

ADSORPTION OF DYES AND HEAVY METAL IONS BY CHITOSAN COMPOSITES: A REVIEW

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ABSTRACT

Various adsorbents have been used to remove different types of dyes from wastewater such as anionic azo dye, methylene blue, etc. Activated carbons, plant or lignocellulosic wastes, clays and clay minerals, bottom ash, zeolite, silica gel, oil palm trunk fiber, cellulose powder, rattan sawdust, rice husk, tea waste, various resins, microorganisms, and biopolymers are among the common adsorbents used. Chitosan a type of biopolymer is a good adsorbent to remove various kinds of anionic and cationic dyes. Chemical modifications that lead to the formation of chitosan derivatives, grafting chitosan and chitosan composites have gained much attention, extensively studied and widely reported in the literatures. This review provides relevant literature of the past two years on the application of chitosan composites for removing dyes activation.

The dye adsorption capacities of chitosan composites adsorbents vary, depending on the pH of solution, initial dye concentration, adsorbent dosage and process temperature. This review also includes Desorption and reusability, kinetic models and adsorption isotherms.

INTRODUCTION

Saving water to save the planet and to make the future of mankind safe is what we need now. One of the important class of the pollutants is dyes. once they enter the water difficult to treat as the dyes have a synthetic origin and a complex molecular structure which makes them more stable and difficult to be biodegraded [1]. Many industries like the textile industry used dyes to color their products and thus produce wastewater containing organics with a strong color, where in the dyeing processes the percentage of dye lost wastewater is 50% of the dye because of the low levels of dye-fiber fixation [2].

In spite of the availability of many techniques to remove these pollutants from wastewaters as legal requirements, such as coagulation, chemical oxidation, membrane separation process, electrochemical and aerobic and anaerobic microbial degradation, these methods are not very successfully due to suffering from many restrictions [3]. Adsorption chitosan composites used recently as an economical and realistic method for removal of different pollutants has proved to be an efficient at removing many types of pollutants such as dyes and heavy metals [4]. The application of biopolymers such as chitin and chitosan is one of the emerging adsorption methods for the removal of dyes and heavy metal ions, even at low concentrations [5]. Chitosan is a type of natural polyaminosaccharide, synthesized from the deacetylation of chitin. Chitin is the second most abundant polymer in nature after cellulose [6]. Chitosan is known as an ideal natural adsorbent because of its special characteristics such as hydrophilicity, biocompatibility, biodegradability, non-toxicity, adsorption properties, etc. [7].

Amino groups of chitosan can be cationized, after which they adsorb anionic dyes strongly by electrostatic attraction in the acidic media [7]. To improve chitosan's performance as an adsorbent, cross-linking reagents such as glyoxal, formaldehyde, glutaraldehyde, epichlorohydrin, ethyleneglycol diglycidyl ether and isocyanates have been used [8]. Recently, chitosan composites have been developed to adsorb heavy metals and dyes from wastewater. Different kinds of substances have been used to form composite with chitosan such as kaolin/ γ -Fe₂O₃ [9], poly(vinylalcohol) [10], graphene oxide [11], g-poly(acrylic acid)/attapulgite [12]. This review paper will highlight the application of chitosan composites as adsorbents, which includes the method of

preparation, mechanisms and factors that can affect its adsorption capacity.

2) DYES

Components: chromophores which are responsible for producing the color and auxochromes which enhance the affinity of the dye toward the fibers [13]. Generally, the dyes used in the textile industry are basic dyes, acid dyes, reactive dyes, direct dyes, azo dyes, mordant dyes, vat dyes, disperse dyes and sulfur dyes [14]. Table 1 show the typical dyes used in textile dyeing operations.

Table 1
Typical dyes used in textile dyeing operations [14]

| <i>Dye class</i> | <i>Description</i> |
|------------------|--|
| Acid | Water-soluble anionic compounds |
| Basic | Water-soluble, applied in weakly acidic dyebaths; very bright dyes |
| Direct | Water-soluble, anionic compounds; can be applied directly to cellulose without mordants (or metals like chromium and copper) |
| Disperse | Not water-soluble |
| Reactive | Water-soluble, anionic compounds; largest dye class |
| Sulfur | Organic compounds containing sulfur or sodium sulfide |
| Vat | Water-insoluble; oldest dyes; more chemically complex |

Dyes can be classified into cationic, anionic and nonionic dyes. Cationic dyes are basic dyes while the anionic dyes include direct, acid and reactive dyes [15]. Cationic dyes considered as toxic colorants and can cause harmful effects such as allergic dermatitis, skin irritation, mutations and cancer [16]. Cationic dyes carry a positive charge in their molecule. Cationic dyes were used intensely as a model in dye adsorption studies such as, Methylene blue [17,18].

