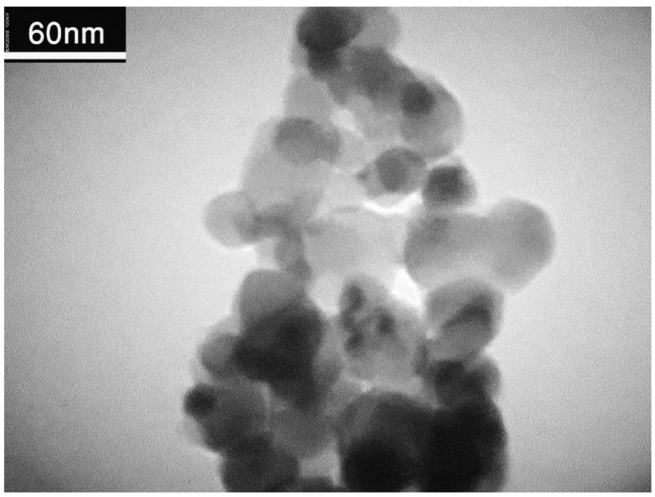

Figure 3: TEM of water-gel crystals.

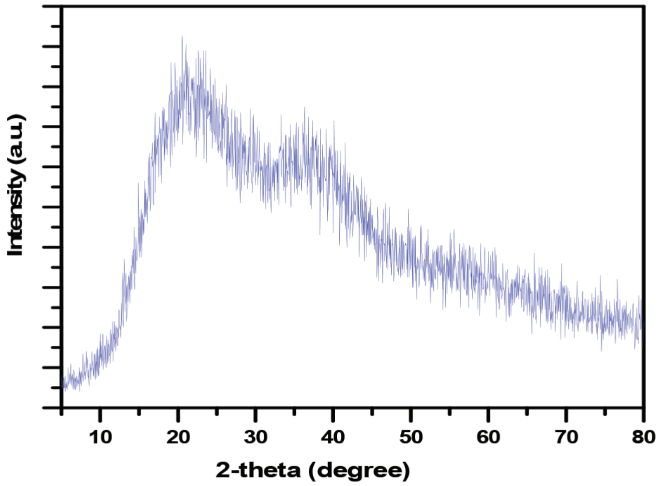

Figure 4: X-ray diffraction (XRD) spectra of water-gel crystals.

Effects of Adsorbent Dosage

The impact of adsorbent dosages on the adsorption capacities of BG dye of water-gel crystals is illustrated in Figure 5. The results indicate that increasing water-gel crystal dosages enhances the removal (R%) but reduces the adsorption capacity (Qe). At low adsorbent dosages (0.1 g/100 mL), the surface adsorption sites become saturated with BG dye. Consequently, a higher adsorbent dosage (0.05–0.15 g/L) leads to an excess of adsorption sites for the reaction. Moreover, an elevated dosage may cause adsorbent aggregation. resulting in a decrease in total surface area and, consequently, a reduction in adsorption (Thakur et al., 2022). The optimal removal of lead ions was observed at the dosage of 0.1 g for all experiments, as depicted in Figure 5.

Effect of Concentration of BG dye

The Water-Gel Crystals base was used to remove the initial BG dye concentration. The amount of adsorption required to remove BG dye initial concentration and the number of sites available on the adsorbent surface. The effect of removal concentration BG dye by water-gel crystals, Figure 6 displays the removal efficiency versus of BG dye initial concentration. The reduction in adsorption caused by a shortage of accessible active sites causes the drug clearance percentage to decline as the concentration of BG dye rises. As drug uptake resistance reduces as BG dye concentration rises, the adsorption capacity ((Qe) mg/g) is proportional to the initial dye concentration (Zhao et al., 2017). Due to an increase in driving force, the adsorption rate likewise rises as the dye's starting concentration does (Radia et al., 2022; Sevda et al., 2021).

