Malachite green “a cationic dye” and its removal from aqueous solution by adsorption

Nirav P. Raval¹ · Prapti U. Shah¹ · Nisha K. Shah²

Received: 12 October 2016 / Accepted: 28 November 2016 © The Author(s) 2016. This article is published with open access at Springerlink.com

Abstract Adsorption can be efficiently employed for the removal of various toxic dyes from water and wastewater. In this article, the authors reviewed variety of adsorbents used by various researchers for the removal of malachite green (MG) dye from an aqueous environment. The main motto of this review article was to assemble the scattered available information of adsorbents used for the removal of MG to enlighten their wide potential. In addition to this, various optimal experimental conditions (solution pH, equilibrium contact time, amount of adsorbent and temperature) as well as adsorption isotherms, kinetics and thermodynamics data of different adsorbents towards MG were also analyzed and tabulated. Finally, it was concluded that the agricultural solid wastes and biosorbents such as biopolymers and biomass adsorbents have demonstrated outstanding adsorption capabilities for removal of MG dye.

Keywords Malachite green · Wastewater · Biosorbents · Biopolymers · Nanomaterials

Introduction

Till the late nineteenth century, all the colorants were extracted from shells, flowers, roots, insects and molluscs. But, with the historic discovery of first synthetic dye, Mauveine, most of the uses of natural dyes have been replaced with synthetic ones as they can be manufactured on a large scale (Gordon and Gregory 1987). At present, more than 1,00,000 synthetic dyes exist with an annual production of over $7 \times 10^5$ tonnes/year and are mostly associated with water pollution (Mittal et al. 2009; Gupta et al. 2011; Saravanan et al. 2016).

Malachite green (MG) is water soluble cationic dye that appears as green crystalline powder and belongs to triphenylmethane category (Raval et al. 2016b). The important physicochemical characteristics of MG were presented in Table 1 and Table 2 narrated its applications and toxic effects. It was revealed from the Table 2 that the extensive usage of MG dye has caused several health hazards and hence, proper treatment of effluent containing MG dye is extremely necessary.

Many treatment technologies have been applied to decolorize MG from aqueous medium, such as biodegradation and decolorization (An et al. 2002; Levin et al. 2004; Ren et al. 2006; Eichlerová et al. 2006; Daneshvar et al. 2007a, b; Ayed et al. 2008; Ali et al. 2009; Wu et al. 2009; Cheriaa and Bakhrouf 2009; Ayed et al. 2010; Du et al. 2011; Khataee et al. 2011a, b; Shedbalkar and Jadhav 2011; Hu et al. 2011; Abd-El-Kareem and Taha 2012); photocatalytic degradation (Hasnat et al. 2003; Kominami et al. 2003; Liu et al. 2005; Yang et al. 2005; Chen et al. 2007; Sayilkan et al. 2007a, b, 2008; Tayade et al. 2007; Wang et al. 2008a; Ju et al. 2008; Asiltürk et al. 2009; Prado and Costa 2009; Bansal et al. 2009; Kaneva et al. 2010; Liu et al. 2010; Bojinova and Dushkin 2011; Chen...
**Table 1** Physicochemical properties of malachite green dye

| Parameters                  | Malachite green chloride | Malachite green oxalate |
|-----------------------------|--------------------------|-------------------------|
| Common name                 | Malachite green chloride | Malachite green oxalate |
| Molecular formula           | C₂₃H₂₅ClN₂               | C₅₂H₅₄N₄O₁₂             |
| Molecular weight            | 364.911 g/mol            | 927.00 g/mol            |
| IUPAC name                  | [4-[(4-Dimethylamino)phenyl]-phenylmethylidene]cyclohexa-2,5-dien-1-ylidene]-dimethylazanium; chloride | [4-[(4-Dimethylamino)phenyl]-phenylmethylidene]cyclohexa-2,5-dien-1-ylidene]-dimethylazanium; 2-hydroxy-2-oxoacetate; oxalic acid |
| Molecular Structure         | ![Molecular structure of Malachite green chloride](image1) | ![Molecular structure of Malachite green oxalate](image2) |
| Other names                 | Aniline green; Basic green 4; Diamond green B; Victoria green B |
| Color index number          | 42000                    |
| CAS number                  | 123333-61-9              |
| Maximum wavelength          | 618 nm                   |

**Table 2** Applications and toxicity of Malachite green dye

**Applications**
- It is used for the dyeing of cotton, paper, jute, silk, wool, leather products and acrylic industries
- Antiseptic and fungicidal for humans
- Antiparasitical, antibacterial and antifungal in aquaculture and commercial fish hatchery industries
- It is also used as a food coloring agent, food additive, a medical disinfectant, and anthelminthic

**Toxicity**
- Environmentally persistent
- Damage to nervous system, brain and liver when ingested
- Eye burns, fast breathing, profuse sweating and cancer of different parts of the body
- Acutely toxic to a wide range of aquatic and terrestrial animals
- Decreases food intake, growth and fertility rates
- Causes damage to the liver, spleen, kidney and heart
- Inflicts lesions on the skin, eyes, lungs and bones
- Produces teratogenic effects
- Cytotoxic to mammalian cells
- Acts as a respiratory enzyme poison
- Decreasing RBC count (Dyscrasia), Hb (Anemia), and HTC (%)
- Increasing WBC count (Leukocytosis) and delay in blood coagulation
- Its presence in the hydrosphere reduces photosynthesis by obstructing light penetration and adversely affects aquatic life
et al. 2011; Tolia et al. 2012; Saha et al. 2012; Aliyan et al. 2013; photooxidative degradation (Modirshahla and Behnajady 2006); Solar degradation (Pirsaheb et al. 2015); coagulation–flocculation (Oladoja and Aliu 2009; Man et al. 2012); ozonation (Zhou et al. 2013); fenton reagent (Chen et al. 2002; Karimi et al. 2012; Bai et al. 2013; Nidheesh et al. 2013); Solvent extraction (Pandit and Basu 2004); sonochemical and sonophotocatalytic degradation (Berberidou et al. 2007; Bejarano-Pérez and Suárez-Herrera 2008; Moumeni and Hamdaoui 2012). However, all these techniques have certain limitations in terms of design, dye separation efficiency, cost and effectiveness. Advantages and disadvantages of various techniques used for the removal of MG dye have been summarized in Table 3 (Dawood and Sen 2014; Yang et al. 2014). More than 250 research articles have been published related to the adsorption of MG which confirmed that amongst all the available treatment techniques, adsorption has more frequently used one.

In addition, though there was a number of review articles such as Microbial decolorization of textile-dye containing effluents: a review by Banat et al. (1996); Fungal decolorization of dye wastewaters: a review by Fu and Viraraghavan (2001); Remediation of dyes in textile effluent: a critical review on current treatment technologies with a proposed alternative Robinson et al. (2001); The removal of color from textile wastewater using whole bacterial cells: a review by Pearce et al. (2003); Removal of synthetic dyes from wastewaters: a review by Forgacs et al. (2004); Decolorization of industrial effluents—available methods and emerging technologies—a review by Anjaneyulu et al. (2005); Adsorption–desorption characteristics of phenol and reactive dyes from aqueous solution on mesoporous activated carbon prepared from waste tires by Tanthapanichkoon et al. (2005); Non-conventional low-cost adsorbents for dye removal: a review by Crini (2006); Methods of dye removal from dye house effluent—an overview by Mondal (2008); Agricultural based activated carbons for the removal of dyes from aqueous solutions: a review by Demirbas (2009); Application of low-cost adsorbents for dye removal—a review by Gupta and Suhas (2009); Biodegradation of synthetic dyes—a review by Ali (2010); Decolorization of dye wastewaters by biosorbents: A review by Srinivasan and Viraraghavan (2010); Cationic and anionic dye adsorption by agricultural solid wastes: a comprehensive review by Salleh et al. (2011); A review on applicability of naturally available adsorbents for the removal of hazardous dyes from aqueous waste by Sharma et al. (2011); Adsorption of dyes and heavy metal ions by chitosan composites: a review by Wan Ngah et al. (2011); Microbial decolouration of azo dyes: A review by Solis et al. (2012); Adsorption of dyes using different types of sand: a review by Bello et al. (2013); Adsorptive removal of dyes from aqueous solution onto carbon nanotubes: a review by Gupta et al. (2013); Agricultural peels for dye adsorption: a review of recent literature by Anastopoulos and Kyzas (2014); Magnetic composite an environmental super adsorbent for dye sequestration—a review by Sivashankar et al. (2014); Dye and its removal from aqueous solution by adsorption: a review by Yagub et al.
(2014), none of them has given comprehensive knowledge on the adsorptive removal of MG from aqueous media.

Therefore, in this review article we tried to congregate the available information on various adsorbents used for the removal of MG, a cationic dye, from water and wastewater. The main objective of this review article was to compile an extensive list of adsorbents which will help the future generation to furnish comprehensive up-to-date research summary on adsorbents used for removal of MG dye. Also the reported optimal experimental conditions (solution pH, contact time and amount of adsorbent) as well as adsorption isotherms, kinetics and thermodynamics data of different adsorbents towards MG were also mentioned. The authors embolden the readers to refer to the original research articles for information regarding the experimental conditions.

**Dyes and their classification**

Dyes (a natural or synthetic substance) are mainly chemical compounds that can affix themselves on the surface of fabrics to impart color (Yagub et al. 2014). It refers as a substance, usually organic, which is designed to be absorbed or adsorbed by, made to react with, or deposited within a substrate to impart color to that substrate with some degree of permanence (Burkinshaw 2016). Dyes may be classified in several ways (Adegoke and Bello 2015). Figure 1 summarizes the complete classification of dyes.

**Based on the source of materials: Dyes can be classified mainly into two types based on their origin**

**Natural dyes**

Natural dyes can be derived from the three primary sources—plants, animals and minerals. They are mostly negatively charged. Positively charged natural dyes can also exist, but they are not very common. Irrespective of the source of origin, natural dyes can be categorized as:

1. **Substantive dyes:** Those dyes which become chemically fixed to the fiber without the aid of any other chemicals or additives are referred to as substantive dyes or direct dyes.
2. **Adjective dyes:** Those natural dyes which require an added substance or mordant to make the dyes colorfast are known as adjective dyes or mordant dyes. Most of the natural dyes belong to this category (Cardon 2007).

**Synthetic dyes**

Dyes derived from organic or inorganic compounds are known as synthetic dyes. Because of their easy use, cost effectiveness and wide range of colors these dyes became popular.

**Based on their method of application to the substrate**

**Acid dyes**

Acid dyes are highly water soluble anionic dyes which contain one or more sulfonic groups/substituents and other acidic groups. They have better light fastness compare to basic dyes. The existence of sulfonic acid groups upsurge their solubility in water and give the dye molecules a negative charge. Acid dyes can be further divided into two sub-groups:

1. Acid-leveling dyes: These dyes are smaller or medium sized, and show a moderate affinity for wool fibers. Hence, due to average affinity these dyes are not very resistant to washing.
2. Acid-milling dyes: These dyes are larger than acid-leveling dyes, and show a much stronger intermolecular attractions for wool fibers. Due to this strong affinity these dyes are very resistant to washing.

**Basic dyes**

These water soluble dyes possess cationic functional groups such as \(-\text{NR}_3^+\) or \(=\text{NR}_2^+\). They are generally amino and substituted amino compounds soluble in acid. They become attached to the fibers by formation of ionic bonds with fiber’s anionic groups.

**Direct dyes**

Although these dyes are water soluble anionic dyes, they cannot be classified as acid dyes because the acid groups are not the means of attachment to the fiber. Since, these dyes do not require any kind of fixing, they are called direct dyes.

**Mordant dyes**

A latin word mordant means ‘to bite’. It acts as ‘fixing agent’ to improve the color fastness of some acid dyes, because they have the ability to form insoluble colored complexes with metal ions. They are usually metal salts. Besides, alum there is a large range of other metallic salt mordants available. Aluminum, chromium and iron salts are frequently used for synthetic mordant dyes.

**Reactive dyes**

Fiber reactive dyes will form a covalent bond while they react with the cellulosic fiber. As a result they are very
difficult to remove, once attached with the fiber. Initially, these dyes were designed for cellulose fibers but now some fiber-reactive dyes for protein and polyamide fibers are also commercially available.

**Disperse dyes**

These dyes have substantially low solubility in water. Their structure is small, planner and non-ionic with attached polar functional groups, such as –NO$_2$ and –CN. They are mainly used for the dyeing of polyesters because they can interact with the polyester chains by forming dispersed particles.

**Solvent dyes**

These dyes are insoluble in water but soluble in alcohols, chlorinated hydrocarbons and liquid ammonia. They are mainly used for coloring plastics, synthetic fibers, gasoline, oils and waxes.

**Sulfur dyes**

Sulfur dyes are applied to cotton from an alkaline reducing bath with sodium sulfide as the reducing agent. These dyes are water insoluble but they are soluble in their reduced form and exhibit affinity for cellulose. They are low cost and have good fastness to light, washings and acids. The actual structures of sulfur dyes are largely unknown although it is considered that they possess sulfur-containing heterocyclic rings.

**Based on their chemical structure:** (Gordon and Gregory 1987; Waring and Hallas 1990)

**Azo dyes**

Approximately half of all dyes are azo dyes, making them the largest group of synthetic colorants used in textile industries. This type of dyes contain minimum one azo group but can also contain two or three, but very rarely,
four azo groups. Azo dyes are complex aromatic compounds with significant structural diversity and are of great environmental concern because the reductive cleavage of azo linkages is responsible for the formation of amines, which are classified as toxic and carcinogenic (Raval et al. 2016a).

**Anthraquinone dyes**

Anthraquinone dyes are the second most important class after azo dyes. They are also one of the oldest types of dyes since they have been found in the covering of mummies dating back over 4000 years. In contrast to the azo dyes, which have no natural counterparts, all the natural red dyes were anthraquinones. The lower tinctorial strength and reduced flexibility increase the production cost of anthraquinone dyes and hence, they are not as widely used as azo dyes.

**Benzodifuranone dyes**

Benzodifuranone (BDF) dyes are one such type which attacking anthraquinone dyes. The BDF chromogen is one of the very few novel chromogens to have been accidently discovered this century.

**Polymethine and related dyes**

Dyes containing a conjugated chain of carbon atoms terminated by an ammonium group and, in addition, a nitrogen, sulfur, or oxygen atom, or an equivalent unsaturated group is termed as polymethine dyes. This type of dyes may be neutral, cationic or anionic. The best known cationic polymethine dyes are the cyanine dyes. Cyanine dyes cannot be used as textile dyes because they have poor light fastness. They are used in photography.

**Polycyclic aromatic carbonyl dyes**

Polycyclic aromatic carbonyl dyes have one or more carbonyl groups. These carbonyl groups are linked by a quinonoid system. These dyes are relatively very large molecules which are made up from smaller units of anthraquinones. These dyes are often termed as anthraquinonoid vat dyes because they are applied to the substrate by a vatting process.

**Indigoid dyes**

Indigoid dyes also contain carbonyl groups, similar to the anthraquinone, benzodifuranone and polycyclic aromatic carbonyl dyes. They are vat dyes and represent one of the oldest known classes of dyes.

**Phthalocyanines**

Phthalocyanines are one of the novel chromophores which have been discovered since the nineteenth century. They are structurally similar to the natural porphyrin pigments haemin and chlorophyll. These natural pigments have poor stability, but phthalocyanines have exceptional stability and tinctorially stronger. All the phthalocyanine compounds are blue to green in color because substituents in their fused benzene rings exert only a minor sway on the color of phthalocyanines. They are widely used in printing inks and paints.

**Di- and tri-aryl carbonium and related dyes**

Di- and triarylcyanine dyes and their heterocyclic derivatives comprise the oldest class of synthetic dyes—the majority of which were discovered in the 19th and early 20th century. Diphenylmethane and Triphenylmethane dyes are the most important aryl carbonium dyes. Structurally and property wise they are similar to the cyanine dyes i.e. exceptional brightness, high tinctorial strength and low light fastness.

**Nitro and nitroso dyes**

Nitro and nitroso dyes are minor commercial importance and constitute only a fraction of the total dyes market. Nitro dyes have simple chemical structures. They are small aromatic molecules which contain minimum one nitro group and one or more amino or hydroxy groups. Initially, the nitro dyes were acid dyes which were used for dyeing the natural animal fibers i.e. wool and silk. Picric acid was the first synthetic nitro dye which imparted a greenish-yellow color to silk but could not be used for longer period of time because of its toxicity and poor fastness properties.

Nitroso dyes are prepared by nitrosation of the appropriate phenol or naphthol. They are generally metal complex derivatives of o-nitrosophenols or naphthols. Nitroso dyes are polygenetic because they form differently colored complexes with different metals. They have good light fastness.

**Based upon the electronic origins of color**

Griffith (1976, 1981) has classified dyes based on the electronic mechanism by which color is generated. According to this, purely on theoretical basis, dyes can be arranged into four classes.

(II) Donor–acceptor chromogens
(III) Polyene chromogens
(III) n → π^∗ chromogens
Cyanine type chromogens

Literature on various adsorbents used for the removal of MG

See (Fig. 2)

Activated carbon adsorbents

Activated carbons (AC) are known as very efficacious adsorbents due to their large surface area, a micro-porous structure and a high degree of surface reactivity. However, due to their high production costs, these materials tend to be more expensive than other adsorbents. Four classes of AC include: powder (PAC), granular (GAC), fibrous (ACF) and cloth (ACC). Also two more frequently used ACs are: (1) commercial activated carbons and (2) activated carbons prepared from agricultural waste materials (Raval et al. 2016c).

Commercial activated carbons

A number of commercially available activated carbons such as powdered activated carbon (Kumar 2006); coal-based activated carbon (Aitcheson et al. 2000); commercially available powdered activated carbon (CPAC) (Malik et al. 2007); activated carbon prepared from lignite (Önal et al. 2007); activated Charcoal (Iqbal and Ashiq 2007); activated carbon prepared from Tuncbilek lignite (Önal et al. 2006); oxyhumolite (Young brown coal) (Janos et al. 2005); Ordered mesoporous carbons (OMCs) (Tian et al. 2011); etc. have been extensively studied for the adsorption of MG.

Mesoporous carbon was synthesized by Anbia and Ghaffari (2012) for the removal of a cationic dye malachite green (MG) from aqueous solution. They carried out study under various experimental conditions and concluded that the equilibrium was attained within 30 min of contact with adsorbent and more than 99% removal of MG was reached at the optimum pH value of 8.5.

Aitcheson et al. (2000) used coal-based activated carbon 207EA (Sutcliffe Speakman) for the removal of aquaculture therapeutics (Malachite Green, formalin, Chloramine-T and Oxytetracycline) which were widely used in aquaculture to control fish parasites and disease. The adsorption process was well fitted to the Freundlich isotherm and confirmed that adsorption was heterogeneous in nature.

Adsorption of MG was studied by Mall et al. (2005) using commercial grade (ACC) and laboratory grade (ACL) activated carbons. Authors conducted batch adsorption studies to evaluate the effect of various parameters such as pH, adsorbent dose, contact time and initial MG concentration on the removal of MG and concluded that the effective pH was 7.0 for adsorption of MG. Equilibrium reached in about 4 h contact time and optimum ACC and ACL dosages were 20 and 4.0 g/L, respectively.

To overcome deficiencies ofCACs the use of activated carbon adsorbents derived from various agricultural waste and industrial solid waste materials have received increasing consideration in the purification of wastewater over the last several years because they are generated in excess, inexpensive, locally available and their use will...
further solve the problem of their disposal (Pehlivan and Arslan 2007).

Activated carbons prepared from agricultural and industrial solid wastes

As biomass and other waste materials have little or no economic value and often present a disposal problem, they offer an inexpensive and additional renewable source of activated carbon. Thus, conversion of these low cost by products into activated carbon would provide an inexpensive substitute to the existing CACs, add monetary value and help in dropping the expenditure of waste disposal (Raval et al. 2016c).

Polygonum orientale Linn is an annual plant of the genus Polygonum in the family Polygonaceae, which is native to eastern Asia and widely distributed in China. This plant has a developed caudex system and generally produces large and continuous caudex masses. Therefore, this plant offers a good basis for the development of adsorbent materials. Looking upon this property of plant (Wang et al. 2010) prepared P. orientale Linn activated carbon (PLAC) from waste P. orientale Linn by chemical activation with \( \text{H}_3\text{PO}_4 \) and used as an adsorbent to remove malachite green (MG) and rhodamine B (RB) from aqueous solution.

Durian (Durio zibethinus Murray) is the most popular seasonal fruit in Southeast Asia, particularly Malaysia, Indonesia, Thailand, and the Philippines, and belongs to the family Bombacaceae. A significant percentage of the planted durian fruit crop is wasted each year. Only one third of durian fruit is edible, whereas the seeds (20–25%) and the shells are usually discarded. The wasted durian seed represents a significant potential for the development of value-added products. Thus, Ahmad et al. (2014) studied the removal of Malachite green dye using durian seed-based activated carbon.

Rambutan (Nephelium lappaceum L.) is a popular tropical fruit which belongs to Sapindaceae family. However, due to the high consumption of rambutan’s edible part, massive amount of the peel is disposed, causing a severe problem in the community as they gradually ferment and release off odors. Therefore, Ahmad and Alrozi (2011) converted rambutan peel into activated carbon by physio-chemical activation for its potential to remove MG dye from wastewater.

Akar et al. (2013) produced active carbon from spent tea leaves (STAC) by activation with 4% NaOH solution for the removal of malachite green dye because tea is basically dried and processed leaves of plant called Camellia sinensis. It is consumed by the most of people in the world and is the second most popular beverage in the world. It is estimated that between 18 and 20 billion cups of tea are drunk daily in world and disposal of spent leaves become a major problem.

Banana (Musa paradisiaca) is native to Southeast Asia, most of the bananas produced are consumed locally and ~10% are exported. Massive amounts of stalk (as waste products) are disposed, resulting in a serious environmental problem through the emission of foul odors when it is left to decompose. Hence, Bello et al. (2012) attempted to use banana stalk, an abundantly available lignocellulosic agricultural waste, as a cheap and renewable precursor for activated carbon preparation for MG dye removal and helped in placing value on this agricultural waste and provide a potentially cheap alternative to existing commercial activated carbons.

In addition to above described materials, a wide variety of other agricultural and industrial waste materials have also been used for the preparation of activated carbon and applied for the adsorptive removal of MG dye from aqueous solution. It includes Tamarind fruit shells carbon (Vasu 2008); Juglans regia shells carbon (Nethaji et al. 2012); Annona squamosa seed (Santhi et al. 2010a); Groundnut shell carbon (Malik et al. 2007); Pine sawdust (Akmil-Başar et al. 2005); Tea leaves (Singh and Rastogi 2004); Bamboo (Hameed and El-Khaiary 2008a); Jute fiber (Porkodi and Vasanth Kumar 2007) and waste printed circuit boards (Kan et al. 2015), etc.