Anionic dyes depend on a negative ion [19]. Anionic dyes includes many compounds from the most varied classes of dyes, such as direct dyes, reactive dyes, Acid dyes.

Dyes have become one of the main sources of severe water pollution. Wastewaters containing dyes are difficult to remove because of their inert properties. Another difficulty found during the removal of dyes is the low concentration of dye molecules in wastewater. The conventional methods of removing dyes become unfavorable to be applied at a large scale because are either expensive or ineffective. Recently, adsorption techniques using chitosan composites have been developed to adsorb dyes as an alternative to conventional wastewater treatment processes [20]. The list of chitosan composites that have been used to remove dyes in wastewater is summarized in Table 2. In the following sections, chitosan composites that have been developed to remove dyes will be discussed separately.

Table 2
Adsorption capacities and experimental conditions of chitosan composites for various synthetic dye removal from wastewater

| Adsorbent | Adsorbate | Removal(%), Adsorption capacity (mg/g) | pH | Temperature (°C) | Kinetic model | Isotherm |
|--|------------------|---|-----------|---------------------|---------------------|------------|
| chitosan/kaolin/ γ -Fe ₂ O ₃ composites | Methyl orange | 0.82 | 2.9 - 7.1 | 37.00 | - | - |
| chitosan/poly(vinyl alcohol) composites | malachite green | 0.97 | 3_10 | 30.00 | pseudo-second order | Freundlich |
| chitosan/poly(vinyl alcohol) composites | Cu ²⁺ | 0.92 | 6.00 | 30.00 | pseudo-second order | Langmuir |
| chitosan/graphene oxide composite | methylene blue | - | 10.00 | - | pseudo-second order | Langmuir |
| chitosan-g-poly(acrylic acid)/attapulgite composite | methylene blue | 1884 mg/g | 5.00 | 30.00 | pseudo-second order | Langmuir |

2.1) chitosan/kaolin/ γ -Fe₂O₃ composites

Kaolinite is a 1:1 aluminosilicate, consists of SiO₂ (42.14 mol%), Al₂O₃ (15.61 mol%) and H₂O (42.25 mol%) [21, 22] prepared a new chitosan bead which was blended with maghemite (γ -Fe₂O₃) and kaolin. Figure. 1 shows the SEM and TEM of different materials. From the SEM and tunneling electron microscope (TEM) images, it was found that there were many pores and pleats on the surface of the composites which provided active sites for dye entrapment. Transmission electron microscopy (TEM) observation of samples was carried out on a JEM 2010 electron microscope (Tokyo, Japan). Morphological features and surface characteristics of samples were obtained from scanning electron microscopy (SEM) using a Hitachi SX-650 scanning electron microscope (Tokyo, Japan). Figure .2 shows Xray of different materials. Wide-angle Xray diffraction (WAXRD) measurement was performed on a D8- Advance XRD diffractometer (Bruker, German) at a scan rate of 4° 2 θ min⁻¹ from 5° to 65° with Cu K α target.