Effect of pH

The pH solutions play a pivotal role in determining the efficiency of BG dye removal, as elucidated in Figure 7. The adsorption equilibrium of BG dye onto water-gel crystals exhibited a direct correlation with increasing pH. Notably, the solution's pH significantly influenced the efficiency of BG dye removal wherein elevated pH levels led to enhanced equilibrium adsorption of BG dye onto water-gel crystals. For solutions with values pH 2-10, the best equilibrium adsorption of BG dye was observed to be 95.4 mg/g (Samiyammal et al., 2022). The positively charged nature of the adsorbent surface at lower pH levels, attributed to an abundance of hydrogen ions in the system, led to the protonation

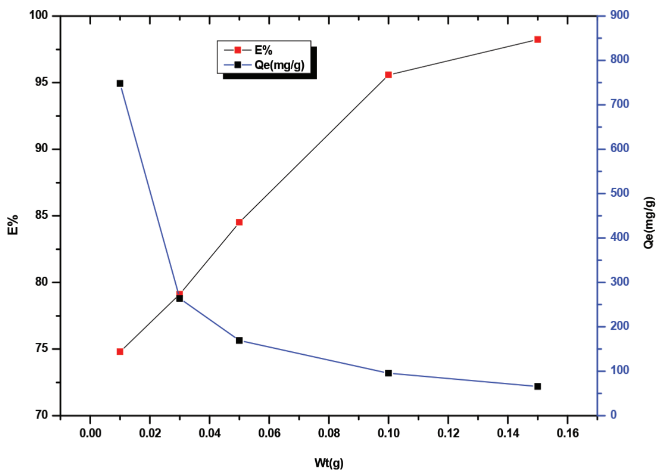

Figure 5: Effect of adsorbent dosage on adsorption capacity and removal of BG dye.

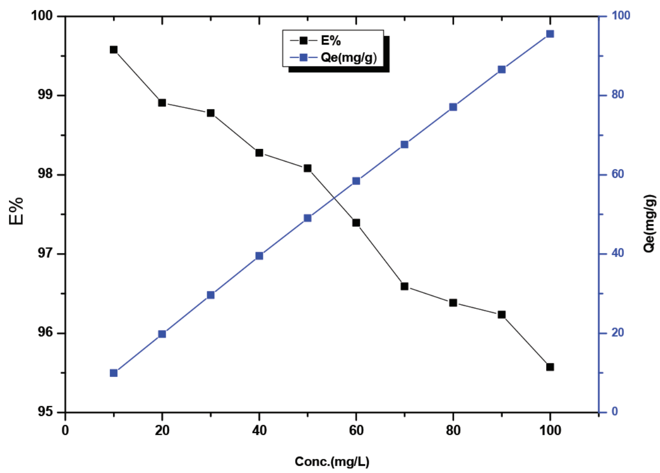

Figure 6: Effect of initial concentration BG dye onto water-gel crystals.

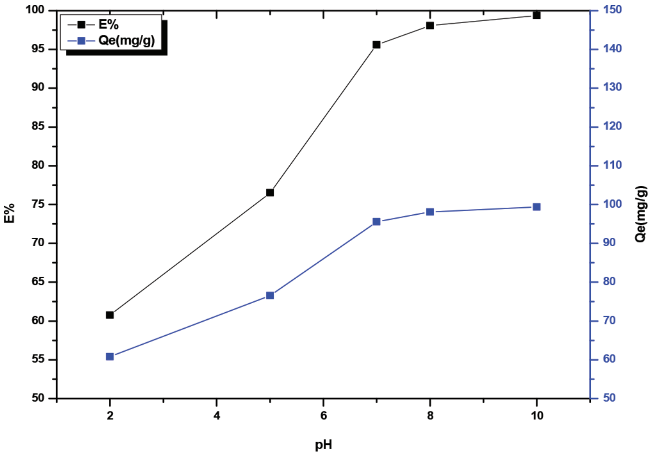

Figure 7: Effect of pH solution on to removal of BG dye by using water-gel crystals.

of significant adsorption sites, resulting in diminished adsorption of BG dye. Through experiments, it was discerned that a pH of 7.0 represented the best optimal condition for efficient removal of BG dye (Raoudha et al., 2022; Yuting and Beigang, 2022).