In addition, Table 4 presented various commercially available and agricultural waste based activated carbon adsorbents used for the removal of MG and their optimum conditions.

Non-conventional low-cost adsorbents

Activated carbon adsorption has been cited by the US Environmental Protection Agency as one of the best available control technologies. However, although activated carbon is a preferred sorbent, its widespread use is restricted due to high cost. To decrease the cost of treatment, attempts have been made to find inexpensive alternative adsorbents. Recently, numerous approaches have been studied for the development of cheaper and effective adsorbents. Thus, there is a need to search for new and economical adsorbent that could remove metal. In this context, agricultural by-products and industrial waste can be seen as having a great potential to be developed as a low cost sorbent. A low-cost adsorbent is defined as the one which is plentiful in nature, or is a by-product or waste from industry and requires little or no processing (Raval et al. 2016c). Literature survey reveals that multifarious materials have been utilized as adsorbents under this category.
Table 4: The maximum adsorption capacities and other optimal conditions of commercially available and agricultural waste based activated carbon adsorbents for adsorption of MG from water and wastewater

| Sr. No. | Adsorbents                                      | Q\textsubscript{max} (mg/g) | Isotherm study                  | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References                   |
|---------|-------------------------------------------------|----------------------------|--------------------------------|----------------|---------------------|----|------------------|----------------------|--------------------------------|
| 1       | Powdered activated carbon                       | 509.00                     | Langmuir and Redlich–Peterson  | –              | Exothermic          | –  | –                | –                    | (Kumar 2006)                   |
| 2       | Activated carbon                                | 490.77                     | Langmuir and Redlich–Peterson  | Pseudo 2nd order | –                   | –  | –                | –                    | (Kumar and Sivanesan 2006)     |
| 3       | Mesoporous Carbon                               | 476.10                     | Langmuir                        | Pseudo 1st order | –                   | 8.5 | 30               | 0.005 g/25 mL          | (Anbia and Ghaffari 2012)       |
| 4       | Coal-based activated carbon                     | 325.00                     | Freundlich                      | –              | –                   | 7.0 | 60 min           | 0.1 g/50 mL            | (Aitcheson et al. 2000)        |
| 5       | Commercially available powdered activated carbon (CPAC) | 222.22               | Freundlich                      | –              | –                   | 7.0 | 240              | 4 g/L                 | (Malik et al. 2007)           |
| 6       | Activated carbon prepared from lignite          | 200.00                     | Langmuir                        | Pseudo 2nd order | Endothermic         | 7.0 | 60 min           | 0.1 g/50 mL            | (Önal et al. 2007)           |
| 7       | Activated Carbon                                | 75.08                      | (batch capacity)                | Langmuir and Freundlich | Pseudo 1st order | 10.0 | 6–8 h            | 1.0 g/L               | (Gupta et al. 1997)          |
|         |                                                 | 94.00                      | (column capacity)               |                | Endothermic         | 7.0 | 120 min          |                      |                               |
| 8       | Laboratory grade activated carbon (ACL)         | 42.18                      | Redlich–Peterson                | Pseudo 2nd order | –                   | 7.0 | 240              | 4 g/L                 | (Mall et al. 2005)           |
| 9       | Acid-activated carbon                           | 9.78                       | Langmuir                        | –              | Endothermic         | 6.0 | 40 min           | –                    | (Hema and Arivoli 2007)       |
| 10      | Commercial grade activated carbon (ACC)         | 8.27                       | Freundlich                      | Pseudo 2nd order | –                   | 7.0 | 240              | 20 g/L                | (Mall et al. 2005)           |
| 11      | Activated Charcoal                              | 0.180                      | Langmuir                        | –              | Exothermic          | 7.0 | 30 min           | 0.1 g                 | (Iqbal and Ashiq 2007)        |
| 12      | Activated carbon prepared from Tuncbilek lignite| 9.92 × 10\textsuperscript{−4} (mol/g) | Freundlich                      | Pseudo 2nd order | Endothermic         | 5.0 | 120 min          | 0.1 g/25 mL            | (Önal et al. 2006)           |
| 13      | Oxyhumolite (Young brown coal)                 | 0.278 mmol/g               | Langmuir                        | –              | –                   | 5.0 | –                | –                    | (Janos et al. 2005)          |
| 14      | Activated carbon                                | 26.19                      | Langmuir                        | Pseudo 2nd order | Endothermic         | 7.0 | 60 min           | 0.5 g/50 mL            | (Arivoli et al. 2008)        |
| 15      | Oxyhumolite (Young brown coal)                 | 0.278 mmol/g               | Langmuir                        | –              | –                   | 5.0 | –                | –                    | (Janoš et al. 2007)          |
| 16      | Ordered mesoporous carbons (OMCs)              | 26.19                      | Langmuir                        | Pseudo 2nd order | Exothermic          | 7.0 | 60 min           | 0.07 g/25 mL           | (Tian et al. 2011)           |
| 17      | Oxyhumolite (Young brown coal)                 | 556.00                     | Langmuir                        | Pseudo 2nd order | Endothermic         | 10.0 | 150 min         | 0.45 g/L              | (Wang et al. 2010)           |
| 18      | Polygonum orientale Linn activated carbon (PLAC)| 476.19                     | Freundlich                      | Pseudo 2nd order | Endothermic         | 8.0 | 24 h             | 0.1 g                 | (Ahmad et al. 2014)         |
| 19      | Durian seed activated carbon (DSAC)             | 370.37                     | Langmuir                        | Pseudo 1st order | –                   | 10.0 | 120 min         | 0.1 g/25 mL            | (Akemi-Basar et al. 2005)     |
| Sr. No. | Adsorbents                                      | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH  | Equilibrium time | Dosage of adsorbent | References                       |
|--------|------------------------------------------------|--------------------------|----------------|----------------|----------------------|-----|------------------|----------------------|-----------------------------|
| 21.    | Rambutan peel-based activated carbon (RPAC)    | 329.49                   | Freundlich     | Pseudo 2nd order | Endothermic         | 8.0 | 24 h             | 0.2 g                | (Ahmad and Alrozi 2011)   |
| 22.    | Tea leaves based activated carbon              | 275.00                   | Langmuir and Freundlich | Pseudo 2nd order | 8.0–10.0             | 1.2 | 120 min          | 1.2 g/L              | (Singh and Rastogi 2004)  |
| 23.    | Bamboo-based activated carbon                  | 263.58                   | Langmuir       | Pseudo 2nd order | Endothermic         | 4.0 | 170 min          | 0.2 g                | (Hameed and El-Khaiary 2008a) |
| 24.    | Spent tea leaves active carbon (STAC)          | 256.40                   | Langmuir       | Pseudo 2nd order | Endothermic         | 4.0 | 170 min          | 0.2 g                | (Akar et al. 2013)       |
| 25.    | Groundnut shell based powdered activated carbon (GSPAC) | 222.22 | Freundlich | –                | –                   | 30  | 60 min           | 0.1 g/50 mL          | (Malik et al. 2007)      |
| 26.    | Cattail carbon                                 | 196.08                   | –              | –               | –                   | –   | –                | –                    | (Shi et al. 2010)        |
| 27.    | Activated carbon prepared waste apricot        | 163.93                   | Langmuir and Freundlich | Pseudo 2nd order | –                   | –   | –                | –                    | (Başar 2006)             |
| 28.    | Banana (*Musa paradisiaca*) stalk-based activated carbon | 141.76 | Langmuir | Pseudo 2nd order | Endothermic         | 8.0 | 220 min          | 0.05 g               | (Bello et al. 2012)     |
| 29.    | Jute fiber carbon (JFC)                        | 136.58                   | Freundlich     | Pseudo 2nd order | –                   | –   | –                | –                    | (Porkodi and Vasanth Kumar 2007) |
| 30.    | Activated carbon prepared waste apricot        | 111.60                   | –              | Pseudo 2nd order | Endothermic         | 6.0 | 60 min           | 0.1 g/50 mL          | (Onal 2006)              |
| 31.    | Tamarind fruit shells activated carbon         | 83.41                    | Langmuir       | Pseudo 2nd order | Endothermic         | 8.0 | –                | –                    | (Vasu 2008)              |
| 32.    | Rubber seed coat based activated carbon (RSCAC) | 72.73 | Langmuir | –                | Endothermic         | 6.0 | 3 h              | –                    | (Idris et al. 2011)     |
| 33.    | Rice husk activated carbon                     | 63.85                    | Langmuir       | Pseudo 2nd order | Exothermic          | 40  | –                | –                    | (Sharma et al. 2009)    |
| 34.    | Activated carbon derived from *Borassus aethiopum* flower biomass (PFAC) | 48.48 | Langmuir | Pseudo 2nd order | Endothermic         | 4.0 | 10 dram          | 0.1 g/10 mL           | (Nethaji et al. 2010)   |
| 35.    | Rice husk activated carbon (RHAC)              | 49.62                    | Langmuir       | Pseudo 2nd order | Endothermic         | 8.0 | 40 min           | 0.1 g/10 mL           | (Sharma 2011)            |
| 36.    | Water nut modified carbon (WNMC)               | 46.27                    | Langmuir       | Pseudo 2nd order | Endothermic         | 8.0 | 40 min           | 0.1 g/10 mL           | (Ahmad and Mondal 2010)  |
| 37.    | *Cucumis sativa* fruit peel based activated carbon | 36.230 | Langmuir | Pseudo 2nd order | –                   | 6.0 | 50 min           | 1 g/50 mL            | (Santhi and Manonmani 2011) |
| 38.    | *Juglans regia* shells-based activated carbon  | 29.74                    | Freundlich     | Intraparticle diffusion and Boyd models | Endothermic | 6.0–7.0 | – | 3.0 g/L          | (Nethaji et al. 2012) |
| 39.    | Activated carbon prepared from the epicarp of *Ricinus communis* | 27.78 | Langmuir | Pseudo 2nd order | –                   | 7.0 | 50 min           | 1 g/50 mL            | (Santhi et al. 2010b)   |
| 40.    | Coconut coir activated carbon                  | 27.44                    | Langmuir       | Pseudo 2nd order | Endothermic         | –   | –                | –                    | (Santhi et al. 2010a)   |
| 41.    | *Annona squamosa* seed based activated carbon  | 25.91                    | Temkin         | Pseudo 2nd order | –                   | 7.0 | –                | –                    | (Santhi et al. 2010a)   |
| 42.    | Arundo donax root carbon (ADRC)                | 9.35                     | Langmuir       | Pseudo 2nd order | Endothermic         | 5.0 | 180 min          | 0.6 g/100 mL          | (Zhang et al. 2008)     |
Waste materials from agriculture and industry

Agricultural solid wastes Agricultural solid wastes are relatively cheap and are available in huge quantities. They can be used as an adsorbent due to their physico-chemical properties. The utilization of these wastes can play a significant role in national economy (Crini 2006).

Orange peel is discarded in the orange-juice and soft-drink industries all over the world. It has been used as an adsorbent for the removal of MG from wastewater by Kumar and Porkodi ( 2007). The results revealed that the adsorption process followed both Langmuir and Redlich–Peterson isotherms, the adsorption capacity was 483.63 mg/g.

A study of Rahman et al. ( 2005) reported the removal of MG from aqueous solutions onto Phosphoric acid (H$_3$PO$_4$) and sodium hydroxide (NaOH) treated rice husks.

Rice straw is a lignocellulosic agricultural stalk containing cellulose (37.4%), hemi-cellulose (44.9%), lignin (4.9%) and silica ash (13.1%). Gong et al. ( 2006) compared MG adsorption efficiency of native and thermos chemically modified rice straw and found their adsorption efficiency 94.34 and 256.41 mg/g, respectively.

Chieng et al. ( 2015) investigated the use of breadnut (Artocarpus camansi) as a low-cost adsorbent for the removal of MG toxic dye. In Brunei Darussalam, breadnut was locally known as ‘Kemangsi’, whose seeds were consumed either cooked or roasted. The skin and core of Artocorpus fruits, the major parts of the fruits, were inedible and have no economical value, and discarded as waste. Authors concluded that the adsorption characteristics of breadnut skin towards MG can be significantly enhanced by modification through treatment with dilute NaOH solution.

Other solid wastes from cheap and readily available resources have also been successfully employed for the removal of MG from aqueous solution and were given in Table 5.

Industrial by-products/industrial solid wastes Industrial by-products, such as metal hydroxide sludge, fly ash, red mud and bio-solids, can be used as low-cost adsorbents for MG removal. Table 6 represented the maximum adsorption capacities together with the isotherm, kinetics and thermodynamic results of various industrial solid wastes adsorbents for MG.

Fly ash: Witek-Krowiak et al. (2012) investigated the use of fly ash for the adsorption of MG from solution with different contact times, initial dye concentrations, pHs and temperatures. The adsorption equilibrium has been described in terms of Langmuir model. The enthalpy values obtained in the experiment were not high, which suggested

---

### Table 5

| Sr. No. | Adsorbents                                      | $Q_{\text{max}}$ (mg/g) | Isotherm study  | Kinetics study  | Thermodynamic study |
|---------|------------------------------------------------|-------------------------|----------------|-----------------|---------------------|
| 43      | Cassava (Manihot esculenta) peels based carbon  | –                       | –              | –               | –                   |
| 44      | Rubber wood (Hevea brasiliensis)                | –                       | –              | –               | –                   |
| 45      | Rice husk-based porous carbon                   | –                       | –              | –               | –                   |
| 46      | Ulva lactuca and Systosiera stricta algal-based activated carbon | –               | –              | –               | –                   |
| 47      | Rice husk-based porous carbons (RHCS)           | –                       | –              | –               | –                   |
| 48      | Activated E. tetrasperma carbon                 | –                       | –              | –               | –                   |
| 49      | Activated carbons prepared from the rice husk solid wastes | –               | –              | –               | –                   |
| 50      | Activated parthenium carbon                     | –                       | –              | –               | –                   |

---

### Table 4 continued

| Sr. No. | Adsorbents                                      | $Q_{\text{max}}$ (mg/g) | Isotherm study  | Kinetics study  | Thermodynamic study |
|---------|------------------------------------------------|-------------------------|----------------|-----------------|---------------------|
| 43      | Cassava (Manihot esculenta) peels based carbon  | –                       | –              | –               | –                   |
| 44      | Rubber wood (Hevea brasiliensis)                | –                       | –              | –               | –                   |
| 45      | Rice husk-based porous carbon                   | –                       | –              | –               | –                   |
| 46      | Ulva lactuca and Systosiera stricta algal-based activated carbon | –               | –              | –               | –                   |
| 47      | Rice husk-based porous carbons (RHCS)           | –                       | –              | –               | –                   |
| 48      | Activated E. tetrasperma carbon                 | –                       | –              | –               | –                   |
| 49      | Activated carbons prepared from the rice husk solid wastes | –               | –              | –               | –                   |
| 50      | Activated parthenium carbon                     | –                       | –              | –               | –                   |

---

### Table 4

| Sr. No. | Adsorbents                                      | $Q_{\text{max}}$ (mg/g) | Isotherm study  | Kinetics study  | Thermodynamic study |
|---------|------------------------------------------------|-------------------------|----------------|-----------------|---------------------|
| 43      | Cassava (Manihot esculenta) peels based carbon  | –                       | –              | –               | –                   |
| 44      | Rubber wood (Hevea brasiliensis)                | –                       | –              | –               | –                   |
| 45      | Rice husk-based porous carbon                   | –                       | –              | –               | –                   |
| 46      | Ulva lactuca and Systosiera stricta algal-based activated carbon | –               | –              | –               | –                   |
| 47      | Rice husk-based porous carbons (RHCS)           | –                       | –              | –               | –                   |
| 48      | Activated E. tetrasperma carbon                 | –                       | –              | –               | –                   |
| 49      | Activated carbons prepared from the rice husk solid wastes | –               | –              | –               | –                   |
| 50      | Activated parthenium carbon                     | –                       | –              | –               | –                   |

---

### Table 4 continued

| Sr. No. | Adsorbents                                      | $Q_{\text{max}}$ (mg/g) | Isotherm study  | Kinetics study  | Thermodynamic study |
|---------|------------------------------------------------|-------------------------|----------------|-----------------|---------------------|
| 43      | Cassava (Manihot esculenta) peels based carbon  | –                       | –              | –               | –                   |
| 44      | Rubber wood (Hevea brasiliensis)                | –                       | –              | –               | –                   |
| 45      | Rice husk-based porous carbon                   | –                       | –              | –               | –                   |
| 46      | Ulva lactuca and Systosiera stricta algal-based activated carbon | –               | –              | –               | –                   |
| 47      | Rice husk-based porous carbons (RHCS)           | –                       | –              | –               | –                   |
| 48      | Activated E. tetrasperma carbon                 | –                       | –              | –               | –                   |
| 49      | Activated carbons prepared from the rice husk solid wastes | –               | –              | –               | –                   |
| 50      | Activated parthenium carbon                     | –                       | –              | –               | –                   |
that physical sorption dominates in the process of cationic dyes bonding on microspheres of fly ash.

Bagasse fly ash (BFA) is a waste collected from the particulate separation equipment attached to the flue gas line of the sugarcane bagasse-fired boilers and has been used as an effective adsorbent for the removal of dyes. This is available in plenty, and almost free of cost from the sugar industry does not contain large amounts of toxic metals and hence, Mall et al. (2005) used bagasse fly ash (BFA) as adsorbent for the removal of MG from aqueous solutions. Maximum adsorption capacity for MG was reported as 170.33 mg/g (at pH 7.0 and adsorbent dosage of 1.0 g/L) and within 240 min of contact time.

Waste red mud: Zhang et al. (2014b) used the acid activated (Acid treatment neutralize the alkalinity of red mud, which could also be recognized as a method for activating the material) sintering process red mud (ASRM) for the adsorption of MG. The optimum process variables were found to be pH > 3.2, 180 min of contact time and 0.25 g/250 mL of adsorbent dosage. The adsorption process followed the Langmuir isotherm with 336.40 mg/g of adsorption capacity.

Activated slag: Steel plants produce granular blast furnace slag as a byproduct, and this material also causes a disposal problem. Hence, Gupta et al. (1997) utilized this waste product for the adsorption of MG from aqueous medium both in batch and column modes. Further, they concluded that the column capacity was found to be higher than the batch capacity. The removal takes place through a film diffusion mechanism at lower concentrations and by particle diffusion at higher concentrations.

Natural materials

Clays Clay is mineral comprised of alumina and silica that usually includes bound water. Clays have a sheet-like structure and are composed of tetrahedrally arranged silicates and octahedrally arranged aluminates. Due to their low-cost, abundance in nature, high sorption capacity, chemical and mechanical stability, layered structure and high cation-exchange capacity (CEC), clay minerals are frequently used as an adsorbent (Krauskopf 1956; da Fonseca et al. 2006). The clays always contain exchangeable ions on their surface and play vital role in the environment by acting as a natural scavengers of contaminants by taking up cations and/or anions through either ion exchange or adsorption (Babel and Kurniawan 2003).

A low-cost inorganic powder (Persian Kaolin) was used as adsorbent for the sequestration of cationic dye from aqueous solution by Tehrani-Bagha et al. (2011). The sorption of the dye malachite green on kaolin confirmed to linear form of Langmuir adsorption equation. The maximum adsorption capacity was 52.91 mg/g. In addition, kinetic and thermodynamic parameters, such as enthalpy ($\Delta H$) and free energy ($\Delta G$) were calculated. The negative values of $\Delta G$ and positive values of $\Delta H$ indicated that the dye adsorption process was spontaneous and endothermic in nature.

The efficacy of montmorillonite clay had been investigated by Tahir et al. (2010) for the adsorptive removal of malachite green dye from aqueous solution. Authors concluded that the MG dye was homogenously adsorbed on the surface of montmorillonite clay adsorbent.

Bulut et al. (2008) investigated the sorption of MG from aqueous solution onto bentonite as a function of contact time, pH and initial dye concentration. The adsorption equilibriums have been described in terms of Langmuir, Freundlich, Temkin and Dubinin–Radushkevich models. Authors reported that the adsorption process obeyed the Langmuir isotherm and pseudo-second-order kinetic model. The results of the thermodynamic study indicated that the sorption process was endothermic and spontaneous.

Tahir and Rauf (2006) utilized the natural bentonite clay for the adsorption of MG dye from aqueous solution. The authors finally concluded that the values of sorption free energy ($E_a$) of 1.00–1.12 kJ/mol indicated physical adsorption of dye on clay mineral.

Siliceous materials Siliceous rocks are sedimentary rocks that have silica (SiO$_2$) as the principal constituent. The most common siliceous rock is chert other types include diatomite. They commonly form silica-secreting organisms, such as radiolarians, diatoms, or some types of sponges. The natural siliceous materials used for MG adsorption were perlite, silica, glass fibers and alunite because of their high abundance, easy availability and low cost.

Govindasamy et al. (2009) studied the removal of MG from aqueous solution by perlite. Authors reported 40 min of contact time, 0.1 g/50 mL of adsorbent dosage and 8.0–9.0 pH value were optimum conditions for the removal of dye. It was suggested that the adsorption of MG onto perlite was spontaneous, chemical and exothermic in nature and followed Freundlich isotherm as well as pseudo-first-order kinetic rate model.

Silica gel is a hydrophilic porous adsorbent. Aromatic compounds are found to involve the pi-cloud in hydrogen bonding with silanol (SiOH) group during adsorption. Cationic and nonionic surfactants adsorb on silica surface involving hydrogen bonding (Parida et al. 2006).