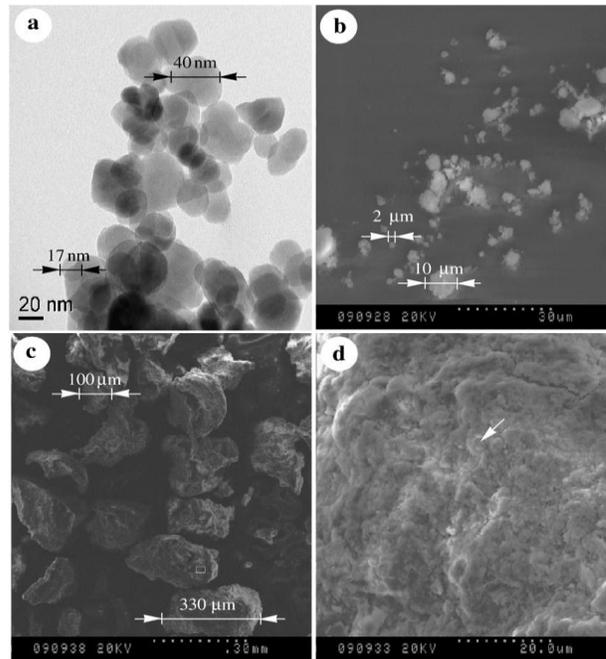


Figure. 1
TEM image of γ -Fe₂O₃ nanoparticles (a) and typical SEM images of kaolin (b) and BKF composites (c,d).[9]

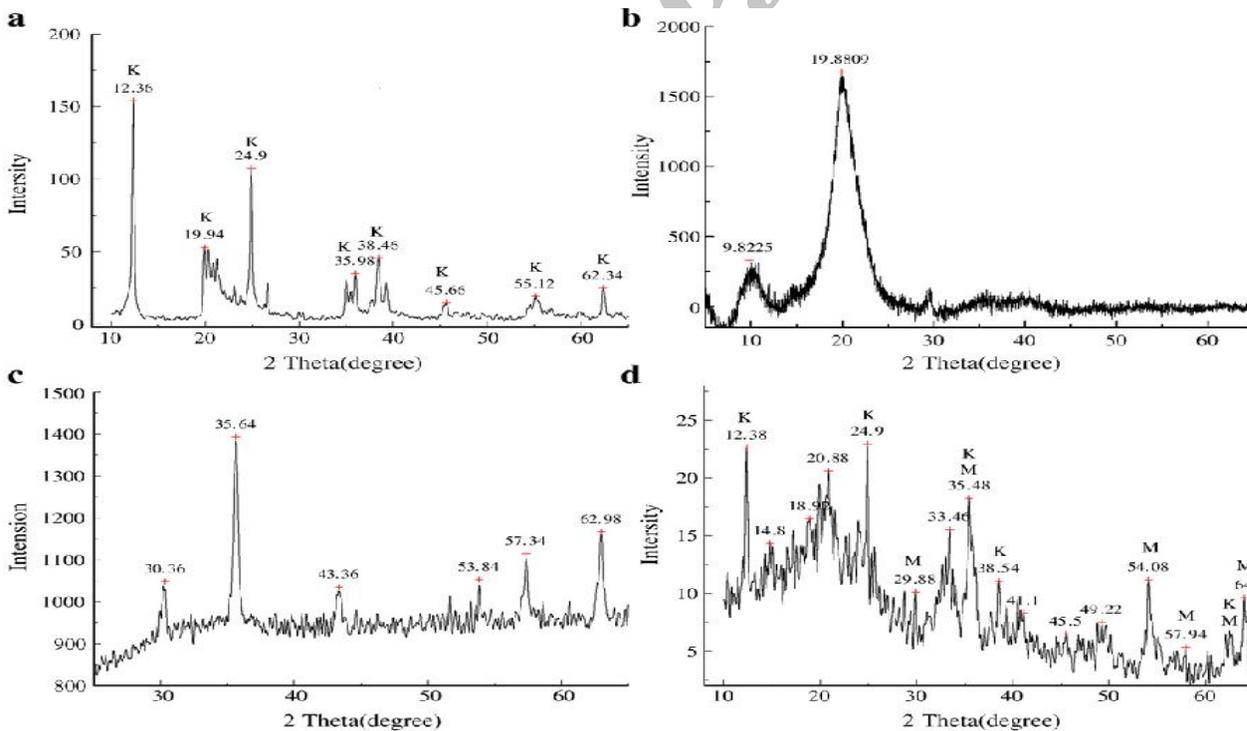


Figure. 2
WAXRD patterns of raw kaolin (a), chitosan (b), nanosized γ -Fe₂O₃ (c) and BKF composites (d).