Effect of Temperature

A solution temperature range of (15 to 35°C) demonstrates that temperature significantly influences adsorption. As illustrated in Figure 8, there is an inverse relationship between temperature and the adsorbent's adsorption capacity (Qe mg/g). The increase in temperature leads to an increase in adsorption capacity, as molecular kinetic energy does not alter adsorbent surfaces. Higher temperatures may cause the degradation of active functional groups on the surface of composite materials. This degradation results in a decrease in the number of active adsorption sites, thereby diminishing adsorption efficiency (Aljeboree et al., 2023; Radia et al., 2022; Taifi et al., 2022). The thermodynamic parameters, namely the change Gibbs free energy (ΔG), change enthalpy (ΔH), and change entropy (ΔS), were calculated using equations (3 and 4).

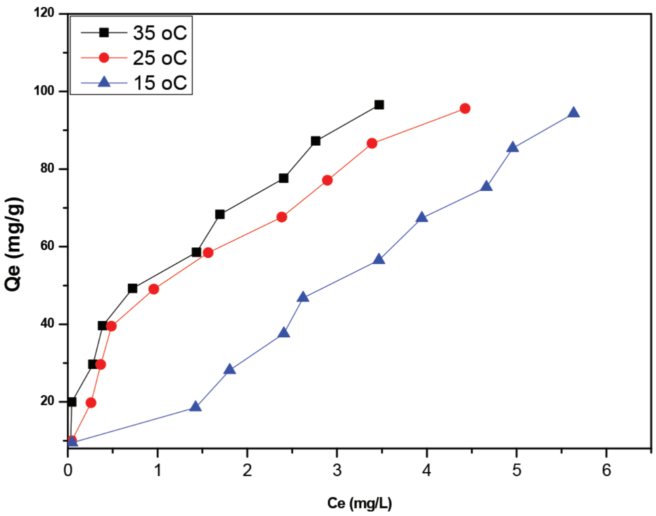

Figure 8: Adsorption isotherms of *BG dye* onto water-gel crystals at several temperatures.

$$\Delta G = -RT \ln K \quad (3)$$

$$\ln X_m = \frac{-\Delta H}{RT} + \text{constant} \quad (4)$$

The results of these calculations are presented in Table 1. The description refers to a plot where the natural logarithm of the adsorption capacity (ln X_m) is plotted against the reciprocal of the absolute temperature (1/T) for the adsorption of *BG* dye onto the water-gel crystals. This type of plot is typically used in thermodynamic studies to analyze the temperature dependence of adsorption processes, allowing for the determination of key thermodynamic parameters (Pinar et al., 2019; Megha et al., 2020; Tainara, 2021).

Table 1: Influence of temperature solution on the maximum adsorbed quantity for adsorption of *BG* dye onto Water-Gel Crystals

T(K)	*1000/T(K^{-1})*	*C_e = 3.3*	
		X_m	ln X_m
298	3.3557	97	4.574
308	3.2467	86	4.454
318	3.1446	59	4.077

Table 2 shows the computed thermodynamic parameters for BG dye adsorption on water-gel crystals. The value change enthalpy (ΔH) indicates an endothermic adsorption process BG dye and the water-gel crystals solvated in water may explain the exothermic adsorption. To be adsorbed, BG dye must shed part of their hydration shell. Dehydration of BG and the adsorbent surface requires energy. Dehydration mechanisms outweigh adsorption's endothermic. Consider values ΔS and ΔG negative as the result of BG dye diffusion within the adsorbent's chemical structure.