Kannan et al. (2008) utilized tetrahedral silica for the adsorption of MG. The adsorbent was characterized by Fourier transformed infrared spectroscopy (FT-IR) to confirm the tetrahedral framework of silica. The
| Sr. No. | Adsorbents                                      | $Q_{\text{max}}$ (mg/g) | Isotherm study          | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References                        |
|--------|------------------------------------------------|------------------------|-------------------------|----------------|---------------------|----|------------------|----------------------|----------------------------------|
| 1.     | Orange Peel                                    | 483.63                 | Langmuir and Redlich–Peterson | –              | –                   | –  | –                | –                    | (Kumar and Porkodi 2007)         |
| 2.     | Pyromellitic dianhydride modified sugarcane bagasse | 377.40                | Langmuir                | Pseudo 2nd order | –                   | 6.0 | 13 h             | –                    | (Yu et al. 2011)                |
| 3.     | NaOH-modified breadfruit peel                  | 353.00                 | Sips                    | Pseudo 2nd order | Exothermic          | 8.02| 240 min          | –                    | (Chieng et al. 2015)            |
| 4.     | NaOH-modified grapefruit peel (MGP)            | 314.90                 | Koble-Corriigan and Dubinin–Radushkevich models | Elovich model | Endothermic         | –  | –                | –                    | (Zou et al. 2013)               |
| 5.     | Oxalic acid modified *Cinnamomum camphora* sawdust (OACS) | 282.50                | Langmuir                | Pseudo 2nd order | Endothermic         | 8.0 | 3 h              | 1.0 g/L              | (Wang et al. 2014a)             |
| 6.     | Modified rice straw (MRS) [rice straw was modified with citric acid (CA)] | 256.41                | Langmuir and Freundlich | Pseudo 1st order | –                   | 6.0 | 10 h             | 2.0 g/L              | (Gong et al. 2006)             |
| 7.     | Citric acid modified *Cinnamomum camphora* sawdust (CACS) | 260.40                | Langmuir                | Pseudo 2nd order | Endothermic         | 8.0 | 3 h              | 1.0 g/L              | (Wang et al. 2014a)             |
| 8.     | Eggshells                                      | 243.20                 | Freundlich              | –              | –                   | 6.0 | –                | 1.0 g/L              | (Podstawczyk et al. 2014)       |
| 9.     | Functionalized sawdust (FS)                    | 196.08                 | Langmuir                | –              | Exothermic          | 6.0 | 4.5 h            | 2.0 g/L              | (Gong et al. 2009)             |
| 10.    | Treated ginger waste (TGW)                     | 188.60                 | Langmuir                | Pseudo 2nd order | Endothermic         | 9.0 | 150 min          | 0.5 g                | (Ahmad and Kumar 2010)          |
| 11.    | Breadfruit peel                                | 180.00                 | Freundlich              | Pseudo 2nd order | Endothermic         | 8.02| 240 min (2 h)    | –                    | (Chieng et al. 2015)            |
| 12.    | Phosphoric acid esterifying soybean hull       | 178.57                 | Langmuir                | Pseudo 2nd order | Exothermic          | 6.0 | –                | 2.0 g/L              | (Gong et al. 2008)             |
| 13.    | Pomelo (*Citrus grandis*) peels                | 178.43                 | Langmuir                | Pseudo 2nd order | Endothermic         | 8.0 | 240 min          | 0.2 g                | (Bello et al. 2014)            |
| 14.    | Treated jack fruit peel                        | 166.37                 | Langmuir                | –              | –                   | –  | –                | –                    | (Inbaraj and Sulochana 2002)     |
| 15.    | Ethylenediaminetetraacetic dianhydride (EDTAD) modified sugarcane bagasse (SB) | 157.20                | Langmuir                | Pseudo 2nd order | Endothermic         | 6.0 | 3 h              | 10 mg                | (Xing and Deng 2009)           |
| 16.    | Tartaric acid modified *Cinnamomum camphora* sawdust (TACS) | 156.70                | Langmuir                | Pseudo 2nd order | Endothermic         | 8.0 | 3 h              | 1.0 g/L              | (Wang et al. 2014a)            |
| 17.    | Oil palm trunk fiber (OPTF)                    | 149.35                 | Langmuir                | Pseudo 1st order | –                   | 8.0 | 195 min          | 0.30 g               | (Hameed and El-Khaiary 2008b)   |
| 18.    | Rice straw-derived char (RSC)                  | 148.74                 | Langmuir                | Pseudo 1st order | –                   | 3.0–7.0| –              | 1.5 g/L              | (Hameed and El-Khaiary 2008c)   |
| 19.    | Effective Microorganisms based compost (EMKC)   | 136.60                 | Sips                    | Pseudo 2nd order | –                   | 8.0 | –                | 4.0 g/L              | (Bhagavathi Pushpa et al. 2015) |
Table 5 continued

| Sr. No. | Adsorbents | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References |
|---------|------------|-------------------------|----------------|---------------|---------------------|----|-----------------|---------------------|------------|
| 21.     | Neem leaf powder | 133.6 | Langmuir | Pseudo 1st order | Endothermic | – | 300 min | 0.63 g/L | (Bhattacharyya and Sarma 2003) |
| 22.     | Formaldehyde-treated Simarouba glauca seed shell powder | 125.00 | Langmuir | Pseudo 2nd order | 8.0 | 60 min | 0.15 g | (Jeyagowri and Yamuna 2015) |
| 23.     | Cellulose modified with phthalic (P) anhydride (CPA) | 111.00 | Langmuir | Pseudo 2nd order | Endothermic | 6.0 | 3 h | (Zhou et al. 2015) |
| 24.     | Poly(methacrylic acid)-modified sugarcane bagasse | 103.20 | Langmuir | Pseudo 2nd order | 6.0 | 25 min | 250 mg/50 mL | (Xing and Wang 2009) |
| 25.     | Brinjal plant root powder (cellulose) | 100.29 | Freundlich | Pseudo 2nd order | Endothermic | 7.0 | – | 2.0 g/L | (Buvaneswari and Kannan 2011) |
| 26.     | Oxidized-activated form HTC-APN | 97.08 | Langmuir | Pseudo 2nd order | Endothermic | 6.0 | 10 h | 5.0 g/L | (Gong et al. 2006) |
| 27.     | Native rice straw | 94.34 | Langmuir and Freundlich | Pseudo 1st order | – | 5.0 | – | 5.0 g/L | (Chowdhury and Saha 2011) |
| 28.     | Conch shell powder (CSP) | 92.25 | Langmuir | Pseudo 2nd order | Endothermic | 8.0 | 120 min | 3.0 g/L | (Rahman et al. 2005) |
| 29.     | 20% Phosphoric acid (H$_3$PO$_4$) treated + carbonized rice husks [PCP 20] | 92.592 | Langmuir and Freundlich | – | Endothermic | 5.0–6.0 | 30 min | 0.6 g/100 mL | (Dahi et al. 2014) |
| 30.     | Walnut shell (WS) | 90.80 | Langmuir | Pseudo 2nd order | Endothermic | 5.0 | 90 | 0.03 g/20 mL | (Rahman et al. 2005) |
| 31.     | 10% Phosphoric acid (H$_3$PO$_4$) treated + carbonized rice husks [PCP 10] | 83.33 | Langmuir and Freundlich | – | Endothermic | 5.0–6.0 | 30 min | 0.8 g/100 mL | (Tavlieva et al. 2013) |
| 32.     | White rice husk ash (WRHA) | 85.56 | Langmuir | Pseudo 2nd order | Exothermic | 7.0 | 120 min | 0.45 g/100 mL | (Gong et al. 2009) |
| 33.     | Crude sawdust (CS) | 85.47 | Langmuir | – | Exothermic | 8.0 | 23 h | 2.0 g/L | (Jalil et al. 2012) |
| 34.     | Bivalve shell-treated Zea mays L. (maize) husk leaf [BS-ZHL] | 81.5 | Langmuir | Pseudo 1st order | Endothermic | 6.0 | 0.5 h | 2.5 g/L | (Sonawane and Shrivastava 2009) |
| 35.     | Maize cob (Zea maize) | 80.64 | Langmuir and Freundlich | Pseudo 2nd order | – | 8.0 | 25 min | 4.0 g/L | (Witek-Krowiak 2013) |
| 36.     | Scots Pine (Pinus silvestris) sawdust | 71.67 | Langmuir | Pseudo 2nd order | – | 5.0 | – | 2.0 g/L | (Ng et al. 2015) |
| 37.     | Luffa acutangula peel | 69.64 | Langmuir | Pseudo 2nd order | Endothermic | 4.0 | – | 8.0 g/L | (Garg et al. 2004) |
| 38.     | Rice bran | 68.97 | Freundlich | Pseudo 2nd order | Spontaneous and physical | 6.0 | 60–90 min | 5.0 g/L | (Wang et al. 2008b) |
| 39.     | Formaldehyde-treated sawdust (PCSD) | 65.80 | – | Pseudo 1st order | – | 6.0–10.0 | 30–45 min | 1.0 g/100 mL | (Rahman et al. 2005) |
| Sr. No. | Adsorbents | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References |
|--------|------------|--------------------------|----------------|---------------|---------------------|----|-----------------|-------------------|------------|
| 40.    | Sulphuric acid-treated sawdust (PCSDC) | 65.8 | – | Pseudo 1st order | – | 6.0 – 10.0 | 30 – 45 min | 1.0 g/100 mL | (Garg et al. 2004) |
| 41.    | Wheat bran | 66.57 | Freundlich | Pseudo 2nd order | Spontaneous and physical | 6.0 | 60 – 90 min | 5.0 g/L | (Wang et al. 2008b) |
| 42.    | Lignocellulosic material (TA modified oil palm tree sawdust) | 65.79 | Langmuir | Pseudo 2nd order | Endothermic | 9.0 | 210 min | 1.0 g/200 mL | (Low et al. 2013) |
| 43.    | Rattan sawdust (RSD) | 62.71 | Langmuir | Pseudo 1st order | – | 4.0 – 9.0 | 210 min | 0.30 g | (Hameed and El-Khaiary 2008d) |
| 44.    | Eucalyptus bark | 59.88 | Langmuir | Pseudo 2nd order | Endothermic | 5.0 | 270 min | 1.0 g/200 mL | (Boutemedjet and Hamdaoui 2009) |
| 45.    | NaOH treated saw dust | 58.4795 | R–P and Temkin | Pseudo 2nd order | Exothermic | 2.9 | 3 h | 4 g/L | (Mane and Babu 2011) |
| 46.    | Sodium hydroxide (NaOH) treated + carbonized rice husks [NCP] | 57.143 | Langmuir | – | Exothermic | 5.0 – 6.0 | 30 min | 0.6 g/100 mL | (Rahman et al. 2005) |
| 47.    | Eggshell | 56.76 | Langmuir and Freundlich | Pseudo 2nd order | Endothermic | 9.0 | 90 min | 2.0 g/L | (Chowdhury and Das 2012) |
| 48.    | Degreased coffee bean | 55.3 | Langmuir and Freundlich | Pseudo 2nd order | Endothermic | 4.0 | 120 min (2 h) | 2.0 g/L | (Bæk et al. 2010) |
| 49.    | Tamarind seed | 54.95 | Langmuir | Pseudo 1st order | – | 7.0 | 202 min | 2.85 g/L | (Rajeshkannan et al. 2011) |
| 50.    | Aerobic granules | 56.80 | Langmuir | Pseudo 2nd order | Endothermic | Alkaline pH | 60 min (50–60 mg/L) | 0.09 g | (Sun et al. 2008) |

| 51. | Ananas comosus (pineapple) leaf powder | 54.64 | Langmuir | Pseudo 2nd order | Exothermic | 9.0 | 150 min | 5.0 g/L | (Chowdhury et al. 2011a) |
| 52. | Hydrothermal carbonization of pine needles (HTC-PN) | 52.91 | Langmuir | Pseudo 2nd order | Endothermic | 7.0 | – | 2.0 g/L | (Hammud et al. 2015) |
| 53. | Lemon peel | 51.73 | Langmuir and Redlich–Peterson | – | – | – | 24 h | 0.5 g/L | (Kumar 2007) |
| 54. | Pine tree root decayed by brown-rot fungi (BRW) | 42.63 | Langmuir | Pseudo 2nd order | Endothermic | 4.0 | 24 h | 3.95 g/L | (Zhang et al. 2011) |
| 55. | Sea shell powder | 42.33 | Langmuir | Pseudo 2nd order | Exothermic | 8.0 | 120 min | 2.0 g/L | (Chowdhury and Saha 2010a) |
| 56. | Limonia acidissima (wood apple) shell | 34.56 | Langmuir | Pseudo 1st order | Endothermic | 7.5–8.0 | 210 min (3.30 h) | 0.4 g | (Sartape et al. 2015) |
| Sr. No. | Adsorbents                                               | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study       | Thermodynamic study | pH    | Equilibrium time | Dosage of adsorbent | References                               |
|---------|----------------------------------------------------------|--------------------------|----------------|----------------------|---------------------|-------|------------------|-------------------------------|------------------------------------------|
| 57.     | Jalshakti® (JS), a super absorbent polymer              | 34.2                     | Langmuir       | Intraparticle        | –                   | –     | 60–90 min        | 0.8 g/L                       | (Dhodapkar et al. 2007)               |
| 58.     | Potato leaves powder, PLP                                | 33.30                    | Freundlich     | Pseudo 2nd order    | Exothermic          | 7.0   | 2.0 g/L          | (Gupta et al. 2014)           |
| 59.     | Fish (Labeo rohita) Scales                             | 38.461                   | Langmuir       | Pseudo 2nd order    | Endothermic         | 8.0   | 60 min           | 2.0 g/L                       | (Chowdhury et al. 2012)           |
| 60.     | Rubber wood (Hevea brasiliensis) sawdust                | 36.45                    | Langmuir and Redlich–Peterson | – | – | – | – | (Vasanth Kumar and Sivanesan 2007) |
| 61.     | Luffa cylindrica                                        | 29.40                    | Langmuir       | Pseudo 2nd order    | Endothermic         | 5.0   | 5 h              | 0.05 g                        | (Altınış et al. 2010)              |
| 62.     | Potato stem powder (PSP)                                | 27.0                     | Freundlich     | Pseudo 2nd order    | Exothermic          | 7.0   | 2.0 g/L          | (Gupta et al. 2014)           |
| 63.     | Peroxide treated rice husk (PRH)                       | 26.60                    | Langmuir       | Pseudo 2nd order    | Endothermic         | 8.0   | 90 min           | 200 mg/100 mL                 | (Ramaraju et al. 2014)            |
| 64.     | Hen feathers                                            | 26.10                    | Langmuir       | Pseudo 1st order    | Endothermic         | 5.0   | 150 min          | 0.1 g                         | (Mittal 2006)                     |
| 65.     | Marine alga Caulerpa Racemosa var. cylindracea (CRC)    | 25.67                    | Freundlich     | Pseudo 2nd order    | Endothermic         | 6.0   | 300 min          | 0.1 g/25 mL                   | (Bekçi et al. 2009)              |
| 66.     | Mesoporous aluminophosphate (AlPO₄) molecular sieve    | 24.51                    | Langmuir       | Pseudo 2nd order    | Endothermic         | 10.0  | 20 min           | 0.5 g                         | (Kannan et al. 2013)             |
| 67.     | Wheat bran                                              | 24.0                     | Freundlich     | –                    | –                   | 7.0–9.0| 40 min           | –                             | (Papinutti et al. 2006)          |
| 68.     | Sugarcane Bagasse (SB)                                  | 23.41                    | Langmuir       | Pseudo 2nd order    | Endothermic         | 6.0   | 3 h              | 10 mg                         | (Xing and Deng 2009)             |
| 69.     | Nitric acid treated rice husk (NRH)                    | 18.10                    | Langmuir       | Pseudo 2nd order    | Endothermic         | 8.0   | 90 min           | 200 mg/100 mL                 | (Ramaraju et al. 2014)            |
| 70.     | Chemically modified rice husk                          | 17.98                    | Freundlich     | Pseudo 2nd order    | Endothermic         | 7.0   | 60 min           | 1.0 g/L                      | (Chowdhury et al. 2011b)         |
| 71.     | Rapeseed press cake                                     | 17.857                   | Langmuir       | Pseudo 2nd order    | Endothermic         | 6.5   | 180 min          | 2.5 mg/L                     | (Jasińska et al. 2013)           |
| 72.     | Char from lotus seed biomass                            | 16.75                    | Langmuir and Freundlich | – | – | 6.84 | – | 1.5 g/150 mL | (Netaji et al. 2013) |
| 73.     | Citric acid (CA) treated pea shells (CAPS)              | 14.49                    | Freundlich     | Pseudo 2nd order    | Endothermic         | 7.0   | 35–40 min        | 6.0 g/L                       | (Khan et al. 2014)               |
| 74.     | Waste Pea (Pisum sativum L.) shell (PS)                 | 6.20                     | Freundlich     | Pseudo 2nd order    | Endothermic         | 7.0   | 35–40 min        | 10.0 g/L                      | (Khan et al. 2014)               |
| Sr. No. | Adsorbents                          | \( Q_{\text{max}} \) (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH  | Equilibrium time | Dosage of adsorbent | References |
|--------|-----------------------------------|-----------------------------|----------------|----------------|---------------------|-----|------------------|---------------------|------------|
| 75.    | Sugar cane dust                   | 4.88                        |                |                |                     |     |                  |                     | (Khattri and Singh 1999) |
| 76.    | Neem sawdust                       | 4.354                       | Langmuir       | Pseudo 1st order | Exothermic          | 7.2 | –                | –                   | (Khattri and Singh 2009) |
| 77.    | Poultry feathers                   | 3.55                        | Langmuir       | Pseudo 1st order | Endothermic         | 4.0 | 120 min          | 0.2 g/100 mL        | (Beak et al. 2009) |
| 78.    | Neem saw dust                      | 3.420                       | Langmuir       | –              | Exothermic          | 7.5 | –                | –                   | (Khattri and Singh 2000) |
| 79.    | Tamarind fruit shell               | 1.951                       | Langmuir       | Pseudo 2nd order | Endothermic         | 5.0 | 60 min           | 30 g/L              | (Saha et al. 2010a) |
| 80.    | Mango bark powder (MBP)            | 0.53 mmol/g                 | Langmuir       | Pseudo 2nd order | Endothermic         | 6.03| 150 min          | 2.0 g/50 mL         | (Srivastava and Rupainwar 2011) |
| 81.    | Neem bark powder (NBP)             | 0.36 mmol/g                 | Langmuir       | Pseudo 2nd order | Endothermic         | 6.80| 120 min          | 2.0 g/50 mL         | (Srivastava and Rupainwar 2011) |
| 82.    | Seashell powder                    | –                           | –              | –              | –                   |     | –                | –                   | (Chowdhury and Saha 2012) |
| 83.    | Eggshell powder                    | –                           | –              | –              | –                   |     | –                | –                   | (Chowdhury and Saha 2012) |
| 84.    | Mesoporous borosilicates (MBS)     | –                           | –              | –              | –                   |     | –                | –                   | (Paul et al. 2012) |
| 85.    | Kapok hull                         | –                           | Langmuir       | Pseudo 2nd order | Endothermic         |     |                  | –                   | (Syed 2011) |
| 86.    | Used black tea (UBT)               | –                           | –              | –              | Exothermic          |     | 10 min           | 0.7 g               | (Tahir et al. 2009) |
| 87.    | Formaldehyde treated and sulphuric acid treated saw dusts | –                           | –              | –              | –                   | 6.9–9.0 | 120 min          | 0.4 g/100 mL        | (Garg et al. 2003) |
| 88.    | NaOH-modified rice husk (NMRH)     | –                           | –              | –              | –                   | 10.0| –                | –                   | (Chowdhury and Saha 2013) |
| 89.    | Sea shell                          | –                           | Pseudo 2nd order | –              | Exothermic          | –   | –                | –                   | (Chowdhury and Saha 2010b) |
| 90.    | Sagaun sawdust                     | –                           | Langmuir       | –              | –                   | 7.5 | –                | –                   | (Khattri and Singh 1999) |
| 91.    | Pretreated rice husk               | –                           | Pseudo 2nd order | –              | –                   | –   | –                | –                   | (Chowdhury and Saha 2011b) |
| 92.    | Sugar cane dust                    | –                           | Langmuir       | –              | –                   | 7.5 | –                | –                   | (Dadhaniya et al. 2006) |
| 93.    | Snail shell (SS)                   | –                           | –              | –              | –                   | –   | –                | –                   | (Oladoja and Aliu 2009) |
thermodynamic studies proved that the adsorption was endothermic and chemisorptions ($\Delta H^0 > 40$ kJ/mol) on silica. Recovery of dye on silica was studied from 30 to 90 $^\circ$C and observed that only 3.5% was recovered from silica. The less recovery on silica proved the strong adsorption of dye on silica.

Talc is the most common silicate material, with an idealized chemical formula of $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$. Its ability to remove aqueous MG from solution had been studied by Lee et al. (2013).

Zeolites Zeolites are highly porous crystalline aluminosilicates with tetrahedrally connected three dimensional frameworks and extra-framework charge balancing cations. Zeolite structures are commonly described in terms of the size, geometry and connectivity of the pore space. The use of natural zeolite as an adsorbent has gained interest among researchers; mainly because of its sorption properties provide a combination of ion exchange and molecular sieve properties which can also be easily modified (Goursot et al. 1997; Sánchez and Pariente 2011).

Zeolites have been used as chemical sieves, as water softeners, as removers of ammonia from urban, agricultural and industrial waste waters and of toxic gases from gaseous emissions, as filters for odor control, as chemical fertilizer, herbicide and pesticide carriers and in animal nutrition (Sand and Mumpton 1978; Breck 1984; Karge and Weitkamp 1989).

Han et al. (2010) investigated the use of natural zeolite, obtained from Xinyang city in China, for the removal of MG from aqueous solution. The rate constants of sorption for different kinetic models were calculated. Good correlation coefficients were obtained for the pseudo-second order kinetic model. In addition, authors were treated spent zeolite by microwave irradiation and it was found that yield of regeneration was 85.8% in the case of microwave irradiated time 10 min at 160 W.

Table 7 represented the maximum adsorption capacities together with the isotherm, kinetics and thermodynamic results of various natural materials used for the removal of MG

**Biosorbents**

Biosorption is defined as the accumulation and concentration of pollutants from aqueous solutions by the use of biological materials. Biological materials, such as yeast, fungi or bacterial biomass and biopolymers are used as adsorbents for the removal of MG from aqueous media (Raval et al. 2016d; Gupta et al. 2015).
to both animal and vegetable derived material. The major advantages of biosorption over conventional treatment methods include, low cost; high efficiency; minimization of chemical or biological sludge; no additional nutrient requirement and possibility of regeneration of biosorbent (Volesky 1990).

Decolorization/bioadsorption of MG dye from wastewater by (dead/living) biomass of submerged aquatic plant (Rajesh Kannan et al. 2010); white-rot fungi (Kuhar and Papinutti 2013); fresh water algae (Kumar et al. 2005); brown marine algae (Kannan et al. 2009) and immobilized baker’s yeast cells (Godbole and Sawant 2006) were studied by many researchers (shown in Table 8).

Wang (2009) used alligator weed (a freshwater macrophyte) as biosorbent for the removal of basic dye malachite green from aqueous solution mainly because alligator weed, originated from South America, occupies agricultural areas and blocks drainage and irrigation channels causing problems on agricultural land. In addition, it causes water pollution from plant decomposition and an increase in mosquito breeding areas. Finally, author concluded that the alligator weed could serve as low-cost adsorbents for removing MG from aqueous medium.