The effect of adsorbent dosage (varying from 0.2 g L⁻¹ to 1.4 g L⁻¹) on Methyl orange (MO) dye removal

investigated. Initially, a rapid increase of adsorption with the increasing adsorbent dosage was attributed

to availability of more adsorption sites [23]. A further increase of the adsorbent dosage from 1.0 g L^{-1} to 1.4 g L^{-1} didn't much increase dye removal (only from 75.8% to 81.9%) [22]. The maximum dye removal was 82.3% at pH 2.9 followed by a slight decrease from pH 2.9 to 7.1. MO removal then decreased significantly at $\text{pH} > 7.1$ [22]. Quinoid form of MO occurs at low pH value and rearranges in azo structure at high pH [24]. The decrease of dye adsorption with increasing pH can be explained by the electrostatic interaction between the adsorbent surface and the dye anions. [22]. Additionally, the abundant presence of OH^- ions in basic solution was competitive with the dye anions [25].

The effect of competitive anions on the adsorption efficiency was studied by adding 0.01 mol L^{-1} sodium salt (NaCl , NaNO_3 , Na_2SO_4 , Na_2CO_3 and Na_3PO_4) to 20 mg L^{-1} MO without pH adjusting, 1.0 g L^{-1} adsorbent dosage.

The order of decolorization was: no addition $\gg \text{Cl}^- \gg \text{NO}_3^- \gg \text{SO}_4^{2-} \gg \text{CO}_3^{2-} > \text{PO}_4^{3-}$. In the presence of 0.01 mol L^{-1} PO_4^{3-} , almost no adsorption of MO was observed. The multivalent charge of phosphate anions could be strongly bound by chitosan/kaolin/ $\gamma\text{-Fe}_2\text{O}_3$ composites.

2.2) chitosan/poly(vinyl alcohol) composites

novel foam adsorbent based on PVA/CS composites was prepared in this work, which was obtained by the interpenetrating polymer network (IPN). The resulting foam adsorbents were characterized by different techniques, such as SEM, BET, TG and elemental analysis. PVA has excellent processing properties and physical-chemical stability. However, it shows low adsorption for pollutants. Chitosan (CS) could adsorb many pollutants very well due to a large number of amine and hydroxyl groups on its surface. PVA/CS foams exhibited higher surface area than PVA foam due to the addition of CS.

The effect of different weight ratios of PVA/ CaCO_3 /CS on the adsorption of malachite green (MG) and Cu^{2+} was investigated by mixing 0.1 g of the obtained foams with 50 mL of the aqueous MG or Cu^{2+} solution of 100 mg/L . The mixture was shaken at 30°C for 24 h . PVA/CS composite foam with PVA/ CaCO_3 /CS weight ratio of $10/7.5/4.5$ had the highest adsorption capacities for MG and Cu^{2+} ions among the samples studied. The percentages of swelling of PVA/CS foam in acidic and alkaline environments showed good mechanical strength and chemical stability. The PVA/CS composite foam also

exhibited well improved thermal stability in comparison to PVA foam.

The effect of solution pH on the adsorption capacities was studied at ranging from 1.0 to 10.0 for MG and 1.0 to 7.0 for Cu^{2+} . The percentage removal of MG & Cu^{2+} increased with increase in pH from 1 to 3 and remained almost constant within the range of pH 4–10. Lower adsorption of MG and Cu^{2+} at lower pH was due to the competitive adsorption between H^+ ions and cations (MG and Cu^{2+}) for the binding sites. As a result, the optimum pH values for MG and Cu^{2+} adsorption were found to be in the range of 3–10 and 6, respectively.

The effects of the initial pollutant concentration on the adsorption of PVA/CS foam for MG and Cu^{2+} were studied in single and binary systems. In single system, it was found that the amount of MG adsorbed onto PVA/CS foam increased monotonously as the initial MG concentration increased from 50 to 800 mg/L at 303 K and Cu^{2+} adsorption increased with increase in the initial Cu^{2+} concentration up to 400 mg/L and then increased slowly. In binary system MG and Cu^{2+} exhibited competitive adsorption and capacities of MG and Cu^{2+} dropped by 40.36 and 42.16%, respectively.