Regeneration and Reused

Four adsorption-desorption cycles were utilised to investigate the water-gel crystal's reusability. Adsorbent regaining is a crucial step in the use of adsorption since it helps to demonstrate adsorbent reactivation. As data shows, both the economic value of the adsorption method and the recovery system of the adsorbed material will considerably increase. HCl 0.1 N, NaOH 0.1 N and water were utilised to study the adsorbed DY desorption behaviour from the water-gel crystals (Alhattab et al., 2023). The performance reactivation of water-gel crystals was studied to limit its feasibility for industrial use. The adsorbent used water as presented in Table 3, compares the adsorption performance of water-gel crystals in this work and other hydrogel surfaces on the high ability to remove several kinds of dyes.

Conclusion

In this study, environmentally friendly water-gel crystal surfaces were used to remove pollutants as model BG dye from aqueous solutions via adsorption with water-gel crystal surfaces have been experimentally determined. The best results have been found in a

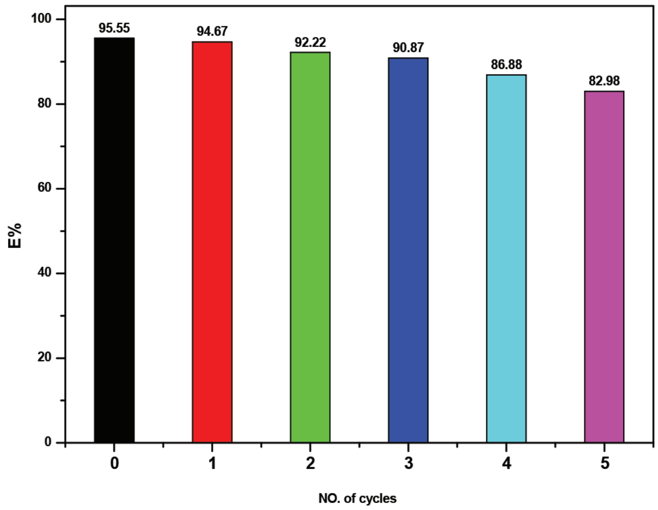

Figure 9: Adsorption-desorption cycles of water-gel crystals.

Table 2: Thermodynamic parameter for *BG dye* adsorption onto water-gel crystals

Water-Gel Crystals				
Thermodynamics parameters T/K	*Ke*	*ΔG/kJ.mol^{-1}*	*ΔH/kJ.mol^{-1}*	*ΔS/J.K^{-1}.mol^{-1}*
298	29.393	–7.9545		
308	26.060	–7.94240		
318	17.878	–7.26423		

Table 3: Removal of dyes by utilising several surfaces

Sorbent	*Dye*	*T (°C)*	*t (hr)*	*Dose (g)*	*E%*	*Qe (mg/g)*	*Co (mg.L–1)*	*Reference*
SA-g-P(AC-co-MA)/TiO_2	BG	25	1	0.05	99.9	1200	700	(Aljeboree 2022)
(AM-g-GO) hydrogel	CR	27	1	0.25	96.6	3002	50	(Huda Salim Al-Niaeem 2022)
Chitosan/ZnO	CR	25	1	0.1	90	120	100	(Mohammad T. ALSamman 2021)
Chitosan/ZnO	MB	25	1	0.1	80	470	100	(Mohammad T. ALSamman 2021)
SA/CMS/TiO_2	MB	25	2	0.15	93.3	600	50	(Mohammad T. ALSamman 2021)
SA/CMS/TiO_2	CR	25	2	0.15	84.3	350	50	(Mohammad T. ALSamman 2021)
SA/(A-AAB)	CV	25	3	0.2	92.39	582.4	100	(Akeem Adeyemi Oladipo 2019)
SA/bentonite beads	CV	25	3	0.2	84.59	498.2	100	(Akeem Adeyemi Oladipo 2019)
PAM/SH/clay	MV	30	1	0.05	86	180	20	(Ju-Zhen Yi 2018)
SA-g-PAA	MV	25	1	0.3	86.55	655	100	(Thakur 2017)
SA-g-PAA/TiO_2	MV	25	1	0.3	98.2	1156	100	(Thakur 2017)
Water-Gel Crystals	BG	25	1	0.1	95.55	96.58	100	In this study