Parthenium (Parthenium hysterophorus L.), also known as white top or carrot weed, an annual herbaceous weed was pretreated with H₃PO₄ and H₂SO₄ by Lata et al. (2008) and employed for the adsorption of MG dye.

**Biopolymers**

Biopolymers are high molecular weight compounds synthesized by living organisms. The performance of chitin hydrogel as an adsorbent to remove MG has been demonstrated by Tang et al. (2012). They found that the maximum adsorption capacity of hydrogel for MG was 26.88 mg/g. Authors concluded from the calculated activation energy (37.18 kJ/mol) and from the results of SEM and FTIR that the adsorption of malachite green on the hydrogel was physical process.

Bekçİ et al. (2008) synthesized chitosan beads and examined its adsorption capacity towards MG. In contrast to the chitin hydrogels the authors concluded from the calculated activation energy (85.6 kJ/mol) that the adsorption of MG onto chitosan beads was chemical in nature.

Although chitin and chitosan are abundantly available biopolymers and are biocompatible and biodegradable material, they have less chemical versatility due to their strong crystal structure, and hence their chemical structures

| Sr. No. | Adsorbents | Q_{max} (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References |
|---------|------------|----------------|----------------|----------------|---------------------|----|------------------|---------------------|------------|
| 1.      | Acid-activated sintering process red mud (ASRM) | 336.40 | Langmuir | Pseudo 2nd order | Endothermic | >3.2 | 180 min | 0.25 g/250 mL | (Zhang et al. 2014b) |
| 2.      | Bagasse fly ash | 170.33 | Freundlich | Pseudo 2nd order | – | 7.0 | 240 min | 1 g/L | (Mall et al. 2005) |
| 3.      | Activated Slag | 74.16 (batch capacity) 78.00 (column capacity) | Langmuir and Freundlich | Pseudo 1st order | Endothermic | 10.0 | 6–8 h | 1.0 g/L | (Gupta et al. 1997) |
| 4.      | Fly ash | 40.65 | Langmuir | Pseudo 2nd order | Endothermic | >6.0 | – | 2.0 g/L | (Witek-Krowiak et al. 2012) |
| 5.      | Ca(OH)₂ –Treated Fly Ash | 17.383 | Langmuir | Pseudo 2nd order | Exothermic | 7.0 | 120 min | 1.0 g | (Chowdhury and Saha 2011a) |
| 6.      | Bottom ash | 6.2 × 10⁻³ | Langmuir | Pseudo 2nd order | Endothermic | 5.0 | 4500 s | 0.1 g | (Gupta et al. 2004) |
| 7.      | Carbon based adsorbents [waste material from paper industry (WMPI) and pine bark (PB)] | – | – | – | – | – | – | 0.05 mg/20 mL | (Méndez et al. 2007) |
Table 7 The maximum adsorption capacities and other optimal conditions of various natural materials for adsorption of MG from aqueous solutions

| Sr. No. | Adsorbents                                      | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | Reference                              |
|---------|-------------------------------------------------|--------------------------|----------------|----------------|---------------------|----|------------------|---------------------|----------------------------------------|
| 1       | Surfactant-modified alumina (SMA)               | 185.00                   | Langmuir       | –              | –                   | 1 h | 1.0 g/L          | 1.0 g/L             | (Das et al. 2009a)                     |
| 2       | Sodium dodecyl sulfate (SDS) modified alumina   | 185.00                   | Langmuir       | –              | –                   | 1 h | 1.0 g/L          | 1.0 g/L             | (Das et al. 2009b)                     |
| 3       | Bentonite                                       | 178.60                   | Langmuir       | Pseudo 2nd order | Endothermic         | 5.0 | 60 min          | 1 g/L               | (Bulut et al. 2008)                  |
| 4       | Aminopropyl functionalized magnesium phyllosilicate (AMP) clay | 130.64                   | Langmuir       | Pseudo 1st order | Endothermic         | 9.8 | 180 min        | 0.1 mg/mL          | (Lee et al. 2011)                     |
| 5       | Clayey soil of Indian origin                    | 78.57                    | Langmuir       | Pseudo 2nd order | Exothermic         | 6.0 | 90 min          | 3 g/L               | (Saha et al. 2010b)                   |
| 6       | Kaolin                                          | 65.42                    | Langmuir       | Pseudo 2nd order | Exothermic         | 7.0 | 90 min          | 2 g/L               | (Nandi et al. 2009)                   |
| 7       | Non-tetrahedral alumina                         | 61.35                    | Langmuir       | –              | Endothermic         | 5.0 | 4 h             | 250 mg/50 mL       | (Kannan et al. 2008)                  |
| 8       | Organically modified clay                       | 56.82                    | Langmuir       | Pseudo 2nd order | Endothermic         | 6.0 | 30 min          | –                   | (Arellano-Cárdenas et al. 2013)       |
| 9       | Low-cost inorganic powder (Persian Kaolin)      | 52.91                    | Langmuir       | Pseudo 2nd order | Endothermic         | 7.0 | 5 min           | 0.8 g/L             | (Tehrani-Bagha et al. 2011)           |
| 10      | Bentonite clay                                  | 7.716                    | Langmuir, Freundlich and D–R | Pseudo 1st order | Endothermic         | 9.0 | 10 min         | 0.05 g              | (Tahir and Rauf 2006)                 |
| 11      | Surfactant-Coated Alumina (SDS-Al2O3)           | 2.78                     | –              | –              | –                   | 4.7 | –               | 500 mg              | (Farhadi et al. 2010)                |
| 12      | Rarasaponin–bentonite                           | 0.93 mmol/g              | Langmuir       | –              | –                   | 8.0 | 2 h             | –                   | (Kurniawan et al. 2012)               |
| 13      | Natural kaolinitic-clay                         | 0.64 mmol/g              | Langmuir       | –              | Exothermic         | 7.0 | 1 day          | 1.0 g/L             | (Issa et al. 2014)                    |
| 14      | Iron humate (IH)                                | 0.0527 mmol/g            | Langmuir       | –              | –                   | –   | –               | –                   | (Janoš 2003)                         |
| 15      | Natural rarasaponin modified kaolin             | –                        | Sips           | Pseudo 1st order | Exothermic         | –   | –               | –                   | (Suwandi et al. 2012)                 |
| 16      | Inorganic–organic pillared clay granules        | –                        | Langmuir       | Pseudo 1st order | –                   | 6.0 | 120 min        | –                   | (Cheknane et al. 2010)                |
| 17      | Montmorillonite                                 | –                        | Langmuir       | –              | Endothermic         | –   | –               | 0.1 g               | (Tahir et al. 2010)                   |
| 18      | Organomineral sorbent–iron humate               | –                        | –              | Pseudo 2nd order | –                   | –   | –               | –                   | (Janoš and Šmídová 2005)              |
| 19      | Bentonite                                       | –                        | Temkin and Redlich-Peterson isotherms | – | – | 8.2 | 60 min | 1.0 g | (Özdemir and Keskin 2009) |
have been modified to overcome this undesirable characteristic. In an effort to increase the chemical versatility and adsorption efficiency, chitin and chitosan biopolymers have been modified or crosslinked by various surfactants and crosslinking agents.

Huang et al. (2012) explored the use of Chitin grafted poly (acrylic acid) (chi-g-PAA) for the removal of MG from wastewater and concluded that the carboxylic groups that are grafted to the surface of chitin can be hydrolyzed to a sodium salt using dilute NaOH (aq) and can be readily utilized to adsorb malachite green from aqueous solution. The monolayer adsorption capacity obtained was 285.70 mg/g which was 10 times higher than the chitin hydrogels (26.88 mg/g).

Wan Ngah et al. (2010) studied the removal of MG from aqueous solutions through adsorption on to chitosan coated bentonite beads. The characterization of adsorbents was performed by Fourier Transform Infrared (FTIR) spectroscopy, scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS) and X-ray diffraction (XRD) analysis. Authors mentioned that the monolayer adsorption capacity obtained was 435.00 mg/g which was five times greater than the chitosan beads (93.55 mg/g).

**Peat** Peat is a porous and complex natural material, widely available and studied as an alternative adsorbent for different pollutants as well as dyes (Raval et al. 2016c).

Coco-peat was used by Vijayaraghavan et al. (2015) as an adsorbent to study the adsorption of malachite green and crystal violet from wastewater. It was found that a contact time of 60 min was sufficient for the adsorption to reach equilibrium. The optimum pH was found to be 7.0. The data for the adsorption of MG was described well by both the Sips adsorption isotherm model. The adsorption process was found to be endothermic.

**Nanomaterials**

Typical nanomaterials include nanotubes, nanoparticles, nanofibers, nanorods, fullerences, and nanowires (Schmidt et al. 2002; Gupta and Saleh 2013; Gupta and Nayak 2012; Saravanan et al. 2013, 2014).

Carbon nanotubes were discovered accidentally by Iijima (1991), while studying the surfaces of graphite electrodes used in an electric arc discharge. CNTs are divided into two types based on the arrangement of their graphene cylinders: (1) single-walled CNTs (SWCNTs)
| Sr. No. | Adsorbents | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References |
|--------|------------|-------------------------|----------------|----------------|---------------------|----|------------------|---------------------|------------|
| 1      | Freshwater macrophyte alligator weed | 185.54 | Langmuir | – | Ritchie second-order | 6.0 | – | 7.0 g/L | (Wang 2009) |
| 2      | *Firmiana simplex* wood fiber | >142.40 | Freundlich | – | Pseudo 2nd order | 11.0 | 180 min | 0.25 g | (Pan and Zhang 2009) |
| 3      | *Pleurotus ostreatus* (A macro-fungus) | 125.00 | Freundlich | – | Pseudo 2nd order | 8.0 | 240 min | 4.0 g/L | (Chen et al. 2014) |
| 4      | *Pithophora* sp., a fresh water algae | 117.65 | Redlich-Peterson | – | Pseudo 2nd order | 5.0 | 8 h | 0.015 g | (Kumar et al. 2005) |
| 5      | *Hydrilla verticillata* biomass | 91.97 | Freundlich | – | Pseudo 2nd order | 8.0 | 200 min | 0.26 g | (Rajeshkannan et al. 2010) |
| 6      | Ashoka (*Saraca asoca*) leaf powder (ALP) | 83.30 | Freundlich | – | Pseudo 2nd order | 6.0 | 25 min | 2.0 g/L | (Gupta et al. 2012) |
| 7      | *Hydrilla Verticillata* Biomass | 69.88 | Langmuir | – | Pseudo 1st order | 8.0 | 150 min | 0.55 g | (Rajesh Kannan et al. 2010) |
| 8      | *Turbinaria conoides* brown marine algae | 66.60 | Langmuir | – | Pseudo 2nd order | 8.0 | 150 min | 0.55 g | (Kannan et al. 2009) |
| 9      | Native anaerobic granular sludge | 61.73 | Langmuir | – | Pseudo 2nd order | 5.0 | 2 h | 2.4 g/L | (Cheng et al. 2008) |
| 10     | Heat-treated anaerobic granular sludge | 59.17 | Langmuir | – | Pseudo 2nd order | 5.0 | 2 h | 2.4 g/L | (Cheng et al. 2008) |
| 11     | Eriobotrya japonica (Thunb.) Lindley (Loquat) seed biomass | 57.47 | Langmuir | – | Pseudo 2nd order | 5.0 | 60 min | 10.0 g/L | (Aksakal et al. 2009) |
| 12     | *Daucus carota* plant (carrot leaves powder: CLP) | 52.60 | Freundlich | – | Pseudo 2nd order | 7.0 | 30 min | 2.0 g/L | (Kushwaha et al. 2014) |
| 13     | Mango (*Mangifera indica* L.) seed husks [MSH] | 47.90 | Freundlich | – | Pseudo 2nd order | 5.0 | 2 h | 5.0 g/L | (Franca et al. 2010b) |
| 14     | *Daucus carota* plant (carrot stem powder: CSP) | 43.40 | Freundlich | – | Pseudo 2nd order | 7.0 | 30 min | 2.0 g/L | (Kushwaha et al. 2014) |
| 15     | Dead needles of Aleppo pine (*Pinus halepensis*) | 33.56 | Freundlich | – | Intraparticle diffusion | – | 330 min | 0.5 g/300 mL | (Hamdaoui et al. 2008a) |
| 16     | Almond Shell (*Prunus dulcis*) | 29.0 | Langmuir | – | Pseudo 2nd order | 5.0 | 2 h | 0.2 g/50 mL | (Ozdes et al. 2010) |
| 17     | Phosphoric acid treated Parthenium hysterophorus Linn. Biomass (PWC) | 25.00 | Langmuir | – | Pseudo 2nd order | 7.0 | 90 min | 0.2 g/50 mL | (Lata et al. 2008) |
| 18     | Microwave assisted zinc chloride activated epicarp of *Ricinus communis* (ZRC) | 24.39 | Langmuir | – | Pseudo 2nd order | 5.0 | – | 0.2 g/mL | (Makeswari and Santhi 2013) |
| 19     | Immobilized *Saccharomyces cerevisiae* | 17.0 | Freundlich | – | – | – | – | – | (Godbole and Sawant 2006) |
| 20     | Sulfuric acid treated Parthenium hysterophorus Linn. Biomass | 16.81 | Langmuir | – | Pseudo 2nd order | 7.0 | 90 min | 0.2 g/50 mL | (Lata et al. 2008) |
| 21     | Microwave activated epicarp of *Ricinus communis* (MRC) | 12.65 | Langmuir | – | Pseudo 2nd order | 5.0 | – | 0.2 g/mL | (Makeswari and Santhi 2013) |
and (2) multi-walled CNTs (MWCNTs) (Khani et al. 2010; Saleh and Gupta 2011).

MWCNTs are collections of several concentric graphene cylinders and are larger structures compared to SWNTs which are individual cylinders of 1–2 nm diameter. The former can be considered as a mesoscale graphite system, whereas the latter is truly a single large molecule (Odom et al. 1998). The mechanisms by which the dye molecules are sorbed onto CNTs are very complicated and appear attributable to electrostatic attraction, sorption, precipitation and chemical interaction between the reactive groups of dye molecules and the surface functional groups of CNTs.

Recently, Rajabi et al. (2016) functionalized MWCNTs with the carboxylate group and used as an adsorbent for the rapid and fast removal of MG dye from the aqueous solutions. The optimized contact time and pH were 10 min and 9, respectively. The effect of temperature revealed that the adsorption capacity of MG dye increased with increasing contact time, temperature and pH. The

| Sr. No. | Adsorbents | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References |
|---------|------------|-------------------------|----------------|----------------|---------------------|----|------------------|---------------------|------------|
| 22.     | Hydrilla verticillata biomass | – | – | – | – | 8.4 | 194.50 min | 11.14 g/L | (Rajeshkannan et al. 2009) |
| 23.     | Pithophora sp., a fresh water algae | – | – | Pseudo 1st order | – | 6.0 | – | – | (Vasanth Kumar et al. 2006) |
| 24.     | Yeast S. cerevisiae MTCC 174 | – | – | Pseudo 2nd order | Endothermic | 6.88 | 60 min | 0.49 g | (Singh et al. 2012) |
| 25.     | Chlorella-based biomass | – | – | Pseudo 2nd order | – | 7.0 | 2.0 g/2.0 dm$^3$ | (Tsai and Chen 2010) |
| 26.     | White-rot fungus Ganoderma lucidum | – | – | – | – | – | – | – | (Kuhar and Papinutti 2013) |
| 27.     | Carboxymethyl cellulose-acrylic acid | 555.56 | Temkin | Pseudo 2nd order | Endothermic | – | 120 min (1 h) | – | (Zhang et al. 2014a) |
| 28.     | Chitosan coated bentonite (CCB) beads | 435.0 | Freundlich | Pseudo 2nd order | – | 6.0 | 30 min | 0.01 g/50 mL | (Wan Ngah et al. 2010) |
| 29.     | Cellulose modified with maleic anhydride (CMA) | 370.00 | Langmuir | Pseudo 2nd order | Exothermic | – | – | – | (Zhou et al. 2015) |
| 30.     | Amylopectin and poly(acrylic acid) (AP-g-PAA) | 352.11 | Langmuir | Pseudo 2nd order | Endothermic | 7.0 | 30 min | 50 mg | (Sarker et al. 2014) |
| 31.     | Chitin grafted poly(acrylic acid) | 285.70 | Langmuir | – | – | – | – | – | (Huang et al. 2012) |
| 32.     | Chitosan beads | 93.55 | Langmuir | Pseudo 2nd order | Endothermic | 8.0 | 300 min (5 h) | 10 g/L | (Bekçi et al. 2008) |
| 33.     | Cyclodextrin-based adsorbent | 91.90 | Langmuir | Pseudo 2nd order | – | 8.0 | 120 min | 0.15 g | (Crini et al. 2007) |
| 34.     | Lignin sulfonate polymer | 70.077 | Langmuir | Pseudo 2nd order | Endothermic | 7.0 | 300 min | 0.05 g | (Tang et al. 2014) |
| 35.     | Bio-polymer (Cellulose) | 2.422 | Langmuir and Freundlich | Pseudo 2nd order | Exothermic | 7.2 | 30 min (0.5 h) | 5 g/L | (Pradeep Sekhar et al. 2009) |
| 36.     | Chitin hydrogels | 26.883 | Langmuir | Pseudo 2nd order | Endothermic | 7.0 | 25 h | – | (Tang et al. 2012) |
| 37.     | Coco-peat | 276.80 | Sips | Pseudo 1st order | Endothermic | 7.0 | 60 min | 0.2 g/100 mL | (Vijayaraghavan et al. 2015) |
| 38.     | Peat of Brunei Darussalam (Keramut peat) | 0.31 mmol/g | Redlich-Peterson (R–P) model | Pseudo 2nd order | Endothermic | 6.0 | 4 h | 0.050 g | (Chiang et al. 2014) |
| Sr. No. | Adsorbents                                                                 | Qₘₐₓ (mg/g) | Isotherm | Kinetics | Thermodynamic | pH | Equilibrium time | Dosage of adsorbent | References                          |
|--------|-----------------------------------------------------------------------------|-------------|----------|----------|---------------|----|------------------|---------------------|-------------------------------------|
| 1.     | Copper nanowires loaded on activated carbon                                 | 434.80      | Langmuir | Pseudo   | –             | 5.0| 20 min           | 0.1 g               | (Ghaedi et al. 2015)              |
| 2.     | Zinc oxide nanoparticle loaded on activated carbon (ZnO-NP-AC)              | 322.58      | Langmuir | Pseudo   | –             | 7.0| 15 min           | 0.005 g              | (Ghaedi et al. 2014)             |
| 3.     | Metal oxide nanoparticles (ZnO)                                             | 310.50      | Langmuir and Freundlich | Pseudo | 2nd order | 8.0| 120 min          |                     | (Kumar et al. 2013)              |
| 4.     | Maghemite nanoparticles (γ-Fe₂O₃)                                          | 227.30      | Langmuir | –        | –             | 3.0| –                | 0.10 g               | (Afkhami et al. 2010)            |
| 5.     | Metal oxide nanoparticles (SnO₂)                                            | 216.90      | Langmuir and Freundlich | Pseudo | 2nd order | 8.0| 120 min          |                     | (Kumar et al. 2013)              |
| 6.     | Gold nanoparticles loaded on activated carbon (Au-NP-AC)                    | 164.57      | Langmuir | Pseudo   | Endothermic   | 7.0| 4.4 min          | 0.015 g              | (Roosta et al. 2014)            |
| 7.     | N-Benzyl-Ο-carboxymethylchitosan magnetic nanoparticles (OC-BzM)           | 144.79      | Langmuir and Freundlich | Pseudo | 2nd order | 7.0| 60 min           | 25 mg                | (Debrassi et al. 2012)           |
| 8.     | Functionalized multi wall carbon nanotubes (f-MWCNTs)                       | 142.85      | Langmuir | Pseudo   | –             | 7.0| 80 min           | 0.08 g/100 mL        | (Shirmardi et al. 2013)          |
| 9.     | NiO nano flake-based flowerlike architectures                               | 142.08      | Langmuir | Pseudo   | Endothermic   | 7.0| –                | 333.3 mg/L           | (Wei et al. 2014)              |
| 10.    | Silver nano particles (AgOH-NP) loaded on activated carbon prepared from Rosa canina tree (AgOH-NP-AC-RC) | 105.00      | Freundlich | Pseudo | 2nd order | 8.0| 20 min           | 0.09 g/50 mL         | (Tavakol et al. 2015)           |
| 11.    | Superparamagnetic sodium alginate-coated Fe₂O₄ nanoparticles (Alg–Fe₂O₄)   | 47.84       | Langmuir | Pseudo   | Endothermic   | 9.0| 20 min           | 0.1 g/50 mL          | (Mohammadi et al. 2014)         |
| 12.    | Cadmium hydroxide nanowires loaded on activated carbon (Cd(OH)₂-NW-AC)     | 19.0        | Langmuir | Pseudo   | Endothermic   | –  | –                | –                    | (Ghaedi and Mosallanejad 2014)   |
| 13.    | Melamine supported magnetic iron oxide nanoparticles (Fe₃O₄@Mel)           | 9.06        | Freundlich | Pseudo | 2nd order | 6.5| 240 min          | 0.3 g                | (Mirzjani and Ahmadi 2015)       |
| 14.    | Citrate stabilized magnetite nanoparticles                                  | 0.704       | Freundlich | Pseudo | 2nd order | 4.0| –                | 10 mg                | (Mishra et al. 2014)            |
| 15.    | FeCl₂/FeCl₃/perlite magnetic nanoparticles (FeCl₂/FeCl₃/PMNs)              | 0.01        | BET       | Pseudo   | –             | 6.0| 120 min          | 0.05 g               | (Heydartaemeh et al. 2014)       |
| 16.    | MnO₂ nanosheets                                                             | –           | –         | Pseudo   | 1st order    | 5.6| 120 min          | 0.5 g/L              | (Saha and Pal 2014)            |
| 17.    | Green tea extract based iron nanoparticles (GT-Fe NPs)                     | –           | –         | Pseudo   | 1st order    | 9.0| –                | 1.12 g/L             | (Weng et al. 2013)             |
| Sr. No. | Adsorbents                                                                 | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References                  |
|--------|------------------------------------------------------------------------------|------------------------|----------------|----------------|---------------------|----|------------------|---------------------|--------------------------|
| 18     | TiO$_2$ nanoparticles                                                        | –                      | –              | Pseudo 2nd order | –                   | 6.9 | –                | 3.0 g/L             | (Suresh and Annadurai 2013) |
| 19     | Iron nanoparticles (Fe NPs)                                                  | –                      | –              | –              | –                   | –   | –                | –                   | (Huang et al. 2014)       |
| 20     | Reduced graphene oxide (RGO–Fe$_3$O$_4$ nanoparticles (NPs)                 | –                      | –              | –              | –                   | –   | –                | –                   | (Geng et al. 2012)        |
| 21     | Halloysite nanotubes (HNTs)                                                 | 99.60                  | Langmuir       | Pseudo 2nd order | Endothermic         | 9.5 | 30 min           | 0.2 g               | (Kiani et al. 2011)       |
| 22     | ZnS                                                                          | 98.3%                  | –              | –              | –                   | 8.0 | 120 min          | 0.08 g/L            | (Rajabi et al. 2013)      |
| 23     | ZnS:Fe                                                                      | 99.0%                  | –              | –              | –                   | 8.0 | 120 min          | 0.08 g/L            | (Rajabi et al. 2013)      |
| 24     | Fe$_3$O$_4$@SiO$_2$-NH$_2$                                                  | –                      | Freundlich     | Pseudo 2nd order | –                   | 7.0 | –                | 100 mg/L            | (Sun et al. 2015b)        |
| 25     | Lac-PAM-CTS                                                                 | –                      | –              | –              | –                   | –   | –                | –                   | (Sun et al. 2015a)        |
| 26     | Magnetic β-cyclodextrin-graphene oxide nanocomposites(Fe$_3$O$_4$/β-CD/GO)  | 990.10                 | Langmuir       | Pseudo 2nd order | Endothermic         | 7.0 | 120 min          | –                   | (Wang et al. 2015)        |
| 27     | K-Carrageenan-g-AA                                                           | 833.33                 | Langmuir       | Pseudo 2nd order | Exothermic          | 7.0 | 180 min          | 0.05 g              | (Pourjavadi et al. 2014)  |
| 28     | Kappa-carrageenan-g-polyacrylic acid/TiO$_2$-NH$_3$ hydrogel nanocomposite (K-Carrageenan-g-AA/ TiO$_2$–NH$_3$) | 666.66                 | Langmuir       | Pseudo 2nd order | Exothermic          | 7.0 | 180 min          | 0.05 g              | (Pourjavadi et al. 2014)  |
| 29     | Melamine/maleic anhydride (S-Mc/MA)                                         | 641.03                 | Langmuir       | Pseudo 2nd order | Endothermic         | 9.0 | 24 h             | 0.06 g              | (Rong et al. 2014)        |
| 30     | Iron nanoparticles loaded on ash (nFe-A)                                     | 500                    | Langmuir       | Pseudo 2nd order | Endothermic         | 8.0 | 30 min           | –                   | (Agarwal et al. 2016)     |
| 31     | Poly(vinyl alcohol) (PVA) and chitosan (CS)/(PVA/CS composite)               | 380.65                 | Freundlich     | Pseudo 2nd order | Endothermic         | 6.0 | 540 min          | 0.1 g/50 mL         | (Li et al. 2012)          |
| 32     | Alginate/polyaspartate composite hydrogel beads                              | 300–350                | –              | –              | –                   | 3.0 | 5 h              | 0.1 g/50 mL         | (Jeon et al. 2008)        |
| 33     | Polyacrylic acid (PAA)–nanoclay nanocomposite                               | 243.11                 | Freundlich     | –              | –                   | 9.2 | 15 min           | 0.5 g/100 mL        | (Sonawane et al. 2009)    |
| 34     | Fe$_3$O$_4$@PANI nanocomposites                                             | 240.00                 | Langmuir       | Pseudo 2nd order | Exothermic          | 7.0 | 4 h              | 0.01 g              | (Mahto et al. 2014)       |
| 35     | Vinyl-modified mesoporous poly(acrylic acid)/SiO$_2$ (PAA/SiO$_2$) composite nanofiber membranes | 220.49                 | Redlich– Peterson | Pseudo 2nd order | –                   | 240 min          | 50 mg/50 mL        | (Xu et al. 2012)         |
| 36     | Activated carbon/CoFe$_2$O$_4$ composite (AC/CFO)                            | 89.29                  | Langmuir       | Pseudo 2nd order | –                   | 5.0 | 5 min            | –                   | (Ai et al. 2010)          |
adsorption equilibrium and kinetic data was well fitted and found to be in good agreement with the Langmuir isotherm model and pseudo second order kinetic model, respectively.