The results showed that MG adsorption correlated well with the Freundlich isotherm ($R^2 > 0.98$) while Cu^{2+} adsorption followed the Langmuir isotherm ($R^2 > 0.99$).

the adsorption of MG or Cu^{2+} onto PVA/CS foam was studied at 298 , 303 , 308 and 313 K at a constant MG or Cu^{2+} concentration of 200 mg/L , pH 6.0 and 24 h of contact time. The results showed that the adsorption capacities of MG and Cu^{2+} increased with increase in temperature, indicating that the adsorption process was endothermic in nature. Positive values of ΔH° further confirmed the endothermic nature of the adsorption of MG and Cu^{2+} onto PVA/CS foam. The positive values of ΔS° suggested that the degrees of freedom increased at the solid-liquid interface during the adsorption. The negative values of ΔG° indicated the feasibility of the process and spontaneous nature of the adsorption. Experimental results indicated that the amount of MG and Cu^{2+} adsorbed increased with increasing contact time and equilibrium was reached at about 360 min for MG and 480 min for Cu^{2+} . Adsorption of MG and Cu^{2+} on PVA/CS foam was well described by the pseudo-second order kinetic model.

The adsorption experiments were carried out using to investigate the effect of ionic strength, NaCl as the ionic medium in the range of 0.01 – 1.0 mol/L used and results shown NaCl had no obvious

effect on the adsorption of MG and Cu^{2+} onto PVA/CS foam. to investigate the effect of foreign pollutants on adsorption pollutants such as Zn^{2+} , Pb^{2+} , Ca^{2+} , Mg^{2+} , SDS, CTAB was added to binary system. Except for CTAB, other pollutants had no significant effect on the adsorption of MG and These cationic pollutants strongly competed with Cu^{2+} ions for available binding sites. for Desorption It was observed that the highest desorption value for Cu^{2+} (more than 97%) was obtained using 0.1 M EDTA-2Na solution. For desorption of MG, the best performance (more than 68%) was obtained with 50% CH_3OH solution [10].

2.3) chitosan/graphene oxide composite:

Magnetic chitosan made from Coating chitosan with magnetic fluids to expand function of the chitosan. Graphene have one-atom-thick structure. This excitement is excellent mechanical and physicochemical properties [26]. Graphene oxide (GO) is an oxidized form of graphene [27] consisting of various functional groups such as hydroxyl, carboxyl, and epoxy groups. GO is with very high negative charge density arising due to the oxygen containing functional groups [28]. Carboxy groups of GO chemically react with the amine group of magnetic chitosan [29].

Characteristic IR features of GO indicate the presence of the abundant oxygen-containing functional groups on the surface of GO. methylene blue (Mb) removal capacity had great change at the pH 2–10. Chitosan becomes strongly anionic after grafting with GO. strong attractive forces, between the positive charged dye and negatively charged MCGO, result in high uptakes as follows[8]. Thus, pH of 10.0 was selected as the optimum pH value.

The pseudo-second-order adsorption model has high value (>99%) for adsorbent. thus pseudo-second-order adsorption mechanism is predominant. the coefficients of determination R^2 of the Langmuir equation demonstrated that the adsorption of MB onto MCGO follows the Langmuir's model [11].

2.4)chitosan-g-poly(acrylicacid)/attapulgit composite:

Hydrogels are formed of three-dimensional crosslinked polymer networks of flexible chains [30]. As hydrogels possess ionic functional groups such as carboxylic acid, amine, hydroxyl and sulfonic acid groups, they can absorb and trap metal ions [31,32]. or cationic dyes such as methylene blue (MB) [33].

IR spectra of APT, CTS, CTS-g-PAA and CTS-g-PAA/APT show that graft reaction has taken place among CTS, AA and APT [12]. The results of morphological analysis indicate that CTS-g-PAA/APT has a relatively loose and fibrous surface compared with CTS-g-PAA [34]. The adsorption capacity of CTS-g-PAA/APT composite was little higher than that of CTS-g-PAA when APT content was less than 20%. Compared with CTS-g-PAA (1868 mg/g), the adsorption capacities of

CTS-g-PAA/APT composites with APT content of 2%, 5% and 10% are 1896, 1884 and 1870 mg/g, respectively [12]. The decreasing tendency of adsorption capacity with increasing APT content. APT could react with AA and there are lots of $-\text{OH}$ groups on the surface of APT, thus APT particles may act as crosslinking points in the network. Generation of more crosslink points CAUSE decrease of elasticity of the polymer chains and adsorption capacity. Additionally hydrophilic groups decreases and caused the shrinkage of the composites and then decreased the adsorption capacity.