temperature 25 ^oC, and an adsorbent dosage of 0.1 g of Water-gel crystals for both studying adsorption effeminacy and percentage removal. The adsorption capacity and parentage removal E% of BG dye removal rise with increasing surface area, equilibrium time, and solution temperature. However, adsorption efficiency has decreased with the rise of the weight of water-gel crystals. The best equilibrium time to be achieved is found to be 2 hr. The negative value (ΔG) for the adsorption processes, indicates that the process was spontaneous. The absorbent material for water gel crystals is considered a very highly efficient and effective material for use in treating water from dyes. The surface regeneration process also excelled because the process of reusing and renewing the beads was completed after four cycles. This confirms the efficiency of the surface in removing contaminants.

Reference

Alhattab, Z.D., Aljeboree, A.M. et al. (2023). Highly adsorption of alginate/bentonite impregnated TiO_2 beads for wastewater treatment: Optimization, kinetics, and regeneration studies. *Caspian Journal of Environmental Sciences*, **21(3):** 657-664.

Aljeboree, A.M., Alhattab, Z.D., et al. (2023). Enhanced removal of amoxicillin and chlorophenol as a model of wastewater pollutants using hydrogel nanocomposite: Optimization, thermodynamic, and isotherm studies. *Caspian Journal of Environmental Sciences*, **21(2):** 411-422.

Aljeboree, A.M., Essa, S.M., Kadam, Z.M., Dawood, F.A., Falah, D. and A.F. Alkaim (2023). Environmentally friendly activated carbon derived from palm leaf for the removal of toxic reactive green dye. *International Journal of Pharmaceutical Quality Assurance*, **14(1):** 12-15.

Aljeboree, A.M., Radia, N.D., Jasim, LS., Alwarthan, A.A., Khadhim, M.M., Salman, A.W. and A.F. Alkaim (2022). Synthesis of a new nanocomposite with the core TiO_2/hydrogel: Brilliant green dye adsorption, isotherms, kinetics, and DFT studies. *Journal of Industrial and Engineering Chemistry*, **109:** 475-485.

Al-Mashhadani, Z.I., Aljeboree, A.M. et al. (2021). Antibiotics removal by adsorption onto eco-friendly surface: Characterization and kinetic study. *International Journal of Pharmaceutical Quality Assurance*, **12(4):** 252-255.

Al-Niaeem, H.S., Ali, A. and W. Hanoosh (2022). Preparation of semi IPNs-hydrogel composite for removing congo red and bismarck brown Y from wastewater: Kinetic and thermodynamic study. *Egypt. J. Chem.*, **56(1):** 19-34.

ALSamman, M.T. and J. Sanchez (2021). Recent advances on biobased hydrogels based on chitosan and alginate for the adsorption of dyes and metal ions from water. *Arabian Journal of Chemistry*, **14(12):** 103455. https://doi.org/10.1016/j.arabjc.2021.103455

Chen, C., Zhu, Y., Cui, Y., Dai, R., Shan, Z. and H. Chen (2021). Fabrication of starch-based high-performance adsorptive hydrogels using a novel effective pretreatment and adsorption for cationic methylene blue dye: Behavior and mechanism. *Chemical Engineering Journal*, **405:** 126953: https://doi.org/10.1016/j.cej.2020.126953

Magriotis, Z.M., Carvalho, M.Z. et al. (2014). Castor bean (*Ricinus communis L.*) presscake from biodiesel production: An efficient low cost adsorbent for removal of textile dyes. *Journal of Environmental Chemical Engineering*, **2(3):** 1731-1740. :https://doi.org/10.1016/j.jece.2014.07.005

Mahdi, T.N., Gholam, B.M. et al. (2018). Poly(AA-co-VPA) hydrogel cross-linked with N-maleyl chitosan as dye adsorbent: Isotherms, kinetics and thermodynamic investigation. *International Journal of Biological Macromolecules*, **117(1):** 152-166.