Shirmardi et al. (2013) prepared functionalized multi-walled carbon nanotubes (f-MWCNTs) by acid treatment and used for the adsorption of MG dye from aqueous solution in batch mode. The results indicated that by increasing contact time, pH and adsorbent dosage, the removal percentage increased, but by increasing the initial MG concentration, the removal percentage decreased. Based on correlation coefficient ($R^2$), the experimental data follows the Langmuir isotherm with maximum adsorption capacity of 142.85 mg/g.

Halloysite, a mineral of the kaolin group [forms hollow tubular crystals (halloysite nanotubes—HNTs)], can be used as MG dye adsorbent by Kiani et al. (2011) and found that the equilibrium adsorption was reached within 30 min. The adsorption of MG by HNTs obeyed pseudo-second-order kinetics with activation energy 18.28 kJ/mol.

| Sr. No. | Adsorbents | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References |
|---------|------------|-------------------------|----------------|---------------|---------------------|----|------------------|--------------------|------------|
| 37      | Unsaturated polyester Ce(IV) phosphate (USPECe(IV)P) composite | 44.85 | Freundlich | Pseudo 2nd order | Endothermic | 8.0 | 30–35 min | 0.1 g/100 mL | (Khan et al. 2013) |
| 38      | Graphene oxide (GO)/cellulose bead (GOCB) composites | 30.090 | Langmuir | Pseudo 2nd order | Endothermic | 7.0 | 12 h | 0.1 g | (Zhang et al. 2015) |
| 39      | Carbon nanotube/polyaniline composites | 15.45 | Langmuir | Pseudo 2nd order | Endothermic | – | – | – | (Zeng et al. 2013) |
| 40      | MWCNTs functionalized with the carboxylate group | 11.73 | Langmuir | Pseudo 2nd order | Endothermic | 9.0 | 10 min | – | (Rajabi et al. 2016) |
| 41      | Magnetoactive nanocomposite fibers | 8.809 | Langmuir | – | Endothermic | 8.0 | 24 h | – | (Savva et al. 2015) |
| 42      | Polyaniline–nickel ferrite magnetic nanocomposite | 4.09 | Langmuir | Pseudo 2nd order | – | 7.0 | 210 min | 5.0 g/L | (Patil and Shrivastava 2014) |
| 43      | Humic acid-immobilized amine modified polyacrylamide/bentonite composite (HA-Am-PAA-B) | 656.50 (μmol/g) | Freundlich | Pseudo 2nd order | – | 8.0 | 3 h | 2.0 g/L | (Anirudhan and Suchithra 2009) |
| 44      | Humic acid-immobilized amine-modified polyacrylamide-bentonite composite (HA-Am-PAA-B) | 656.50 (μmol/g) | Freundlich | Pseudo 2nd order | – | 5.0–8.0 | 1 h | 2.0 g/L | (Anirudhan et al. 2009) |
| 45      | Glycine–modified silica nanoparticles | – | Langmuir | Pseudo 1st order | – | 10.0 | 40 min | – | (Mansa et al. 2016) |
| 46      | Magnetic Pycnoporus sanguineus-Loaded Alginate Composite Beads | – | – | – | – | – | – | – | (Yang et al. 2014) |
| 47      | Polyaniline/ZnO nanocomposite | – | – | – | – | 5 h | 0.4 g/L | (Eskizybek et al. 2012) |
| 48      | Fe$_{0.01}$Ni$_{0.01}$Zn$_{0.98}$O/polyacrylamide nanocomposite | – | – | – | – | – | – | – | (Kant et al. 2014) |
| 49      | Hierarchically macro/micro-porous silicon–carbon–nitrogen (Si–C–N) hybrid material | – | – | – | – | – | – | – | (Meng et al. 2015) |
suggested that the process was physisorption. The best-fit adsorption isotherm was achieved with the Langmuir model, indicating that homogeneous adsorption occurred. The negative values of $\Delta G^\circ$ and positive value of $\Delta H^\circ$ showed that the adsorption was a spontaneous and endothermic.

The particles of at least one dimension smaller than 1 nm, and potentially as small as atomic and molecular length scales (0.2 nm) are called nanoparticles. Nanoparticles can have amorphous or crystalline form (Buzea et al. 2007). Due to some of the unique characteristics such as small size, catalytic potential, large surface area, ease of separation, and large number of active sites for interaction with different contaminant nanoparticles have established themselves as excellent adsorbents (Raval et al. 2016d).

**Composites and nano-composites**

The nano-scale inclusions that are imbedded within matrix of a material are referred as composites (Chen et al. 2013). Poly(vinyl alcohol) (PVA) is a water-soluble material containing many reactive hydroxyl groups. It has been extensively applied in biomedical and pharmaceutical fields due to its low cost, non-toxicity, biocompatibility, good mechanical strength and chemical stability. However, the PVA foam illustrated low adsorption for organic and inorganic pollutants. Chitosan (CS) is one of the most abundant biopolymers in nature. It exhibits good adsorption capacity for organic dyes and heavy metals because it has a large number of hydroxyl and amine groups. However, the use of CS in the form of flake or powder cannot be separated easily. Therefore, Li et al. (2012) prepared a novel foam adsorbent based on PVA/CS composites by the interpenetrating polymer network (IPN), foaming process and freeze-thaw treatment and found that the composite material had higher adsorption efficiency (380.65 mg/g) compared with the single component.

Hussain et al. (2006) defined nanocomposites as materials consisting of at least two phases with one dispersed in another that is called matrix, and thus forms a three dimensional network.

Wang et al. (2015) prepared Magnetic β-cyclodextrin-graphene oxide nanocomposites (Fe$_3$O$_4$/β–CD/GO) as an adsorbent for MG dye because graphene oxide have abundant hydrophilic groups on its surface, and thus it has good adsorption capacity still its separation was difficult task from sample solution and hence, to simplify the retrieval procedure, magnetic adsorbent (Fe$_3$O$_4$) has been incorporated with GO. In addition, β-CD was also added onto composite (Magnetic-graphene oxide) to provide hydrophobic inner cavity and a hydrophilic exterior which can enhance the adsorption capacity of composite adsorbent for MG dye.

Table 9 presented the maximum adsorption capacities of various nanomaterials, composite and nanocomposite adsorbents used for MG.

### Miscellaneous adsorbents

See Table 10.

| Sr. No. | Adsorbents                                      | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References                          |
|--------|------------------------------------------------|-------------------------|----------------|----------------|---------------------|----|------------------|----------------------|-------------------------------------|
| 1      | Zeolitic imidazole framework-67 (ZIF-67)       | 3227.00                 | Langmuir       | Pseudo 2nd order | Endothermic         | 2  | 2 h              | 0.25 g/L              | (Lin and Chang 2015)              |
| 2      | Graphite oxide (GO)                            | 248.00                  | Langmuir       | Pseudo 2nd order | –                   | –  | 20 min           | 10 mg/500 mL           | (Bradder et al. 2011)              |
| 3      | Poly-γ-glutamic acid (γ-PGA)                   | 293.32                  | Redlich-Peterson | Pseudo 2nd order | >5.0                | 2  | 2 h              | 0.4 g/L               | (Stephen Inbaraj et al. 2006)      |
| 4      | Defective coffee beans press cake              | 208.30                  | Langmuir       | Pseudo 2nd order | –                   | 5  | 4.0 h            | 5.0 g/L               | (Franca et al. 2010a)             |
| 5      | Polyethylene terephthalate (PET) by chemical activation with NaOH (PETNa8) | 169.49                  | Langmuir       | Pseudo 1st order | –                   | 10 | 90 min           | 0.1 g/25 mL            | (Akmil-Başar et al. 2005)          |
| 6      | Magnetic sorbent (“blue magnetite”)            | 93.20                   | Langmuir       | –              | –                   | 30 | 30 min           | –                     | (Šafarík et al. 1995)            |
Conclusions and future perspectives

Adsorption process being very easy, economical, effective and versatile had become the most favored methods for amputation of toxic and hazardous dyes from wastewater. This review article revealed about various adsorbents, such as activated carbons, low-cost materials, nanomaterials, composites and nanocomposites, used for the adsorption and removal of MG from water and wastewater. It was concluded that amongst all the other adsorbents, agricultural solid wastes and biosorbents, such as biopolymers and biomass, have been extensively used for the removal of MG and are acknowledged as effective and economic adsorbents for the removal of MG dye. Various experimental conditions (pH, temperature, contact time and amount of adsorbent) have been also mentioned for related adsorbents in the present article.

This review article also disclosed that the Langmuir and Freundlich adsorption isotherm models were frequently applied to evaluate the adsorption capacity of various adsorbents towards MG. In kinetic study, it was observed that the pseudo-second-order rate model was been followed for the adsorption of MG and according to thermodynamic parameters the adsorption process was found to be spontaneous in nature.

Since, most of the reported studies had been performed using batch and small-scale column adsorption tests, further research is required for the development of more effective adsorbents, modeling of adsorption mechanism, regeneration of spent adsorbents and treatment of real industrial wastewater.

### Table 10 continued

| Sr. No. | Adsorbents | $Q_{\text{max}}$ (mg/g) | Isotherm study | Kinetics study | Thermodynamic study | pH | Equilibrium time | Dosage of adsorbent | References |
|---------|------------|--------------------------|----------------|----------------|---------------------|----|-----------------|-------------------|------------|
| 7.      | Polymeric gel | 4.900 | Langmuir | Pseudo 2nd order | Exothermic | – | – | – | (Malana et al. 2010) |
| 8.      | Poly(lactide (PLA)/spent brewery grains (SBGs) films | 1.484 | Freundlich | Pseudo 2nd order | – | 6.89 | 95 min | 0.42 g | (Chanzu et al. 2012) |
| 9.      | Polyethylene glycol (PEG) micelles | – | Langmuir | – | Endothermic | – | 10 min | – | (Chen et al. 2009) |
| 10.     | Polystyrene microspheres | – | – | – | – | – | – | – | (Eckenrode et al. 2005) |
| 11.     | Magnetic affinity adsorbent (blue magnetite) | – | – | – | – | – | – | – | (Šafarík and Šafaríková 2002) |
| 12.     | Loosely bound extracellular polymeric substances (LB-EPS), tightly bound EPS (TB-EPS) | – | – | – | – | 7.0 | – | – | (Gao et al. 2011) |
| 13.     | Amberlite XAD-4 resin | – | – | Pseudo 1st order | Endothermic | – | 150 min | – | (Dos Reis et al. 2011) |
| 14.     | AmberliteXAD-2 resin | – | – | Pseudo 1st order | Endothermic | – | 150 min | – | (Dos Reis et al. 2011) |
| 15.     | Metal–organic framework MIL-100(Fe) | – | Freundlich | Pseudo 2nd order | Endothermic | 5.0 | – | – | (Huo and Yan 2012) |
| 16.     | D201_Lac | – | – | – | – | – | – | – | (Zhang et al. 2012) |
| 17.     | Mesoporous Cu/Al$_2$O$_3$–MCM-41 | – | – | – | – | 11.0 | 30 min | 1.0 g/L | (Pradhan et al. 2011) |
| 18.     | Calcium oxalate—bromopyrogallol red inclusion sorbent | – | – | – | – | – | – | – | (Wang and Gao 2009) |
| 19.     | Polyurethane foam (PUF) loaded with sodium dodecylsulfate (SDS) | – | – | – | – | – | – | – | (Robaina et al. 2009) |
| 20.     | Functionalized magnetic adsorbents (FMAs) | – | – | – | – | – | – | – | (Wang et al. 2014b) |
Acknowledgements  The authors gratefully acknowledge the financial assistance provided by the INSPIRE Programme under the Assured Opportunity for Research Careers (AORC) scheme, funded by the Department of Science and Technology (DST) (Sanction Order No.: DST/INSPIRE Fellowship/2013/66).

Open Access  This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

References

Abd-El-Kareem MS, Taha HM (2012) Decolorization of malachite green and methylene blue by two microalgal species. Int J Chem Environ Eng 3:297–302

Adegoke KA, Bello OS (2015) Dye sequestration using agricultural wastes as adsorbents. Water Resour Ind 12:8–24. doi:10.1016/j.wri.2015.09.002

Afkhami A, Moosavi R, Madarakian T (2010) Preconcentration and spectrophotometric determination of low concentrations of malachite green and leuco-malachite green in water samples by high performance solid phase extraction using maghemite nanoparticles. Talanta 82:785–789. doi:10.1016/j.talanta.2010.05.054

Agarwal S, Tyagi I, Gupta VK et al (2016) Kinetics and thermodynamics of Malachite Green dye removal from aqueous phase using iron nanoparticles loaded on ash. J Mol Liq. doi:10.1016/j.molliq.2016.04.039

Ahmad MA, Ahmad N, Bello OS (2014) Adsorptive removal of malachite green dye using durian seed-based activated carbon. Water Air Soil Pollut 225:1–18. doi:10.1007/s11270-014-2057-z

Ahmad MA, Alrozi R (2011) Removal of malachite green dye from aqueous solution using rambutan peel-based activated carbon: equilibrium, kinetic and thermodynamic studies. Chem Eng J 171:510–516. doi:10.1016/j.cej.2011.04.018

Ahmad R, Kumar R (2010) Adsorption studies of hazardous malachite green onto treated ginger waste. J Environ Manag 91:1032–1038. doi:10.1016/j.jenvman.2009.12.016

Ahmad R, Mondal PK (2010) Application of modified water nut carbon as a sorbent in congo red and malachite green dye contaminated wastewater remediation. Sep Sci Technol 45:394–403. doi:10.1080/01496390903484875

Ai L, Huang H, Chen Z et al (2010) Activated carbon/CoFe2O4 composites: facile synthesis, magnetic performance and their potential application for the removal of malachite green from water. Chem Eng J 156:243–249. doi:10.1016/j.cej.2009.08.028

Aitcheson SJ, Arnett J, Murray KR, Zhang J (2000) Removal of aquaculture therapeutants by carbon adsorption: 1. Equilibrium adsorption behaviour of single components. Aquaculture 183:269–284. doi:10.1016/S0044-8486(99)00304-X

Akbar E, Altniisik A, Seki Y (2013) Using of activated carbon produced from spent tea leaves for the removal of malachite green from aqueous solution. Ecol Eng 52:19–27. doi:10.1016/j.ecoleng.2012.12.032

Akmil-Basar C, Onal Y, Kilicert T, Eren D (2005) Adsorption of high concentration malachite green by two activated carbons having different porous structures. J Hazard Mater 127:73–80. doi:10.1016/j.jhazmat.2005.06.025

Aksakal O, Ucun H, Kayy Y (2009) Application of Eriobotrya japonica (Thunb.) Lindley (Loquat) seed biomass as a new biosorbent for the removal of malachite green from aqueous solution. Water Sci Technol Int Assoc Water Pollut Res 59:1631–1639. doi:10.2166/wst.2009.130

Ali H (2010) Biodegradation of synthetic dyes—a review. Water Air Soil Pollut 213:251–273. doi:10.1007/s11270-010-0382-4

Ali H, Ahmad W, Haq T (2009) Decolorization and degradation of malachite green by Aspergillus flaves and Alternaria solani. Afr J Biotechnol. doi:10.4314/ajb.v8i8.6023

Aliyan H, Fazaei R, Jalili R (2013) Fe3O4@mesoporous SBA-15: a magnetically recoverable catalyst for photodegradation of malachite green. Appl Surf Sci 276:147–153. doi:10.1016/j.apsusc.2013.03.049

Almusg A, Gur E, Seki Y (2010) A natural sorbent, Luffa cylindrica for the removal of a model basic dye. J Hazard Mater 179:658–664. doi:10.1016/j.jhazmat.2010.03.053

An S-Y, Min S-K, Cha I-H et al (2002) Removal of malachite green from dye wastewater using mesoporous carbon adsorbent. J Iran Chem Soc 8:S67–S76. doi:10.1007/BF03254283

Anirudhan TS, Suchithra PS (2009) Adsorption characteristics of humic acid-immobilized amine modified polyacrylamide/bentonite composite for cationic dyes in aqueous solutions. J Environ Sci China 21:884–891

Anirudhan TS, Suchithra PS, Radhakrishnan PG (2009) Synthesis and characterization of humic acid immobilized-polymer/bentonite composites and their ability to adsorb basic dyes from aqueous solutions. Appl Clay Sci 43:336–342. doi:10.1016/j.clay.2008.09.006

Anjaneyulu Y, Chary NS, Raj DDS (2005) Decolorization of industrial effluents—available methods and emerging technologies—a review. Rev Environ Sci Biotechnol 4:245–273. doi:10.1007/s11274-005-0076-z

Anirudhan TS, Suchithra PS, Radhakrishnan PG (2009) Synthesis and characterization of humic acid immobilized-polymer/bentonite composites and their ability to adsorb basic dyes from aqueous solutions. Appl Clay Sci 43:336–342. doi:10.1016/j.clay.2008.09.006

Anjaneyulu Y, Chary NS, Raj DDS (2005) Decolorization of industrial effluents—available methods and emerging technologies—a review. Rev Environ Sci Biotechnol 4:245–273. doi:10.1007/s11274-005-0076-z

Anirudhan TS, Suchithra PS, Radhakrishnan PG (2009) Synthesis and characterization of humic acid immobilized-polymer/bentonite composites and their ability to adsorb basic dyes from aqueous solutions. Appl Clay Sci 43:336–342. doi:10.1016/j.clay.2008.09.006

Asilturk M, Saylan F, Arpac E (2009) Effect of Fe3+ ion doping to TiO2 on the photocatalytic degradation of malachite green dye under UV and vis-irradiation. J Photochem Photobiol Chem 203:64–71. doi:10.1016/j.jphotchem.2008.12.021

Ayed L, Chiaib K, Cheref A, Bakhrouta A (2008) Biodegradation of triphenylmethane dye Malachite Green by Sphingomonas paucimobilis. World J Microbiol Biotechnol 25:705–711. doi:10.1007/s11274-008-9941-x

Ayed L, Chiaib K, Cheref A, Bakhrouta A (2010) Biodegradation and decolorization of triphenylmethane dyes by Staphylococcus epidermidis. Desalination 260:137–146. doi:10.1016/j.desal.2010.04.052

Babel S, Kurniawan TA (2003) Low-cost adsorbents for heavy metals uptake from contaminated water: a review. J Hazard Mater 97:219–233. doi:10.1016/S0304-3804(02)00526-3

Baek M-H, Ijagbemi CO, Se-Jin O, Kim D-S (2010) Removal of malachite green from aqueous solution using degreased coffee bean. J Hazard Mater 176:820–828. doi:10.1016/j.jhazmat.2009.11.110