It was found that with the pH value increased from 2.0 to 9.0 adsorption capacities increased. To explain this phenomenon, the carboxylic groups in CTS-g-PAA and CTS-g-PAA/APT are ionized and interacted with the dye molecules.

the mobility of the large dye ions increases with increasing temperature, which leads to a decrease in the adsorption capacity of composite with further increasing temperature[35]. It is clear that the adsorption capacities of CTS-g-PAA and CTS-g-PAA/APT increased rapidly with the increase of the adsorption time from 0 to 15 min and more than 90% of the equilibrium adsorption capacities. The results indicated that the adsorption of MB on CTS-g-PAA and CTS-g-PAA/APT followed the pseudo-second-order.

The values of R^2 of Freundlich model for CTS-g-PAA and CTS-g-PAA/APT are 0.9158 and 0.9446, respectively. So, the adsorption of CTS-g-PAA and CTS-g-PAA/APT does not follow the Freundlich isotherm. The values of R^2 for CTS-g-PAA and CTS-g-PAA/APT are all 1 in the Langmuir isotherm so, the adsorption follow the Langmuir isotherm.

If the dye adsorbed onto the adsorbent can be desorbed by water, it can be concluded that the attachment of the dye onto the adsorbent is by weak bonds. If the strong acids, such as HCl can desorb the dye, it can be concluded that the attachment of the dye onto the adsorbent is by ion exchange or electrostatic attraction [36]. Desorption percentage of CTS-g-PAA and CTS-g-PAA/APT decreased sharply

with the increase of the pH of distilled water. The relatively high desorption amount at pH 2.0 suggests that adsorption of MB onto CTSg-PAA and CTS-g-PAA/APT was carried out partially via electrostatic attraction.

FUTURE PERSPECTIVES

Here, we would like to highlight some points which might help future research. The cost factor should be taken into consideration as low production cost with high removal efficiencies are much preferred. Regeneration studies need to be performed in detail as it will enhance the economic feasibility. Regeneration could be done using several techniques but solvent extraction is the most common way found in literatures. EDTA, hydrochloric acid, nitric acid, sodium chloride solution, and sodium hydroxide solution are the common solvents found in literatures for regeneration studies.

The use of scanning electron microscope (SEM), energy dispersive X-ray spectroscopy (EDX), X-ray diffraction (XRD) analysis, electron spin resonance (ESR), X-ray photoelectron spectroscopy (XPS), and thermo gravimetric analysis (TGA) are highly recommended. Different techniques can provide various kinds of information on the composites. Therefore, combining different techniques will give a better picture in exploring the adsorption mechanism.

Industrial effluents contain various pollutants. There is a need to investigate the simultaneous removal of many co-existing pollutants. It is more preferable to develop a multipurpose adsorbent which can remove different kinds of pollutants. Although multi-purpose adsorbent tends to make the characterization of the adsorbent more complicated, it represents a more realistic approach to the design. Thus, a novel reactor system should be designed and their operation conditions should be optimized for large scale use.

CONCLUSIONS

During the last few years many articles concerning the adsorption of dyes by chitosan composites have been published, therefore a lot of assumptions and results exist. It can be concluded that the chitosan composites are effective adsorbents for cationic and anionic dyes. arguments on which type of adsorbent is better in adsorption is still going on.

Amino groups of chitosan composites can undergo protonation (forming protonated amine) which can adsorb dye molecules through various

types of interaction mechanisms such as electrostatic attractions and chelation the Langmuir model is usually used to evaluate the adsorption capacity. chitosan composites as adsorbents and most of studies of dye adsorption. The kinetic data of adsorption on to chitosan composites usually follows the Pseudo-second-order model. This field of research has a great room for improvement in the hope that chitosan composites can be applied commercially instead of only at laboratory scale.