Mahmood, A.A. and A.A. Hassan (2023). Green synthesis of AC/ZnO nanocomposites for adsorptive removal of organic dyes from aqueous solution. *Inorganic Chemistry Communications*, **157:** 111415.

Malek, N.N.A., Jawad, A.H. et al. (2021). "Fly ash modified magnetic chitosan-polyvinyl alcohol blend for reactive orange 16 dye removal: Adsorption parametric optimization. *International Journal of Biological Macromolecules*, **189:** 464-476.

Mandal, B. and S.K. Ray (2016). Removal of safranine T and brilliant cresyl blue dyes from water by carboxy methyl cellulose incorporated acrylic hydrogels: Isotherms, kinetics and thermodynamic study. *Journal of the Taiwan Institute of Chemical Engineers*, **60:** 313-327. https://doi.org/10.1016/j.jtice.2015.10.021

Manelle, R., Hana, F., et al. (2022). Adsorptive removal of cationic and anionic dyes on a novel mesoporous adsorbent prepared from diatomite and anionic cellulose nano fibrils: Experimental and theoretical investigations. *Journal of Molecular Liquids*, **361**: 119670.

Salman, M.S., Sheikh, M.C., Hasan, M.S., et al. (2023). Chitosan-coated cotton fiber composite for efficient toxic dye encapsulation from aqueous media. *Applied Surface Science*, **622(15):** 157008.

Megha, S., Amit, L., et al. (2021). Asparagine functionalized MWCNTs for adsorptive removal of hazardous cationic dyes: Exploring kinetics, isotherm and mechanism. *Surfaces and Interfaces*, **25:** 101187.

Megha, S., Niharika, S., et al. (2020). Highly efficient and rapid removal of atoxic dye: Adsorption kinetics, isotherm,and mechanism studies on functionalized multiwalled carbon nanotubes. *Surfaces and Interfaces*, **21:** 100639.

Oladipo, A.A. and M. Gazi (2019). Enhanced removal of crystal violet by low cost alginate/acid activated bentonite composite beads: Optimization and modelling using non-linear regression technique. *Journal of Water Process Engineering*, **2:** 43-52.

Pinar, I., Hava, O., et al. (2019). Selective adsorption of cationic dyes from colored noxious effluent using a novel N-tert-butylmaleamic acid based hydrogels. *Reactive and Functional Polymers*, **124:** 189-198.

Radia, N.D., Kamona, S.M.H., et al. (2022). Role of hydrogel and study of its high-efficiency to removal streptomycin drug from aqueous solutions. *International Journal of Pharmaceutical Quality Assurance*, **13(2):** 160-163.

Radia, N.D., Mahdi, A.B., et al. (2022). Removal of Rose bengal dye from aqueous solution using low cost (SA-g-PAAc) hydrogel: Equilibrium and kinetic study. *International Journal of Drug Delivery Technology*, **12(3):** 957-960.

Raoudha, S., Mahjoub, J., et al. (2022). Synthesis and characterization of a new meso-tetrakis (2,4,6-trimethylphenyl) porphyrinto) zinc(II) supported sodium alginate gel beads for improved adsorption of methylene blue dye. *International Journal of Biological Macromolecules*, **202:** 161-176. :https://doi.org/10.1016/j.ijbiomac.2022.01.087.

Samiyammal, P., Kokila, P., et al. (2022). Adsorption of brilliant green dye onto activated carbon prepared from cashew nut shell by KOH activation: Studies on equilibrium isotherm. *Environmental Research*, **212:** 113497.

Sevda, P., Seyed, J., et al. (2021). Crystal violet dye sorption over acrylamide/graphene oxide bonded sodium alginate nanocomposite hydrogel. *Chemosphere*, **270:** 129419.