Bai C, Xiao W, Feng D et al (2013) Efficient decolorization of Malachite Green in the Fenton reaction catalyzed by [Fe(III)-
Bekçi Z, Özveri C, Seki Y, Yurdakoc K (2008) Sorption of malachite green on silica gel column: effect of FeCl3 complex. Chem Eng J 215–216:227–234. doi:10.1016/j.cej.2012.09.124
Banat IM, Nigam P, Singh D, Marchant R (1996) Microbial decolorization of textile-dye containing effluents: a review. Bioresearch Technol 58:217–227. doi:10.1016/S0960-8524(96)00113-7
Bansal P, Bhullar N, Sud D (2009) Studies on photodegradation of malachite green using TiO2/ZnO photocatalyst. Desalin Water Treat 12:108–113. doi:10.5004/dwt.2009.944
Başar CA (2006) Applicability of the various adsorption models of three dyes adsorption onto activated carbon prepared waste apricot. J Hazard Mater 135:232–241. doi:10.1016/j.jhazmat.2005.11.055
Beak MH, Ijagbemi CO, Kim DS (2009) Treatment of malachite green-containing wastewater using poultry feathers as adsorbent. J Environ Sci Health Part A Tox Hazard Subst Environ Eng 44:536–542. doi:10.1080/10934520902720132
Bejarano-Pérez NJ, Suárez-Herrera MF (2008) Sonochemical and sonophotocatalytic degradation of malachite green: the effect of carbon tetrachloride on reaction rates. Ultrason Sonochem 15:612–617. doi:10.1016/j.uls.2007.09.009
Bekçi Z, Ozveri C, Seki Y, Yurdakoc K (2008) Sorption of malachite green on chitosan bead. J Hazard Mater 154:254–261. doi:10.1016/j.jhazmat.2007.10.021
Bekçi Z, Seki Y, Cavas L (2009) Removal of malachite green by using an invasive marine alga Caulerpa racemosa var. cylindracea. J Hazard Mater 161:145–1460. doi:10.1016/j.jhazmat.2008.04.125
Bello OS, Ahmad MA, Ahmad N (2012) Adsorptive features of banana (Musa paradisiaca) stalk-based activated carbon for malachite green dye removal. Chem Ecol 28:153–167. doi:10.1080/02757540.2011.628318
Bello OS, Ahmad MA, Semire B (2014) Scavenging malachite green dye from aqueous solutions using pomelo (Citrus grandis) peels: kinetic, equilibrium and thermodynamic studies. Desalin Water Treat 56:521–535. doi:10.1080/19443994.2014.940337
Bello OS, Bello IA, Adegoke KA (2013) Adsorption of dyes using different types of sand: a review. South Afr J Chem 66:117–129
Berberidou C, Poulios I, Xekoukoulotakis NP, Mantzavinos D (2007) Sonolytic, photocatalytic and sonophotocatalytic degradation of malachite green in aqueous solutions. Appl Catal B Environ 74:63–72. doi:10.1016/j.apcatb.2007.01.013
Bhatnaththi Pushpa T, Vijayaraghavan J, Sardhar Basha SJ et al. (2015) Investigation on removal of malachite green using EM based compost as adsorbent. Ecotoxicol Environ Saf 118:177–182. doi:10.1016/j.ecosaf.2015.04.033
Bhattacharyya KG, Sarma A (2003) Adsorption characteristics of the dye, brilliant green, on neem leaf powder. Dyes Pigments 57:211–222. doi:10.1016/S0143-7208(03)00009-3
Bojinova A, Dushkin C (2011) Photodegradation of malachite green in water solutions by means of thin films of TiO2/WO3 under visible light. React Kinet Mech Catal 103:239–250. doi:10.1007/s11164-011-0295-2
Boutemedjet S, Hamdaoui O (2009) Sorption of malachite green by eucalyptus bark as a non-conventional low-cost biosorbent. Desalin Water Treat 8:201–210. doi:10.5004/dwt.2009.684
Bradler P, Ling SK, Wang S, Liu S (2011) Dye adsorption on layered graphite oxide. J Chem Eng Data 56:138–141. doi:10.1021/je101049g
Breck DW (1984) Zeolite molecular sieves. Krieger. Chicago
Bulut E, Özazar M, Sengil IA (2008) Equilibrium and kinetic data and process design for adsorption of Congo Red onto bentonite. J Hazard Mater 154:613–622. doi:10.1016/j.jhazmat.2007.10.071
Burkinshaw SM (2016) Physico-chemical aspects of textile coloration, 1st edn. Wiley, New York
Buvaneswari N, Kannan C (2011) Plant toxic and non-toxic nature of organic dyes through adsorption mechanism on cellulose surface. J Hazard Mater 189:294–300. doi:10.1016/j.jhazmat.2011.02.036
Buza C, Pacheco II, Robbie K (2007) Nanomaterials and nanoparticles: sources and toxicity. Biointerphases 2:MR17–MR71. doi:10.1116/1.2815690
Cardon D (2007) Natural dyes: sources, tradition, technology and science. Archetype, London
Chanzu HA, Onyari JM, Shiumu PM (2012) Biosorption of malachite green from aqueous solutions onto polylactide/spent brewery grains films: kinetic and equilibrium studies. J Polym Environ 20:665–672. doi:10.1007/s10924-012-0479-5
Cheknane B, Baudu M, Basly J-P, Bouras O (2010) Adsorption of basic dyes in single and mixture systems on granular inorganic–organic pillared clays. Environ Technol 31:815–822. doi:10.1080/09593331003667758
Chen CC, Lu CS, Chung YC, Jan JL (2007) UV light induced photodegradation of malachite green on TiO2 nanoparticles. J Hazard Mater 141:520–528. doi:10.1016/j.jhazmat.2006.07.011
Chen F, Ma W, He J, Zhao J (2002) Fenton degradation of malachite green catalyzed by aromatic additives. J Phys Chem A 106:9485–9490. doi:10.1021/jp0144350
Chen J, Mao J, Mo X et al (2009) Study of adsorption behavior of malachite green on polyethylene glycol micelles in cloud point extraction procedure. Colloids Surf Physicochem Eng Asp 345:231–236. doi:10.1016/j.colsurf.a.2009.05.015
Chen Y, Zhang Y, Liu C et al (2011) Photodegradation of malachite green by nanostructured Bi2WO6 visible light-induced photocatalyst. Int J Photoenergy 2012:e510158. doi:10.1155/2012/510158
Chen Z, Deng H, Chen C et al (2014) Biosorption of malachite green from aqueous solutions by Pleurotus ostreatus using Taguchi method. J Environ Health Sci Eng 12:63. doi:10.1186/2052-336X-12-63
Chen Z-Y, Gao H-W, He Y-Y (2013) Selective photodegradation and backfilling for regeneration of the inorganic–organic hybrid composite Fe3O4@C18ADB@Zn2SiO4 which captures organic pollutants from aqueous solution. RSC Adv 3:5815–5818. doi:10.1039/C3RA22324H
Cheng W, Wang S-G, Lu L et al (2008) Removal of malachite green (MG) from aqueous solutions by native and heat-treated anaerobic granular sludge. Biochem Eng J 39:538–546. doi:10.1016/j.bej.2007.10.016
Cheriaa J, Bakhrouf A (2009) Triphenylmethanes, malachite green and crystal violet dyes decolourisation by Sphingomonas paucimobilis. Ann Microbiol 59:57–61. doi:10.1007/BF03175599
Chhieng HI, Lim LBL, Priyantha N (2015) Enhancing adsorption capacity of toxic malachite green dye through chemically modified breadnut peel: equilibrium, thermodynamics, kinetics and regeneration studies. Environ Technol 36:86–97. doi:10.1080/09593330.2014.938124
Chieng HI, Zehra T, Lim LBL et al (2014) Sorption characteristics of peat of Brunei Darussalam IV: equilibrium, thermodynamics and kinetics of adsorption of methylene blue and malachite green dyes from aqueous solution. Environ Earth Sci 72:2263–2277. doi:10.1007/s12665-014-3135-7
Chowdhury S, Chakraborty S, Saha P (2011a) Biosorption of Basic Green 4 from aqueous solution by Ananas comosus (pineapple) leaf powder. Colloids Surf B Interfases 84:520–527. doi:10.1016/j.colsurfb.2011.02.009
Chowdhury S, Das P (2012) Utilization of a domestic waste—eggshells for removal of hazardous malachite green from aqueous solutions. Environ Prog Sustain Energy 31:415–425. doi:10.1002/ep.10564
Chowdhury S, Mishra R, Saha P, Kushwaha P (2011b) Adsorption thermodynamics, kinetics and isoelectric point of malachite green onto chemically modified rice husk. Desalination 265:159–168. doi:10.1016/j.desal.2010.07.047

Chowdhury S, Saha P (2010a) Sea shell powder as a new adsorbent to remove Basic Green 4 (malachite green) from aqueous solutions: equilibrium, kinetic and thermodynamic studies. Chem Eng J 164:168–177. doi:10.1016/j.cej.2010.08.050

Chowdhury S, Saha P (2010b) Pseudo-second-order kinetic model for sorption of malachite green onto sea shell: comparison of linear and non-linear methods. IIOAB J 1:3–7

Chowdhury S, Saha P (2011a) Adsorption thermodynamics and kinetics of malachite green onto Ca(OH)2-treated fly ash. J Environ Eng 137:388–397. doi:10.1061/(ASCE)EE.1943-7870.0000334

Chowdhury S, Saha PD (2011) Mechanistic, Kinetic, and Thermodynamic Evaluation of Adsorption of Hazardous Malachite Green onto Conch Shell Powder. Sep Sci Technol 46:1966–1976. doi:10.1080/01496395.2011.584930

Chowdhury S, Saha PD (2012) Fixed-bed adsorption of malachite green onto binary solid mixture of adsorbents: seashells and eggshells. Toxicol Environ Chem 94:1272–1282. doi:10.1080/02772248.2012.703205

Chowdhury S, Saha PD (2013) Adsorption of malachite green from aqueous solution by naoh-modified rice husk: fixed-bed column studies. Environ Prog Sustain Energy 32:633–639. doi:10.1002/ep.11674

Chowdhury S, Saha PD (2011b) Comparative analysis of linear and nonlinear methods of estimating the pseudo-second-order kinetic parameters for sorption of malachite green onto pretreated rice husk. Bioremediat J 15:181–188. doi:10.1080/10889868.2011.624140

Chowdhury S, Saha PD, Ghosh U (2012) Fish (Labeo rohita) scales as potential low-cost biosorbent for removal of malachite green from aqueous solutions. Bioremediat J 16:235–242. doi:10.1080/10889868.2012.731444

Crini G (2006) Non-conventional low-cost adsorbents for dye removal: a review. Bioresour Technol 97:1061–1085. doi:10.1016/j.biortech.2005.05.001

Crini G, Peindy HN, Gimbert F, Robert C (2007) Removal of C.I. Basic Green 4 (malachite green) from aqueous solutions by adsorption using cyclodextrin-based adsorbent: kinetic and equilibrium studies. Sep Purif Technol 53:97–110. doi:10.1016/j.seppur.2006.06.018

da Fonseca MG, de Oliveira MM, Arakaki LNH (2006) Removal of cadmium, zinc, manganese and chromium cations from aqueous solution by a clay mineral. J Hazard Mater 137:288–292. doi:10.1016/j.jhazmat.2006.02.001

Daradaniya PV, Patel MP, Patel RG (2006) Swelling and dye adsorption study of novel superswelling [acrylamide/N-vinylpyrrolidone/3-(2-hydroxyethyl carbamoyl) acrylic acid] hydrogels. Polym Bull 57:21–31. doi:10.1007/s00289-006-0531-5

Dahi MK, Kooh MRR, Lim LBL (2014) Water remediation using low cost adsorbent walnut shell for removal of malachite green: equilibrium, kinetics, thermodynamic and regeneration studies. J Environ Eng Chem 2:1434–1444. doi:10.1016/j.jece.2014.07.008

Daneshvar N, Ayzazlo M, Khataee AR, Pourhassan M (2007a) Biological decolorization of dye solution containing malachite green by microalgae Cosmarium sp. Bioresour Technol 98:1176–1182. doi:10.1016/j.biortech.2006.05.025

Daneshvar N, Khataee AR, Rasoulifard MH, Pourhassan M (2007b) Biodegradation of dye solution containing malachite green: optimization of effective parameters using Taguchi method. J Hazard Mater 143:214–219. doi:10.1016/j.jhazmat.2006.09.016

Das A, Pal A, Saha S, Maji SK (2009a) Behaviour of fixed-bed column for the adsorption of malachite green on surfactant-modified alumina. J Environ Sci Health Part A Tox Hazard Subst Environ Eng 44:265–272. doi:10.1080/10934520802597929

Das AK, Saha S, Pal A, Maji SK (2009b) Surfactant-modified alumina: an efficient adsorbent for malachite green removal from water environment. J Environ Sci Health Part A 44:896–905. doi:10.1080/10934520902958708

Dawood S, Sen TK (2014) Review on dye removal from its aqueous solution into alternative cost effective and non-conventional adsorbents. J Chem Process Eng 1:1–7

Debrassi A, Corrêa AF, Baccarin T et al (2012) Removal of cationic dyes from aqueous solutions using N-benzyl-O-carboxymethyl-chitosan magnetic nanoparticles. Chem Eng J 183:284–293. doi:10.1016/j.cej.2011.12.078

Demirbas A (2009) Agricultural based activated carbons for the removal of dyes from aqueous solutions: a review. J Hazard Mater 167:1–9. doi:10.1016/j.jhazmat.2008.12.114

Dhodapkar R, Rao NN, Pande SP et al (2007) Adsorption of cationic dyes on Jhalshakti®, super absorbent polymer and photocatalytic regeneration of the adsorbent. React Funct Polym 67:540–548. doi:10.1016/j.reactfunctpolymer.2007.03.007

Dos Reis LGT, Robaina NF, Pacheco WF, Cassella RJ (2011) Separation of malachite green and methyl green cationic dyes from aqueous medium by adsorption on Amberlite XAD-2 and XAD-4 resins using sodium dodecylsulfate as carrier. Chem Eng J 171:532–540. doi:10.1016/j.cej.2011.04.024

Du L-N, Wang S, Li G et al (2011) Biodegradation of malachite green by Pseudomonas sp. strain DY1 under aerobic condition: characteristics, degradation products, enzyme analysis and phytotoxicity. Ecotoxology 20:438–446. doi:10.1080/s1064-011-0595-3

Eckenrode HM, Jen S-H, Han J et al (2005) Adsorption of a cationic dye molecule on polystyrene microspheres in colloids: effect of surface charge and composition probed by second harmonic generation. J Phys Chem B 109:4646–4653. doi:10.1021/jp045610q

Eichlerová I, Homolka L, Nerud F (2006) Synthetic dye decolorization capacity of white rot fungus Dichomitus squalens. Bioresour Technol 97:2153–2159. doi:10.1016/j.biortech.2005.09.014

Eskizyrybek V, Sar F, Gilce H et al (2012) Preparation of the new polyaniline/ZnO nanocomposite and its photocatalytic activity for degradation of methylene blue and malachite green dyes under UV and natural sun lights irradiations. Appl Catal B Environ 119–120:197–206. doi:10.1016/j.apcata.2012.02.034

Farhari K, Maleki R, Nezhad NM, Samadi N (2010) Spectrophotometric determination of malachite green residue in water samples after preconcentration on surfactant-coated alumina. Spectrosc Lett 43:101–107. doi:10.1080/00387010903278309

Fargues E, Cserháti T, Oros G (2004) Removal of synthetic dyes from wastewaters: a review. Environ Int 30:953–971. doi:10.1016/j.envint.2004.02.001

Franca AS, Oliveira LS, Nunes AA (2010a) Malachite green adsorption by a residue-based microwave-activated adsorbent. CLEAN—Soil Air Water 38:843–849. doi:10.1002/clet.201000153

Franca AS, Oliveira LS, Saldanha SA et al (2010b) Malachite green adsorption by mango (Mangifera indica L.) seed husks: kinetic, equilibrium and thermodynamic studies. Desalin Water Treat 19:241–248. doi:10.5004/dwt.2010.1105

Fu Y, Viraraghavan T (2001) Fungal decolorization of dye wastewaters: a review. Bioresour Technol 79:241–252. doi:10.1016/S0960-8524(01)00028-1
Gao J-F, Zhang Q, Wang J-H et al (2011) Contributions of functional groups and extracellular polymeric substances on the biosorption of dyes by aerobic granules. Bioresour Technol 102:805–813. doi:10.1016/j.biortech.2010.08.119

Garg VK, Gupta R, Bala Yadav A, Kumar R (2003) Dye removal from aqueous solution by adsorption on treated sawdust. Bioresour Technol 89:121–124. doi:10.1016/S0960-8524(03)00058-0

Garg VK, Kumar R, Gupta R (2004) Removal of malachite green dye from aqueous solution by adsorption using agro-industry waste: a case study of Prosopis cineraria. Dyes Pigments 62:1–10. doi:10.1016/j.dyepig.2003.10.016

Geng Z, Lin Y, Yu X et al (2012) Highly efficient dye adsorption and removal: a functional hybrid of reduced graphene oxide–Fe3O4 nanoparticles as an easily regenerative adsorbent. J Mater Chem 22:3527. doi:10.1039/c2jm15544c

Ghaedi M, Ansari M, Habibi MH, Asghari AR (2014) Removal of malachite green from aqueous solution by zinc oxide nanoparticle loaded on activated carbon: kinetics and isotherm study. J Ind Eng Chem 20:17–28. doi:10.1016/j.jiec.2013.04.031

Ghaedi M, Mosallanejad N (2014) Study of competitive adsorption of malachite green and sunset yellow dyes on cadmium hydroxide nanowires loaded on activated carbon. J Ind Eng Chem 20:1085–1096. doi:10.1016/j.jiec.2013.06.046

Ghasedi M, Shojaiepour E, Ghadie AM, Sahraei R (2015) Isotherm and kinetics study of malachite green adsorption onto copper nanowires loaded on activated carbon: artificial neural network modeling and genetic algorithm optimization. Spectrochim Acta A Mol Biomol Spectrosc 142:135–149. doi:10.1016/j.saa.2015.01.086

Godbole PT, Sawant AD (2006) Removal of malachite green from aqueous solutions using immobilised Saccharomyces cerevisiae. J Sci Ind Res 65:440–443

Gong R, Feng M, Zhao J et al (2009) Functionalization of sawdust with monosodium glutamate for enhancing its malachite green removal capacity. Bioresour Technol 100:975–978. doi:10.1016/j.biortech.2008.06.031

Gong R, Jin Y, Chen F et al (2006) Enhanced malachite green removal from aqueous solution by citric acid modified rice straw. J Hazard Mater 137:865–870. doi:10.1016/j.jhazmat.2006.03.010

Gong R, Sun J, Zhang D et al (2008) Kinetics and thermodynamics of basic dye sorption on phosphoric acid esterifying soybean hull with solid phase preparation technique. Bioresour Technol 99:4510–4514. doi:10.1016/j.biortech.2007.08.061

Gordon PF, Gregory P (1987) Organic Chemistry in Colour. Springer, Berlin, Heidelberg

Goursot A, Vasilyev V, Arbuznikov A (1997) Modeling of adsorption properties of zeolites: correlation with the structure. J Phys Chem B 101:6420–6428. doi:10.1021/jp971230b

Govindasamy V, Sahadevan R, Subramanian S, Mahendradas DK (2009) Removal of malachite green from aqueous solutions by peroxide. Int J Chem Eng React 7:1–22. doi:10.2202/1542-6580.1889

Griffiths J (1976) Colour and constitution of organic molecules. Academic Press, London

Griffiths J (1981) Recent developments in the colour and constitution of organic dyes. Rev Prog Color Relat Top 11:37–57. doi:10.1111/j.1478-4408.1981.tb03714.x

Guo Y, Yang S, Fu W et al (2003a) Adsorption of malachite green on micro- and mesoporous rice husk-based active carbon. Dyes Pigments 56:219–229. doi:10.1016/S0143-7208(02)00160-2

Guo Y, Zhang H, Tao N et al (2003b) Adsorption of malachite green and iodine on rice husk-based porous carbon. Mater Chem Phys 82:107–115. doi:10.1016/S0252-5084(03)00191-3

Gupta N, Kushwaha AK, Chattopadhyaya MC (2014) Application of potato (Solanum tuberosum) plant wastes for the removal of methylene blue and malachite green dye from aqueous solution. Arab J Chem. doi:10.1016/j.arabjc.2011.07.021

Gupta N, Kushwaha AK, Chattopadhyaya MC (2012) Adsorption studies of cationic dyes onto Ashoka (Saraca asoca) leaf powder. J Taiwan Inst Chem Eng 43:604–613. doi:10.1016/j.tice.2012.01.008

Gupta VK, Jain R, Nayak A et al (2011) Removal of the hazardous dye—tartrazine by photodegradation on titanium dioxide surface. Mater Sci Eng C 31:1062–1067. doi:10.1016/j.msec.2011.03.006

Gupta VK, Kumar R, Nayak A et al (2013) Adsorptive removal of dyes from aqueous solution onto carbon nanotubes: a review. Adv Colloid Interface Sci 193–194:24–34. doi:10.1016/j.cis.2013.03.003

Gupta VK, Mittal A, Krishnan L, Gajbe V (2004) Adsorption kinetics and column operations for the removal and recovery of malachite green from wastewater using bottom ash. Sep Purif Technol 40:87–96. doi:10.1016/j.seppur.2004.01.008

Gupta VK, Nayak A (2012) Cadmium removal and recovery from aqueous solutions by novel adsorbents prepared from orange peel and Fe3O4 nanoparticles. Chem Eng J 180:81–90. doi:10.1016/j.cej.2011.11.006

Gupta VK, Nayak A, Agrawal S (2015) Biosorbents for remediation of heavy metals: current status and their future prospects. Environ Eng Res 20:1–18

Gupta VK, Saleh TA (2013) Sorption of pollutants by porous carbon, carbon nanotubes and fullerene—an overview. Environ Sci Pollut Res 20:2828–2843. doi:10.1007/s11356-013-1524-1

Gupta VK, Srivastava SK, Mohan D (1997) Equilibrium uptake, sorption dynamics, process optimization, and column operations for the removal and recovery of malachite green from wastewater using activated carbon and activated slag. Ind Eng Chem Res 36:2207–2218. doi:10.1021/ie960442c

Gupta VK, Suhas (2009) Application of low-cost adsorbents for dye removal—a review. J Environ Manage 90:2313–2342. doi:10.1016/j.jenvman.2008.11.017

Hamdaoui O, Chiba M, Naffrechoux E (2008a) Ultrasound-assisted removal of malachite green from aqueous solution by dead pine needles. Ultrason Sonochem 15:799–807. doi:10.1016/j.ultsonch.2008.01.003