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REFERENCE

1. Forgacs, E, Cserhati, and T, Oros, G, 2004, Removal of synthetic dyes from wastewaters:a review, *Environ. Int.*, **30**, pp. 953–971.
2. Mohan, N, Balasubramanian, N, and Basha, C. A, 2007, Electrochemical oxidation of textile wastewater and its reuse, *Hazard. Mater.*, **147**, pp. 644–651.
3. Sulak, M.t, Demirbas, E, and Kobya, M, 2007, Removal of Astrazon Yellow 7GL from aqueous solutions by adsorption onto wheat bran, *J. Biores. Technol.*, **98**, pp. 2590–2598.
4. Mohd Salleh, M. A, Mahmoud, D.K, Wan Abdul Karim, W.A, and Idris, A, 2011, Cationic and anionic dye adsorption by agricultural solid wastes: A comprehensive review, *Desalination*, **280**, pp. 1–13.
5. Crini, G, 2006, Non-conventional low-cost adsorbents for dye removal: A review, *Bioresource Technology*, **97**, pp. 1061–1085.
6. Wan Ngah, W. S, and Isa, I. M, 1998, Comparison study of copper ion adsorption on chitosan dowex A-1 and zerolit 225. *Journal of Applied Polymer Science*, **67**, pp. 1067–1070.
7. Kumar, M. N. V. R, 2000, A review of chitin and chitosan applications. *Reactive & Functional Polymers*, **46**, pp. 1–27.
8. Crini, G, and Badot, P. M, 2008, Application of chitosan, a natural aminopolysaccharide, for dye removal from aqueous solution by adsorption process using batch studies: A review of recent literature. *Progress in Polymer Science*, **33**, pp. 399–447.
9. Zhu, H.Y, Jiang, Ru, Xiao, and Li, 2010, Adsorption of an anionic azo dye by chitosan/kaolin/ γ -Fe₂O₃ composites, *Applied Clay Science*, **48**, pp. 522–526.