Sharma, S., Sharma, G., et al. (2021). Adsorption of cationic dyes onto carrageenan and itaconic acid-based superabsorbent hydrogel: Synthesis, characterization and isotherm analysis. *Journal of Hazardous Materials*, **421:** 126729. https://doi.org/10.1016/j.jhazmat.2021.126729.

Shen, Y., Li, B., et al. (2023). Super-efficient removal and adsorption mechanism of anionic dyes from water by magnetic amino acid-functionalized diatomite/yttrium alginate hybrid beads as an eco-friendly composite. *Chemosphere*, **336:** 139233. https://doi.org/10.1016/j.chemosphere.2023.139233

Shirsath, S.R., Patil, A.P., et al. (2015). Ultrasonically prepared poly(acrylamide)-kaolin composite hydrogel for removal of crystal violet dye from wastewater. *Journal of Environmental Chemical Engineering*, **3(2):** 1152-1162. https://doi.org/10.1016/j.jece.2015.04.016

Shweta, S., Gaurav, S., et al. (2022). Adsorption of cationic dyes onto carrageenan and itaconic acid-based superabsorbent hydrogel: Synthesis, characterization and isotherm analysis. *Journal of Hazardous Materials*, **421(5):** 126729.

Syahida, F.A., Nurul, N.M.N., et al. (2021). Binary adsorption of textile dyes onto zwitterionic adsorbent coating: performance study. *Current Research in Wastewater Management*, **1(1):** 3. doi: 10.31586/wastewater101003

Taifi, A., Alkadir, O.K.A., et al. (2022). Environmental removal of reactive blue 49 dye from aqueous solution by (lemon peels as activated carbon): A model of low cost agricultural waste. *IOP Conference Series: Earth and Environmental Science*, **1029:** 012010.

Tainara, V., Samantha E.S., Artifon, C.T. ,Pâmela, B.V., Valter, A.B. andT.P. Alexandre (2021). Chitosan-based hydrogels for the sorption of metals and dyes in water: isothermal, kinetic, and thermodynamic evaluations. *Colloid and Polymer Science,* **299:** 649-662.

Tayebeh , E., Navid, N., et al. (2017). Characterization and absorption studies of cationic dye on multi walled carbon nanotube–carbon ceramic composite. *Journal of Industrial and Engineering Chemistry* **46:** 35–43.

Thakur, S. (2017). Synthesis, characterization and adsorption studies of an acrylic acid-grafted sodium alginate-based TiO_2 hydrogel nanocomposite. *Adsorption Science & Technology*, **0:** 1-20.

Thakur, S., Chaudhary, J. et al. (2022). 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*, **303:** 134917.

Yi , J.-Z. and L.-M. Zhang (2018). Removal of methylene blue dye from aqueous solution by adsorption onto sodium humate/polyacrylamide/clay hybrid hydrogels. *Bioresource Technology*, **99:** 2182-2186.

Yongde, L., Yao, C. et al. (2020). Adsorption of toxic dye Eosin Y from aqueous solution by clay/carbon composite derived from spent bleaching earth. *Journal of Hazardous Materials*, **93(1):** 4656-5544.

Yuting, Z. and L. Beigang (2022). Preparation and superstrong adsorption of a novel La(III)-crosslinked alginate/modified diatomite macroparticle composite for anionic dyes removal from aqueous solutions. *Gels*, **8:** 810.

Zhao, Y., Chen, Y. et al. (2017). Preparation of SA-g-(PAA-co-PDMC) polyampholytic superabsorbent polymer and its application to the anionic dye adsorption removal from effluents. *Separation and Purification Technology*, **188:** 329-340. https://doi.org/10.1016/j.seppur.2017.07.044

Zhu, L., Guan, C. et al. (2017). Adsorption of dyes onto sodium alginate graft poly(acrylic acidco-2-acrylamide-2-methyl propane sulfonic acid)/ kaolin hydrogel composite. *Polymers & Polymer Composites*, **25(8):** 627-634.