Hamdaoui O, Saoudi F, Chiba M, Naffrechoux E (2008b) Sorption of malachite green by a novel sorbent, dead leaves of plane tree: equilibrium and kinetic modeling. Chem Eng J 143:73–84. doi:10.1016/j.cej.2007.12.018

Hameed BH, El-Khaiairy MI (2008a) Equilibrium, kinetics and mechanism of malachite green adsorption on activated carbon prepared from bamboo by K2CO3 activation and subsequent gasification with CO2. J Hazard Mater 157:344–351. doi:10.1016/j.jhazmat.2007.12.105

Hameed BH, El-Khaiairy MI (2008b) Batch removal of malachite green from aqueous solutions by adsorption on oil palm trunk fibre: equilibrium isotherms and kinetic studies. J Hazard Mater 154:237–244. doi:10.1016/j.jhazmat.2007.10.017

Hameed BH, El-Khaiairy MI (2008c) Kinetics and equilibrium studies of malachite green adsorption on rice straw-derived char. J Hazard Mater 153:701–708. doi:10.1016/j.jhazmat.2007.09.019

Hameed BH, El-Khaiairy MI (2008d) Malachite green adsorption by rattan sawdust: isotherm, kinetic and mechanism modeling. J Hazard Mater 159:574–579. doi:10.1016/j.jhazmat.2008.02.054

Hammad HH, Shmait A, Hourani N (2015) Removal of malachite green from water using hydrothermally carbonized pine needles. RSC Adv 5:7909–7920. doi:10.1039/C4RA15505J

Han R, Wang Y, Sun Q et al (2010) Malachite green adsorption onto natural zeolite and reuse by microwave irradiation. J Hazard Mater 175:1056–1061. doi:10.1016/j.jhazmat.2009.10.118
Hasnat MA, Siddiquey IA, Saiful IS (2003) Photodegradation of malachite green in the aqueous medium. Indian J Chem Sect A 42:1865–1867

Hema M, Arivoli S (2007) Comparative study on the adsorption kinetics and thermodynamics of dyes onto activated low cost carbon. Int J Phys Sci 2:10–17

Heydartaemeh MR, Ardejani FD, Badii K et al (2014) FeCl₂/FeCl₃ perlite nanoparticles as a novel magnetic material for adsorption of green malachite dye. Arab J Sci Eng 39:3383–3392. doi: 10.1007/s13369-014-0497-x

Hu R, Huang J-B, Yang Z-P et al (2011) Biosorption of crystal violet and malachite green by Rhodotorula glutinis Y-5. Ying Yong Sheng Tai Xue Bao J Appl Ecol Zhongguo Sheng Tai Xue Hui Zhongguo Ke Xue Yuan Shenyang Ying Yong Sheng Tai Yan Jiu Suo Zhu Ban 22:3293–3299

Huang C-M, Chen L-C, Yang H-C et al (2012) Preparation of acrylic acid-modified chitin improved by an experimental design and its application in absorbing toxic organic compounds. J Hazard Mater 241–242:190–196. doi:10.1016/j.jhazmat.2012.09.032

Huang L, Weng X, Chen Z et al (2014) Green synthesis of iron nanoparticles by various tea extracts: comparative study of the reactivity. Spectrochim Acta A Mol Biomol Spectrosc 130:295–301. doi: 10.1016/j.saa.2013.10.010

Hui R, Xu X, Wang Z et al (2013) Study on the adsorption of basic and acid dyes from aqueous solutions onto oxihumolite. J Hazard Mater 157:137–145. doi: 10.1016/j.jhazmat.2010.07.028

Huang J, Wang G et al (2014) Preparation of acrylic polymer-matrix nanocomposites, processing, manufacturing, and application: an overview. J Compos Mater 48:1511–1575. doi: 10.1177/002199830607521

Idris MN, Ahmad ZA, Ahmad MA (2011) Adsorption equilibrium of malachite green dye onto rubber seed coat based activated carbon. Int J Basic Appl Sci 11:32–37

Iijima S (1991) Helical microtubules of graphitic carbon. Nature 354:56–58

Inbaraj BS, Sulochana N (2002) Basic dye adsorption on a low cost carbonaceous sorbent—kinetic and equilibrium studies. Indian J Chem Technol 9:201–208

Iqbal MJ, Aship MN (2007) Adsorption of dyes from aqueous solutions on activated charcoal. J Hazard Mater 139:57–66. doi:10.1016/j.jhazmat.2006.06.007

Issa AA, Al-Degs YS, Al-Ghouti MA, Olimat AAM (2014) Studying competitive sorption behavior of methylene blue and malachite green using multivariate calibration. Chem Eng J 240:543–564. doi:10.1016/j.cej.2013.08.084

Jalil AA, Triwahyono S, Yaakob MR et al (2012) Utilization of bivalve shell-treated Zea mays L. (maize) husk leaf as a low-cost biosorbent for enhanced adsorption of malachite green. Biore-Source Technol 120:218–224. doi:10.1016/j.biortech.2012.06.066

Janos P (2003) Sorption of basic dyes onto iron humate. Environ Sci Technol 37:5792–5798. doi:10.1021/es020142o

Janoš P, Michálek P, Turek L (2007) Sorption of ionic dyes onto untreated low-rank coal–oxihumolite: a kinetic study. Dyes Pigments 74:363–370. doi:10.1016/j.dypig.2006.02.017

Janos P, Sedivy P, Ryznarova M, Grötschelová S (2005) Sorption of basic and acid dyes from aqueous solutions onto oxihumolite. Chemosphere 59:881–886. doi:10.1016/j.chemosphere.2004.11.018

Janos P, Šmídová V (2005) Effects of surfactants on the adsorptive removal of basic dyes from water using an organomimetic sorbent—iron humate. J Colloid Interface Sci 291:19–27. doi:10.1016/j.jcis.2005.04.065

Jasińska A, Bernat P, Paraszkiewicz K (2013) Malachite green removal from aqueous solution using the system rapeseed press cake and fungus Myrothecium roridum. Desalin Water Treat 51:7663–7671. doi:10.1080/19443994.2013.779939

Jayaraj R, Mohan MC, Prasath PMD, Khan TH (2011) Malachite green dye removal using the seaweed enteromorpha. J Chem 8:649–656. doi:10.1155/2011/141305

Jeon YS, Lei J, Kim J-H (2008) Dye adsorption characteristics of alginate/polyaspartate hydrogels. J Ind Eng Chem 14:726–731. doi:10.1016/j.jiec.2008.07.007

Jeyagowri K, Kavipriya M, Karthika C et al (2003) Utilization of various agricultural wastes for activated carbon preparation and application for the removal of dyes and metal ions from aqueous solutions. Bioresour Technol 87:129–132. doi:10.1016/S0960-8524(02)00201-8

Kan Y, Yue Q, Kong J et al (2015) The application of activated carbon produced from waste printed circuit boards (PCBs) by H3PO4 and steam activation for the removal of malachite green. Chem Eng J 260:541–549. doi:10.1016/j.cej.2014.09.047

Kaneva N, Stambolova I, Blaskov V et al (2010) Photocatalytic activity of nanostructured ZnO films prepared by two different methods for the photoinitiated decolorization of malachite green. J Alloys Compd 502:250–258. doi:10.1016/j.jallcom.2010.04.020

Kannan C, Mutheraja K, Devi MR (2013) Hazardous dyes removal from aqueous solution over mesoporous aluminoephosphate with textural porosity by adsorption. J Hazard Mater 244–245:10–20. doi:10.1016/j.jhazmat.2012.11.016

Kannan C, Sundaram T, Palvannan T (2008) Environmentally stable adsorbent of tetrahedral silica and non-tetrahedral alumina for removal and recovery of malachite green dye from aqueous solution. J Hazard Mater 157:137–145. doi:10.1016/j.jhazmat.2007.12.116

Kannan RR, Rajasimman M, Rajamohan N, Sivaprakash B (2009) Brown marine algae Turbinaria conoides as biosorbent for malachite green removal: equilibrium and kinetic modeling. Front Environ Sci Eng China 4:116–122. doi:10.1007/s11783-010-0006-7

Kant S, Pathania D, Singh P et al (2014) Removal of malachite green and methylene blue by Fe0.01Ni0.01Zn0.98O/polyacrylamide nanocomposite using coupled adsorption and photocatalysis. Appl Catal B Environ 147:340–352. doi:10.1016/j.apcatb.2013.09.001

Karge HG, Weitkamp J (1989) Zeolites as catalysts, sorbents and detergent builders: applications and innovations. Elsevier, Amsterdam

Karimi A, Aghbolaghy M, Khatae A, Shaw Bargh S (2012) Use of enzymatic bio-fenton as a new approach in decolorization of malachite green. Sci World J. doi:10.1100/2012/691569

Kattri SD, Singh MK (1999) Adsorption of basic dyes from aqueous solution by natural adsorbent. Indian J Chem Technol 6:112–116

Khan AA, Ahmad R, Khan A, Mondal PK (2013) Preparation of unsaturated polyester Ce(IV) phosphate by plastic waste bottles and its application for removal of Malachite green dye from water samples. Arab J Chem 6:361–368. doi:10.1016/j.arabjc.2010.10.012

Khan TA, Rahman R, Ali I et al (2014) Removal of malachite green from aqueous solution using waste pea shells as low-cost adsorbent—adsorption isotherms and dynamics. Toxicol Environ Chem 96:569–578. doi:10.1080/07224800.2014.969268

Khani H, Rofouei MK, Arab P et al (2010) Multi-walled carbon nanotubes-ionic liquid-carbon paste electrode as a super...
selectivity sensor: application to potentiometric monitoring of mercury ion(II). J Hazard Mater 183:402–409. doi:10.1016/j. jhazmat.2010.07.039

Khataee AR, Dehghan G, Zarei M et al (2011a) Neural network modeling of biotreatment of triphenylmethylene dye solution by a green macroalga. Chem Eng Res Des 89:172–178. doi:10.1016/j.cherd.2010.05.009

Khataee AR, Zarei M, Dehghan G et al (2011b) Biotreatment of a triphenylmethylene dye solution using a Xanthophyta alga: modeling of key factors by neural network. J Taiwan Inst Chem Eng 42:380–386. doi:10.1016/j.tice.2010.08.006

Khatri S, Singh M (1999) Colour removal from dye wastewater using sugar cane dust as an adsorbent. Adsorp Sci Technol 17:269–282

Khatri SD, Singh MK (2009) Removal of malachite green from dye wastewater using neem sawdust by adsorption. J Hazard Mater 167:1089–1094. doi:10.1016/j.jhazmat.2009.01.101

Khatri SD, Singh MK (2000) Colour removal from synthetic dye wastewater using a biosorbent. Water Air Soil Pollut 120:283–294. doi:10.1023/A:1005207803041

Kiani G, Dostali M, Rostami A, Khataee AR (2011) Adsorption studies on the removal of malachite green from aqueous solutions onto halloysite nanotubes. Appl Clay Sci 54:34–39. doi:10.1016/j.clay.2011.07.008

Kominami H, Kumamoto H, Kera Y, Ohtani B (2003) Photocatalytic decolorization and mineralization of malachite green in an aqueous suspension of titanium(IV) oxide nanoparticles under aerated conditions: correlation between some physical properties and their photocatalytic activity. J Photochem Photobiol Chem 169:99–104. doi:10.1016/S1010-6030(03)00227-2

Krauskopf KB (1956) Factors controlling the concentrations of thirteen rare metals in sea-water. Geochim Cosmochim Acta 9:1-132. doi:10.1016/0016-7037(56)90055-2

Kuhar F, Papinutti L (2013) Protective effect of vanilloids against chemical stress on the white-rot fungus Piptopora sp., a fresh water algae: revisited of extended Langmuir model. Chem Eng J 264:17–28. doi:10.1016/j.cej.2012.02.070

Kushwaha AK, Gupta N, Chattopadhaya MC (2014) Removal of cationic methylene blue and malachite green dyes from aqueous solution by waste materials of Daucus carota. J Saudi Chem Soc 18:200–207. doi:10.1016/j.jscs.2011.06.011

Lata H, Gupta RK, Garg VK (2008) Removal of basic dye from aqueous solution using chemically modified parthenium hysterothorus linn. Biomass Chem Eng Commun 195:1185–1199. doi:10.1080/00986440701691103

Lee Y-C, Kim EJ, Yang J-W, Shin H-J (2011) Removal of malachite green by adsorption and precipitation using aminopropyl functionalized magnesium phyllosilicate. J Hazard Mater 192:62–70. doi:10.1016/j.jhazmat.2011.04.094

Lee Y-C, Kim J-Y, Shin H-J (2013) Removal of malachite green (MG) from aqueous solutions by adsorption, precipitation, and alkaline fading using talc. Sep Sci Technol 48:1093–1101. doi:10.1080/01496395.2012.723100

Levin L, Papinutti L, Forchiassin F (2004) Evaluation of Argentinean white rot fungi for their ability to produce lignin-modifying enzymes and decolorize industrial dyes. Bioresearch Technol 94:169–176. doi:10.1016/j.biortech.2003.12.002

Li X, Li Y, Zhang S, Ye Z (2012) Preparation and characterization of new foam adsorbents of poly(vinyl alcohol)/chitosan composites and their removal for dye and heavy metal from aqueous solution. Chem Eng J 183:88–97. doi:10.1016/j.cej.2011.12.025

Lin K-YA, Chang H-A (2015) Ultra-high adsorption capacity of zeolitic imidazolate framework-67 (ZIF-67) for removal of malachite green from water. Chemosphere. doi:10.1016/j. chemosphere.2015.01.041

Liu Y, Oko Y, Zhang R et al (2010) Degradation of malachite green on Pd/WO3 photocatalysts under simulated solar light. J Hazard Mater 184:386–391. doi:10.1016/j.jhazmat.2010.08.047

Low LW, Teng TT, Rafatullah M et al (2013) Adsorption studies of methylene blue and malachite green from aqueous solutions by pretreated lignocellulosic materials. Sep Sci Technol 48:1688–1698. doi:10.1016/j.seppur.2012.756912

Lv X, Xu Y, Lv K, Zhang G (2005) Photo-assisted degradation of anionic and cationic dyes over iron(III)-loaded resin in the presence of hydrogen peroxide. J Photochem Photobiol Chem 173:121–127. doi:10.1016/j.jphotoch.2005.01.011

Mahto TK, Chowdhuri AR, Sahu SK (2014) Polyaniol-functionalized magnetic nanoparticles for the removal of toxic dye from wastewater. J Appl Polym Sci 131:1–9. doi:10.1002/app.40840

Mahlavari M, Santhi T (2013) Removal of malachite green dye from aqueous solutions onto microwave assisted zinc chloride chemically activated epicarp of Ricitus communis. J Water Resour Prot 5:222–238. doi:10.4236/jwarp.2013.52023

Malana MA, Ijaz S, Ashiq MN (2010) Removal of various dyes from aqueous media onto polymeric gels by adsorption process: their kinetics and thermodynamics. Desalination 263:249–257. doi:10.1016/j.desal.2010.06.066

Malik R, Ramteke DS, Wate SR (2007) Adsorption of malachite green on groundnut shell waste based powdered activated carbon. Waste Manag 27:1129–1138. doi:10.1016/j.wasman.2006.06.009

Mall ID, Srivastava VC, Agarwal NK, Mishra IM (2005) Adsorptive removal of malachite green dye from aqueous solution by bagasse fly ash and activated carbon-kinetic study and equilibrium isotherm analyses. Colloids Surf Physicochem Eng Asp 264:17–28. doi:10.1016/j.colsurfa.2005.03.027

Man LW, Kumar P, Teng TT, Wasewar KL (2012) Design of experiments for malachite green dye removal from wastewater using thermolysis–coagulation–flocculation. Desaline Water Treat 40:260–271. doi:10.1080/19443994.2012.671257

Mane VS, Babu PVV (2011) Studies on the adsorption of brilliant green dye from aqueous solution onto low-cost NaOH treated
saw dust. Desalination 273:321–329. doi:10.1016/j.desal.2011.01.049
Mansa RF, Sipaut CS, Rahman IA et al (2016) Preparation of glycine-modified silica nanoparticles for the adsorption of malachite green dye. J Porous Mater 23:35–46. doi:10.1007/s11093-015-0053-3
Méndez A, Fernández F, Gascó G (2007) Removal of malachite green using carbon-based adsorbents. Desalination 206:147–153. doi:10.1016/j.desal.2006.03.564
Meng L, Zhang X, Tang Y et al (2015) Hierarchically porous silicon-carbon-nitrogen hybrid materials towards highly efficient and selective adsorption of organic dyes. Sci Rep 5:7910. doi:10.1038/srep07910
Mirzajani R, Ahmadi S (2015) Melamine supported magnetic iron oxide nanoparticles (Fe3O4@Mel) for spectrophotometric determination of malachite green in water samples and fish tissues. J Ind Eng Chem 23:171–178. doi:10.1016/j.jiec.2014.08.011
Mishra RR, Chandran P, Khan SS (2014) Equilibrium and kinetic studies on adsorptive removal of malachite green by the citrate-stabilized magnetite nanoparticles. RSC Adv 4:51787–51793. doi:10.1039/C4RA07651F
Mittal A (2006) Adsorption kinetics of removal of a toxic dye, malachite green, from wastewater by using hen feathers. J Hazard Mater 133:196–202. doi:10.1016/j.jhazmat.2005.10.017
Mittal A, Krishnan L, Gupta VK (2005) Removal and recovery of malachite green from wastewater using an agricultural waste material, de-oiled soya. Sep Purif Technol 43:125–133. doi:10.1016/j.seppur.2004.10.010
Mittal A, Mittal J, Malviya A, Gupta VK (2009) Adsorptive removal of hazardous anionic dye “Congo Red” from wastewater using waste materials and recovery by desorption. J Colloid Interface Sci 340:16–26. doi:10.1016/j.jcis.2008.09.019
Modirshahla N, Behnajady MA (2006) Photooxidative degradation of malachite green (MG) by UV/H2O2: influence of operational parameters and kinetic modeling. Dyes Pigments 70:54–59. doi:10.1016/j.dyepig.2005.04.012
Mohammadi A, Daemi H, Barikani M (2014) Fast removal of malachite green dye using novel superparamagnetic sodium alginate-coated Fe3O4 nanoparticles. Int J Biol Macromol 69:447–455. doi:10.1016/j.ijbiomac.2014.05.042
Mondal S (2008) Methods of dye removal from dye house effluent—an overview. Environ Eng Sci 25:383–396. doi:10.1089/ees.2007.0049
Moumen O, Hamaoua O (2012) Intensification of sonochemical degradation of malachite green by bromide ions. Ultrason Sonochem 19:404–409. doi:10.1016/j.ultsonch.2011.08.008
Nandi BK, Goswami A, Purkait MK (2009) Adsorption characteristics of brilliant green dye on kaolin. J Hazard Mater 161:387–395. doi:10.1016/j.jhazmat.2008.03.110
Nethaji S, Sivasamy A, Kumar RV, Mandal AB (2013) Preparation of char from lotus seed biomass and the exploration of its dye removal capacity through batch and column adsorption studies. Environ Sci Pollut Res Int 20:3670–3678. doi:10.1007/s11356-012-1267-4
Nethaji S, Sivasamy A, Mandal AB (2012) Adsorption isotherms, kinetics and mechanism for the adsorption of cationic and anionic dyes onto carbonaceous particles prepared from Juglans regia shell biomass. Int J Environ Sci Technol 10:231–242. doi:10.1007/s13732-012-0112-0
Nethaji S, Sivasamy A, Thennarasu G, Saravana S (2010) Adsorption of malachite green dye onto activated carbon derived from Borassus aethiopum flower biomass. J Hazard Mater 181:271–280. doi:10.1016/j.jhazmat.2010.05.008
Ng HW, Lee LY, Chan WL et al (2015) Luffa acutangula peel as an effective natural biosorbent for malachite green removal in aqueous media: equilibrium, kinetic and thermodynamic investigations. Desalin Water Treat 57:7302–7311. doi:10.1080/19443994.2015.1016460
Nidheesh PV, Gandhi Mathi R, Ramesh ST (2013) Degradation of dyes from aqueous solution by Fenton processes: a review. Environ Sci Pollut Res 20:2099–2132. doi:10.1007/s11356-012-1385-z
Odom TW, Huang J-L, Kim P, Lieber CM (1998) Atomic structure and electronic properties of single-walled carbon nanotubes. Nature 391:62–64. doi:10.1038/34145
Oladjoo NA, Aliu YD (2009) Snail shell as coagulant aid in the alum precipitation of malachite green from aqua system. J Hazard Mater 164:1496–1502. doi:10.1016/j.jhazmat.2008.09.114
Onal Y (2006) Kinetics of adsorption of dyes from aqueous solution using activated carbon prepared from waste apricot. J Hazard Mater 137:1719–1728. doi:10.1016/j.jhazmat.2006.05.036
Onal Y, Akmil-Başar C, Eren D et al (2006) Adsorption kinetics of malachite green onto activated carbon prepared from Tuncbilek lignite. J Hazard Mater 128:150–157. doi:10.1016/j.jhazmat.2005.07.055
Onal Y, Akmil-Başar C, Sarıcı-Özdemir Ç (2007) Investigation kinetics mechanisms of adsorption malachite green onto activated carbon. J Hazard Mater 146:194–203. doi:10.1016/j.jhazmat.2006.12.006
Özdemir A, Keskin C (2009) Removal of a binary dye mixture of congo red and malachite green from aqueous solutions using a bentonite adsorbent. Clays Clay Miner 57:695–705. doi:10.1346/CCMN.2009.0570603
Ozdes D, Gundogdu A, Duran C, Senturk HB (2010) Evaluation of adsorption characteristics of malachite green onto Almond Shell (Prunus dulcis). Sep Sci Technol 45:2076–2085. doi:10.1080/01496395.2010.504479
Pan X, Zhang D (2009) Removal of malachite green from water by Firniana simples wood fiber. Electron J Biotechnol 12:9–10
Pandit P, Basu S (2004) Removal of ionic dyes from water by solvent extraction using reverse micelles. Environ Sci Technol 38:2435–2442
Papinutti L, Mouso N, Forchiassin F (2006) Removal and degradation of the fungicide dye malachite green from aqueous solution using the system wheat bran–Fomes fomentarius. Enzyme Microb Technol 38:2435–2442
Patil MR, Shrivastava VS (2014) Adsorption of malachite green by polyaniline–nickel ferrite magnetic nanocomposite: an isotherm and kinetic study. Appl Nanosci 5:809–816. doi:10.1007/s13204-014-0383-5
Paul M, Pal N, Bhauikin A (2012) Selective adsorption and release of cationic organic dye molecules on mesoporous borosilicates. Mater Sci Eng C Mater Biol Appl 32:1461–1468. doi:10.1016/j.msec.2012.04.026
Pearce CI, Lloyd JR, Guthrie JT (2003) The removal of colour from textile wastewater using whole bacterial cells: a review. Dyes Pigments 58:179–196. doi:10.1016/S0143-7208(03)00395-X
Pehlivan E, Arslan G (2007) Removal of metal ions using lignite in aqueous solution—low cost biosorbents. Fuel Process Technol 88:99–106. doi:10.1016/j.fuproc.2006.09.004
Pirsaheb M, Shahmoradi B, Khorasvi T et al (2015) Solar degradation of malachite green using nickel-doped TiO2 nanocatalysts. Desalin Water Treat 57:9881–9888. doi:10.1080/19443994.2015.1033764
Podstawczyk D, Witek-Krowiak A, Chojnacka K, Sadowski Z (2014) Biosorption of malachite green by eggshells: mechanism
identification and process optimization. Bioresour Technol 160:161–165. doi:10.1016/j.biotech.2014.01.015