10. Xiaoli Li , Yanfeng Li , Sidi Zhanga, and Zhengfang Ye, 2012, Preparation and characterization of new foam adsorbents of poly(vinylalcohol)/chitosan composites and their removal for dye and heavy metal from aqueous solution, *Chemical Engineering Journal*, **18**, pp. 88– 97.
11. Fan,L, Luo,C, Sun,M, Li,X, Lu,F, and Qiu,H, 2012, Preparation of novel magnetic chitosan/graphene oxide composite as effective adsorbents toward methylene blue, *Bioresource Technology*, **114**, pp.703-706.
12. Wang,L , Zhang,J, and Wang ,A, 2011, Fast removal of methylene blue from aqueous solution by adsorption onto chitosan-g-poly (acrylic acid)/attapulgitic composite, *Desalination*, **266**, pp. 33–39.
13. Gupta, V.K, Suhas, 2009, Application of low-cost adsorbents for dye removal — a review, *J. Environ. Manage*, **90**, pp. 2313–2342.
14. Demirbas, A, 2009, Agricultural based activated carbons for the removal of dyes from aqueous solutions: a review, *J. Hazard. Mater*, **167**, pp. 1– 9.
15. Mishra, G, Tripathy, M, 1993, A critical review of the treatment for decolorization of textile effluent, *Colourage*, **40**, pp. 35–38.
16. Eren, E, 2009, Investigation of a basic dye removal from aqueous solution onto chemically modified Unye bentonite, *J. Hazard. Mater*, **166**, pp. 88–93.
17. Qada, E.N. El, Allen, S.J, and Walker , G.M, 2008, Adsorption of basic dyes from aqueous solution onto activated carbons, *Chem. Eng. J*, **135**, pp. 174–184.
18. Al-Futaisi, A, Jamrah, A, and Al-Hanai, R, 2007, Aspects of cationic dye molecule adsorption to palygorskite, *Desalination*, **214**, pp. 327–342.
19. Tyagi, O.D, Yadav, M.S, and Yadav, M, 2002, Anmol-PVT, LTD, *A Textbook of Synthetic Dyes*, 67.
20. Mouzdahir, Y, Elmchaouri, A, Mahboub, R, Gil, A, and Korili, S. A, 2010, Equilibrium modeling for the adsorption of methylene blue from aqueous solution on activated clay minerals. *Desalination*, **250**, pp. 335–338.
21. Nandi, B.K, Goswami, A, and Purkait, M.K, 2009a, Removal of cationic dyes from aqueous solutions by kaolin: kinetic and equilibrium studies. *Appl. Clay Sci*, **42** (3–40), pp. 583–590.
22. Zhu, H.Y, Jiang, R, Xiao, L, Chang, Y.H, Guan, Y.J, Li, X.D, and Zeng, G.M, 2009, Photocatalytic decolorization and degradation of Congo Red on innovative crosslinked chitosan/nano-CdS composite catalyst under visible light irradiation, *J. Hazard. Mater*, **169** (1–3), pp. 933–940.
23. Almeida, C.A.P, Debacher, N.A, Downs, A.J, Cottet, L, and Mello, C.A.D, 2009, Removal of methylene blue from colored effluents by adsorption on montmorillonite clay, *J. Colloid Interface Sci*, **332** (1), pp. 46–53.
24. Ma, H.Z, Wang, B, and Luo, X.Y, 2007, Studies on degradation of methyl orange wastewater by combined electrochemical process, *J. Hazard. Mater*, **149** (2), pp. 492–498.
25. Vimonses, V, Lei, S, Jin, B, Chow, C.W.K, and Saint, C, 2009, Adsorption of Congo Red by three Australian kaolins, *Appl. Clay Sci*, **43** (3–4), pp. 465–472.
26. Rao, C.N.R, Sood, A.K, Subrahmanyam, K.S, and Govindaraj, A.A, 2009, Graphene: the new two dimensional nanomaterial. *Angew, Chem. Int. Ed*, **48**, pp. 7752.
27. Dreyer, D.R, Park, S, Bielawski, C.W, and Ruoff, R.S, 2010, The chemistry of graphene oxide, *Chem. Soc. Rev*, **39**, pp. 228.
28. Ramesha, G.K, Vijaya Kumara, A, Muralidhara, H.B, and Sampath, S, 2011, Graphene and graphene oxide as effective adsorbents toward anionic and cationic dyes, *J. Colloid Interface Sci*, **361**, pp. 270–277.
29. Depan, D, Girase, B, Shah, J.S, and Misra, R.D.K, 2011, Structure–process–property relationship of the polar graphene oxide-mediated cellular response and stimulated growth of osteoblasts on hybrid chitosan network structure nanocomposite scaffolds, *Acta Biomater*, **7**, pp. 3432–3445.
30. Bell, C.L, and Peppas, N.A, 1995, Biomedical membranes from hydrogels and interpolymer complexes, *Adv. Polym. Sci*, **122**, pp. 125–175.
31. Bekiar, V, Sotiropoulou, i. M, Bokias, and G, Lianos, p, 2008, Use of poly(N, N-dimethylacrylamide- co-sodium acrylate) hydrogel to extract cationic dyes and metals from water, *Colloids Surf. A*, **312**, pp. 214–218.
32. Yetimoğlu, E.K, Kahraman M.V, Ercan O.E, Akdemir, Z.S, and Apohan, N.K, 2007, N-vinylpyrrolidone/ acrylic acid/2-acrylamido-2-methylpropane sulfonic acid based hydrogels: synthesis, characterization and their application in the removal of heavy metals, *React. Funct. Polym*, **67**, pp. 451–460.
33. Paulino, A.T, Guilherme, M.R, Reis, A.V, Campese, G.M, Muniz, E.C, and Nozaki, j, 2006,

- Removal of methylene blue dye from an aqueous media using superabsorbent hydrogel supported on modified polysaccharide, *J. Colloid Interface Sci.*, **301**, pp. 55–62.
34. Zhang, J.P, Wang Q, and Wang, A.Q, 2007, Synthesis and characterization of chitosan-g-poly (acrylic acid)/attapulgate superabsorbent composites, *Carbohydr. Polym.*, **68**, pp. 367–374.
35. Bhattacharyya, K.G, and Sarma, A, 2003, Adsorption characteristics of the dye, Brilliant Green, on Neem leaf powder, *Dyes Pigm.*, **57**, pp. 211–222.
36. Mall, I.D, Srivastava, V.C, Kumar, G.V.A, and Mishra, I.M, 2006, Characterization and utilization of mesoporous fertilizer plant waste carbon for adsorptive removal of dyes from aqueous solution, *Colloids Surf. A*, **278**, pp. 175–187.

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