Porkodi K, Vasanth Kumar K (2007) Equilibrium, kinetics and mechanism modeling and simulation of basic and acid dyes sorption onto jute fiber carbon: eosin yellow, malachite green and crystal violet single component systems. J Hazard Mater 143:311–327. doi:10.1016/j.jhazmat.2006.09.029

Pourjavadi A, Doulabi M, Doroudian M (2014) Adsorption characteristics of malachite green dye onto novel kappa-carrageenan-g-polyacrylic acid/TiO$_2$-NH$_2$ hydrogel nanocomposite. J Iran Chem Soc 11:1057–1065. doi:10.1016/j.s三代378-013-0374-6

Pradeep Sekhar C, Kalidhasan S, Rajesh V, Rajesh N (2009) Biopolymer adsorbent for the removal of malachite green from aqueous solution. Chemosphere 77:842–847. doi:10.1016/j.chemosphere.2009.07.068

Pradhan AC, Parida KM, Nanda B (2011) Enhanced photocatalytic and adsorptive degradation of organic dyes by mesoporous Cu/Al$_2$O$_3$-MCM-41: intra-particle mesoporosity, electron transfer and OH radical generation under visible light. Dalton Trans Camb Engl 40:7348–7356. doi:10.1039/c1dt10363f

Prado AGS, Costa LL (2009) photocatalytic decoulorization of malachite green dye by application of TiO$_2$ nanotubes. J Hazard Mater 169:297–301. doi:10.1016/j.jhazmat.2009.03.076

Rahman IA, Saad B, Shaidan S, Sya Rizal ES (2005) Adsorption characteristics of malachite green on activated carbon derived from rice husks produced by chemical–thermal process. Bioresour Technol 96:1578–1583. doi:10.1016/j.biotech.2004.12.015

Rajabi HR, Khani O, Shamsipur M, Vatanpour V (2013) High-performance pure and Fe$_3$O$_4$–ion doped ZnS quantum dots as green nanophotocatalysts for the removal of malachite green under UV-light irradiation. J Hazard Mater 250–251:370–378. doi:10.1016/j.jhazmat.2013.02.007

Rajabi M, Mirza B, Mahanpour K et al (2016) Adsorption of malachite green from aqueous solution by carboxylate group functionalized multi-walled carbon nanotubes: determination of equilibrium and kinetics parameters. J Ind Eng Chem 34:130–138. doi:10.1016/j.jiec.2015.11.001

Rajesh Kannan R, Rajasimman M, Rajamohan N, Sivaprakash B (2010) Equilibrium and kinetic studies on sorption of malachite green using hydridilla verticillata biomass. Int J Environ Res 4:817–824

Rajeshkannan R, Rajamohan N, Rajasimman M (2009) Removal of malachite green from aqueous solution by sorption on hydridilla verticillata biomass using response surface methodology. Front Chem Eng China 3:146–154. doi:10.1007/s11705-009-0007-x

Rajeshkannan R, Rajasimman M, Rajamohan N (2011) Decolourization of malachite green using tamarind seed: optimization, isotherm and kinetic studies. Chem Ind Eng Chem Quart 17:67–79. doi:10.2298/CICEQ100716056R

Rajeshkannan R, Rajasimman M, Rajamohan N (2010) Removal of malachite green from aqueous solution using hydridilla verticillata-optimization, equilibrium and kinetic studies. Int J Civ Environ Eng 2:222–229

Rajeshwarisivaraj Sivakumar S, Senthilkumar P, Subburam V (2001) Carbon from Cassava peel, an agricultural waste, as an adsorbent for the removal of dyes and heavy metal ions from aqueous solution. Bioresour Technol 80:233–235. doi:10.1016/S0960-8524(00)00179-6

Rajeshwarisivaraj, Subburam V (2002) Activated parthenium carbon as an adsorbent for the removal of dyes and heavy metal ions from aqueous solution. Bioresour Technol 85:205–206. doi:10.1016/S0960-8524(02)00089-5

Rajgopal S, Karthikeyan T, Prakash Kumar BG, Miranda LR (2006) Utilization of fluidized bed reactor for the production of adsorbents in removal of malachite green. Chem Eng J 116:211–217. doi:10.1016/j.cej.2005.09.026

Ramaraju B, Manoj Kumar Reddy P, Subrahmanyam C (2014) Low cost adsorbents from agricultural waste for removal of dyes. Environ Prog Sustain Energy 33:38–46. doi:10.1002/ep.11742

Rauf MA, Bukallah SB, Hamour FA, Nasir AS (2008) Adsorption of dyes from aqueous solutions onto sand and their kinetic behavior. Chem Eng J 137:238–243. doi:10.1016/j.cej.2007.04.025

Raval NP, Shah PU, Ladha DG et al (2016a) Comparative study of chitin and chitosan beads for the adsorption of hazardous anionic azo dye Congo Red from wastewater. Desalin Water Treat 57:9247–9262. doi:10.1080/19443994.2015.1027959

Raval NP, Shah PU, Shah NK (2016b) Nanoparticles loaded biopolymer as effective adsorbent for adsorptive removal of malachite green from aqueous solution. Water Conserv Sci Eng 1:69–81. doi:10.1016/s11356-016-0004-0

Raval NP, Shah PU, Shah NK (2016c) Adsorptive amputation of hazardous azo dye Congo red from wastewater: a critical review. Environ Sci Pollut Res 23:14810–14853. doi:10.1007/s11356-016-6970-0

Raval NP, Shah PU, Shah NK (2016d) Adsorptive removal of nickel(II) ions from aqueous environment: a review. J Environ Manag 179:1–20. doi:10.1016/j.jenvman.2016.04.045

Ren S, Guo J, Zeng G, Sun G (2006) Decolorization of triphenylmethane, azo, and anthraquinone dyes by a newly isolated Aeromonas hydrophila strain. Appl Microbiol Biotechnol 72:1316–1321. doi:10.1007/s00253-006-0418-2

Robaina NF, Soriano S, Cassella RJ (2009) Polyurethane foam loaded with SDS for the adsorption of cationic dyes from aqueous medium: multivariate optimization of the loading process. J Hazard Mater 167:653–659. doi:10.1016/j.jhazmat.2009.01.033

Robinson T, McMullan G, Marchant R, Nigam P (2001) Remediation of dyes in textile effluent: a critical review on current treatment technologies with a proposed alternative. Bioresour Technol 77:247–255. doi:10.1016/S0960-8524(00)00080-8

Rogaieh Z, Gharbani P (2013) Study on malachite green dye removal by adsorption onto activated nano-alumina. Appl Chem Environ 3:71–77

Rong X, Qu F, Qin J et al (2014) Removal of malachite green from the contaminated water using a water-soluble melanine/maleic anhydride sorbent. J Ind Eng Chem 20:3808–3814. doi:10.1016/j.jiec.2013.12.083

Roosta M, Ghaedi M, Shokri N et al (2014) Optimization of the combined ultrasonic assisted/adsorption method for the removal of malachite green by gold nanoparticles loaded on activated carbon: experimental design. Spectrochim Acta A Mol Biomol Spectrosc 118:55–65. doi:10.1016/j.saa.2013.08.082

Safarik I, Lunackova P, Mosiniewicz-Szablewska E et al (2007) Adsorption of water-soluble organic dyes on ferrofluid-modified sawdust. Holzforschung 61:247–253. doi:10.1515/HF.2007.0060

Šafarík I, Šafaríková M, Vrchotová N (1995) Study of sorption of triphenylmethane dyes on a magnetic carrier bearing an immobilized copper phthalocyanine dye. Collect Czechoslov Chem Commun 60:34–42. doi:10.1135/ccc19950034

Šafarík I, Šafaríková M (2002) Detection of low concentrations of malachite green and crystal violet in water. Water Res 36:196–200. doi:10.1016/S0043-1354(01)00243-3

Saha P, Chowdhury S, Gupta S et al (2010a) Assessment on the removal of malachite green using tamarind fruit shell as biosorbent. CLEAN—Soil Air Water 38:437–445. doi:10.1002/c cla.200900234

Saha P, Chowdhury S, Gupta S, Kumar I (2010b) Insight into adsorption equilibriums, kinetics and thermodynamics of
malachite green onto clayey soil of Indian origin. Chem Eng J 165:874–882. doi:10.1016/j.cej.2010.10.048
Saha S, Pal A (2014) Microporous assembly of MnO 2 nanosheets for malachite green degradation. Sep Purif Technol 134:26–36. doi:10.1016/j.seppur.2014.07.021
Saha S, Wang JM, Pal A (2012) Nano silver impregnation on commercial TiO 2 and a comparative photocatalytic account to degrade malachite green. Sep Purif Technol 89:147–159. doi:10.1016/j.seppur.2012.01.012
Sahel TA, Gupta VK (2011) Functionalization of tungsten oxide into MWCNT and its application for sunlight-induced degradation of rhodamine B. J Colloid Interface Sci 362:337–344. doi:10.1016/j.jcis.2011.06.081
Saravanan R, Benouda B, Nourreddine B, Duclaux L (2013) Application of Ulva lactuca and Systoectria stricta algae-based activated carbons to hazardous cationic dyes removal from industrial effluents. Water Res 47:3375–3388. doi:10.1016/j.watres.2013.03.038
Salleh MAM, Mahmoud DK, Karim WAWA, Idris A (2011) Cationic and anionic dye adsorption by agricultural solid wastes: a comprehensive review. Desalination 280:1–13. doi:10.1016/j.desal.2011.07.019
Samiey B, Toossi AR (2010) Adsorption of malachite green on silica gel: effects of NaCl, pH and 2-propanol. J Hazard Mater 184:739–745. doi:10.1016/j.jhazmat.2010.08.101
Sanchez PCM, Pariente JP (2011) Zeolites and ordered porous solids: fundamentals and applications. Editorial Universitat Politecnicà de Valencia, Valencia
Santhi T, Manonmani S (2010b) Removal of malachite green from aqueous medium by maize cob (Zea mays). Ultrason Sonochem 16:351–355. doi:10.1016/j.ultsonch.2009.03.008
Santhi T, Manonmani S, Smitha T (2010a) Kinetics and isotherm studies on cationic dyes adsorption onto annona squamosa seed activated carbon. Int J Eng Sci Technol 2:287–295
Santhi T, Manonmani S, Smitha T (2010b) Removal of malachite green from aqueous solution by activated carbon prepared from the epicarp of Ricinus communis by adsorption. J Hazard Mater 179:178–186. doi:10.1016/j.jhazmat.2010.02.076
Saravanan R, Gupta VK, Prakash T et al (2013) Synthesis, characterization and photocatalytic activity of novel Hg doped ZnO nanorods prepared by thermal decomposition method. J Mol Liq 178:88–93. doi:10.1016/j.molliq.2012.11.012
Saravanan R, Prakash T, Gupta VK, Stephen A (2014) Tailoring the electrical and dielectric properties of ZnO nanorods by substitution. J Mol Liq 193:160–165. doi:10.1016/j.molliq.2013.12.029
Saravanan R, Sacari E, Gracia F et al (2016) Conducting PANI layer thin films for malachite green dye degradation under UV and vis-lights. J Hazard Mater 144:140–146. doi:10.1016/j.jhazmat.2006.10.011
Sayilkan F, Asiltürk M, Tatar P et al (2007b) Preparation of re-usable photocatalytic filter for degradation of malachite green dye under UV and vis-irradiation. J Hazard Mater 148:735–744. doi:10.1016/j.jhazmat.2007.03.036
Sayilkan F, Asiltürk M, Tatar P et al (2008) Photocatalytic performance of Sn-doped TiO 2 nanostructured thin films for photocatalytic degradation of malachite green dye under UV and VIS-lights. Mater Res Bull 43:127–134. doi:10.1016/j.materresbull.2007.02.012
Schmidt D, Shah D, Giannelis EP (2002) New advances in polymer/layered silicate nanocomposites. Curr Opin Solid State Mater Sci 6:205–212. doi:10.1016/S1359-0286(02)00049-9
Sharma P, Kaur H, Sharma M, Sahore V (2011) A review on applicability of naturally available adsorbents for the removal of hazardous dyes from aqueous waste. Environ Monit Assess 183:151–195. doi:10.1007/s10661-011-1914-0
Sharma YC (2011) Adsorption characteristics of a low-cost activated carbon for the reclamation of colored effluents containing malachite green. J Chem Eng Data 56:478–484. doi:10.1021/ je1008922
Sharma YC, Singh B, Uma (2009) Fast removal of malachite green by adsorption on rice husk activated carbon. Open Environ Pollut Toxicol J 1:74–78. doi:10.2174/1876397970900901010074
Shedlbalkar U, Jadhav JP (2011) Detoxification of malachite green and textile industrial effluent by Penicillium ochrochloron. Biotechnol Bioprocess Eng 16:196–204. doi:10.1007/s12257-010-0069-0
Shi Q, Zhang J, Zhang C et al (2010) Preparation of activated carbon from cattail and its application for dyes removal. J Environ Sci China 22:91–97
Shirmardi M, Mahvi AH, Hashemzadeh B et al (2013) The adsorption of malachite green (MG) as a cationic dye onto functionalized multi walled carbon nanotubes. Korean J Chem Eng 30:1603–1608. doi:10.1007/s10118-013-0800-0
Singh A, Manju Rani S, Bishnoi NR (2012) Malachite green dye decolorization on immobilized dead yeast cells employing sequential design of experiments. Ecol Eng 47:291–296. doi:10.1016/j.ecoleng.2012.07.001
Singh DK, Rastogi K (2004) Adsorptive removal of basic dyes from aqueous phase onto activated carbon of used tea leaves: a kinetic and thermodynamic study. J Environ Sci Eng 46:293–302
Sivashankar R, Suthya AB, Vasantharaj K, Sivasubramanian V (2014) Magnetic composite an environmental super adsorbent for dye sequestration—a review. Environ Nanotechnol Monit Manag 30:1603–1608. doi:10.1007/s10661-013-0400-0
Solis M, Solis A, Pérez HI et al (2012) Microbial decolouration of azo dyes: a review. Process Biochem 47:1723–1748. doi:10.1016/j.procbio.2012.08.014
Sonawane GH, Shrivastava VS (2009) Kinetics of decolourization of malachite green from aqueous medium by maize cob (Zea maize): an agricultural solid waste. Desalination 247:430–441. doi:10.1016/j.desal.2009.01.006
Sonawane SH, Chaudhari PL, Ghodke SA et al (2009) Ultrasound assisted synthesis of polyacrylic acid-nanoclay nanocomposite and its application in sonosorption studies of malachite green dye. Ultrason Sonochem 16:351–355. doi:10.1016/j.ultrasonch.2008.10.008
Srivasstava A, Viraraghavan T (2010) Decolorization of dye wastewaters by biosorbents: a review. J Environ Manag 91:1915–1929. doi:10.1016/j.jenvman.2010.05.003
Srivasstava R, Rupainwar DC (2011) A comparative evaluation for adsorption of dye on Neem bark and Mango bark powder. Indian J Technol 18:67–75
Yang C-H, Shih M-C, Chiu H-C, Huang K-S (2014) Magnetic
Yagub MT, Sen TK, Afroze S, Ang HM (2014) Dye and its removal
Xu R, Jia M, Zhang Y, Li F (2012) Sorption of malachite green on
Xing Y, Wang G (2009) Poly(methacrylic acid)-modified sugarcane
Xing Y, Deng D (2009) Enhanced adsorption of malachite green by
Wu X, Wang Y, Liu J et al (2010) Study of malachite green
Witek-Krowiak A, Szafran RG, Modelski S, Dawiec A (2012)
Witek-Krowiak A (2013) Biosorption of malachite green from aqueous
Weng X, Huang L, Chen Z et al (2013) Synthesis of iron-based
Waring DR, Hallas G (eds) (1990) The chemistry and application of
Wang XS (2009) Invasive freshwater macrophyte alligator weed:
novel adsorbent for removal of malachite green from aqueous solution. Water Air Soil Pollut 206:215–223. doi:10.1007/s11270-009-0097-6
Wang XS, Zhou Y, Jiang Y, Sun C (2008b) The removal of basic dyes from aqueous solutions using agricultural by-products. J Hazard Mater 157:374–385. doi:10.1016/j.jhazmat.2008.01.004
Waring DR, Hallas G (eds) (1990) The chemistry and application of dyes. Springer US, Boston
Wei A, Liu B, Zhao H et al (2014) Synthesis and formation mechanism of flowerlike architectures assembled from ultrathin NiO nanoflakes and their adsorption to malachite green and acid red in water. Chem Eng J 239:141–148. doi:10.1016/j.cej.2013.10.079
Weng X, Huang L, Chen Z et al (2013) Synthesis of iron-based nanoparticles by green tea extract and their degradation of malachite. Ind Crops Prod 51:342–347. doi:10.1016/j.indcrop.2013.09.024
Witek-Krowiak A (2013) Biosorption of malachite green from aqueous solutions by pine sawdust: equilibrium, kinetics and the effect of process parameters. Desalin Water Treat 51:3284–3294. doi:10.1080/19443994.2012.749053
Witek-Krowiak A, Szafran RG, Modelski S, Dawiec A (2012) Removal of cationic dyes from aqueous solutions using micro-spherical particles of fly ash. Water Environ Res Res Publ Water Environ Fed 84:162–169
Wu J, Jung B-G, Kim K-S et al (2009) Isolation and characterization of Pseudomonas otitidis WL-13 and its capacity to decolorize triphenylmethane dyes. J Environ Sci China 21:960–964
Wu X, Wang Y, Liu J et al (2010) Study of malachite green adsorption onto natural zeolite in a fixed-bed column. Desalin Water Treat 20:228–233. doi:10.5004/dwt.2010.1212
Xing Y, Deng D (2009) Enhanced adsorption of malachite green by EDTAD-modified sugarcane bagasse. Sep Sci Technol 44:2117–2131. doi:10.1080/00986390902775588
Xing Y, Wang G (2009) Poly(methacrylic acid)-modified sugarcane bagasse for enhanced adsorption of cationic dye. Environ Technol 30:611–619. doi:10.1080/09593330902838098
Xu R, Jia M, Zhang Y, Li F (2012) Sorption of malachite green on vinyl-modified mesoporous poly(acrylic acid)/SiO2 composite nanofiber membranes. Microporous Mesoporous Mater 149:111–118. doi:10.1016/j.micromeso.2011.08.024
Yagub MT, Sen TK, Afroze S, Ang HM (2014) Dye and its removal from aqueous solution by adsorption: a review. Adv Colloid Interface Sci 209:172–184. doi:10.1016/j.cis.2014.04.002
Yang C-H, Shih M-C, Chiu H-C, Huang K-S (2014) Magnetic Pycnoporus sanguineus-loaded alginate composite beads for removing dye from aqueous solutions. Mol Basel Switz 19:8276–8288. doi:10.3390/molecules19068276
Yang J, Chen C, Ji H et al (2005) Mechanism of TiO2-assisted photocatalytic degradation of dyes under visible irradiation: photoelectrocatalytic study by TiO2-film electrodes. J Phys Chem B 109:21900–21907. doi:10.1021/jp0540914
Yu J, Chi R, He Z, Qi Y (2011) Adsorption performances of cationic dyes from aqueous solution on pyromellitic dianhydride modified sugarcane bagasse. Sep Sci Technol 46:452–459. doi:10.1080/01463385.2010.510125
Zeng Y, Zhao L, Wu W et al (2013) Enhanced adsorption of malachite green onto carbon nanotube/polyaniline composites. J Appl Polym Sci 127:2475–2482. doi:10.1002/app.37947
Zhang G, Yi L, Deng H, Sun P (2014a) Dyes adsorption using a synthetic carbamylmethoxycarboxylic acid adsorbent. J Environ Sci China 26:1203–1211. doi:10.1016/S1001-0742(13)60513-6
Zhang H, Tang Y, Liu X et al (2011) Improved adsorptive capacity of pine wood decayed by fungi Poria cocos for removal of malachite green from aqueous solutions. Desalination 274:97–104. doi:10.1016/j.desal.2011.01.077
Zhang J, Li Y, Zhang C, Jing Y (2008) Adsorption of malachite green from aqueous solution onto carbon prepared from Arundo donax root. J Hazard Mater 150:774–782. doi:10.1016/j.jhazmat.2007.05.036
Zhang L, Zhang H, Guo W, Tian Y (2014b) Removal of malachite green and crystal violet cationic dyes from aqueous solution using activated sintering process red mud. Appl Clay Sci 93–94:85–93. doi:10.1016/j.clay.2014.03.004
Zhang X, Yu H, Yang H et al (2015) Graphene oxide caged in cellulose microbeads for removal of malachite green dye from aqueous solution. J Colloid Interface Sci 437:277–282. doi:10.1016/j.jcis.2014.09.048
Zhang X, Zhang S, Pan B et al (2012) Simple fabrication of polymer-based Trametes versicolor laccase for decolorization of malachite green. Bioresour Technol 115:16–20. doi:10.1016/j.biortech.2011.11.063
Zhou X-J, Guo W-Q, Yang S-S et al (2013) Ultrasonic-assisted ozone oxidation process of triphenylmethane dye degradation: evidence for the promotion effects of ultrasonic on malachite green decolorization and degradation mechanism. Bioresour Technol 128:827–830. doi:10.1016/j.biortech.2012.10.086
Zhou Y, Min Y, Qiao H et al (2015) Improved removal of malachite green from aqueous solution using chemically modified cellulose by anhydride. Int J Biol Macromol 74:271–277. doi:10.1016/j.ijbiomac.2014.12.020
Zou W, Gao S, Zhou X, Bai H (2013) Adsorption of neutral red and malachite green onto grapefruit peel in single and binary systems. Water Environ Res Res Publ Water Environ Fed 85:466–477